# The Doctoral Consortium of the 2010 IEEE International Conference on Networking, Sensing and Control

**April 10-12, 2010**

**Chicago, IL, U.S.A**

The Doctoral Consortium of the 2010 IEEE International Conference on Networking, Sensing and Control was held on April 11, 2010, in Chicago, USA. The objective of this Doctoral Consortium is to provide an opportunity for the Ph.D. students to discuss their dissertation research topics, research plans, and research methodologies with peers in the community, and use such feedbacks and suggestions to further guide their dissertation research. Furthermore, this Doctoral Consortium also provides a unique platform for the Ph.D. students to access the latest research development in this field, and develop the networking with the research community for their future career development.

We have received a totally of 22 research proposals for this program, ranging from 16 countries and regions (Brazil, Canada, Chile, China, Czech Republic, India, Iran, Japan, Mexico, Portugal, Romania, Singapore, Thailand, United Kingdom, and U.S.A). Among these submission, 12 proposals were awarded for financial support based on the quality of the proposals in terms of originality, significance, correctness, and clarity. There proposals cover a wide range of critical research fields in networks, sensors, and control. To highlight the success of this Doctoral Consortium, we printed this document aiming to provide a platform to share research ideas and promote research collaborations.

We would like to take this opportunity to thank the ICNSC 2010 for the generous support to make this Doctoral Consortium possible and the organizing committees for their great help and efforts in coordination of the entire organization process of this program.

We hope you will enjoy reading these research proposals!

Sincerely,

Doctoral Consortium Organizing Committee
2010 IEEE ICNSC

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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Research field
Genetic Programming in Nonlinear Systems Identification

# Research Proposal

## Genetic Programming Based Tools for Nonlinear Systems Identification

### 1. RESEARCH PROBLEM STATEMENT

The purpose of this work is to develop a nonlinear systems identification method, capable of finding an appropriate model by means of self organization at both structural and parametric levels. Given the inherent complexity of most real-life identification problems, it is compulsory for a proficient model design tool to manage a wide range of nonlinearities, based only on a high level statement of the task at hand. The authors strive to achieve that goal within the specific context of automatic control, which imposes severe model accuracy and parsimony requirements, thus naturally leading towards formulating the identification problem as a multiobjective optimization one. A way of properly addressing all the issues above is represented by **G**enetic **P**rogramming (GP), an evolutionary technique capable of adapting to unpredictable changes in the search space, with minimal outside intervention. In addition, GP algorithms process several potential models at a time, a feature which, if carefully exploited, facilitates the obtaining of a set of various trade-off solutions, required in all identification problems that employ multiple optimization objectives.

In more specific terms, the proposed identification procedure works with **N**onlinear, **L**inear in **P**arameters (NLP) models, a formalism proven to be a universal approximator of any bounded continuous system. To better exploit parameter wise linearity, the main evolutionary algorithm is hybridized with a local deterministic parameter computation procedure; therefore, the field of memetic evolutionary algorithms is also a research topic of interest. In an attempt to optimize computational resource consumption, the authors suggest a method of establishing a balance between exploration and exploitation, by developing enhanced versions of the classic genetic operators. Finally, the interest of the present research is centered on several specific issues regarding multiobjective optimization, in both its basic and elitist forms, such as dynamic selection pressure tuning, diversity preservation and efficient search space exploration.

### 2. SIGNIFICANCE AND OBJECTIVES

In the field of automatic control, efficiently exploiting an industrial plant means including it in a feedback loop governed by a control law. Such a law cannot be obtained in the absence of a sound mathematical model of the targeted plant, which is in most practical cases a nonlinear process, hence the importance of nonlinear systems identification. Out of all available methods for obtaining nonlinear models, GP is worthy of special consideration due to a series of arguments. Firstly, it features remarkable search space exploration capabilities, as it simultaneously handles several possible solutions evenly spread out across the problem domain. This is an important advantage that GP has over other identification procedures that work on a singular solution at a time, thus being bound by the quality of the initial search point choice. Another GP strength is that it is able to conduct an efficient, unsupervised model search. In other words, there is no need for extensive aprioric information (such as model structure, its complexity, the landscape of the search space, etc.), which renders the GP based tool suitable for “black box” approaches while eliminating the inconvenience of unrealistic mathematical restrictions. In addition, GP evolves populations of potential solutions via stochastic transitions, a trait common to all evolutionary procedures. On the one hand,

this represents a downside of the approach, as it makes it difficult to mathematically prove the method's convergence. On the other hand, there are two main positive aspects that emerge from the randomness of the search process. The first one is robustness, as the danger of blockage in local optima points is eliminated due to the absence of derivatives. Secondly, as the transformations produced by the genetic operators are not restricted by fixed mathematical formulae, the algorithm is likely to discover unexpected relationships in between system variables, and thus to capture certain aspects of the plant's behavior that were not preempted pre-design (Poli *et al.*, 2008).

As nonlinear systems identification within the framework of automatic control is a problem with specific requirements, the main goal of the authors' research is that of customizing the classic GP loop, to better respond to the model quality standards imposed by the identification task. The main criteria used to evaluate a model, in the context described above, are accuracy and parsimony, therefore, the suggested GP algorithm employs exactly those two optimization objectives in order to generate a diverse set of tradeoff solutions. Overfitted models, that feature good accuracy at the cost of being exaggeratedly complex, usually show a poor generalization capacity which makes them of no practical significance. Solutions situated at the other extreme of the Pareto front, considered in the objectives space, feature a simple structure and poor accuracy, hence they are of no use as well. In response to this observation, one of the specific goals of this work is to encourage the generation of models within the central area of the Pareto front. As this interest zone should preferably be populated by an increased number of tradeoff solutions, another target was set, namely preserving diversity within the population. This task bares increased importance in the context of elitist approaches, which increase selection pressure in favor of the best models, thus speeding up the search process at the risk of premature convergence due to loss of diversity. Finding a balance between exploration speed and preservation of non-redundant genetic material within the population is another important goal of this research.

## 3. SUMMARY OF THE CURRENT STATE-OF-THE-ART

According to the Weierstrass theorem, any bounded function can be uniformly approximated as closely as desired by a polynomial function. Considering that numerical applications can directly evaluate polynomials and that these simple functions can be encrypted by a tree data structure in a straightforward manner, the idea of considering the NLP pattern for model generation becomes appealing. Formally, the NLP model of an *m* input, *n* output system is a linear combination of regressors, which represent nonlinear factors made up of one or several terminals connected by multiply operators. The $q^{th}$ estimated output of such a system is described by the following matrix equation:

$$\begin{bmatrix} F_{1q}(\mathbf{x}(1)) & .. & \cdots & F_{rq}(\mathbf{x}(1)) \\ F_{1q}(\mathbf{x}(2)) & .. & \cdots & F_{rq}(\mathbf{x}(2)) \\ \vdots & \vdots & & \vdots \\ F_{1q}(\mathbf{x}(p)) & .. & \cdots & F_{rq}(\mathbf{x}(p)) \end{bmatrix} \begin{bmatrix} c_{1q} \\ c_{2q} \\ \vdots \\ c_{rq} \end{bmatrix} = \begin{bmatrix} \hat{y}_q(1) \\ \hat{y}_q(2) \\ \vdots \\ \hat{y}_q(p) \end{bmatrix}, \tag{1}$$

where $F_{ij}$ are the model regressors, $c_{ij}$ are the model parameters and *p* is the length of the training data set. Vector **x** (2) contains lagged values of all system inputs $u_i$, $i = 1..m$, and outputs $y_j$, $j = 1..n$, called terminals, going back from the current time instant *k* as far as the input and output lags, $n_u$ and $n_y$ respectively, allow it.

$$\mathbf{x}(k) = (u_1(k),\ldots,u_1(k-n_u),\ldots,u_m(k),\ldots,u_m(k-n_u),y_1(k-1),\ldots,y_1(k-n_y),\ldots,y_n(k-1),\ldots,y_n(k-n_y)) \tag{2}$$

The simplest way to generate a model compliant with (1) is to consider all possible combinations of terminals (Fonseca and Flemming, 1998), resulting in an increased number of regressors, and consequently in a large regression matrix **F**. The coefficients $c_i$ are easy to compute, given the model's parameter wise linearity, making it possible to find a solution to the identification problem in one single step. However, in addition to the numerical strain caused by working with large matrices, it is to be expected that many of the considered regressors are redundant, with no significant contribution to the overall model accuracy, therefore, they will have to be eliminated post design.

To avoid that inconvenience, a combination between the idea behind NLP models and the principles of GP has been suggested (Rodriguez-Vasquez *et al*., 2005) (Madar *et al.*, 2005). Thus, potential models are generated in the form of tree encrypted individuals (Koza, 1992), each of them encapsulating a compact combination of regressors, compliant with (1), yet reduced in dimension. During evolutionary loop stages like reproduction or selection, the individuals will be given the opportunity to adjust their complexity, accuracy and other features to better adapt to the considered objectives, making any offline reduction of terms unnecessary. One way of gradually spotting redundant terms, during the evolutionary process, is to compute error ratios for each regressor in the current individual, a technique known as **O**rthogonally **L**east **S**quare (OLS). The regressors found to be least significant are excluded from the model (Madar *et al.*, 2005). The approach is greedy in nature as one nonlinear atom, irrelevant with respect to the containing individual at the current generation, may be just one mutation away from becoming useful, in which case its exclusion from the model would be premature.

As most practical identification problems require models to meet several quality criteria, researchers focused their work on implementing **M**ulti **O**bjective **O**ptimization (MOO) tools. Aggregating the involved objectives into a single one (Wey and Billings, 2004) makes use of weight vectors, which are difficult to prescribe before design, especially when the model evaluation functions have different minima points. Hence, dominance analysis was introduced as a MOO technique for individual fitness computation (Deb, 2001). It separates each population into various order nondominated sets, each subjected to a static niching procedure designed to preserve tree diversity.

Other important results in the field of MOO target dynamic search spaces, where the objective functions vary abruptly and unexpectedly. Under these circumstances, the individuals' adaptation may be aided by a technique called decision variable relocation (Woldesenbet and Yen, 2009) that translates individuals in the decision space according to the fitness variations computed in the objectives space. Such an approach is applicable only to problems involving fixed width decision variables vectors, which is not the case of nonlinear system models. The idea of using information from both the decision and the objective spaces is further exploited in the form of mapping one space to the other by using neural networks (Adra *et al.*, 2009). It is also interesting to note a recent method of maintaining focus on the knees of the Pareto front (Rachmawati and Srinivasan, 2009), which identifies representative individuals for each bulge of interest in the Pareto front and uses their information to reconfigure the optimization objectives. This way, selection pressure is dynamically increased in favor of the trees situated in the knee regions, which stand a better chance of being highly populated.

## 4. PROPOSED RESEARCH METHODOLOGY AND PLAN

The current research comprises three main categories of enhancements. Firstly, the basic stages of the evolutionary loop are targeted, namely initial population generation, tree format processing and offspring generation. The second area of interest is that of nonelitist MOO, specifically selection pressure adjustment and focus control on

the significant region of the Pareto front. Finally, elitist MOO is upgraded by implementing diversity preservation mechanisms designed to balance decision making and search space exploration, in an unsupervised manner.

### 4.1 BASIC ALGORITHM ENHANCEMENTS

In order to assure good search space coverage, the authors suggest a method of building the trees in the initial population based on a set of six rules (Patelli and Ferariu, 2009a). The result is a quasi uniform distribution of the individuals yielding heightened exploration capabilities. Furthermore, the six rule tree building procedure prevents the undesirable cases of degenerated or ill balanced trees, encouraging the formation of well shaped chromosomes, processed at a minimal computational cost.

The suggested tree generation routine cannot guarantee NLP compliance. Therefore, the trees are transformed by rearranging all ill positioned "+" nodes, so that the resulting individual is NLP compliant, and in the same time, mathematically equivalent with the original chromosome (Patelli and Ferariu, 2009b). This way, the quasi uniform distribution of the trees is preserved, and, in addition, parameter wise linearity is assured, facilitating the successful hybridization of the evolutionary algorithm with a local parameter computing procedure based on QR decomposition.

An efficient parameters computation, on its own, cannot guarantee the quality of the current model as genetic operators play an equally important part in generating well adapted individuals. The regressors that survive within several trees over generations are, most likely, well adapted nonlinear atoms, thus crossover is enhanced to spot them and exclude all their component nodes from the potential cut point list (Patelli and Ferariu, 2009c). Mutation is upgraded to target both terminal names and their exponents, in order to control tree size by discouraging regressor compensation (Patelli and Ferariu, 2009b).

### 4.2 MULTIOBJECTIVE NONELITIST ENHANCEMENTS

In automatic control, the objective of keeping model complexity to a minimum is pursued only as long as overall accuracy is not affected. As an individual $M$ with a reasonable number of regressors $r$, is not necessarily parsimonious, a more refined **C**omplexity **F**unction (*CF*) is in order, including information about the number of terminals within each regressor, as well as a measurement of their relevance:

$$CF(M) = r + \frac{t}{n_u + n_y + 1} - \sum_{q=1}^{r} \lg\left|c_q\right| . \tag{3}$$

In (3), $t$ represents the total number of terminals to be found in the tree's structure, $n_u$ and $n_y$ are the input and output lags respectively, and $c_q$ denote the model parameters.

To dynamically balance the priorities of the two considered objectives, the initial population is split into two subpopulations out of which one is subjected to fitness assignment only relative to the **S**quared **E**rror **F**unction (*SEF*), which evaluates accuracy. The other subpopulation is further separated into two groups, as shown in Fig. 1. The individuals with better objective values than the average ones make up the first group, and will be evaluated relative to *SEF*, as they encode reasonably simple structures. The rest of the trees form the second group, subject to both *SEF* and *CF* assessment via dominance analysis (Deb, 2005). The purpose of the described clustering mechanism (Ferariu and Patelli, 2009a) is to increase selection pressure in favor of accurate and reasonably simple individuals, like the ones populating the interest region of the first order Pareto front (marked with "o" in Fig. 1). Once every *no_migr* generations, the two subpopulations exchange genetic material, namely their best chromosomes, according to a transfer rate that adapts to average tree complexity (Ferariu and Patelli, 2009b).

Migration unifies the two insular evolution processes, in a way that dynamically balances the two involved objectives.

### 4.3 MULTIOBJECTIVE ELITIST ENHANCEMENTS

To favor solitary elites over the ones on clusters, the radius of a niche has to be accurately computed. To meet that end, a dynamic niching technique is implemented by re-evaluating the cluster radius parameter after each new insertion in the elite set (Patelli and Ferariu, 2010). To focus the search on the interest region of the Pareto front, elites are grouped in a similar fashion to the case of nonelitist clustering. The elites in the target group take part in a separate offspring generation process, simultaneously with the one of the regular individuals. The resulted elite offspring is inserted in the active population after a similarity analysis meant to eliminate resembling chromosomes. Should diversity remain low, an infusion of fresh genetic material is performed to regain it.

## 5. PRELIMINARY RESULTS

**Table 1.** Input configurations (290 data point training set)

| Run | Lags | Population size [nr. of individuals] |
|---|---|---|
| **R1** | $n_y = 2$ $n_u = 2$ | 75 |
| **R2** | $n_y = 2$ $n_u = 2$ | 150 |
| **R3** | $n_y = 2$ $n_u = 2$ | 500 |
| **R4** | $n_y = 4$ $n_u = 5$ | 75 |
| **R5** | $n_y = 4$ $n_u = 5$ | 150 |
| **R6** | $n_y = 4$ $n_u = 5$ | 500 |
| **R7** | $n_y = 10$ $n_u = 11$ | 75 |
| **R8** | $n_y = 10$ $n_u = 11$ | 150 |
| **R9** | $n_y = 10$ $n_u = 11$ | 500 |

**Fig. 1** MOO evolved subpopulation clustering

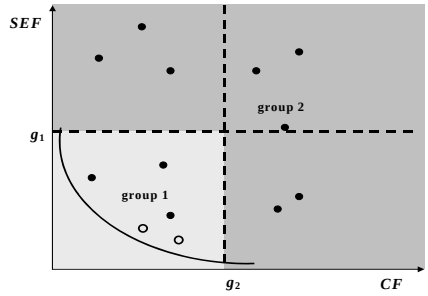


**Table 2.** CV models assessment MRE = mean relative error, reg = regressor no, term = terminal no

| Run | CMOO | | | | PCAM | | | | DNEC | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **MRE** | **reg** | **term** | **gen** | **MRE** | **reg** | **term** | **gen** | **MRE** | **reg** | **term** | **gen** |
| **R1** | 1.61% | 9 | 38 | 100 | 1.21% | 8 | 17 | 50 | 1.45% | 9 | 18 | 25 |
| **R2** | 1.79% | 11 | 49 | 100 | 1.31% | 9 | 34 | 43 | 1.23% | 20 | 34 | 31 |
| **R3** | 1.43% | 14 | 54 | 100 | 1.43% | 12 | 19 | 51 | 1.34% | 13 | 20 | 20 |
| **R4** | 1.98% | 45 | 86 | 100 | 1.29% | 10 | 15 | 45 | 1.45% | 15 | 34 | 34 |
| **R5** | 2.35% | 34 | 76 | 100 | 1.25% | 13 | 20 | 32 | 1.45% | 10 | 25 | 35 |
| **R6** | 1.33% | 38 | 56 | 100 | 1.41% | 11 | 21 | 43 | 1.36% | 11 | 25 | 29 |
| **R7** | 4.12% | 67 | 121 | 100 | 1.37% | 12 | 11 | 49 | 1.29% | 12 | 28 | 31 |
| **R8** | 3.65% | 89 | 245 | 100 | 1.38% | 9 | 13 | 54 | 1.35% | 12 | 19 | 29 |
| **R9** | 5.34% | 112 | 345 | 100 | 1.41% | 11 | 15 | 32 | 1.39% | 13 | 21 | 34 |

**Table 3**. Migration interval and laxity coefficient calibration

| | | | | | |
|---|---|---|---|---|---|
| *migrInt* | **10** | **10** | **10** | **3** | **25** |
| $g_1$ | ***m*** | ***m*** | ***m*** | ***m*** | ***m*** |
| $g_2$ | ***m*** | **1.5*m*** | **2*m*** | **2*m*** | **2*m*** |
| *MRE* | **75.33%** | **2.55%** | **1.33%** | **1.32%** | **2.85%** |
| reg | **1** | **3** | **7** | **13** | **6** |
| gen | **5** | **40** | **50** | **53** | **61** |

**Table 4.** DNEC and SADP for CV subsystem

| Run | Nr of trees in the interest zone | |
|---|---|---|
| | DNEC | SADP |
| **R1, R9** | 5 | 13 |
| **R2** | 6 | 4 |
| **R3,R7** | 7 | 11 |
| **R4** | 4 | 12 |
| **R5, R8** | 5 | 11 |
| **R6** | 9 | 9 |

The **C**ontrol **V**alve (CV) subsystem of the **E**vaporation **S**tation (ES) within the sugar factory in Lublin, Poland, with no available model, was identified via **C**lassic **M**ulti **O**bjective **O**ptimization (CMOO), **P**opulation **C**lustering and **A**daptive **M**igration (PCAM), **D**ynamic **N**iching and **E**lite **C**lustering (DNEC) and **S**imilarity **A**nalysis and **D**iversity **P**reservation (SADP) algorithms, respectively. For each of the nine runs (Table 1), the most accurate model from the first order Pareto set generated by each identification method was analyzed on a 300 data point validation set, as seen in Table 2. The optimum multiplier of the complexity boundary $g_2$ (Fig. 1), called laxity coefficient, determined by trial and error, is 2 (Table 3). The effects of frequent and rare migration are also presented. Table 4 shows that, on most runs, the SADP approach succeeds in populating the interest region with more individuals than in the case of DNEC.

## 6. FUTURE PLANS

Useful genetic material may be protected by encapsulating well adapted nonlinear blocks within trees. A concrete implementation could consider a fuzzy logic controlled aggregation of cut point smart search cross-over on the one hand, and the encapsulation genetic operator, on the other hand.

Dominance analysis is, by far, the most resource consuming stage of the multiobjective optimization procedure. A computationally cheaper implementation of Pareto front separation may be ensured by dedicated algorithms especially designed for the processing of partially ordered sets.

The authors also intend to build a wider, more diverse palette of test cases including complex industrial plants, chemical processes, biological systems, etc. Running the proposed algorithms to solve practical problems involving multiple inputs and outputs, dynamic objectives space landscape, model parameters inaccessible for direct measurements, etc, would outline the advantages of the described approaches, while also suggesting other possible improvement directions.

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8. *Elite Based Multiobjective Genetic Programming in Nonlinear Systems Identification*, **A.Patelli**, L.Ferariu, Advances in Electrical and Computer Engineering, ISSN 1582-7445, e-ISSN 1844-7600, 10(1), pp. 94-99, **2010**

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# Doctoral Consortium

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Interplanetary Networks, Wireless Networks, Routing, Homology Theory, Algebraic Topology

# Research Proposal

## Applied Homology Theory to Wireless Network Routing Protocol in the Interplanetary Context

### 1. Research problem statement

The developments in the space technologies are enabling the realization of deep space scientific missions such as Mars exploration. Interplanetary network is expected to be the next step in the design and development of deep space networks as the Internet of the deep space planetary networks. However, there exist significant challenges and unique characteristics of the deep space networking paradigm that need to be addressed for this objective as follows:

- extremely long and variable propagation delays;
- asymmetric forward and reverse link capacities;
- high link error rates for radio-frequency (RF) communication channels;
- intermittent link connectivity;
- lack of fixed communication infrastructure;
- effects of planetary distances on the signal strengh and the protocol design;
- power, mass, size and cost constraint for communication hardware and protocol design;
- backward compatibility requirement due to high cost involved in deployment and launching process

These characteristics lead to different research and hence necessitate different approaches and protocol designs at each of the networking layers for the interplanetary (IPN) Internet. Interplanetary routing consist of two majors phases. The first, to route between source and destination planet nodes, and the second, to route within a planet node. Static routing has been the method of choice for most routing in space networks. Network engineers manually program the routing tables and decide the next hop for that message. This technique works well if the nodes and links as well as traffic characteristics are fixed and well-know ahead of time. Static routing also works well for inter-node communication in a flying system. But if new satellites become available, routing tables on nodes that need to communicate with that satellite need to be changed. Newly deployed nodes might also provide on alternate path for communication and better communication services such as higher bandwidth. It is possible to manually update routing tables in order to accommodate new nodes and capabilities, of course. However, when the number of such nodes increase it becomes increasingly vital to have a system that can adapt itself the network dynamics without requiring a manual intervention. There are some challenges that make the design of mobile ad hoc network routing protocols a tough task. Firstly, in mobile ad hoc networks, node mobility causes frequent topology changes and network partitions. Secondly, because of the variable and unpredictable capacity of wireless links, packet losses may happen frequently. Moreover, the broadcast nature of wireless medium introduces the hidden terminal and exposed terminal problems. Additionally, mobile nodes have restricted power, computing and bandwidth and require effective routing schemes. There is a growing need to accomplish new types of missions in space where unusually large number of satellites are required. This scenario of a distributed satellites system consisting of a large number of satellites with intersatellite communication links (ISL) is analogous to the concept of terrestrial wireless sensor networks (WSNs), where numerous devices, or nodes, are spread out over large areas to fulfill a particular monitoring/ communication purpose.

Spacecraft platforms are highly complex systems. Harnessing and electrical interconnections of spacecraft components require a high level of assembly, integration and verification (AIV) effort. Our work is driven by the following factors. First, it is impossible to manually control the node in a network, so the node has to be able to self-configurate. Second, each node does not know its location (they are devices without GPS (Global Positioning System) or other sophisticated positioning systems). Third, it is concerned with the application of wireless protocols for communication between satellites (intersatellite communication).

## 2. Significance and Objectives

Recent advances in micro electro-mechanical systems permit robust microsatellites to be built. The combined resources of several of these smaller, smarter satellites for applications such as distributed aperture remote sensing, has significant scientific, performance and cost advances over using large heavy, single-mission satellites. In order to effectively combine the resources of autonomous, formation flying constellations of smaller satellites, the satellite must have the ability to communicate with each other.
Autonomy implies minimal dependence on ground stations for communication purpose, and so ISLs must be used to allow satellites to share their individual information and use their combined resources to achieve a more complex goal.
Many of the problems associated with ad hoc wireless systems involve deducing global (environment) features of a system based on local (node) data. The problem of passing from local to global is one of the oldest challenges in mathematics. Many of the great theorems of calculus can be viewed as local-to-global results: e.g.,Taylor's Theorem, which relates derivatives at a point to the global function. In particular, the 100 year history of algebraic topology is a formal algebraic response to the problem of deducing the global features of a topological space from local combinatorial properties. There is a strong analogy between the network-topology of a wireless network and the types of algebraic chain complexes used in homology theory. For example, consider a topological space X with a decomposition into cells or simplices of various dimensions. The only information required to derive the homology of X, $H_*(X)$, is the local combinatorial data associated to each cell: who is connected to whom, and in what order. No coordinates, no orientations, and no geometric data are required. In like fashion, in ad hoc wireless network, individual nodes have local extent. They can communicate with a small subset of neighboring nodes in the network. They very naturally can arrange themselves into cliques, the analogues of simplices for a network, by passing and recording signals. By importing perspectives and techniques from algebraic topology, it is possible to deduce rigorous results about coverage, hole detection and repair, time-dependent network behavior, node localization, and other desirable features based on little more that relative communication links. We intend to exploit the algebraic topology to map the topology of planets, satellite and spacecraft to achieve optimal routing between planet nodes. The constellation is considered as an independent routing domain made of nodes (the satellite) and links (the ISL). The purpose of ISL routing is therefore to compute an appropriate path (or route) between the source and destination satellite. The route is made of satellite and ISLs. Because broadband satellite systems are dedicated to the transport of multiservice traffic, routing should be able to satisfy the different set of requirement for these traffic flows. The characteristics of the routes have to fulfill the requirement for service. These characteristics may have network wide scope and are therefore better controlled if the route computation process is performed in a single node (decentralized routing) and is sensitive to changes of the network state (adaptative routing). Homology theory is a powerful theoretical tool that makes it possible to identify quickly all the coverage holes

in a wireless networks. This feature only requires from the nodes the knowledge of connectivity information from direct neighbors. Compared, to classical approaches, the homology theory makes it possible to design tractable distributed routing algorithms in a determinist context (propagation model takes only into account the pathloss component of attenuation) and for which performance does not decrease with the number of nodes. The main goal of this PhD is to investigate the possible extensions of homology theory in a random context, and more precisely to design routing protocol and algorithms that rely on these extensions. The potential applications of PhD development will be routing protocols for wireless networks, in deployment such as inter spacecraft communication, inter-satellite or surface planetary communication.

## 3. Summary of the Current State-of-the-Art

Three distinct bodies of research related directly to the focus of this thesis. The first is interplanetary internet which aims to establish a communication infrastructure and a network architecture in deep space and connect planets and satellites, etc. The second field is routing where the connectivity of the network is intermittent, affected by movement of planets out of range of each other and occlusion of a planet by another. Also the satellite and mission stations are power constrained, which makes traditional routing protocols extremely expensive in terms of time and energy consumed. The third body of relevant research focuses on algebraic topology, a mathematical tool, which uses network topological spaces and their topological invariants. The idea behind this is that the local properties, for instance, of a sensors network, obtained by local interactions among nodes, can be captured by certain topological spaces. Also the global properties of the sensor network characteristics correspond to certain topological invariants of these spaces. The next subsections describe the summary of the current state of the art in each one of these fields.

### 3.1 Interplanetary Internet

The interplanetary internet is a next-generation space network architecture proposed by NASA (National Aeronautics and Space Administration) which aims to establish a communication infrastructure in deep space and connect planets and satellites etc. In [15] is presented a detailed description of routing problems in IPN (InterPlanetary Network) and a summary of the existing routing algorithms, with an evaluation for these routing schemes. A number of studies [4] [12] [8] [5] propose exploiting the geometry of orbits to compute the next hop towards the destination. These schemes assume that the information relevant to path computation (topologies and orbits and number of satellites) are well-known and programmed into the satellite ahead of time. Given this information, custom algorithms that exploit geometry can be used to compute the paths to the destination at any given time. These studies are limited to various earth orbits (LEO – low-earth-orbit, MEO – medium earth orbit , GEO - geostationary). A survey of the proposed architectures and communication protocols and algorithms for deep space networks and Interplanetary Internet is presented in [3]. The authors investigated the current and proposed protocol stacks for the communication throughout the Interplanetary Internet. In addition, they explore the challenges, related work and the open research issues pertaining to the Interplanetary Internet communication protocols for each layer.

### 3.2. Routing in Space

A survey of mobile ad hoc network routing protocols is presented in [11]. Active research work for mobile ad hoc network is carrying on mainly in the fields of medium access control routing, resource management, power control and, security. Because of the

importance of routing protocols in dynamic multi-hop networks, a lot of mobile ad hoc network routing protocols have been proposed in the last few years. The design of the protocols are driven by specific goals and requirements based on respective assumptions about the network properties or application area. The survey tries to review typical routing protocol and reveal the characteristics and trade-offs. MARVIN [13] is a routing protocol for interplanetary network and leverages predictability of the orbits to compute paths. MARVIN uses an augmented Dijkstra's algorithm to compute the shortest path according to a given metric. However, they use published ephemeris tables and only address path computation and the algorithm can not rapidly adapt to expected as well as unexpected changes. They propose computing the paths in a centralized node and disseminating the routing table to the nodes. We believe this will not scale to large number of satellite nodes we envision in the future. Advanced architectures and efficient routing protocols for satellite and space networks to support applications with different traffic types and heterogeneous quality of service requirements are presented in [6]. Specifically, the authors propose a new QoS-based routing algorithm (QRA) as a connection-oriented routing scheme to support real-time multimedia applications in satellite networks. Also, the satellite grouping and routing protocol (SGRP) is presented as a unicast routing protocol in a two-layer satellite IP network architecture. The border gateway protocol - satellite version (BGP-S) is then proposed as a unified routing protocol to accomplish the integration of the terrestrial and satellite IP networks at the layer.

### 3.3. Algebraic Topology

Homology theory is used in [7] to give coverage criteria for networked sensors which are "nearly senseless". It seems counterintuitive that one can provide rigorous answers for a network with neither localization capabilities nor distance measurements. The results reviewed by the authors evolve are of applied computational topology. Recently, it has been demonstrated that homology theory is useful for problems in data analysis and shape reconstruction, computer vision, robotics, rigorous dynamics from experimental data, and control theory. See [9] for an overview of some current applications. In our work, inspired by the idea first presented by Robert Ghrist [10], we take into account algebraic topology tool, homology and homotopy theory to design routing protocol to space wireless networks. Of the most fundamental problems in this domain is the coverage and routing problem. One of most prominent approaches for addressing the coverage problem has been the computational geometry approach, in which the coordinates of the nodes and standard geometric tools are used to determine coverage. Such geometric approaches often suffer from the drawback that they can be too expensive to compute in real time. Moreover, in most applications, they require exact knowledge of the locations of the sensing nodes. Although, this information can be made available in real-time by a localization algorithm or by means of localization devices (such as GPS) it can only be used most effectively in an offline pre-deployment analysis for large networks or when there are strong assumptions about the geometrical structure of the network and the environment. This drawback becomes more evident if the network topology changes due to node mobility or node failure. Finally, localization equipment adds to the cost of the network, which can be a limiting factor as the size of the network grows. Consequently, an approach for addressing these issues becomes essential. More recently, topological spaces and their topological invariants have been used in addressing the coverage problem in the absence of geometric data, such as location or orientation. The work presented in [16] is based on calculation of nodes coverage, the idea is to let networks be adaptative to ongoing changing network situation. An algebraic topology tool, homology, is used by the authors to calculate

sensor node coverage since the local properties of a sensor network, obtained by local interactions among nodes can be captured by certain topological spaces. Also the global properties of the WSN characteristic correspond to certain topological invariants of these space. With the network coverage information a WSN then can adjust itself based on current network topology. The simplicial complexes model, the connectivity of agents in the network, and the homology groups of simplicial complexes provides information about the coverage properties of the network.

## 4. Proposed Research Methodology and Plan

The objectives of the proposed research would be to:

- Survey published and unpublished sources to obtain information regarding into satellite communication and routing.
- Investigate the possible extensions of homology theory in a random context and more precisely to design routing protocol and algorithms that rely on these extensions.
- Specify a spatial scenario including satellites, planets and spacecrafts to compose a protocol testing program.
- Implement the designed routing protocol taking into account algebraic topology issues (Homology Theory).
- Conduct a simulation study using STK/OPNET [1] [2].
- Conduct numerical analysis to estimate the proposal routing protocol performance,
- Compare our proposal routing protocol to other routing protocol taking into account spatial context and dynamic routing.

Research Period: the estimated time needed to compute the research described here will be on the order of 48 months.

## 5. Preliminary Results

The initial scenario that we envision there is no means of determining relative position. In situations where geographically large countries or regions cannot obtain uniform, high-elevation coverage from single satellite in a less than ideal orbital slot, as few as two ISL linked (and differently positioned) GEO craft can became a virtual single satellite. Multiple interconnected satellite permit the use of smaller, higher gain spot-beams, while continuing to maintain good elevation angles. From this scenario we create the relationship between simplicial complex and the space network. The sensing and communication properties of network can be captured by simplicial complexes and their homological groups. Considering in a satellite network, each identical node has same communication range r and they form a communication graph. In this graph, each vertex stands for a satellite node and an edge between two vertices means that the two nodes are within the communication range r of each other. Then, we build the Rips complex which is generated from communication graph.

Given the Rips complexes, we intend to integrate it together STK (Satellite Tool Kit) and OPENET modeler. Following this, we are going to create the protocol business rules over this integration.

We do not have any quantitative result over the proposal protocol yet. Our studies in topological methods has been showing interesting perspectives to deduce rigorous results about coverage, hole detection and repair, time-dependent network behavior, node localization, and other desirable features based on little more that relative communication links. We believe that topological results being based not on precise distances or displacements but rather upon global features, tend to be very robust and

insensitive to noise and various errors, a useful feature for real-world problems. Specifications are being conducted in homology theory to attend some necessity of space Internet. This specification will be taken into account to design and implement the routing protocol. The proposal homological routing protocol is still in the specification and design phases. The goal is that, the protocol could adapt itself to use new resources available in a space network and keep on functioning gracefully in a dynamic space.

## 6. Future Plans

To design a homological routing protocol using algebraic topology issues for future space science missions is a new research in the wireless networks field. These missions involve an increasingly large number of satellites, which render the current manual and static routing practice ineffective because those techniques do not scale with the number of nodes. We intend to use Euler Characteristics to compute the path into the routing protocol and to study the routing state and route stability to evaluate the paths. Also, we intend to extend the use of homological routing protocol in planetary networks, for instance, space wireless sensor network in the Mars surface. Further, we are going to do simulation experiments and formal verification to validate our proposal.

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**Brief CV**

## Academic Formation

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## Professional Experience

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# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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# Research Proposal

## Prosthetic Ankle Intelligent Control

### Research problem statement

Amputation of the limb below the knee is prescribed for people who have undergone extreme trauma or those suffering from vascular or circulatory disorders. Such amputees are typically fitted with a prosthetic device that is designed to restore a minimal level of comfort and mobility. However, the prostheses currently available to below-knee (transtibial) amputees are passive devices that focus primarily on the ability of the individual to bear his/her body weight on the affected limb, have adequate balance, and a minimal degree of mobility. Such a prosthetic device has long term pathological consequences for a majority of amputees while impacting their quality of life. In this research proposal, this issue is addressed through the development of an intelligent prosthetic ankle that can mimic the biomechanical function and natural human locomotion. In order to meet this goal, a mechanical ankle joint is developed and control algorithms are designed to adapt the performance of this device to changing user requirements. The performance of the ankle is validated in a simulated robotic test cell prior to its clinical trials involving human subjects.

### Significance and objectives

Human ankle is a unique design with capabilities of shock absorption and propulsion generation which can guarantee the stability, mobility, and withstand 1.5 times the body weight during normal ambulation and eight times the body weight during running [1]. During ambulation, the ankle can change the stiffness at the ankle joint, perform dorsiflexion and plantarflexion on the ankle angle, and provide propulsion power to aid the human body moves forward. These capabilities help human walk effortlessly in different walking conditions (walking speed, step length, etc.) on different terrains (level ground, ramps, staircases, etc.) with additional perspectives (type of shoes, height of a heel, extra carried heavy object, etc.).

After a below-knee amputation, a patient preserves a residual limb that can be fitted with a transtibial prosthetic foot. Comfort and the degree of mobility provided by the prosthesis are the top two factors in obtaining optimal restoration of function. To provide the maximal comfort and near-to-normal performance, the prosthetic foot must have capabilities of changing ankle joint stiffness, manipulating ankle angle, and providing power to the human body. Beside the mechanical design of the device, one also needs to develop an efficient control system so that the prosthesis can adapt to different activities resulting in different gain on different types of terrain.

Most of the prosthetic devices in the market today are passive which means that the performance of the device cannot be modified to meet varying patient requirements. This limitation results in instability and asymmetric gaits. Some of these devices use energy storage and return elements to absorb energy during the loading phase and release energy during the propulsion phase. Several active controlled prostheses are developed including Ossur's Proprio Foot$^{TM}$ [2] and Powered Foot One [3]. The lack of an accurate dynamic model describing the characteristics of the prosthetic ankle and the variations of the biomechanics of human ankles makes it difficult to implement the traditional approaches in controlling these devices.

According to a 1996 study sponsored by the Center for Disease Control (CDC) [4],[5], there were 1,285,000 persons with limb loss in the United States. A significant majority of the amputees also suffered from diabetes as well as circulatory and vascular problems. Ill fitting or non-functional prostheses can result in sores and other long term pathological conditions in these users. Improving the fit and functionality of the prosthetic device will improve the mobility of these individuals thereby enabling them to join the active work force. Improved prosthetic devices will also improve the quality of life and long term health of the individuals and reduce the cost of long term care.

The development of an intelligent prosthetic foot that can better mimic the biomechanical function and natural human locomotion is necessary in order to meet the demand for comfort, degree of mobility, symmetric gait, and near-to-optimal performance. To achieve maximal restoration of function, the control mechanism must be able to adapt the performance of the ankle joint to walking environment in real time and must be robust to dynamic uncertainties of the prosthetic ankle, measurement and actuator noises, and intent of a patient (e.g., walking versus sitting and crossing legs). In this research, the development of a mechanical prosthetic ankle and its performance using a neural network based controller will be studied. The result is a prosthetic foot whose joint stiffness, ankle angle, and ankle power can be controlled in real time. The user perceived performance of the computer controlled ankle and the traditional prosthetic devices like the SACH foot [6] will be documented in order to identify areas for improvement.

**Summary of the current state-of-the-art**

Recent advances in prosthetic ankle technology highlight the ability of active devices to control the stiffness and the position of the ankle, as well as their ability to provide return power to aid locomotion. Ossur's Proprio Foot$^{TM}$ is based on neural network technology and enables the prosthetic device to adapt its position to the walking conditions. However, this device is not fully active and only controls flexion during the swing phase. During the stance phase, the ankle joint is passive and the ankle stiffness is fixed making it difficult to alter its performance. In Powered Foot One, control algorithms are derived from a linearized stiffness model of an ankle and result in fixed control parameters for each type of gaits. Since the biomechanics of the human ankle changes dramatically with respect to walking speed even on the level ground [7], this

approach might have difficulty in accommodating different walking environment in real time.

**Proposed research methodology and plan**

Human gait can be divided into two phases: the “stance” phase when the foot is in contact with the ground and the “swing” phase when the foot is swinging in the. In each phase, there is a typical control requirement for the prosthetic ankle in order to mimic the human ankle and guarantee symmetric gait. Our approach is to use the neural network technology to provide efficient stiffness and power control during the stance phase and position control during the swing phase of the gait cycle.

This neural network based mechanism will comprise of a classifier/detector and a controller. First, a neural network based classification/detection scheme will be developed in order to recognize the gait and the associated Temporal-Spatial parameters as well as detect the occurrence of different events in the gait. Then, a neural dynamic programming (NDP) controller will be designed to guarantee a desired performance in each phase of the gait. The learning-based NDP controller can guarantee the optimal performance in the absence of the analytical model and in the presence of measurement as well as approximation errors. It is noted that both the classifier/detector and controller perform in real time. A foot prototype with the abilities of changing the stiffness at the ankle joint, changing the angular position of the ankle, and providing power to the remaining part of the human body will be developed and used as the test bench for the combined classifier/detector – controller scheme. The prototype device is also equipped with sensory information systems to provide typical biomechanics measurement of the foot during walking periods. Finally, the prototype with developed control algorithms will be tested using a robot test cell (Figure 1) before human-in-the-loop simulation is performed to evaluate the prosthetic foot.

Figure 1. Robot test cell with a simple foot prototype

**Preliminary results [8]**

Interfacial force between the socket and residual limb of a transtibial amputee was collected at the Health Science Department, University of Oklahoma [9]. Twelve force sensors (FlexiForce® [10]) were placed inside the socket at four locations: anterior, posterior, lateral, and medial at three levels: distal, middle, and proximal of the residual limb. These sensors are thin enough to enable non-intrusive measurement. Each force sensor was calibrated and tested for contact prior to the experimental tests. The patient was asked to walk in different conditions (types of gait): forward ambulation at normal speed, forward ambulation with high speed, ascending and descending a flight stairs. Figure 2 shows the arrangement of the force sensors inside the prosthetic socket.

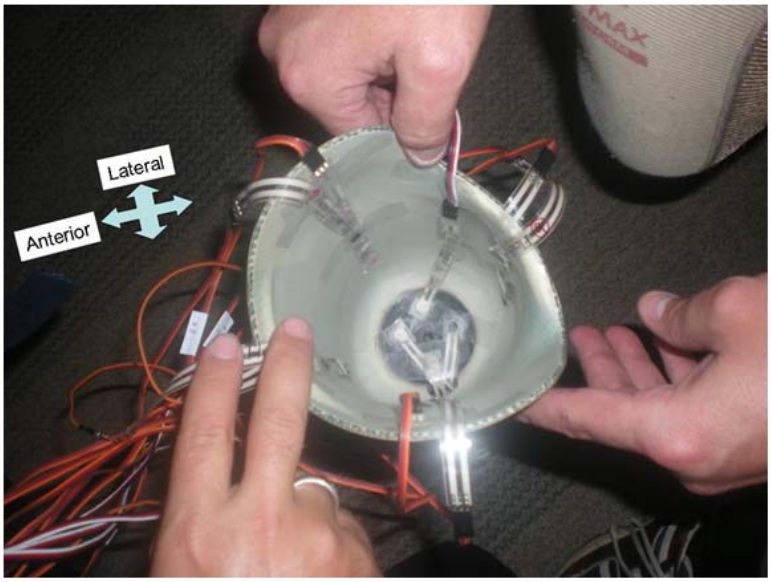


Figure 2. Arrangement of force sensors inside the prosthetic socket

A multilayer feed-forward neural network was implemented to classify the types of gait. Force data of five steps from each test were extracted and super-imposed to create the set of training data. The validation set contained force data from all remaining steps. After training, the neural network showed the ability of classifying the steps corresponding to “forward”, “forward brisk”, and “stair descent” very well (success rate of 100%). In the validation set of twelve steps from “stair ascent” gait, one step was misclassified as “stair descent”. From the literature, the following events occur during the stance phase of the human gait in forward direction: “heel strike”, “foot flat”, “middle stance”, “heel off”, and “toe off”. Since a human ankle has a typical function in each sub-phase of the stance phase, a step event detection scheme was implemented and force data from the “forward” and “forward brisk” walking conditions were used for detection. The events “heel strike” and “toe off” can be easily detected by examining the activation of the interfacial force data. The implemented scheme showed the ability of detecting other events with very similar results showed in literatures.

## Future plans

The development of the intelligent prosthetic ankle in this research will advance the extension of the NDP control methodology to the bioengineering area. The proposed approach will also broaden the horizons for prosthesis design and control implementation for a knee joint. The coordination and control of both knee and ankle joints will benefit both unilateral and bilateral above-knee amputees.

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Brief CV

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## Education

**Currently:** Ph.D. student, Electrical Engineering, University of Oklahoma, Norman, OK, USA
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**M.Sc.** Electrical Engineering
University of Oklahoma, Norman OK, 2008
GPA: 4.0

**B.Sc.** Department of Automatic Control, 2004
Hanoi University of Technology, Hanoi, Vietnam
Ranking: 1/94

## Research Interests

Nonlinear Systems, Adaptive Control, Optimal Control, Intelligent Systems, Optimization

## Professional Experience

**1/2006 - present:** School of Electrical and Computer Engineering, University of Oklahoma

- Current project: Neural network-based control for a prosthetic ankle
  - Develop an online learning control for a prosthetic ankle
- Project: Intelligent Compaction (1/2006 - present)
  - Develop a Calibration and Analyzer tool for the neural network-base asphalt compaction quality predictor
  - Implement a real-time asphalt compaction quality predictor running on different hardware platforms
  - Field trip coordinator: in Oklahoma and other states in the US
- Project: Hybrid Robust Control for Unmanned Aerial Vehicles (2/2007 – 9/2007)
  - Develop an intelligent fault detection scheme for an UAV.
- Paper review: Journal of Intelligent and Robotic Systems
- Teaching Assistant: Associated classes – Energy Conversion, Signals and Systems, Digital Signal Processing, Modern Control Engineering

**10/2004 - 12/2005:** Department of Automatic Control, Hanoi University of Technology, Vietnam

- Teaching Assistant: Associated classes –Control Theory; C/C++
- Instructor at Siemens Automation Training Center, OMRON Automation Laboratory, Simulation Laboratory

## Publications

1. Sesh Commuri, Anh Mai, Musharraf Zaman, *"Neural Network-based Intelligent Compaction Analyzer for Estimating Compaction Quality of Hot Asphalt Mixes"*, ASCE's Journal of Construction Engineering and Management, (accepted)
2. Sesh Commuri, Anh Mai, Musharraf Zaman, *"Calibration Procedures for the Intelligent Asphalt Compaction Analyzer"*, Journal of Testing and Evaluation, Vol. 37, No. 5, September 2009, pp. 454-462
3. Sesh Commuri, Anh Mai, *"Field Validation of the Intelligent Asphalt Compaction Analyzer"*, MED '09, 17th Mediterranean Conference on Control and Automation, June 2009, pp. 651-656
4. Fares Beainy, Anh Mai, Sesh Commuri, *"Unmanned Aerial Vehicles Operational Requirements and Fault-Tolerant Robust Control in Level Flight"*, MED '09, 17th Mediterranean Conference on Control and Automation, June 2009, pp. 700-705
5. Sesh Commuri, Anh Mai, Musharraf Zaman, *"Neural Network-based Intelligent Compaction Analyzer for Estimating Compaction Quality of Hot Asphalt Mixes"*, Proceedings of the 17th World Congress, The International Federation of Automatic Control, Seoul, Korea, July 2008, pp. 2224-2229

**Honors and Awards**

- 2008: Haskell Scholarship, OG&E Scholarship, University of Oklahoma
- 2008: Cleo Cross International Student Scholarship, University of Oklahoma
- 2006-2009: Sooner Heritage Foundation Scholarship, University of Oklahoma
- 2008: Outstanding Leadership Award, University of Oklahoma
- 2002: Toyota Cooperation Scholarship, Vietnam
- 1999-2004: Excellent Academic Achievement Scholarships, Vietnam

**Other Experience and Activities**

- **Activities**
  - 4/2007 - 5/2008: General Secretary, Graduate Student Society, School of Electrical and Computer Engineering, University of Oklahoma
  - 8/2006 - 5/2008: Vice President, President, Society of Vietnamese Students, University of Oklahoma
- **Affiliations**
  - Student Member of the Institute of Electrical and Electronics Engineers
  - Member of the Golden Key International Honor Society

**Skills**

- Strong mathematical background
- Programming languages: Pascal, C/C++, Visual C++, Visual Basic…
- Engineering design tools: Matlab/Simulink, Step7, Protel, CAD…
- Excellent team work spirit and field work experience

# Application for the the Doctoral Consortium ICNSC 2010

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**Research field: Adaptive Dynamic Programming(ADP)， Adaptive Critic Design**

**Year in the Ph.D. program: 2nd year**

# RESEARCH DESCRIPTION

(a) Research problem statement;

In certain real-world applications, it may not be possible for the agent to know the environment thoroughly and completely. Let's consider, for example, a robot equipped with sensors that return an observation [1]. The robot may not know its exact location, but only the limited information from a camera with which sensory observations are recorded. Instead of telling the robot its exact location, the sensors observe whether it is in a corridor, an open room, a T-junction, or, the fact that there is a wall to its left [2]. This category of problems is referred in the community as various terms such as "hidden state", or less often used "incomplete perception", or "perceptual aliasing"[1]. Mathematically speaking, this category of problems, known as partially observable Markov decision process (POMDP), introduces the Hidden Markov Model (HMM) into reinforcement learning [3]. The POMDP differs from HMM in that there is not as yet known computationally tractable algorithm for POMDPs [4].

(c) Summary of the current state-of-the-art;

So far, there are two approaches to tackle this kind of problems [1]: state-free stochastic policies and policies with internal states. For instance, the policies with internal states approaches can trace back its root in the system theory: the observability and state observer theory of linear systems. Such approaches integrate the state estimation with learning control and construct an internal representation of the system states by feature extraction from past internal representations and the observation states from sensors [5]. This involves a discussion of the length of the past time-window frame: how long should the critic keep in mind? Recurrent neural network has been suggested to be a powerful tool in memory [2], which is successfully demonstrated in [6].

The prevailing research on POMDP up to now is based on building up a state estimator to output a "belief state" to estimate the underlying state [7], [8]. Briefly speaking, a belief state is a probability distribution over states of the environment, indicating the likelihood, given the agent's past experience that the environment is actually in each of those states. By introducing this term to summarize the past experience, the hidden states are kept Markov [2]. The state estimator can be constructed using either the estimated model or Bayes rule. Fig 1 illustrates the basic structure for a perfect-memory controller. The component on the left is the state estimator, which computes the agent's belief state, $b(t)$ as a function of the old belief state, the last action $a(t)$, and the current observation $i(t)$. In this context, a belief state is a probability distribution over states of the environment, indicating the likelihood, with knowledge of the history of the system. The state estimator can be constructed either straightforwardly using the estimated world model or by Bayes rule in a statistical sense.

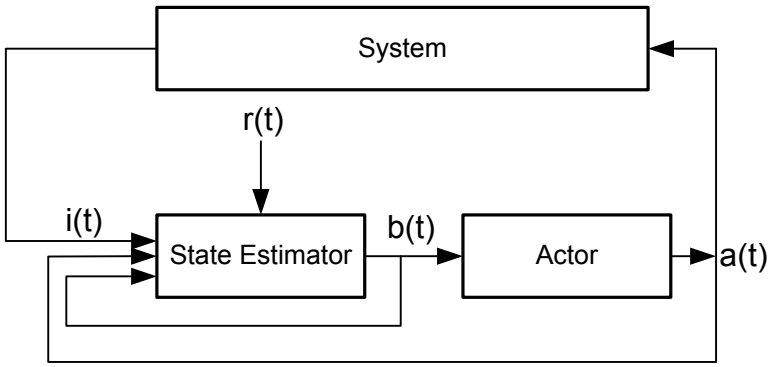


Fig1 Structure of a POMDP with State Estimator [Kaelbling, Littman, and Moore, 1996]

However, an inevitable drawback of this kind of approach lie in that state estimation puts strong restrictions on the environment, which becomes unrealistic assumption in real applications. In addition, the computation cost expands by introducing state estimate, in that other component must wait to work until the state estimate converges and output an idea estimate. The difficulty lies in that once the state estimate have been obtained, dynamic programming (DP) must be performed in the continuous probability space, and this DP implementation is computationally intractable except for small state spaces. Thirdly, the convergence is also a concern because introducing in the state estimator not only introducing the convergence of the state estimator itself but also the impact of convergence on other component of the system, like the critic and actor. Finally, as we discussed in [2], the critic based on estimator deviates from the principle of a good critic: t should have the "generalization" or "stationary" property: If we know that similar $(x,u)$ pairs have similar cost-to-go $J$ values, a good generalized function approximator is supposed to output with a similar $J$ value even if that state-action pair has never been encountered before. However, since critic is based on past traces and experience, it might not be "generalized" enough, i.e., not "memory-less" [4].

(d) Proposed research methodology and plan;

In our current work advised by Prof. Haibo He, we analyze a class of actor-critic algorithms under a POMDP environment. Specifically, in this work, we focus on the two-time-scale framework in which the critic uses temporal difference with neural network (NN) as nonlinear function approximator, and the actor is updated using greedy algorithm with the stochastic gradient approach. Instead of the common construction of hidden state estimator, we develop the idea originated in [4] from semi-batched Q-learning to online action-dependent actor-critic structure.

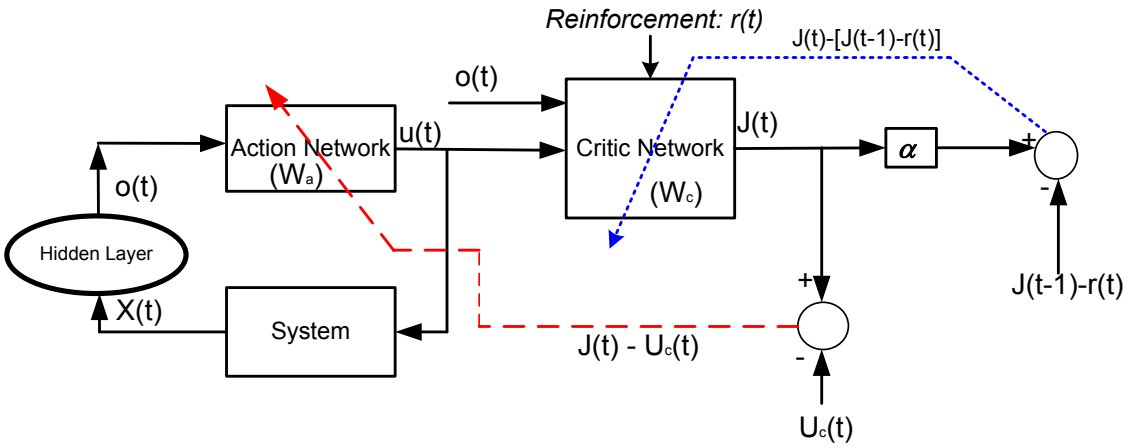


Fig. 2. The framework from the actor-critic perspective

Fig. 2 shows the main architecture of the actor-critic paradigm motivated by the work in [9]. In this architecture, chain backpropagation rule is the key to the training and adaptation of the parameters of all these networks (action network, and critic network) [9]. Since the learning in the action network is similar to the classic ADP model, we will only focus on the system architecture and the convergence issue. In order to focus on the learning principle, we assume neural networks with a simple 3-layer nonlinear network (with 1 hidden layer) are used in both action network and critic network. We would like to note that the learning principles discussed here can also be generalized to any arbitrary function approximator by properly applying backpropagation rule.

(b) Significance and objectives;

This framework explores the ability of the adaptive dynamic programming (ADP) approach in POMDP environment without implementing extra architectures such as state estimators. This is an intriguing topic since it explores the capability of the adaptive dynamic programming (ADP) approach in POMDP environment without implementing extra architectures such as state estimators. To our best knowledge, this is the first time to extend the theoretical framework in [4] to an online action-dependent actor-critic paradigm with neural network as nonlinear function approximator.

(e) Preliminary results;

We tested the performance of the proposed approach in a Furuta pendulum swing-up and balancing task. In the simulation, a run consists of a maximum of 1000 consecutive trials. Note that only angle of the driving arm and angle of the pole are observable whereas angular velocity of the driving arm and angular velocity of the pole are not. A run is considered successful if the last trial (trial number less than 1000 in this case) of the run lasted 100,000 time steps. Otherwise, the run is considered unsuccessful. All the results are based on 20 random runs with zero initial states and random initial weight matrices. In our simulation, the time step was set 0.02s; a pole is considered failure once the pole is outside the range of [-12; 12] degrees or the driving arm is beyond the range of [-170; 170] degrees in reference to the central position. The control u generated by the action network is converted into force by an analog amplifier through a conversion gain Mag = 10 (in Newton/volt). This is an important topic since it explores the ability of the adaptive dynamic programming approach in POMDP environment without building up state estimators to output belief states. Both theoretical research and detailed simulation results based on the Furuta pendulum balancing task are used to demonstrate the effectiveness of this approach.

(f) Future plans

In my research work, we also delve into the ADP research with a focus on its learning principles, architectures, and applications for machine intelligence research. Based on the existing community efforts on this topic, we also propose an ADP architecture with deep learning framework, i.e., a hierarchical learning architecture with multiple goal representations based on adaptive dynamic programming (ADP). In addition to the classic ADP design with an action network and a critic network, the proposed ADP architecture in this work integrates another network, the reference network, to provide the internal reinforcement representation (secondary reinforcement signal) to interact with the operation of the learning system. Such a reference network serves an important role to build the internal goal representations. Meanwhile, instead of using the single binary reinforcement signal of the traditional ADP design, the proposed architecture enables the system to use two types of reinforcement signals for improved generalization and learning capability, a primary reinforcement signal from external environment and a secondary reinforcement signal from reference network. Furthermore, motivated by recent research in neurobiological and psychology research, the proposed ADP architecture can also be designed in a hierarchical way, in which different levels of internal reinforcement signals can be developed to represent multi-level goals for the intelligent system. Detailed system level architecture, learning and adaptation principle, and simulation results are presented in this work to demonstrate the effectiveness of this work.

In our future work, we will also focus on, but not limited within, the mathematical foundation for the ADP design with deep learning architecture. Currently there are two ways of mathematical foundations for stochastic programming problem: one is the sub-gradient based stochastic approximation, e.g. Robbins-Monro algorithm and sampling-based approximation methods, e.g., sample average approximation (SAA) method. Neither of the two categories has satisfactory on convergence analysis so far. In our future study, we will focus on the convergence analysis of the first stochastic programming method, namely, stochastic approximation. The prevailing method originates from ODE (ordinary differential equation) approach and finally comes down to a contraction mapping and fixed-point iteration problem. The other approach is more from a statistic perspective, which is based on martingale theory. In our current research, we follow the second approach.

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[10] B. Liu, H. He, and D. W. Repperger, “Two-time-scale online actor-critic paradigm driven by POMDP”, submitted to ICNSC2010.

# RESUME


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## RESEARCH INTEREST

| | |
|---|---|
| Reinforcement Learning | Adaptive Dynamic Programming(ADP)， Adaptive Critic Design |
| Stochastic Optimization | Stochastic Approximation, Markov Decision Process, Partially Observable Markov Decision Process(POMDP) |

## EDUCATION

| | | |
|---|---|---|
| 2008- | Stevens Institute of Technology | |
| | ***Ph.D candidate*** | ***Computer Engineering*** |
| 2005-2008 | University of Science and Technology of China | |
| | ***M.E*** | ***Control Science and Engineering*** |
| 2001-2005 | Nanjing University of Posts and Telecommunications | |
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## PUBLICATIONS

### Statistical Machine Learning

1. Adaptive Dual Network Design for a Class of SIMO Systems with Nonlinear Time-variant Uncertainties
   **Bo Liu**, Haibo He, Sheng Chen, *Acta Automatica Sinica*, in press
2. A Dual-System Learning and Control Method for Machine Intelligence
   **Bo Liu**, Haibo He, and Sheng Chen, *Thirteenth International Conference on Cognitive and Neural Systems (ICCNS)*, Boston University, May 27-30, 2009
3. A Hierarchical Learning Architecture with Multiple-Goal Representations based on Adaptive Dynamic Programming
   Haibo He, **Bo Liu**, *2010 IEEE International Conference on Networking, Sensing and Control*, submitted
4. Two-Time-Scale Online Actor-Critic Paradigm Driven by POMDP
   **Bo Liu**, Haibo He, Daniel.Repperger, *2010 IEEE International Conference on Networking, Sensing and Control*, submitted

### Adaptive Sliding Mode Control and Optimization on Power Systems

5. Arbitrary-order Robust Differentiation Based Sliding Control on PM Stepper Motor
   **Bo Liu**, *et al.*, *International Conference on Automation Science & Technology (iCAST, Chinese Academy of Sciences, 2007)*, Best Paper Award
6. Adaptive Motion Control Based on Fourier Series and Sliding Mode Control
   Che Jing, **Bo Liu**, *IEEE 7th World Congress on Intelligent Control and Automation (WCICA'08)，Chongqing, China, 2008.6*
7. Hierarchical FTSMC of a Class of Under-actuated Systems *(in Chinese)*
   **Bo Liu**, Wang Yong, *Computer Simulation*
8. Robust Output Feedback Control Based on LMI of Induction Motors *(in Chinese)*

Zhang Bao-li, **Bo Liu**, Wang Jun, Wu Gang， Zhang Fa-ming, *Micromotors*

## PATENT

Hydraulic Flap gate Zhang Yang, Wang Yong, **Bo Liu,** Shao Chang-xing ZL200630188416.7

## RESEARCH EXPERIENCE

*2008.9~*

2008.9--- Adaptive Dynamic Programming and Reinforcement Learning

*2005.9~2008.2*

2007.3---2008.6 Optimization on distributed Network based on Queuing Network Theory

2006.2-2007.9 Adaptive Stochastic Optimization on Nonlinear Time-variant Systems

## ACADEMIC SERVICES

### REVIEWER

2008 27th Chinese Control Conference, Kunming, Yunnan, China

2009 6th International Symposium on Neural Networks, Wuhan, Hubei, China

2009 *Acta Automatica Sinica*

## HONORS AND AWARDS (in USA)

2009 **ICCNS Student Fellowship**
*Thirteenth International Conference on Cognitive and Neural Systems (ICCNS),*
Boston University, May 27-30, 2009

## PROFICENT COMPUTER SKILLS

Programming C/C++, Matlab, Mathematica
Database Access, Powerbuilder
Typography LATEX, MS Office

## TEACHING EXPERIENCE

| | | |
|---|---|---|
| 2008.9—2009.1 | TA Undergraduate Course: VHDL | Stevens, NJ |
| 2007.9—2008.1 | TA Graduate Course: Stochastic Estimation and Control | USTC, China |
| 2007.2- 2007.7 | TA Graduate Course: Intelligent Control | USTC, China |

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

Ph.D. Candidate: Congzhi Huang

Advisor: Professor Yan Bai

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Research field:
Distributed Control System(DCS), Fieldbus Control System(FCS), Networked Control System(NCS), Control Theory and Applications.

# Research Proposal

## Modeling, Analysis, and Control of Networked Cascade Control Systems

### (a) Research problem statement;

Cascade control system is the most widely used control architecture in industrial process control besides single loop control system. Cascade control system, wherein the control loops are closed via real-time networks, is called **Networked Cascade Control System** (**NCCS** for short hereinafter). The insertion of networks into the control loops inevitably brings in a series of fundamental issues, such as network-induced delay, data packet dropout, and so on. As a result, it makes the analysis and synthesis of an NCCS extremely complicated.

In the dissertation, the concept of NCCS is proposed based on practical industrial process control. The issues of modeling, stability analysis, controller design and performance analysis of NCCS will be investigated and studied.

### (b) Significance and objectives;

**Significance:** On one hand, the NCCS has found a great number of applications in practical industrial process control. For example, the main steam temperature control system in a thermal power plant is a typical kind of NCCS. On the other hand, it lacks systematic theory for the analysis and synthesis of NCCS. Different form a traditional cascade control system, the insertion of networks into the control loops of an NCCS makes some assumptions no longer valid, such as accurate non-delayed transmission of real-time information, and so on. As a special type of **Networked Control System** (**NCS** for short thereinafter), there are two control loops and two controllers in an NCCS, which makes the analysis and synthesis of an NCCS much more complicated than those of a single loop NCS. As a result, it's necessary and emergent to develop a new systematic theory for the analysis and synthesis of NCCS.

The development of the NCCS theory can enrich the theoretical system for the NCS and cascade control system, make a solid foundation and provide valuable reference for the practical applications of NCCS.

**Objectives:** We aim to develop a systematic theory for the NCCS, including the modeling, stability analysis, controller design, and performance analysis of NCCS. An NCCS pilot plant based on FF will also be designed and implemented.

## (c) Summary of the current state-of-the-art;

At present, a large number of papers can be found about various aspects of the analysis and synthesis for NCS, see surveys in [1]-[5]. Many special issues concerning on NCS have been published by some international journals, see [6]-[10]. NCS has also been one of the most important topics in many international conferences.Many papers have studied the analysis and synthesis of an NCS from different respects. In an NCS, the fundamental issues are the network-induced delay, data packet dropout, and so on.

**Cascade control system**(**CCS** for short), firstly proposed by Franks and Worley in [11], is a very effective control strategy for the system with disturbances in the control loops. The main idea of CCS is to divide the controlled process with large time constant into two processes with different time constants, i.e., a primary process and a secondary process[12]. Cascade control system is the most widely used control architecture in industrial process control[13], and it has been successfully used in the temperature control loops for the substantially improved system performance.

However, in spite of widely applications in industrial process control, the theoretical research of NCCS hasn't been given enough attention in the past several decades. The present research on NCS has mainly focused on networked control for the single loop system and multiple-input-multiple-output system, few papers have studied the networked control for cascade control systems. Up to now, a systematic theory for the analysis and synthesis of NCCS hasn't far been perfect, and therefore it's necessary to study it thoroughly.

## References


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## (d) Proposed research methodology and plan;

**Problem 1 :** How to develop a uniform model for the closed-loop system of an NCCS with uncertain network-induced delays?

**Proposed Solution 1 :** We plan to use the augmented state vector method to develop the uniform model of the NCCS closed-loop system in discrete time in the form of state space representations.

**Problem 2 :** In two typical kinds of NCCSs with constant network-induced delays, the problem is how to design the primary and secondary controllers by PID simultaneously.

**Proposed Solution 2 :** Based on the primary and secondary process models and the desired closed-loop system responses, we will use first-order Páde approximation method, and then obtain the PID tuning parameters of both the primary and secondary controllers in the NCCS simultaneously at a time in analytical expressions.

**Problem 3 :** The third problem is how to design robust $H\infty$ state feedback control laws for a type of NCCSs with uncertain network-induced delays, which makes: (1) the NCCS without disturbances is robust asymptotically stable; (2) the NCCS with disturbances is robust asymptotically stable and has a certain attenuation ability of disturbances.

**Proposed Solution 3 :** Based on Lyapunov stability theory and LMI approach, we will transform the uncertainty of network-induced delay into the uncertainty of the coefficient matrices of the system, derive the robust $H\infty$ state feedback control laws for the NCCS without disturbances, and then design the $\gamma$-optimal robust $H\infty$ state feedback control laws for the NCCS with disturbances.

**Problem 4 :** The fourth problem is how to design robust $H\infty$ output feedback control laws for a type of NCCSs with uncertain network-induced delays, which makes: (1) the NCCS without disturbances is robust asymptotically stable; (2) the NCCS with disturbances is robust asymptotically stable and has a certain attenuation ability of disturbances.

**Proposed Solution 4 :** Based on Lyapunov stability theory and LMI approach, we will transform the uncertainty of network-induced delay into the uncertainty of the coefficient matrices of the system, derive the robust $H\infty$ output feedback control laws for the NCCS without disturbances, and then design the $\gamma$-optimal robust $H\infty$ output feedback control laws for the NCCS with disturbances.

**Problem 5 :** In two typical kinds of NCCSs with uncertain but bounded network-induced delays, the secondary controller is a conventional PI controller, the problem is how to design the primary controller which can be implemented in practical process control so as to maintain the stability and a certain robust performance of the NCCS.

**Proposed Solution 5 :** Based on $\mu$-synthesis control theory, we will develop the $\mu$-synthesis framework for the two kinds of NCCSs, and then design the $\mu$-synthesis primary controller. Since the order of the designed primary controller is too high, a low-order controller can be obtained by using the optimal Hankel norm appropriate method, and therefore it can be used in practical process control.

**Problem 6 :** In an NCCS with different control strategies, how to evaluate and optimize the system performance is still an open issue.

**Proposed Solution 6 :** A new comprehensive control performance will be proposed to evaluate the performance of an NCCS. Advanced control strategies may be employed to improve performance of the NCCS.

## (e) Preliminary results;

**1** . The concept of NCCS was proposed based on industrial process control. Four typical configurations of NCCSs were proposed based on practical industrial process control. The concepts of node-device connecting matrix and network transmission matrix were proposed, taking into account the multiple networks and control loops in an NCCS. Three different methods were used to describe the four typical configurations of NCCSs, and they were: configuration diagram, block diagram, node-device connecting matrix and network transmission matrix, respectively.

**2** . For a typical configurations of NCCS with positional and incremental PID controllers, the closed-loop system models have been developed. Taking into account the network-induced delays and data packet dropout, the concepts of general controller and general plant were proposed. For the NCCS with uniform configuration, a closed-loop model of the system with network-induced delays and data packet dropout in the form of discrete time state space representations has been obtained.

**3** . Based on Lyapunov stability theory and LMI approach, in a class of NCCSs with uncertain but bounded network-induced delays, the robust $H_\infty$ state feedback control laws for the NCCS without disturbances were derived by solving an LMI feasible problem, and the $\gamma$-optimal robust $H_\infty$ state feedback control laws for the NCCS with disturbances were designed via solving an LMI minimization problem.

**4** . Based on Lyapunov stability theory and LMI approach, in a class of NCCSs with uncertain but bounded network-induced delays, the robust $H_\infty$ output feedback control laws for the NCCS without disturbances were derived by solving an LMI feasible problem, and the $\gamma$-optimal robust $H_\infty$ output feedback control laws for the NCCS with disturbances were designed via solving an LMI minimization problem.

**5** . Based on the primary and secondary process models and the desired closed-loop system responses, the PID tuning parameters of both the primary and secondary controllers in the NCCS have been derived simultaneously at a time by using Páde

approximation method. Simulation results and computational results of performance index have been given to demonstrate the effectiveness of the proposed approaches.

**6** . In two typical kinds of NCCS with uncertain delays, the robust μ-synthesis primary controllers were designed based on robust μ-synthesis theory. Simulation results indicate the NCCS with the designed controllers is stable and has robust performance.

**7** . Based on the performance indices of the NCCS without any networks inserted in the control loops, a comprehensive control system performance index will be proposed, including the rise time, the settling time, overshoot, and ITAE(Integration of Time multiplied by Absolute Error). Fuzzy PID control method may be employed to replace traditional PID control method so as to achieve better system performance.

## (f) Future plans

**1** . **Stability Analysis of NCCS**

How shall we find a uniform feasible solution to analyze the stability of an NCCS with network-induced delays and data packet dropout?

**2 . Design and implementation of a practical NCCS in a pilot plant based on FF(Foundation Fieldbus)**

Based on the FF ( Fieldbus Foundation ) pilot plant in our lab(see Fig.1), a networked cascade control system for the water temperature in the tank will be designed and implemented so as to maintain it at a predefined value. Then, an optimization software will be designed to automatically tune the PID parameters of the primary controller in the NCCS online by fuzzy PID control method.

Fig.1. NCCS Pilot Plant based on FF in
North China Electric Power University, Beijing, P.R.China

# Brief CV

Congzhi Huang, male, was born in June 1982, Xishui County, Huanggang City, Hubei Province, P.R.China. Now he is a Ph.D. candidate at the School of Control and Computer Engineering, North China Electric Power University, Beijing, P.R.China, and his major is Control Theory & Control Engineering.

## Rewards：

November 2009—Excellent Paper Award, 2009 National Ph.D. Candidates Academic Conference on Automation & Information of Power Station;

2008-2009 Academic Year—Science and Technological Innovation Model, Excellent Graduate Student Model, Sifang Excellent Graduate Student Model;

2007-2008 Academic Year—Excellent Graduate Student Model, Bona Scholarship;

2006-2007 Academic Year—Excellent Graduate Student, Daquan Scholarship;

September 2005—Sifang Scholarship for New Entrant Students;

2003-2004 Academic Year—First-class Scholarship, National Second-class Scholarship;

October 2003—Third Prize in the 2003 National English Contest for College Students.

**Academic Services:** Reviewer of "**Journal of Control Theory & Applications**", Reviewer of Chinese Control & Decision Conference.

## Research Projects Involved:

1. Construction Project sponsored by Beijing Municipal Commission of Education, Beijing, P. R. China. (Primary Investigator)
2. National Natural Science Foundation of China under Grant 60974051. (Involved)

## Publication Lists: — 21 Papers Published

1 **Congzhi Huang**, Yan Bai, Xiangjie Liu. H-infinity state feedback control for a class of networked cascade control systems with uncertain delay. **IEEE Transactions on Industrial Informatics**, 2010, 6(1):62-72. (**SCI**, **EI**)

2 **Congzhi Huang**, Yan Bai, Xiangjie Liu. Robust *H*∞ output feedback control for a class of networked cascade control systems with uncertain delays. **ICIC Express Letters**, 2010, 4(1):231-237. **(EI**)

3 **Congzhi Huang**, Yan Bai, Xinli Li. Fundamental issues in networked cascade control systems. IEEE International Conference on Automation and Logistics, ICAL2008, Qingdao, China, September 2008, 3014-3018. (**EI**)

4 **Congzhi Huang**, Yan Bai, Xinli Li. Modeling of a type of networked cascade control system. 2008 International Conference on Intelligent Computation Technology and Automation, ICICTA2008, Changsha, China, October 2008, 631-635. (**EI**)

5 Xinli Li, Yan Bai, **Congzhi Huang**. Nonlinear system identification using dynamic neural networks based on genetic algorithm. 2008 International Conference on Intelligent Computation Technology and Automation, ICICTA2008, Changsha, China, October 2008, 213-217. (**EI**)

6 **Congzhi Huang**, Yan Bai, Xiangjie Liu. Fuzzy PID control method for a class of networked cascade control systems.2010 International Conference on Computer and Automation Engineering, ICCAE2010, Singapore, February 2010, 140-144. (**EI**)

7 **Congzhi Huang**, Yan Bai, Xinli Li. Simulation for a class of networked cascade control system by PID control. 2010 IEEE International Conference on Networking, Sensing, and Control, ICNSC2010, Chicago, IL, USA, April 2010. (**EI**)

8 **Congzhi Huang**, Yan Bai, Yaochun Zhu. PID controller design for a class of networked cascade control systems. 2010 IEEE International Conference on Advanced Computer Control, ICACC 2010, Shenyang, China, March 2010. (**EI**)

9 **Congzhi Huang**, Yan Bai, Xiangjie Liu. PID controller tuning of networked cascade control systems. National Ph.D. Candidates Academic Conference on Modeling and Optimization of Industrial Process, October16-18, 2009, Shanghai, P.R.China, Sponsored by East China University of Science and Technology. (In Chinese)

10 **Congzhi Huang**, Yan Bai. Application of fuzzy auto-tuning PID in a class of networked cascade control systems. 2009 National Ph.D. Candidates Academic Conference on Automation & Informatization of Power Station, November 20-22, 2009, Beijing, P.R.China, Sponsored by North China Electric Power University. (In Chinese)

11 Yan Bai, **Congzhi Huang**. Analysis and modeling of a class of networked cascade control systems. **Information and Control**, 2007, 36(3):273-277. (In Chinese)

12 Yan Bai, **Congzhi Huang**. Analysis and modeling of a class of networked cascade control systems. **Control Engineering**, 2008, 15(2): 120-123,134. (In Chinese)

13～21 Other journal papers in Chinese (Omitted for limitation of space )

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

Ramon da Cunha Lopes
UnilesteMG
ramon@unilestemg.br

Research field
Fault diagnosis, Fractional Transformation Systems

# Research Proposal

## Research proposal title

(a) Research problem statement;
In this text we present an systematic study about integrals and derivates of arbitrary order or fractional cauculus. We discusses its applications into several uses of the digital and analog filters.

(b) Significance and objectives;
The use of the Fractional Transformation and Fractional Cauculus improve the performance of fractional differenctial filter. It has been applied successfully on fractional order PID controller, signal processing, image processing. This work deals an maquinary to be used in the project and sinthesys in control theory.

(c) Sumary of the current state-of-the-art
The applications of Fractional Calculus has been used frequently in PID Controller project and sinthesys [1], [2]. Some applications has oriented to filters design [3], but this study has been disassociate. Some systematic study about fractional integrals and derivates has been presents in scientific literature [4], [5].

(d) Proposed research methodology and plan;
This study proposes a mathematical maquinary based in Linear Matrix Inequalities (LMIs) formulation in some contexts:
• optimal control;
• optimal state observers;
• robust control;
• robust observers with unknown inputs;
• robust filters for fault detection, diagnosis and isolation.

For this research we use academic models for simulation in Matlab software and real time plants with LabVIEW implementation in level, temperature, flow, velocity, pH and pressure variables.

(e) Preliminary results;
1 Introduction - Context of the fractional calculus.
1.1 The use of fractional transformation can to improve the perform of the electrical filters. This approach has been apply in PID controle with fractional order, signal processing and image processing. This work presents a metodology to design electrical filters with fractional order.

1.1.1 Functions
The concept of fractional derivate bases on the definition of the Beta and Gamma functions:

$$\Gamma(n) = \int_0^\infty e^{-t} t^{n-1} dt$$

and

$$\beta(n,m) = \int_0^1 (1-t)^{n-1} t^{m-1} dt$$

1.1.2 Lacroix

Sylvestre Francois Lacroix propose in 1819 a generalization of the caluculus of the derived of polynominal functions like $x^m$ with positive expoent m as (Ricieri, 1993):

$$\frac{d^n}{dx^n}[x^m] = \frac{m!}{(m-n)!} x^{m-n} = \frac{\Gamma(m+1)}{\Gamma(m-n+1)} x^{m-n} \tag{3}$$

where

$$\Gamma(t+1) = t$$

1.1.3 Liouville

Joseph Liouville present a solution in 1832 for derived fractional based in the function for negative exponents of m in polynominal functions of the type $x^m$:

$$\frac{d^n}{dx^m}[x^{-m}] = \frac{(-1)^n (m+n-1)!}{(m-1)!} x^{-(m+n)} = \frac{(-1)^n \Gamma(m+n)}{\Gamma(m)} x^{-(m+n)} \tag{4}$$

1.1.4 Riemann e Liouville

Riemann and Liouville generalize in 1876 a definition of the fractional calculus for positive and negative exponents of polynominal functions:

$$D^n[f(x)] = \frac{1}{\Gamma(-n)} \int_0^x (x-t)^{-n-1} f(t) dt \tag{5}$$

para $m-1 < \alpha < m$ with the Lacroix definitions and incorporate Liouville.

1.2 Formulations of fractional systems

A dynamic system whose represents is described by the following transfer function (Vinagre et al., 2002):

$$G(s) = \frac{1}{s - 2s^{\frac{1}{2}} + 1.25} \tag{6}$$

In Equation (6) where $s^{\frac{1}{2}} = \lambda$

$$G(\lambda) = \frac{1}{\lambda^2 - 2\lambda + 1.25} \tag{7}$$

The new characteristic equation:

$$Q(\lambda) = \lambda^2 - 2\lambda + 1.25 \tag{8}$$

it has the roots like $\lambda_{1,2} = 1 \pm j0{,}5$. Return the values for $s = \lambda^2$, obtain the new transfer function in Laplace:

$$G(s) = \frac{1}{s^2 - 2s + 1.25} \tag{9}$$

2 Methodology

The present works propose the utilization of an genetic algorithm (Valerio and Costa, 2006) for get the parameters of a generic function of the type:

$$G(s) = \frac{s + \lambda_1 s^{\lambda_2} + \lambda_3}{s + \lambda_4 s^{\lambda_5} + \lambda_6} \tag{10}$$

The transfer function acted by the equation (10) it was chosen being taken in considaration that the terms $\lambda_1$, $\lambda_3$, $\lambda_4$ and $\lambda_6$ explore the dynamic features more directly as dumping coeficient and cutoff frequency, while the terms $\lambda_2$ and $\lambda_5$ determines the structure of the system in terms of zeros and poles. The unique constraits imposed to the system is done in the sense of guaranteeing that the degree of the numerador is smaller or equal to the degree of the denominator. As the problem is multimodal, allows a search uniform place around each possible solution of the genetic algorithm. A small variation in the parameters $\lambda_2$ and $\lambda_5$ suggests new structures as possible solution for the problem of parameters identification.

3 Illustrative examples

Example 1 – Electrical Filter

The band-pass filter is given by:

$$H(s) = \frac{(s + .1)(s + 100)}{(s + 1)(s + 10)} \tag{11}$$

Using the generic model presented in Equation (10) the fractional order model shown in the Illustration (1) is given by:

$$H(s) = \frac{s^2 + 8.1s^{1.12} + .95}{s^2 + .09s^{2.17} + .91} \tag{12}$$

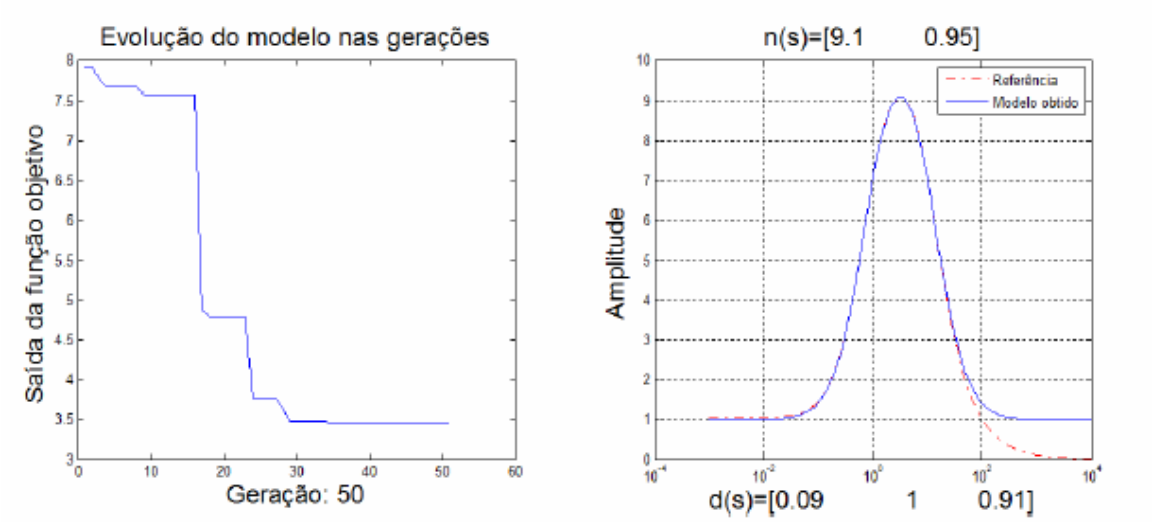


Illustration 1: Fractional order filter

3.2 Example 2 - Dynamic Model

The second application of the Illustration (2) it consists of the collection of data of level of the didatic plant Smar (Smar, n.d.) starting from a pseudo-random signal applied in the input of the system.

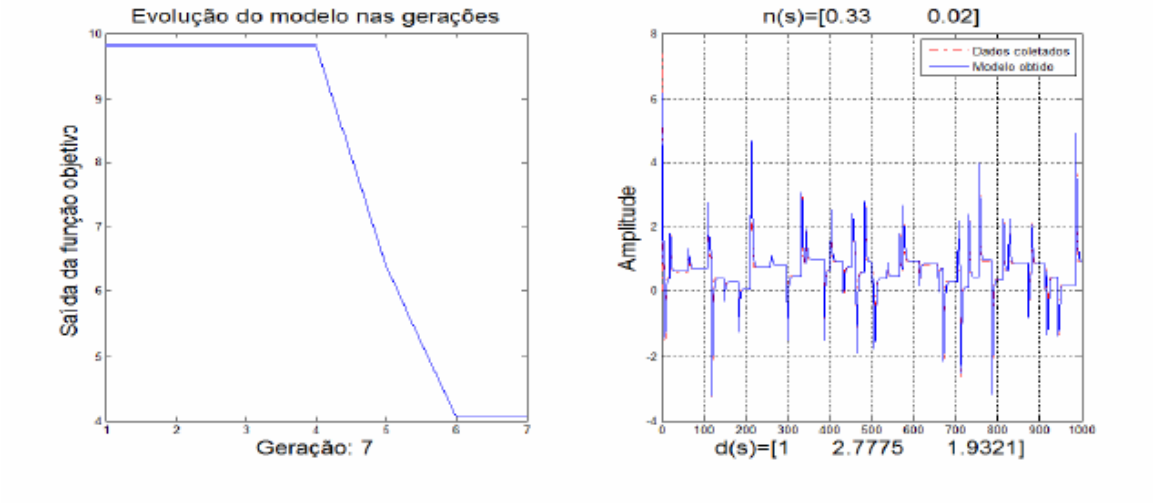


Illustration 2: Fractional model

The fractional model obtained was:

$$G(s) = \frac{s^2 - 0.67s^{1.1} + 0.02}{s^2 + 0.02s^{0.46} + 1.39} \tag{13}$$

3.3 Example 3 - Fault detection

The flow of water of the same plant mentioned in the Example 2 is used here. A bypass valve is present with a flow control valve. For the openings of the bypass valve of 0% (nominal), 25%, 75% and 100% were obtained the following fractional models:

$$G_n(s) = \frac{s^2 - 0.56s^{072} + 0.58}{s^2 + 1.8s^{1.25} + 0.42} \tag{14}$$

$$G_{25\%}(s) = \frac{s^2 + 0.51s^{0.28} - 0.44}{s^2 - 2.38s^{1.39} + 0.72} \tag{15}$$

$$G_{75\%}(s) = \frac{s^2 + 2.63s^{2.68} + 1.55}{s^2 + 2.44s^{1.77} + 0.50} \tag{16}$$

$$G_{100\%}(s) = \frac{s^2 + 2.33s^{1.43} + 1.29}{s^2 - 0.84s^{1.56} - 1.39} \tag{17}$$

and basing on the proposal of deconvolution filter presented in the article (Casavola et al. ,2005), a genetic algorithm has been used for the problem of project of a filter of fault detection:

$$\lambda^* = \arg\min_{\lambda} a\gamma_n + b\gamma_{25\%} + c\gamma_{75\%}$$
$$s.a: \begin{cases} \left\|G_n(s)*u\right\|_2 - \left\|F(\lambda,s)*u\right\|_2 \le \gamma_n \\ \left\|G_{25\%}(s)*u\right\|_2 - \left\|F(\lambda,s)*u\right\|_2 \le \gamma_{25\%} \\ \left\|W_f(s)*u\right\|_2 - \left(\left\|G_{75\%}(s)*u\right\|_2 - \left\|F(\lambda,s)*u\right\|_2\right) \le \gamma_{75\%} \end{cases} \tag{18}$$

where a, b and c are real numbers used for the cost function to the design of the filter.

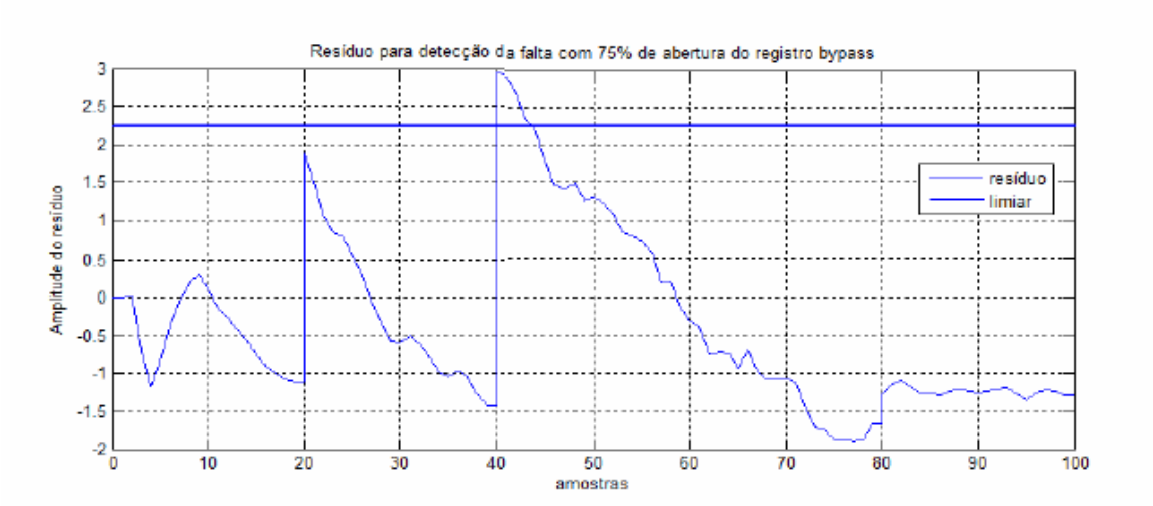


Illustration 3: Fault detection

(f) Future plans

This research deals a complete formulation to provide a fractional transformation to validate robust controllers and observers in industrial area applications.

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**Brief CV**

I'm graduate in Electric Engineering for the Pontificia Universidade Catolica de Minas Gerais (1987), specialization in Improvement In Industrial Automation for the Catholic Institute of Minas Gerais (1993), specialization in Specialization In Industrial Automation for the Federal University of Minas Gerais (1998), master's degree in Electric Engineering for the Federal University of Minas Gerais (1999) and course-technician-vocational in Technician In Electronics for the Technical School of Colonel Fabriciano Padre of Man (1982). Teacher of the UnilesteMG. I have experience in the area of Electric Engineering, with emphasis in Industrial Electronics, Systems and Electronic Controls. Acting mainly in the following themes: Recovery of Information, Nets Artificial Neurais, Bases of Textual Data, Classification of Documents, Analysis of Acting of Algorithms and Redes Neurais of Radial Base.

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3. LOPES, R. C.; BARBOSA, E. F.; PANTY, A. P.. Use of Nets Artificial Neurais in the Recovery of Information in Bases of Textual Data. In: IV Brazilian Congress of Redes Neurais, 1999, São José dos Campos. Annals of the IV Brazilian Congress of Redes Neurais. São José dos Campos: ITA, 1999. p. 192-197.

Technical production - Technological products

1. LOPES, R. C.. Didactic computer. 1988.
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2. Congress of the Area of Sciences semi-defined Exatas. Programação in the optimization of administrative systems and dynamic processes. 2005. (Congress).
3. training PlantWeb.Treinamento: PlantWeb - A Revolutionary architecture of Automation of Processes. 2001. (Other).

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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Research field
Biomedical engineering, e-health, instrumentation, signal processing, wheelchair measurements

# Research Proposal

## Vital Signals Monitoring Wheelchair

### Research problem statement

Unobtrusively and continuously monitor the cardiovascular and respiratory physiological signatures of a wheelchair user, while interacting with him and providing real-time evaluation of his state to remote users by creating an intelligent environment.

### Significance and objectives

Wheelchair technology developments are welcomed by the vast community of 2 million users, only in the US, who use wheelchairs as their most important means of mobility. Besides the natural motivation to enhance the users' quality of living, various other patients have special needs in their use of wheelchairs, as both elder citizens, diabetics, and stroke victims often require extended accompaniment, essentially of cardiac parameters, such as heart rate, blood pressure, and their variabilities, to be aware for atrial fibrillation, hypertension and other heart condition symptoms.

Being able to unobtrusively assess the body's cardiac and respiratory physiological signatures is by itself an achievement of utmost impact. Unobtrusive measurement devices present in objects of common use, such as the recent implementations of ballistocardiographs in beds or chairs, reduce the examinations' stress and the subject's involuntary psychophysiological responses, while relieving the workload of medical staff too.

Therefore, the development of a totally inconspicuous physiologic monitoring system, embedded in a regular wheelchair, with wireless communication capabilities will be an important advance in remote and continuous patient care.

Detailing the objectives of the dissertation:

1. Model the user posture and evaluate how the wheelchair movement is reflected in the user.
2. As the ballistocardiogram and the impedance plethysmogram suffer greatly with motion artifacts, extract features from the sensors' noise to evaluate the person's posture.
3. Real-time analysis of the stability of both the wheelchair and the user.
4. Locally process the acquired signals in order to compute cardiovascular system markers, such as heart rate, pre-ejection period, pulse transit time, and others.
5. Classify the subject's status based on personalized analysis of the homeostasis markers, and transmit the data wirelessly.
6. Create a Wheelchair Area Network (WAN) composed of other sensors spread in the environment, adding up to the knowledge produced at the wheelchair level which will be shown to the user by an interactive device.
7. Integrate the abovementioned wireless network in an Health Care Monitoring Network, to provide central coordination of the various WANs simultaneously present in the environment.

### Summary of the current state-of-the-art

The most recent developments in ballistocardiography (BCG) have been centered in piezoelectric pressure sensors, embedding it in chairs, and gathering the signal from its backrest, seat, or both,

while wheelchairs are practically unexplored. Since the 50's it is known that this signal has unique long-term prognostic capabilities, so, BCG deserves particular interest.
Nevertheless, in the field of unobtrusive measurements, radar BCG is a 2007 novelty, moreover few devices are now able to do through-clothing measurement of electrocardiogram (ECG) and impedance plethysmogram (IPG). Both these devices and the ballistocardiographs are fit for immobile user settings, consequently much work has to be done to allow unconstrained wheelchair user movement.

Regarding automatic processing of the aforementioned signals, the ECG is the foremost cardiac signal, and accordingly numerous applications and systems are able to extract detailed information and automatically recognize its most important features, classifying numerous arrhythmias and cardiac pathologies with high accuracy. No such thing exists for BCG and IPG, as their sensibility to respiration and motion artifacts brings extreme difficulties to automatic classifiers. Novel digital signal processing techniques have recently improved the control of baseline wandering using wavelet decomposition, independent (ICA) and principal component analysis (PCA) improved the BCG and IPG quality by guessing which components are not due to physiological factors.
The latest BCG classifiers are based on biorthogonal wavelet decomposition together with neural networks, and, at most allow patient classification in four classes. The set of developments included the use of the well-known multilayer perceptrons, and radial-basis functions, as well as the novel supervised fuzzy adaptive resonance theory, and time-frequency moments single value decomposition. The use of BCG or IPG noise in classification has not been explored yet.

## Proposed research methodology and plan

The first step consists of developing robust signal acquisition hardware. This initial development allows pursuing the several objectives of the dissertation with some degree of parallelism, even if it is not the final version, as improvements are likely to appear.

The research plan aims at solving the objectives already mentioned:

1. Develop a stable and robust hardware solution for BCG and IPG acquisition.
2. Implement signal processing algorithms to clear these signals in real-time when the wheelchair is moving.
3. Estimate precisely the physiological features provided by the gathered data.
4. Relate the user posture with the BCG and IPG changes, and with the modifications in vibration and acceleration of the wheelchair structure.
5. Recognize the user based on the wheelchair data and in measurements provided by sensors spread in the environment.
6. Identify the subject's characteristics for continuous personalized long-term care, and to produce meta-data, presented in an interactive device placed in the wheelchair.
7. Integrate all the devices in the environment in an Health Care Monitoring Network, and aggregate the data gathered by the sensors in a database with remote access for certified users.

The developments will firstly be tested in a few healthy young subjects in a controlled environment. Afterwards, regular wheelchair users, with different medical backgrounds, will experiment the system. Hospital facilities will subsequently be the test scenario, to implement the definitive hardware solution and the wireless Health Care Monitoring Network.

## Preliminary results

Inconspicuous circuitry has been developed and embedded in a wheelchair, allowing the acquisition of BCG and IPG without the user's awareness. A radio transmitter is being used to transmit the data wirelessly to a laptop which processes and saves the data acquired. Photoplethysmogram (PPG) and ECG circuitry was also implemented so that known and stable references are saved as well.

Summarizing the results attained:

I. Six healthy subjects tested the system in with the wheelchair stopped, and the software developed was able to estimate HR, pulse arrival time (PAT), pre-ejection period (PEP), and pulse transit time (PTT), being validated the devices developed. Time and frequency domain analysis was done, with the variabilities of these parameters being computed, and it were verified important correlations in the recordings.
II. Software was developed applying ICA and Hilbert-Huang transform, with good results on improving the signal-to-noise ratio of new recordings obtained while having motion in the wheelchair. This important improvement imposes a computational overhead of a few seconds, so supplementary advances are needed.
III. Spectrogram-based techniques are being applied to characterize the posture-noise relation in a wheelchair motion scenario. The promising results obtained still lack further investigation.
IV. Compressed sensing was applied to the ECG, PPG and BCG recordings, being confirmed their compressibility and recoverability, however, the accuracy requirements of these signals for HR and PAT variability are not respected after compressed sensing reconstruction. Nevertheless, given the great amount of data to circulate in the wireless network to be built, whenever coarser estimates are acceptable this paradigm may be implemented, under a strict control of the quality of service.

While several manuscripts are under review, some of these developments have already been published in a book chapter and four papers in international conferences with peer review. Moreover, after being addressed a personal invitation, the work was presented in a workshop organized by DARPA.

## Future plans

While several manuscripts are under review, some of these developments have already been published in a book chapter and four papers in international conferences with peer review. Moreover, after being addressed a personal invitation, the work was presented in a workshop organized by DARPA.

A. Enlarge the recordings database, by inviting more volunteers to participate, and executing a number of different paths, so that the noise generated by the person motion is described for varied situations and persons. With this it is expected to be identified the relation between BCG and IPG noise, and the posture of the wheelchair user, while also gathering very noisy recording sets to test the signal processing algorithms.
B. Supplementary sensors will be added to the wheelchair, namely tri-axial accelerometers, to measure the vibration in the wheelchair structure and then use data fusion techniques to improve the signal-to-noise ratio. System identification techniques will also be employed to obtain the relation between the BCG signal and the acceleration.

C. Launch new digital signal filtering and processing techniques, and try to improve the ones already applied, so that the BCG and the IPG may still be obtained in noisier settings, and in real-time. Eventually personalized calibration will appear as a necessity, but this is affordable given the importance of having clearer signals in real-time.
D. A central coordination system, with ability to manage the communications with the wheelchair, the interactive device, and with other devices added to the environment, shall be implemented to serve as a database with Web access, to start the foundations of the Health Care Monitoring Network.

# Brief CV


| | |
|---|---|
| Surnames, Given name | Correia Pinheiro, Eduardo |
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| Birth | Portugal, 01/17/85 |


## Work experience

| | |
|---|---|
| Position held (08/2008 → present) | *Researcher* |
| | Research in the Instrumentation and Measurement Group of the Telecommunications Institute, focused in biological signal (BCG, BP, ECG, IPG, PPG) acquisition and processing, and profound study on the subject's cardiovascular and circulatory system status. Activities lead to invitation to speak at a DARPA workshop, publication of 1 patent, 1 book chapter, 7 papers in international conferences (+ under review: 1 patent, 1 book chapter, 3 journal papers, and 4 conference papers) |
| Employer, Business | Instituto de Telecomunicações Lisbon – Portugal, Science and Education |
| Position held (02/2006 → 09/2008) | *Laboratory technical responsible* |
| | Technical responsible by the Instrumentation and the Automation and Robotics laboratories in the College of Technology of the Setúbal Polytechnic Institute, with maintenance and classes assistance responsibilities Research activities lead to the publication of 5 papers in international conferences |
| Employer, Business | Escola Superior de Tecnologia of the Polytechnic Institute of Setúbal – Portugal, Science and Education |

## Education and training

| | |
|---|---|
| Qualification (08/2008 → *ca.* 08/2012) | *PhD. in Electrical and Computer Engineering* |
| | Frequency of 6 disciplines and thesis entitled "Vital Signals Monitoring Wheelchair" related to the embedding of a set of sensors in a wheelchair and creating an intelligent environment which communicates wirelessly with it. Gathering and providing health status information on user's homeostasis parameters, via ubiquitous computation and advanced data processing. Under supervision of Octavian Postolache and Pedro Girão |
| Organization | Instituto Superior Técnico of the Lisbon Technical University |
| Qualification (09/2002 → 07/2007) | *Automation Control and Instrumentation Engineer* |
| | 5 years degree focused on Automation, Control and Instrumentation disciplines finished with grade point average of 18.4 out of 20. Awarded Merit Scholarships for exceptional scholar performance in the years of 2002/03, 2003/04, 2004/05 and 2005/06 by the Portuguese Ministry of Science, Technology and Higher Education, and Banco Santander Prize for Best Faculty Graduate of the year |
| Organization | Setúbal College of Technology of the Setúbal Polytechnic Institute |
| Qualification (09/1999 → 07/2002) | *Electronics and Industrial Instrumentation Technician* |
| | High-school diploma, concluded with a GPA of 18 out of 20 and 19 values in the Professional Aptitude Project |
| Organization | Sines Technological School, currently Litoral Alentejano Technological School |

## Personal skills

| | |
|---|---|
| Technical skills and competences | Large experience in development and test of instrumentation, electronic circuitry, and programming<br>Experience with AutoCAD, C, HTML, Labview, Matlab, OrCAD, and Wiki syntax |
| Languages | Portuguese (native), English (fluent), Spanish (independent), French (basic), Japanese (basic) |
| Artistic skills and competences | 2nd degree of clarinet studies obtained in Setúbal's conservatoire<br>Author of the book "Wikipédia – Guia Prático de Consulta e Edição", ISBN: 978-989-615-037-2 |

## Awards and scientific activity

| | |
|---|---|
| Awards | → "Bolsa de Mérito Santander-IPS 2006-2007", established by protocol between the two institutions. Grant to the best graduate of the Setúbal College of Technology in the 2006/07 academic year<br>→ "Bolsa de Mérito IPS 2006/2007", "Bolsa de Mérito IPS 2005/2006", "Bolsa de Mérito IPS 2004/2005", and "Bolsa de Mérito IPS 2003/2004", established by the Portuguese Ministry of Sci., Tech. and Higher Education. Grant per exceptional scholar performance in 2005/06, 2004/05, 2003/04, 2002/03 academic years |
| Other scientific activities | → Reviewer for the 31st Annual Conference of the IEEE EMBS, IEEE Transactions on Instrumentation and Measurement, International Journal of General Medicine, and Medical Devices: Evidence and Research<br>→ Member of the "Núcleo de Consultores" (Group of Consultants) of the Superior School of Technology, Polytechnic Institute of Setúbal. |
| Scientific output | → E.C. Pinheiro, O. Postolache, P.M. Girão, "Recent Advances on Unobtrusive Measurements of the Cardiovascular Function", 4th Int. Conf. on Sensing Technology, Lecce, Italy, June 2010<br>→ E.C. Pinheiro, O. Postolache, P.M. Girão, "Implementação de Filtros Notch em Aritmética de Ponto Fixo", VI Jornadas sobre Sistemas Reconfiguráveis, Aveiro, Portugal, pp. 91–96, Feb. 2010<br>→ E.C. Pinheiro, O. Postolache, "*Modelling of Oscillometric Blood Pressure Monitor - from white to black box models*" - Chapter in *Recent Advances in Biomedical Engineering*, In-Tech, Vienna, 2009<br>→ O. Postolache, P.M. Girão, G. Postolache, E.C. Pinheiro, R. Madeira, Patent PT104602, Sept. 2009<br>→ E.C. Pinheiro, O. Postolache, P.M. Girão, "*Compressed Sensing Implementation in Cardiac Signals*", 5th IEEE Int. Work. on Intelligent Data Acq. and Advanced Computing Syst., Rende, Italy, pp. 96–101, Sept. 2009<br>→ E.C. Pinheiro, O. Postolache, P.M. Girão, "*Digital Notch Filters Implementation with Fixed-point Arithmetic*", XIX IMEKO World Congress, Lisbon, Portugal, pp. 491–496, Sept. 2009<br>→ E.C. Pinheiro, O. Postolache, P.M. Girão, "*Unifying Visions on Continuous, Non-Invasive Blood Pressure Monitoring*", DARPA Work. on Continuous, Non-Invasive Monitoring of BP, San Diego, US, June 2009<br>→ E.C. Pinheiro, O. Postolache, P.M. Girão, "*Blood Pressure and Heart Rate Variabilities Estimation Using Ballistocardiography*", 7th Conference on Telecommunications, Feira, Portugal, pp. 125–128, May 2009<br>→ E.C. Pinheiro, O. Postolache, P.M. Girão, "*Pulse Arrival Time and Ballistocardiogram Application to Blood Pressure Variability Estimation*", 4th IEEE Int. Work. on Med. Meas. and App., Italy, pp. 132–136, May 2009<br>→ E.C. Pinheiro, "*Oscillometric Blood Pressure Monitor Modeling*", 30th Ann. Conf. of the IEEE EMBS, Vancouver, Canada, pp. 303–306, Aug. 2008<br>→ E.C. Pinheiro, "*Multiple Models Oscillometric Blood Pressure Monitor Identification*", 30th Ann. Conf. of the IEEE EMBS, Vancouver, Canada, pp. 319–322, Aug. 2008<br>→ E.C. Pinheiro, O. Postolache, "*A Wireless Monitoring System for Health Care Applications*", 6th IASTED Biomedical Engineering Conf., Innsbruck, Austria, pp. 372–377, Feb. 2008<br>→ E.C. Pinheiro, O. Postolache, "Heart *Rate Variability Virtual Sensor Application in Blood Pressure Assessment System*", 6th IASTED Biomedical Engineering Conf., Innsbruck, Austria, pp. 79–82, Feb. 2008<br>→ E.C. Pinheiro, O. Postolache, J.M. Dias Pereira, "*A Practical Approach Concerning Heart Rate Variability Measurement and Arrhythmia Detection Based on Virtual Instrumentation*", 6th Conference on Telecommunications, Peniche, Portugal, pp. 112 - 115, May 2007 |

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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Research field
Modeling, Analyzing and Motion Planning
of a special kind of Object Manipulators
named Wheeled-tip Robots

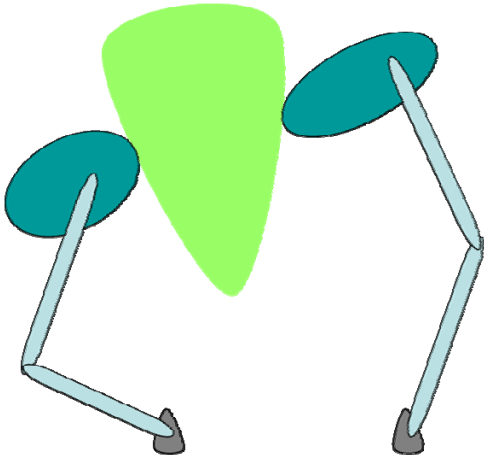
# Research Proposal

## Kinematic analysis of Object Manipulation using Wheeled- tip Manipulators

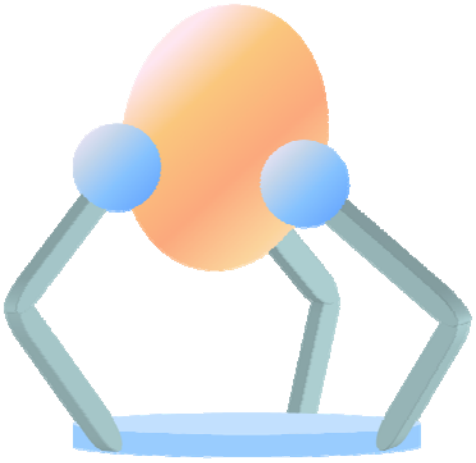
### (a) Research problem statement

In this research we introduce a new mechanism and analyze its characteristics. Based on the provided model, motion planning algorithms are also discussed. The mechanism consists of an **active** wheel incorporated at the finger tip of a robot. By robot, we refer to any arbitrary multi-finger robotic hand. It can also refer to a group of arbitrary articulated robotic arms that cooperating in an object manipulation task. The wheel is not limited to the circular ordinary wheel, but can have any arbitrary shape. Similarly, the object has no constraint and may have corners and/or discontinuity. Below figure shows the mechanism in 2D and 3D. In my research, I used the following simplifying assumptions:

1- Kinematic modeling and analyzing
2- Rigidity of the object and the robot (non- deformability)
3- Uniqueness of contact point, between each wheel and the object
4- Closeness, simplicity, twice-continuous differentiability of the wheels



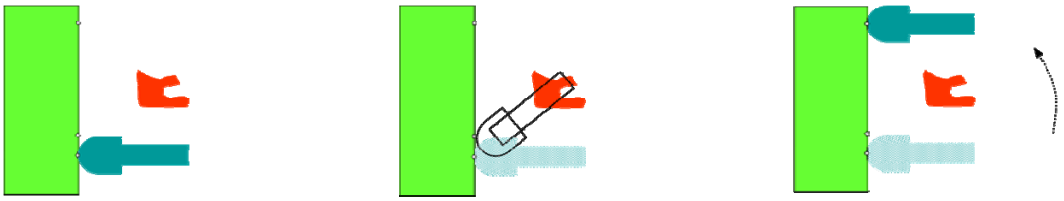
Wheeled-tip robot (2D Case)



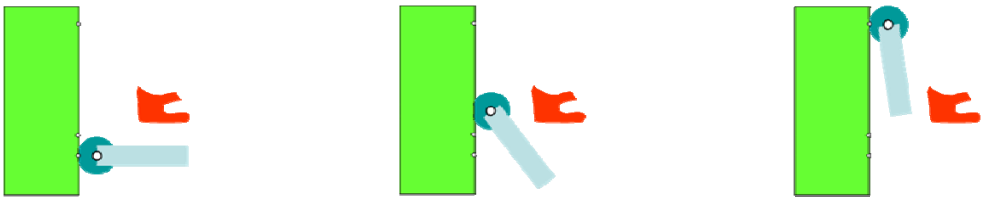
Wheeled-tip robot (3D Case)

### (b) Significance and objectives

This research is part of a project that aims to make this mechanism applicable. Taking advantage of the wheel's rolling nature; the configuration space is expanded considerably. Consequently, the robot motion planning will be facilitated chiefly. In fact, in some cases there exists no feasible solution ignoring this mechanism. As an example, we cannot manipulate an object with just two normal fingers in presence of gravity, if it necessitates finger gaiting. In contrast, using wheeled-tip fingers can eliminate the need to finger gaiting and can introduce feasible solutions. The omission of redundant fingers/arms, the reduction of re-grasp/finger-gaiting phases, and simplification in planning algorithms are the economic motivations of employing this mechanism, practically.



Rolling Contact necessitates Re-Grasp/Finger-Gaiting



Wheeled-tip passes the Obstacle easily

## (c) Summary of the current state-of-the-art

Wheeled-tip manipulation is categorized in “rolling contact manipulation” under “dexterous manipulation”. There exists a rich treasury of articles in this field, containing papers as old as 1986. A complete and detailed model of rolling contact in 2D and 3D has been presented. Several valuable attempts have been made to perform the manipulation task practically dexterous. In this literature, grasp stability in the limited rolling area at the robot’s finger tip is considered as a tight constraint which should be respected during the manipulation. Proposed planning methods are complex and mostly inapplicable which made the field out of focus in recent years. Our proposed mechanism, in contrast, extends this rolling area unlimitedly and reduces the burden of motion planning.

Prehensile Grasp  Sliding Contact  Rolling Contact  Wheeled-tip

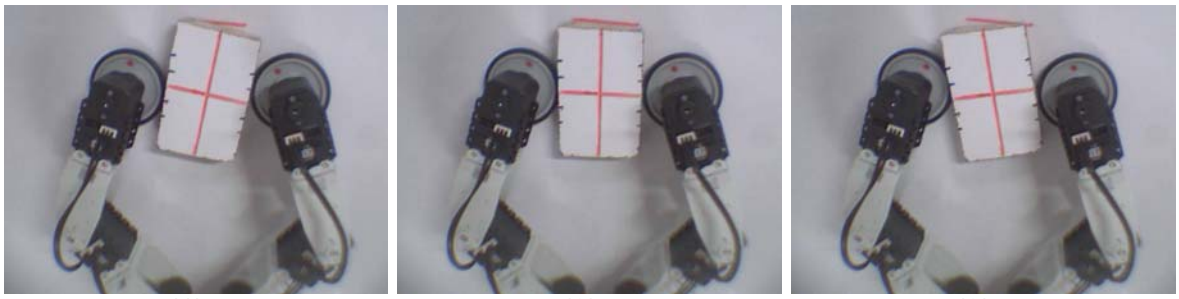
## (d) Proposed research methodology and plan

Based on the kinematic model, I proposed a framework that concerns the grasp stability in 2D. It takes advantage of some offline preprocesses to provide a **grasp stability map** which can be integrated in motion planning algorithms. It relaxes the tight constraint of grasp stability, at least in part, and facilitates the motion planning. The generality of this framework and its ability to merge with different planners makes the planning process easy and flexible. Simulation results show the efficiency of this framework for two planners, Voronoi and PRM.

We also investigated a general solution in 3D case. Using some constraining assumptions, the same method can be employed in 3D and **grasp stability map** is obtainable. However, the planning procedure is not as easy as in 2D. In any non-planar 3D case, a nonholonomic constraint inherently exits in the system equations, which makes the planning process too complex and expensive. Our proposed algorithm provides a map that just represents the kinematic constraints of the grasp stability and all other constraints (holonomic/nonholonomic) should be satisfied within this map.

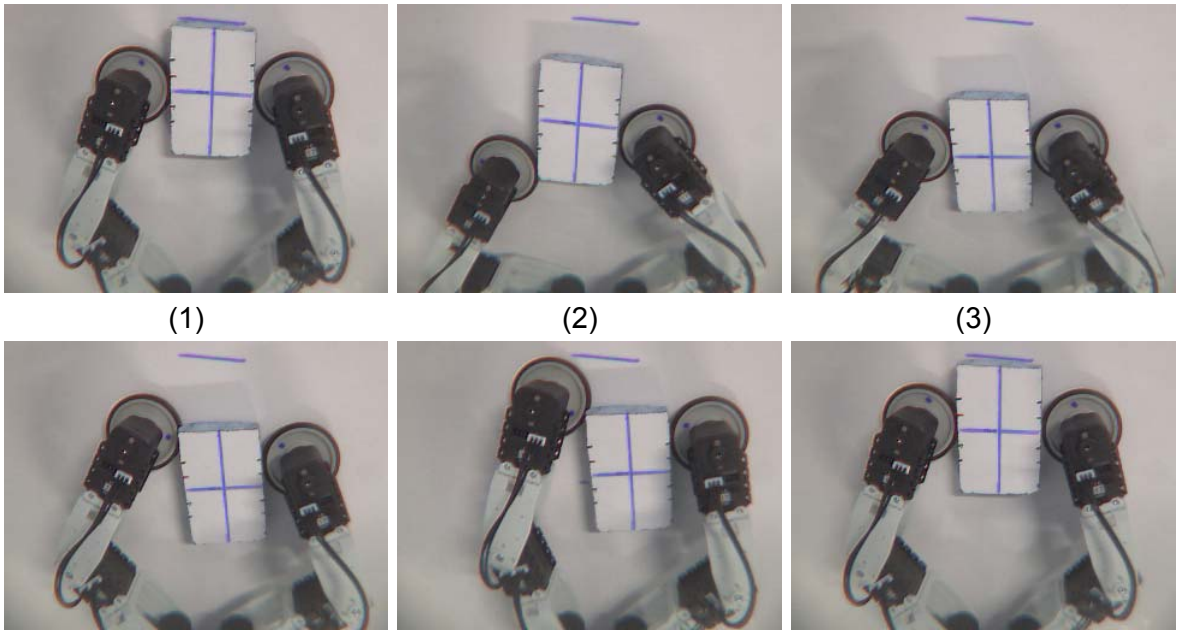
## (e) Preliminary results

We used two robots, a planar (2D) robot and a non-planar (3D) robot, to verify our proposed method. Below figures show that, taking advantage of wheeled-tip manipulation in 2D, the robot can perform the requested task in an open loop manner (no feedback control is used) perfectly.



(1) (2) (3)

Part reorientation by contact points displacement



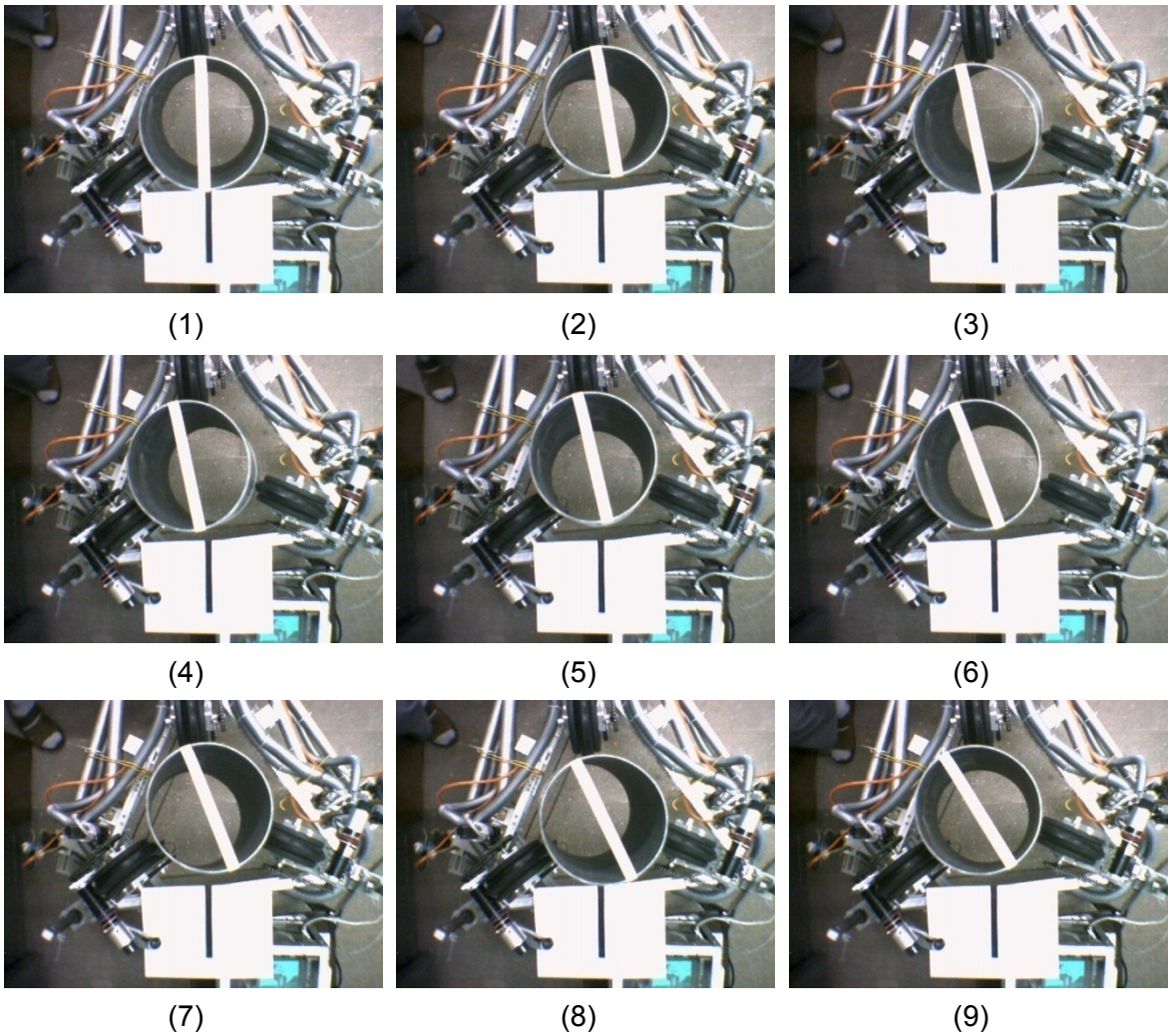
(1) (2) (3)

(4) (5) (6)

Snapshots of object manipulation on a diamond path

In case of 3D, we modified a wheel based pole climbing robot to obtain a 3-finger wheeled-tip manipulator. The robot consists of one active wheel and one passive joint in each finger. As shown in the below figures, the object is a cylindrical pipe and the wheels should not slide on the object. There exist a lot of complex maneuvers that the robot could not perform, if the wheels are replaced by some normal links.

Considering the nonholonomic constraints, several canonical paths are designed and implemented. Below figures show the experiment, in which the object is rotated 30 degrees counterclockwise around z-axis, while the wheels are always parallel with this axis. This canonical path should always belong to the objects' grasp stability map. Again, successful implementation of the planned path obtained without using any force or torque control which strongly validates our kinematic planning algorithm.



(1) (2) (3)

(4) (5) (6)

(7) (8) (9)

Snapshots of the film of 3D object manipulation (top view)

**(f) Future plans**

We plan to pursue our investigation on a general solution or a framework in 3D case. In a manuscript, we discussed the challenges included in contact positioning of wheeled-tip robots. The grasp stability map introduces an ideal framework for analyzing and planning a robust path, when uncertainty exists in positioning of the fingers on the object. It also shows some guidelines in re-grasp planning.

Afterwards, we target the dynamic model of the robot and plan to find and propose similar solutions in presence of system dynamics. The rest of simplifying assumptions would also be relaxed later, considering deformability of the object, adhesive contact points, uncertainty in object's shape and presence of multiple contacts between each finger and the object.

# Brief CV

**EDUCATION:**

PhD Electrical Engineering, Control Systems and Robotics. 2004-2010
University of Tehran, Tehran, Iran.
**Dissertation topic**: *Kinematic Analysis of Wheeled-tip Manipulators*. March, 2010
**Advisor**: Dr. Majid Nili Ahmadabadi.
**Overview**: The new mechanism, *Wheeled-tip Manipulator*, is an extension to the well-known class of manipulators, rolling contact manipulators. The research domain includes kinematic modeling and analysis of this mechanism. However, its path planning and kinematic control is also considered.

M.Sc. Electrical Engineering, Control Systems. 1999-2002
K.N.Toosi University of Technology, Tehran, Iran.
**Thesis title**: *Sensorless Vector Control of PMS Motors*. April, 2002
**Advisor**: Dr. Hamid D. Taghiraad.
**Overview**: The Master's thesis was to implement an especial control strategy (sensorless vector control) for special electrical motors (permanent magnet synchronous motors). It introduced a different vector control method in which velocity is not estimated. The algorithm is also implemented on hardware for practical verification.

B.Sc. Electrical Engineering, Electronics. 1995-1999
University of Tehran, Tehran, Iran.
**Thesis title**: *Voice Compression Software for WEB Applications*. Nov., 1999
**Advisor**: Dr. Mahmoud Kamareiee.
**Overview**: The project consisted of developing software that can facilitate communication between two parties through the web, when the bandwidth is limited. It reduced the voice bandwidth from 64Kbps to 2.4Kbps, using MELP vocoder. The software was developed and tested between Tehran and Dubai, using line modems.

**HONORS:**

- ✓ Graded “A” in all courses of PhD and therefore in GPA
- ✓ Ranked 1st of graduated Master students of ECE (Control branch), 2002
- ✓ Ranked top 10% of graduated seniors of ECE, based on overall GPA, 1999.
- ✓ Ranked 17 among more than 400,000 applicants in B.Sc. National Universities Entrance Exam, 1995.
- ✓ Silver medal of 2nd National Computer Olympiad, Young Scholars Club, 1993.
- ✓ Finalist in National Olympiad in 2 majors : Computer, Mathematics, 1993

**PUBLICATIONS:**

1. ***E. Noohi***, H. Moradi, N. Noori, and M. Nili Ahmadabadi. “**Object Manipulation Planning for Wheeled-tip Robots in Presence of Contact Position Error**”. SUBMITTED to Robotics and Autonomous Systems.

2. ***E. Noohi***, S. Mahdavi, A. Baghani and M. Nili Ahmadabadi, "**A Wheel Based Climbing Robot: Modeling and Control"**. *Advanced Robotics,* Vol. 24, No. 8-9.

3. N. Noori, ***E. Noohi***, H. Moradi, A.H. Bakhtiary, and M. Nili Ahmadabadi. "**A probabilistic roadmap based planning algorithm for wheeled-tip robots manipulating polygonal objects"**. In *Proceedings of ASME/IEEE International Conference on Advanced Intelligent Mechatronics (AIM'09),* pages 1040–1046, July 2009.

4. ***E. Noohi***, H. Moradi, and M. Nili Ahmadabadi. "**Manipulation using wheeled tips: benefits and challenges"**. In *Proceedings of 39th International Symposium on Robotics (ISR'08),* pages 442–447, Korea, October 2008.

5. S. Mahdavi, ***E. Noohi*** and M. Nili Ahmadabadi, "**Basic movement of a nonholonomic wheel-based pole climbing robot"**. In *Proceedings of IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM'07),* ETH Zurich, Switzerland, Sept 4-7 2007.

6. S. Mahdavi, ***E. Noohi***, and M. Nili Ahmadabadi, "**Path planning of the nonholonomic pole climbing robot UT-PCR"**. In *Proceedings of IEEE International Conference on Robotics and Biomimetics (ROBIO'06),* pages 1517-1522, Kunming, China, Dec. 17-20 2006.

7. H. D. Taghirad, N. Abedi, ***E. Noohi***, "**A New Sensorless Vector Control Method for Permanent Magnet Synchronous Motors without Velocity Estimator"**. In *Proceedings of 7th International Workshop on Advanced Motion Control (AMC'02),* pages 242-247, Maribor, Slovenia, July 3-5 2002.

**TECHNICAL AND COMPUTER SKILLS:**

- **Software development:**
  - C, C++, Microsoft Visual C++
  - Matlab, Maple
  - Orcad, Spice, Protel
  - ADAMS
  - Latex, Microsoft Office, Microsoft Visio

- **Hardware development:**
  - Board design in mixed mode(digital & analog)
  - DSP parallel programming:
    - Texas Instrument: DSPs from 2000, 5000 and 6000 families, especially TMS320C2040, TMS320C5409 and TMS320C6209.
    - Analog devices: SHARC processor family.
  - Logic design and program: especially using Xilinx CPLDs and FPGAs.
  - IO bridging, using ADC, DAC, USB2 (project manager), PCI, etc.

- **Project Management:** especially in the case of automation systems that integrate data gathering hardware with the operation/management software.

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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Computer Network Laboratory
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Centro de Investigación y de Estudios Avanzados del I.P.N.
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enavarro@gdl.cinvestav.mx

Research field
(Wireless localization, Friis equation, EM light theory)

# Research Proposal

## Distance Estimation in 802.14.5-based Sensor Networks

(a) Research problem statement.

Different definitions for the localization problem can be found in the related literature. In [5] the localization problem is defined as "determining an assignment of coordinates for nodes in a wireless ad-hoc or sensor network that is consistent with measured pair wise node distances". In [5] is defined as "determining where a given node is physically located in a network. But, the core of the localization problem consists in estimating the position (spatial coordinates) of randomly placed nodes within a Wireless Network. The localization problem can be formally stated as follow:

*Given a graph G=(V,E,ψ), with |V| = n, |E| = m (nodes labeled 1 through n), and the distance measurement between each pair of nodes ω(ψ(i,j)), i,j ϵ {1,2,..,n}, produce an assignment of vertices V to points in* $R^3$ *(coordinates)* $x_i,y_i,z_i$ *for each node i, such that the assigned distance between nodes i,j,* $\sqrt{(x_i + x_j)^2 + (y_i + y_j)^2 + (z_i + z_j)^2}$ *equals the measured Euclidean distance.*

(b) Significance and objectives.

Received Signal Strength (RSS) is a measure of the voltage (power) of a received radio signal. RSS is highly unpredictable and non-uniform. An accurate prediction of signal strength level is a complex and difficult task. However, this is an essential issue for Sensor Networks Localization Algorithms, especially for those RSS based. The uncertainty and randomness in RSS measurements can be explained by the different physical phenomenon's that propagate a signal: *reflection*, *refraction*, *scattering* and *diffraction*. These phenomenons are responsible for multipath effect, scattering, shadowing, and other major source of measurements errors.

The basic premise of this work is that propagation mechanism of a signal mentioned above (and its effects) can be better understood and modeled under the perspective of Electromagnetic Theory of light (EMTL). Using these modeling different localization algorithms could infer a distance between all pair of nodes.

GENERAL OBJECTIVE: The main goal of this research work is to provide a computational model based on EMTL for locating nodes within a network. This model could be used for different localization algorithms, especially those RSS-based.

PARTICULAR OBJECTIVES: 1).- Implement a localization scheme based in the computational model proposed and any of the existing techniques (see summary state of the art). 2).-the implementation is intended for WPAN with short-range, 2.4 GHz ISM transceivers compliant with the IEEE 802.15.4. (zigbee). 3). It must be able to work with and without the help of beacons nodes in infrastructure (ad-hoc type) networks and consider the node mobility. A beacon node has a known position (either placed at known positions or using a GPS). The unknown node does not know its position, it estimate a location with the help of the beacons.

(c) Summary of the current state-of-the-art.

Localization algorithms can be mainly classified in two categories: *Range-free* algorithms infer the distance (estimation) between nodes based on constraints from the proximity to beacons nodes. *Range-based* algorithms rely on precise range measurements to estimate the position of the nodes. Range-based algorithms are also divided in three basic categories: *Received Signal Strength* (RSS), *Angle of arrival* (AOA) and *Time of Arrival* (TOA). a).-*Time of arrival* is based on signal travel time between nodes. The distance is derived from the arrival time difference between two signals. b).-*Direction (angle) of arrival* is a technique in which the node location is estimated using signal angle arrival between the unknown location node and an array of nodes. c). - *Received Signal Strength* based technique uses the received radio signal power to estimate distance. Next, various localization algorithms that relay only on RSS are reviewed.

TRIANGULATION: Radar System [2] and Spot ON [3] are two indoor location systems. RADAR uses signal strength measurements from multiple receivers to *triangulate* the user's coordinates. The receivers are positioned to provide coverage in the area of interest. Spot ON is based on a RFID technology and similar to RADAR, signal strength measurements and distance estimation to nodes are provided by multiple base stations.

RADIO HOP COUNT is one of the simplest schemes. It is based on the principle that when two nodes communicate using a radio signal the distance between each other is less than the maximum range of their radios, no matter the signal strength level [4]. In [5] the Ad Hoc Positioning System (APS) solution uses hop counts to estimate distance.

GEOMETRIC CONVEX CONSTRAINTS is based on the forming of geometric constrains around the network nodes [6]. These are referred to as convex regions (bounding). These geometrical shapes characterize the radio signal transmitted.Four shapes are interpreted from the constraints: *radial*, *angular*, *quadrant* and *trapezoid*.

OVERLAPPING COVERAGE AREAS uses a given number of beacon nodes to cover established areas. The beacons transmit packet with their position every certain period *t*. The unknown nodes use this information to calculate connectivity metric for locating themselves using intersection areas of the coverage regions. Bulusu *et al* in [7].

PROBABILISTIC APPROACH is based on an a priori probabilistic density function (PDF) [8]. This function is derived from signal strength vs. distance experiment. Signal strength measurements at different distance are considered as a random variable because of the effects of environmental conditions, errors, noise, fading, disturbs, etc.
***MULTIDIMENSIONAL SCALING (MDS) is based on a data analysis technique originated in psychometrics [9]. It aims to display the structure of distance-like data in a Euclidean space. The basic principle consists in transforming a distance matrix into a cross-product matrix in order to find its eigen-descomposition using principal component analysis (PCA) [10]. Shang et al. propose a solution is called MDS-MAP [11].***

CENTROID: in [12] an algorithm specifically for Zigbee-based networks is presented. It is derived from centroid determination that average coordinates from known reference point and uses weights to attract the estimated position to close reference points. The Link Quality Indicator (LQI) in Zigbee devices and Friis free space equation are used to estimate a distance from a node to reference points.

(d) Proposed research methodology and plan;

The methodology consists in the use of numerical simulations to describe signal propagation mechanisms (via ETML) and antennas radiation characteristics like *far field radiation*, *intensity*, *directivity* and *gain*. To simulate antenna far field radiation at different points, this work uses the Matlab scripts provided by [13]. The scripts are based on the method o moments (MoM). MoM relay on the Integra Equation (IE) which can be solved with a numerical technique solution. By solving this equation, the impedance (driving point) of the antenna is obtained. For simulation, a quarter-wavelength monopole on a finite ground plane was created with the following dimensions: a). Plate (finite ground) length 0.05m (along the x-axis). b). Plate width 0.05m (along the y-axis). c). Monopole height 0.03m. See Figure 1A. A monopole is a half of a dipole place over an in finite ground plane. This half mirrors in the ground plane or counterpoise and can be consider same behavior as a dipole (same doughnut radiation pattern). Same results could be obtained by using EM antennas modeling commercial programs like FEKO [14].

The simulation calculates the following far field values: **E**-field (V/m), **B**-field (A/m), the cross product (Poynting vector) **S**, and the average of **S** (V/m$^2$). The average $\langle S \rangle_T$ which is equivalent to the irradiance (**I**) and proportional to **E** field is calculated using the formula $I = \frac{c\epsilon_0}{2} E_o^2$. ***c*** is the speed of light (2.99792458 X $10^8$ m/s). $\epsilon_o$ is the electric permittivity of free space (8.8542 X $10^{-12}$ C$^2$/N•m$^2$). The resultant values of the far field at different points in spaces (B and C) are tabulated in Table A1.(for a distance from 1 to 40 meters). These coordinates shall be further explained.

TABLE A1

| **Point B** | | **Point C** | |
|---|---|---|---|
| (X=0, Y=-1.5, Z= 0.5) | W = 4.11E-04 w/m$^2$ | (X=0, Y=0, Z= 1.0) | W = 8.60E-07 w/m$^2$ |
| (X=0, Y=-1.5, Z= 1.0) | W = 2.64E-04 w/m$^2$ | (X=0, Y=0, Z= 2.0) | W = 1.25E-07 w/m$^2$ |
| (X=0, Y=-1.5, Z= 1.5) | W = 1.48E-04 w/m$^2$ | (X=0, Y=0, Z= 3.0) | W = 4.50E-08 w/m$^2$ |
| (X=0, Y=-1.5, Z= 2.0) | W = 8.00E-05 w/m$^2$ | (X=0, Y=0, Z= 4.0) | W = 2.29E-08 w/m$^2$ |
| … | … | … | … |
| (X=0, Y=-1.5, Z= 5.0) | W = 4.56E-06 w/m$^2$ | (X=0, Y=0, Z= 10.0) | W = 3.19E-09 w/m$^2$ |
| … | … | … | … |
| (X=0, Y=-1.5, Z= 10.0) | W = 3.30E-07 w/m$^2$ | (X=0, Y=0, Z= 20.0) | W = 7.79E-10 w/m$^2$ |
| … | … | … | … |
| (X=0, Y=-1.5, Z= 15.0) | W = 6.75E-08 w/m$^2$ | (X=0, Y=0, Z= 30.0) | W = 3.45E-10 w/m$^2$ |

An EM wave change of medium while travelling (for example form free space to a dielectric), this causes a change of wave speed, wavelength, etc. originated by the different index of refraction on both side of the boundary ($\epsilon_o$ changes to $\epsilon$, $\mu_o$ changes to $\mu$). See Figure 1B. Since this research is concern with irradiance (***I***) flow, it is important to calculate how much of the incident energy on the ground (mirror) is reflected from point B and how much is transmitted directly from point A. It is means we must obtain total ***I*** from the two signals received at point C. In order to do this calculation, the reflectance and transmittance ratios are used. The **reflectance** ratio is defined as follows: $R_{parallel} = r^2_{parallel}$, where $r_{parallel}$ is amplitude reflection coefficient $r_{parallel} = \left(\frac{n_t \cos\theta_i - n_i \cos\theta_t}{n_t \cos\theta_i + n_i \cos\theta_t}\right)$. The **transmittance** ratio is defined as follows: $T_{parallel} = \left(\frac{n_t \cos\theta_i}{n_i \cos\theta_i}\right) t^2_{parallel}$

where $t_{parallel}$ is the amplitude transmission coefficient. To validate the simulations, real measured RSS data from [15],[16] shall be used to test models obtained.

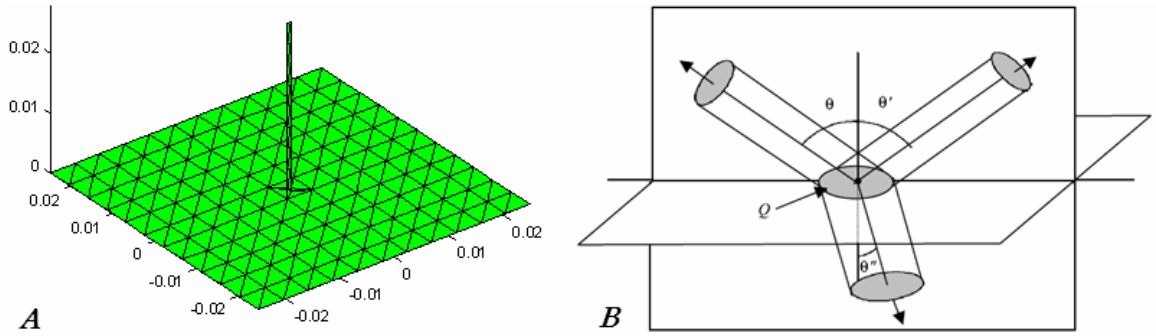



*FIGURE 1*. a) ¼ monopole on finite ground used in the simulation. B) boundary conditions.

(e) Preliminary results.

OUTDOOR: An open field environment (as basketball court, a soccer pitch or parking lot) is a common range test scenario for transceivers, see [15], [16] and [17]. Based on my experience and own experiments [18], the most important factor affecting the signal are *reflection on the ground.* Noise and other radio source are considered to affect a minimum. This factor can be modeled with Lloyd's mirror interference phenomenon from optics [20]. This consists of a flat surface of dielectric material (ground) which serves as a mirror from which one portion of the electromagnetic (EM) wave is reflected and the other portion proceeds directly to the screen. As shown in Figure 2 an EM wave from source point A is detected by a receiver at point C. If part of this wave is reflected off a mirror at point B, this reflection will also be detected by the receiver. Due to this, the reflected wave will be out of phase with respect to the incident wave. When the two waves meet at the receiver, constructive and destructive interference can occur.

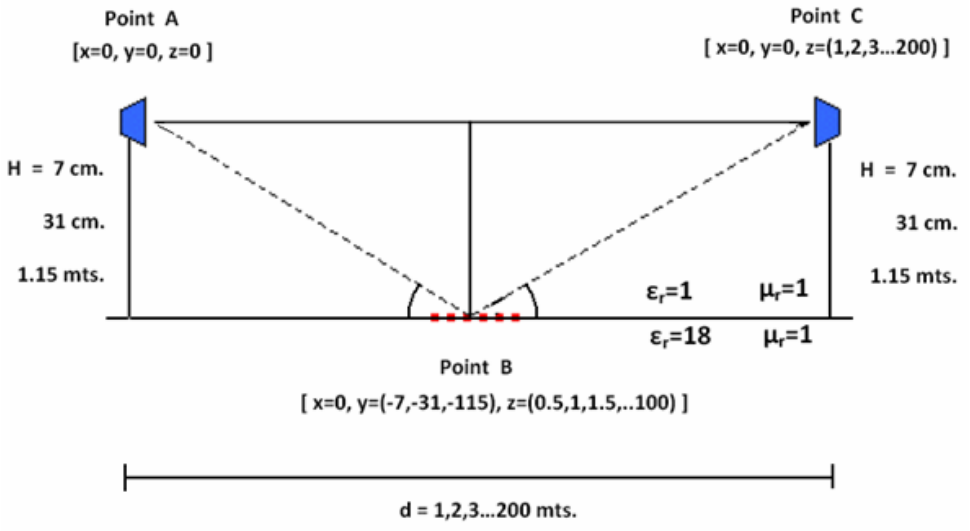



*FIGURE 2*. Lloyds mirror.

Maximum signal strength will be detected when the two waves reach the detector in phase. Minimum is detected when the waves are 180$^{o}$ out of phase. The optical path length of the reflected signal is defined as AB+BC while for the un-reflected signal is just AC. To simulate Lloyd's mirror combined with monopole antenna radiation simulation, a configuration was planned similar to real experiment performed in [15], [17] and [18]: a) a transmitting antenna is placed at a reference point A. b) a second (receiving) antenna is placed 1 meter away. c) the transmitting antenna is moved to 7 cm, 31 cm and 1.15 meters height. d) simulation is performed several times. e) the second antenna is moved incrementally 1 meter away from the reference point A. f) steps *c*, *d* and *e* are repeated until a 100 meters range is reached. See figure 2. Using the same boundary condition as [15], $\epsilon_{r1}=1$, $\mu_{r1}=1$ $\epsilon_{r2}=18$, $\mu_{r2}=1$, the reflected irradiance at point B and direct irradiance from A are showed in table A2.

TABLE A2.

| **Incidence** | **$R_{parallel}$** | **Reflected I at B** | **Direct I from A** |
|---|---|---|---|
| Θ = 18.43494883 | 0.36345369 | 0.000149303 | 8.60E-07 |
| … | … | … | …. |
| Θ = 53.13010236 | 0.19644397 | 1.57153E-05 | 2.29E-08 |
| … | … | … | … |
| Θ = 63.43494882 | 0.10237241 | 2.65104E-06 | 9.31E-09 |
| Θ = 66.80140949 | 0.06891351 | 1.0878E-06 | 6.70E-09 |
| … | … | … | … |
| Θ = 71.56505118 | 0.02509827 | 1.67021E-07 | 3.96E-09 |
| … | … | … | … |
| Θ =80.53767779 | 0.02713571 | 1.34691E-08 | 9.64E-10 |
| … | … | … | … |
| Θ =84.28940686 | 0.15558002 | 1.05046E-08 | 3.45E-10 |

The first column is the incident angle $\theta_i$ ranging from θ=18.43494883$^{O}$ to θ= 84.28940686$^{O}$. In second column the **reflectance** ratio is shown. In the third column the incidence ***I*** from point B is calculated. In the fourth column the direct ***I*** from point A is calculated. Employing these values of the irradiance from point B (reflected) and irradiance from point A (direct), the total power at received antenna is calculated. The adding of both irradiances must be done via an Interference formula due to both irradiance comes from to EM waves interfering at point C. This formula is $I_C = I_B + I_A + 2\sqrt{I_B I_A}\cos\theta$.The plotting of the resultant power (express en *dBmW*) at point C, for height 1.50 meters and distance from 1 to 30 meters is shown in Figure 3.

INDOOR: Based on the preliminary results presented for outdoor simulation, is reasonable to think other environment can be modeled via EMTL. For example, a multiple waves interference caused by the bouncing of the signal on walls and ceiling (indoor environment) could be modeled via a random arrangement of source signal points (Lloyd's mirror can be extended to cover this). To simulate Indoor signal propagation a 3D setting as described in [16] was programmed. This is a 3D structure measuring 4.5 m (W) x 6.0 m (L) x 3.0 m (H). Also, [16] provides 15,000 measurements database (http: //www.eng.yale.edu/enalab/rssidata/) of RSS values obtained from 38 sensors. See Figure 4A. Particularly, sensors no.1 and sensor no.13 were chosen to test our model. See Figure 4B.

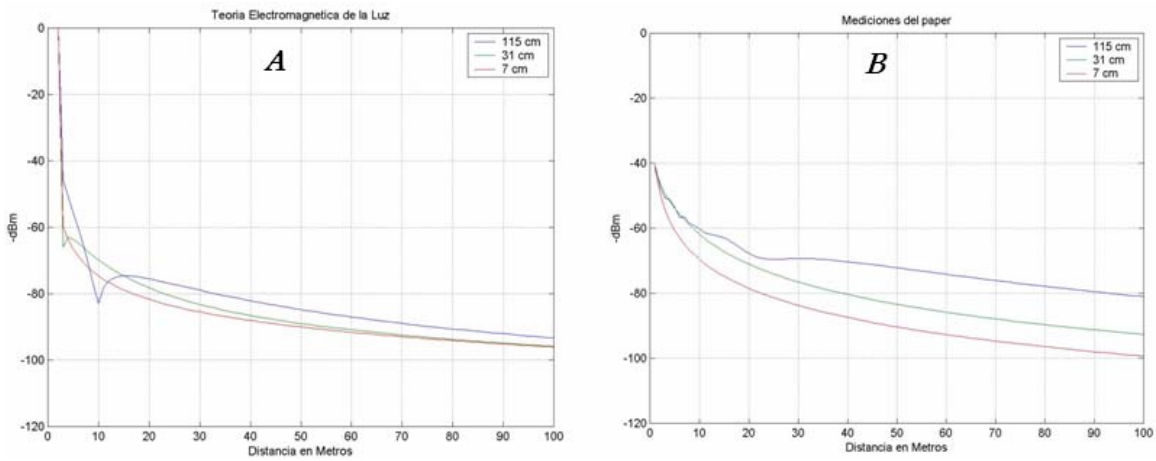



*FIGURE 3*. a) Simulation results. B). Results from [15].

The premise of this research work is that the RSS information provides a mean of inferring distance. In order to do this inference, a statistical technique is needed. The estimation theory provides such a tool: hypothesis testing (HT). HT is used in this work as a basic mechanism of inference. A hypothesis about RSS population parameters value at a given distance (in this case 7.672 meters) is required. HT (significance level 0.05) is performed to match RSS database values predicted by the computational model proposed. It tests all RSS values drawn from the database. If the hypothesis is accepted the distance estimate is obtained. If it is rejected the significance level is changed. Thorough this mechanism, position estimation for nodes no.1 and no.13 is calculated:

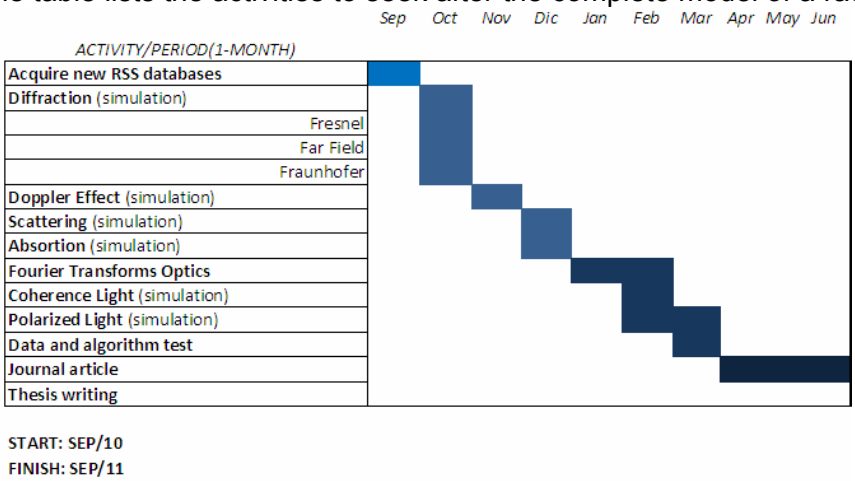
$H_0$ = -45:4808 dBm. $\alpha$ = 0.05
$H_1$ = -45:4808 dBm. *Critical Region*: (-1.96, +1.96)

$$Z = \frac{-45.5-(-45.4808)}{\sqrt{0.25}/\sqrt{10}} = -0.12$$

The result of HT over all database measurement output a position with and error of 2.03 mts. with regard to the node real position. (Arrow in figure 4).

(f) Future plans

The next time table lists the activities to seek after the complete model of a radio signal. .



These activities are schedule to include the last 1 year of the PhD. Program and are the modeling (via EMTL) of the phenomena they describe.

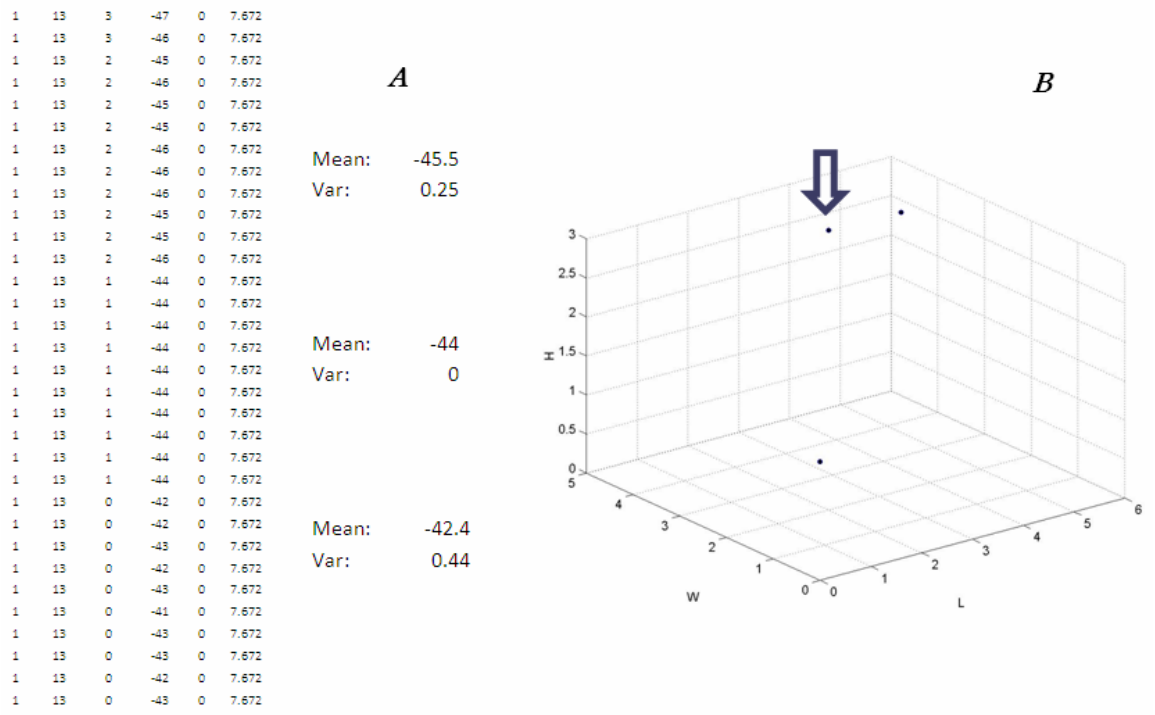



*FIGURE 4*. a) Database measurements. b) 3D setting.

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# Brief CV

**Ernesto Navarro Álvarez** was born in Colima, México on November 7, 1976. He received his Computer engineering degree from *Instituto Tecnológico de Colima*, México, in 2001 and the Master in Sciences in the specialty of Electrical Engineering (Computer Sciences orientation) degree from *The Centro de Investigación y de Estudios Avanzados del I.P.N.(CINVESTAV-IPN) Unidad Guadalajara* on September 26, 2008. The thesis he presented to obtain the degree was: “An algorithm for node localization in WSN based on Multidimensional Scaling.” This thesis proposes an algorithm for node localization in wireless sensor network (WSN) that uses only connectivity information, by taking advantage of the inherent Radio Frequency (RF) communication capability present in each node, to infer distance and derivate coordinates. Currently, he is a postgraduate student in the Laboratory of Computer Networks of the CINVESTAV-IPN under Dr. Mario Siller supervision. Other interests are: electromagnetic numerical simulation and embedded devices programming in C.

**PUBLICATIONS (**Papers in Conferences Proceedings**)**

1. E. Navarro, M. Siller. A Node Localization Scheme for a Zigbee-based Sensor Network, in Proceeding of the 2009 IEEE International Conference on Systems, Man, and Cybernetics (SMC2009). San Antonio, Texas. United States. Oct 11-14, 2009.
2. E. Navarro, M. Siller. Overview on Node Localization for WSN Based only on RSSI with and without Node Mobility, in Proceeding of the 2009 World Congress in Computer Engineering and Applied Computing (WORLDCOMP2009). Las Vegas, Nevada. United States. July 12-15, 2009.

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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Formal Analysis, Dynamic Networks, Reliability

# Research Proposal

## Network-wide Security Analysis

(a) Research problem statement

Computer networks have become large, advanced and complex systems. These networks involve different types of devices, configurations, dynamic routing protocols and complex design patterns. The effect of links' up/down changes on small network segment in a large dynamic network can be propagated to other network segments affecting the qualitative properties. It is difficult to predict how this will affect the whole network. Manually checking and collecting routing updates from each device is a difficult and a time consuming task. Therefore network administrators tend to use network management tools to monitor their networks and perform adjustments when necessary.
Current scanning, monitoring and testing tools are useful for analysis of existing stable networks or for analysis of the next stable state of a network after its topology has been changed. These tools cannot predict network behaviors before a topology change occurs. This reactive nature may easily lead to performance degradation because of a link or a device failure [1]. Therefore, a formal network analysis is becoming a demand and necessity for the industry. Among the available industrial software tools we could not find such a product.

(b) Significance and objectives

The main objective of this research is to model dynamic networks and predict properties such as service reliability, security, and safety. These networks are configured with dynamic routing protocols such as RIP, OSPF or EIGRP. In a case of a device or a link failure, consequent topology changes appear and response of the network can be different. Therefore building a proper model which can predict dynamic behaviours is very important and will be useful for the practical applications in the industry.
The research was divided into three main sections namely modeling, analysis and implementation. The following are the individual objectives of each section.

I. Modeling

- One objective is to develop a model which is independent of the dynamic routing protocols in use. Model should be facilitated to analyze the reach-ability and security properties between any nodes under any network state. Modeling is the most significant part of the research and the rest of the research will be heavily dependent on this.
- Another objective is to build an universal model which is independent of the given network state, therefore the model needs not to be rebuilt each and every time for analysis with link changes.
- Then the security properties should be embedded into the model. As security properties different filtering rules of Cisco access control lists (ACL) are considered. Due to link failures the communication paths and the applied ACL's will be changed and need to evaluate the newly applied rules.

- Final objective in modeling section is to incorporate the traffic loads, delays and quality of services (QoS) to the model. This will be useful to predict the quality of services once the network converges to another state.

II. Analysis

- To reduce the state space an effective representation of network states should be introduced. If the representation of the link states (up, down) is by using the available links and its states then the state space will be exponential to the number of links, therefore a better way of representing the state space needs to be researched.
- The analysis approach should be simple and have minimal complexity of processing for each network state to determine the reach-ability and security properties. Once the network reach-ability is analyzed then it should be checked for the QoS to ensure the required service level of delivery.
- After implementing the analysis for the wired network it should be extended for wireless networks to predict security, safety and behavioral properties.

III. Implementation

- Finally the model and the analysis approach will be embedded into a simulation tool. The main objective in implementation is to build the simulation framework which is capable of acquiring the online network configurations, link states and QoS parameters from the network devices and to build the model without any human interaction. This will be a very useful tool for the administrators and the main advantage of this is that they do not need to disturb the running network during the analysis.

(c) Summary of the current state-of-the-art

The requirement of developing a system for predicting network behaviors in dynamic environment was addressed previously on Automated Network Wide Security Analysis (ANSA) project. The authors of ANSA project have outlined how the formal modeling can be used to predict reach-ability and security properties. This has been addressed in the paper [3]. The ANSA project has shown that it is possible to develop a model that combines static and dynamic behaviors using techniques described in [5], [2] and [4].
Modeling and analysis of dynamic networks are difficult due to state space explosion. All the above papers have indicated that the analysis may lead to state space explosion hence there should be a reduction method on representing the states. One effective method was introduced in [6] which limits the state space based on the probabilities of the occurrence of link failures.
In [5], authors showed that a static model can be implemented to predict dynamic network behaviors and security properties. The detailed implementation is not directly shown but authors discuss some approaches which could be applied for modeling and analysis. The main goal of [5] is to develop a model of a network for a full domain considering all the possible scenarios such as IOS bugs of devices, configuration errors, static routing, networks with mixture of different protocols, dynamic routing, networks with network address translations (NAT) and packet filtering. Since this has a broader area of dependencies and hence a huge state space, practically it is impossible to develop a model which has all the above variables embedded into it. Therefore authors

show that it is possible to have a static model with boundaries using some approximations. Approach in [5] has some differences to my approach. The main difference is that they compute all virtual paths according to the states of links, devices, applied filters, IOS bugs, states of routing tables, traffic etc. Then the computed virtual paths are compared with the physical paths. If there is a match then that virtual path can be used otherwise no communication is possible. This approach has less efficiency since it computes all virtual paths first which require complicated and time consuming algorithms as no available physical path can be found. In my approach, first identify the available physical paths and then do the analysis to find the communication path depending on the network state.
Another similar work is based on pre-computed routing tables to find the communication paths [3]. Constructing the routing tables for each router and for each network state is a time consuming process. Therefore a different approach was used and will be described under proposed research methodology section. Further the paper [3] shows how formal modeling can be used to model filters and match packets to predict security properties which I plan to use the same with some improvements.
All above researches assume that after the link failure the network will converge to another topology and be stable. The research done by [6] considers further link failures due to the loads after the network convergence from the first failure. One advantage of this approach is that they have considered the probabilities of the link failures and limited the number of link failures at a time. This will reduce the state space significantly. From the previous statistics of link failures they have identified that a link failure has the probability of $10^{-3}$ hence they have eliminated more than 3 consecutive link failures at a time. One advantage of this method is that they have eliminated working on extreme cases which have very less probability of occurrence in practice.
The approaches described above are different from my approach in terms of modeling and reach-ability analysis. In my approach, the plan is to implement one global model which contains all behavioral information of the network for all states. I also propose a different method to reduce the state space effectively than in [6].

(d) Proposed research methodology and plan

The proposed methodology and the plan to achieve the individual goals described are as follow

I. Modeling

- A method is used based on graph theory, lattices and first order logic's to define the required properties of the network. Subsequently formal methods and techniques are used to define the semantics of networks and its dynamic behaviors. My intention is to develop a model which is independent of the routing protocol in use. The behavior of the protocol is limited to one variable and hence planning to hide protocol dependency. Unlike previous approaches, the proposed approach is to build a model which is unique for the given network and for any given network state.
- To embed the security properties the Interval Decision Diagrams (IDD) will be used. Most of the variable fields in an ACL are intervals eg. networks( IPs), subnet masks, tcp ports etc. Thus matching process requires the interval matching and the use of IDD will improve the performance. This method was proposed in one previous paper [3] and I am planning to further work on the implementation.

- To incorporate QoS into the model, my approach is to first model the multicast traffic. And then relate it with other parameters such as load, delays to QoS.

II. Analysis

- The proposed plan is to reduce the computational complexity and the number of iterations by eliminating the rebuilding of the model for each and every network state. To represent the network states more compactly the network states which have the common network impact are identified and form a set called general-state. From this the state space can be significantly reduced and the state space explosion problem can be eliminated during the analysis process.
- The unified model defined in [5] will be used, but employs different approach for analysis. Unlike [3], the analysis does not pre-compute all possible routing tables in order to verify behavioral properties. In the analysis approach the failed links and the devices are categorized into three sets as critical points (CP), universal points (UP) and dependent points. The set of CP contains the links and devices which are essential for a given communication while the set of UP contains the links and devices which are not required for the given communication and have no impact on communication. This analysis approach will eliminate the extensive processing of trivial cases, and when the failed links and devices are in dependent points it will be analyzed in detail.
- The result will be a static model, so static analysis will be used in the analysis process. During the analysis the reach-ability and security properties for a given network state are computed from the static model. Since it is a model-based verification process I am planning to use an existing model-checking tool to automate this task.
- Further to determine the importance of links, a factor called criticalness for the links will be introduced. Different criteria such as whether the link belongs to the first path or backup path, number of data networks use by the link, load of the link, number of existing redundant links available etc. are considered when defining the criticalness factor.

III. Implementation

- The last stage of the research is to develop a simulation tool. Proposed plan is to code the formal model and the analysis process by using C or java programming languages. Once it is tested on several network topology's and optimized for efficiency, it will be integrated into OMNET++ environment.

(e) Preliminary results

At the moment the static model was formally defined with limited behaviors. Current results contain the analysis approach, state space reduction process and programming the model by using java. These results are still in the testing and improving stage.

I. Modeling

- The built static model was named as Modified Topology Table (MTT). MTT is unique for a given network and is invariant to link changes unlike the conventional topology

table. MTT is independent of the dynamic routing protocols used in the network and is able to limit its behaviors into one variable which is hidden in calculating the cost. Using MTT topology, routing table and available paths for any network state can be easily determined. Further MTT is also capable of generating similar network states for same topology, filters applied for any link state, costs of communication paths and criticalness of links.

- A method to incorporate the filtering rules into the model and the analysis process of security properties were formally defined. The correctness of this modeled filtering rules was checked by using different paths and filtering rules. This is in the stage of implementing by using the IDDs.

II. Analysis

- A process was introduced to reduce state space by grouping the network states which have common behaviors and named it as general-state in the static model. This process was precisely defined mathematically and tested for different networks including our university network. Using general-state it can be easily predicted the communication paths and the applied filtering rules under any network state. At the moment it is capable of predicting the reach-ability and security properties between any source and any destination on dynamic networks.
- Formally defined the the critical points (CP) and the universal points (UP). For several different networks the CP's and UP's were computed and checked against the expected properties. Further using a mathematical model the criticalness of different link segments in our university network were computed but to make the results more meaningful the semantics of the criticalness need to be defined properly.

III. Implementation

- An algorithm to compute MTT was implemented using java programming language. It is able to generate different paths, costs, and part of the general-states. This program was tested with different topology's. These topology's were generated by a separate java program. To generate 85,000 odd paths in a Lattice Ring type Regular network of degree 4 with 20 nodes consumed one minute and ten seconds, which is a very satisfactory result. This testing was done on 2xDual Xeon Core2/3GHz with 8 GB RAM machine.

(f) Future plans

To achieve the main objectives an intensive research work needs to be done. The future research in different sections are as below:

I. Modeling

- Extend the approach to predict wireless network securities and predict behaviors.
- Extend the research of analysis techniques for complex networks. Further to improve the model by adding more behavioral properties onto it.

II. Analysis

- Static analysis should be used to check soundness of configuration files, simulation of behaviors and automatic verification using model checking or SAT-solving.
- Extend the formal analysis phase with more advanced techniques which are able to determine various qualitative parameters on the network under different conditions.
- Incorporate traffic engineering concepts into the research. Further readings on traffic engineering on this area is required and applicability of traffic engineering concepts should be explored.

## III. Implementations

- Improve the program codes and incorporate them in to OMNET++ environment.
- Research on extracting online network configurations and automate the building of the model.

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# Curriculum Vitae


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## 1. PERSONAL DETAILS

| | |
|---|---|
| **Name in Full** | : Hidda Marakkala Gayan Ruchika de Silva |
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## 2. CURRENT STATUS

Employment : IT Specialist at IBM Global Service Delivery Centre, Czech Republic

Studies : Ph.D. research student at Brno University of Technology, Czech Republic.

## 3. INDUSTRIAL EXPERIENCE

1. Managing ISP data center
2. Managing operating systems, networks, and applications
3. Design, implementation and troubleshooting on networks
4. Disaster recovery planning and implementations
5. Implementation of security standards such as BS7799
6. Research and development for innovative solutions, forecasting and capacity planning

## 4. EMPLOYMENT HISTORY

| Company | Address | Post | Duration |
|---|---|---|---|
| IBM Global Service Delivery Center | Building F/G, Technicka 21, 616 00 Brno, Czech Republic | IT Specialist | 2007 todate |
| Ceylinco Internet Service Pvt. Ltd. | 2A, R.A. de Mel Mawatha, Colombo 04, Sri Lanka | Senior Systems Engineer | 2002 to 2007 (5 years) |
| Eureka online Pvt. Ltd. | 321, Galle Road, Colombo 03, Sri Lanka | Systems Engineer | 1999 to 2002 (3 years) |

## 5. Ph.D. Research Overview (Enrolled in 11/2008)

My research topic is Network-wide Security Analysis. The main objective of the research is to model dynamic behaviors of networks to predict the reach-ability and security properties under different network states and incorporate the model into a simulation tool.

## 6. EDUCATION QUALIFICATIONS

| **MASTERS DEGREE** | | | | | |
|---|---|---|---|---|---|
| **University** | **Degree** | **Field** | **Results** | | **Year** |
| University of Keele UK | MSc. in IT | Information Technology | Average 57% | | 2005 |
| | | | | | |
| **BACHELORS DEGREE** | | | | | |
| **School** | **Degree** | **Subjects** | **Results** | | **Year** |
| University of Moratuwa Sri Lanka | BSc. Eng (hons) | Electronics and Telecommunication Engineering | GPA 3.73<br>2nd Class Upper | | 1999 |
| | | | | | |
| **SECONDARY EDUCATION** | | | | | |
| **School** | **Exam** | **Subjects** | **Results** | | **Year** |
| Dharmashoka College Ambalangoda, Sri Lanka | GCE A/L | Pure Mathematics<br>Applied Mathematics<br>Chemistry<br>Physics | A<br>A<br>A<br>A | marks 344 | 1992 |

## 7. ACHIEVEMENTS

1. Third place in Student EEICT Conference 2009 in the area of information systems, multimedia and communication.
2. Mahapola Higher Education (Merit) Scholarship from Sri Lanka government for undergraduate studies: awarded for higher marks in university entrance exam (GCE A/L )
3. Sri Lanka National Mathematical Olympiad Association: Finalist in all Island contest.
4. Pure Mathematics and Applied Mathematics school price winner in 1990 - 1992
5. School Science Program: Conducted by Institute of Fundamental Studies (IFS) for selected candidates Island wide.
6. Runner-up in the open Chess tournament - National Youth Council, Ambalangoda branch, Sri Lanka.
7. Awarded the e-Sri Lanka government project to distribute IT to villages for my technical proposal submitted through Ceylinco Internet Services Pvt. Ltd., Sri Lanka.

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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**Research field**

**Statistical Model Based Control**

## Research Proposal

***Title :Solar powered battery state of charge estimator using Remote Sensor Technology***

***Research problem statement***

One of the main problem of a solar PV plant is low generation of electricity during bad weather when the generated power is less than the claimed demand of power. Under this condition it is not possible to generate more electricity as per demand once the power plant is designed. When the supply of electricity to the consumers reduces drastically and when there is no option for manipulation of power - a blackout out or load shedding is the inevitable. Online demand regulation i.e regulate the claimed demand of the individual consumer depending on predicted power generation is an alternate option in this constrained situation. The present research will address this particular problem through an adaptive load controller. Our goal is to design an adaptive load controller which incorporates a policy of meeting the base load primarily and loads exceeding the base load secondarily depending on predicted energy generation.

***Significance and objectives***

.Rapid variation of solar energy induce large variations of output voltage of solar photovoltaic cell used for electricity generation in a solar power plant. Therefore, in a power distribution system through an isolated solar electric grid leads to an unpredictable variation of the node voltage in the small electric network under a power plant. Such electric grid is available in an island (like SAGAR ISLAND in south 24 parganas of West Bengal , India) where the fluctuation in solar radiation can cause instabilities of power to the consumers. Apart from this, in an constrained and non manipulative electric environment the ability to limit the demand of power at the consumers end is an useful feature. The power shortage in such electric environment always seems like there is someone who wants to run a high power consuming device like an arc welder, taking all of the power available on the feeder line and knocking out his neighbor's power.

The other application for this kind of setup is related to the supply of electrical energy to some critical loads such as the refrigeration of vaccines and medication in hospital situated at a remote island without access to a reliable conventional electrical grid. While the refrigeration-related power drawl is a part of the high-priority base load which cannot be disturbed in spite of poor power condition without disconnecting the load with low priority demand. This justifies the implementation of an adaptive load controller in the consumers node to improve the quality of overall power situation in the region under an adverse weather condition - which is the primary concern of the work. Implementation of the proposed load regulation policy will lead to avoid frequent tripping or non availability of power in the region which may creates serious consequences in the establishments like hospital , night school, shops etc. operational under an isolated solar electric grid in a bad weather condition.

The objective of this research is to develop a predictive model using distributed remote signal detection for a solar powered battery state of charge prediction. The research will investigate weather it is possible to predict the time of failure of the battery through state of charge estimation- from a distant place where the generated power is delivered. The proposed work will be based on Hidden Markov model and will investigate the effect of distance on prediction accuracy through smoothing splines. A polynomial regression model is used to validate the model.

***Summary of the current state-of-the-art:***

A continuous, on-line indication of SOC of batteries, and estimation of their available capacity is of considerable importance for predicting the continuity of service. Estimation of State of charge (SOC) of Lead Acid Batteries has been a subject of active research for a long time and continues to be so even today.

A large number of techniques and algorithms have been proposed to predict state of charge (SOC) of Lead Acid batteries, each having its own limitations. In one of the earliest reported works (around 1897) Peukart proposed a semi empirical formula for calculating SOC using the discharge current. Mathematical model based SOC prediction methods were proposed by Salameh and Cassaca, among others. Several researchers have proposed SOC indicators based on neural networks, the work reported by Chan et al. is one such effort. Comparatively a new method for estimation of SOC of lead Acid battery is proposed which uses Radial Basis Functions combined with coulomb metric method. Apart from these several practical techniques are available to estimate SOC of lead–acid batteries such as specific gravity, open-circuit voltage, loaded voltage, and coulomb metric measurements (ampere-hour counting).Various models have been proposed based on the discharge voltage versus time characteristics.. Most recently radial basis function, support vector machine and relevance vector machine used for soc prediction.

***Proposed research methodology and plan:***

It is extremely difficult task to accurately predict the stored energy of a rechargeable battery from online State of charge estimation under environmental charging conditions like charging a rechargeable battery from solar PV cell. This is where advanced regression, classification and state estimation algorithms have an important role to play.

The proposed methodology consists of development of a battery state of charge classifier for a photovoltaic solar power plant using remotes sensor based signal modeling technique. This can classify the quality of future available energy in a solar electric grid from a distant consumers house without any extra power consuming and costly networking hardware**.** This is a model based technique based on collected data available from the various distributed consumers house under solar photovoltaic power generating station.

Hidden Markov model which is generally used for biologically sequencing and speech processing is utilized as a trainable model for prediction of battery state of charge during the charging process of a battery through solar energy. This is primarily used to perform a classification task using remote sensor technology with a reasonable level of success.

The output of the Hidden Markov Model describe the probabilistic likelihood of battery state of charge at a particular cycle of day (day light)which is to be delivered in the next cycle(night) to the consumer.

The proposed methodology is based on development of a trainable Hidden Markov model (HMMs) from the observations of noisy data that has a simple structure with Markovian dependence. We are interested for a trainable HMM with supervisory learning capability which can take a set of input vectors corresponding to their targets. The aim is to learn the dependency of the target variables on the basis of input variables for an accurate prediction of the unobserved variables from the observed input data.

Next we will try to identify the polynomial function corresponding to the input and output variable along with the noise components using smoothing spline regression technique which can predict the response variable eliminating the induced noise.. Once the polynomial is identified the battery state of charge can be predicted from the covariate i.e light intensity pattern at a distant place eliminating the noise components (confounders) like distance, cloud movement , season, time etc.

Finally validate output of the trainable hidden Markov model with the quantified predicted output available from regression model. This will finally used for the quantification of the optimum load cut off limit to support the maximum duration of service to the high priority load.

After the model validation corresponding code will be utilized on a suitable hardware platform for implementation of an adaptive load controller.

***The proposed plan of work:***

1. Collection of data like battery charging current and light sensor on each day at various locations.
2. Scan the entire data to find the maximum and minimum.
3. Depending upon this to estimate the sampling intervals for the light sensor.
4. From this interval evaluation of corresponding intervals of battery state of charge.
5. Compute transition probability Matrix both for light sensor and battery State of charge.
6. Investigation for dissimilarity due to noise component using smoothing spline.
7. Adjustment of Model parameters of corresponding Hidden Markov Model for correct estimation of output variable corresponding to specific input sequences.
8. Validate the model.
9. Set the cut off limit according to the available output.
10. Develop the corresponding hardware for controller.

***Preliminary results:***

An experiment was conducted to get a pattern of the solar intensity variations at different locations surrounding the power generating system in a rechargeable lead acid battery connected to a solar pv panel. The solar intensity variations incident on a Solar Panel and a light sensing device (LDR) were recorded, at the same time instants, for around a month. The Location of the Solar Panel was kept fixed, while the LDR was placed at different distances, within a certain radius, from the Solar Panel. ***Advantech USB-4718 Data Acquisition Module*** was used to collect and store the LDR readings. On one end the charging current flowing in the circuit due to the Solar Panel was recorded and stored in a personal computer using a multimeter, while on the LDR end the potential drop across the LDR was recorded.

***Observations***

On plotting both the panel current and the LDR voltage readings for different days, a correlation was found between the two. When the LDR was placed closer to the Solar Panel, the intensity variations of the two were highly correlated and the pattern was almost similar. If the distance between the two were increased, it was found that the correlation between the two was slightly decreased, but nevertheless, a correlation used to exist.The correlation would also depend on the type of the day. If the day was clear, sunny and without any clouds, then the correlation between the two data sets would be higher, irrespective of the distance. On the other hand, if the day was cloudy or rainy, the level of correlation degraded.

The charging current generated by the Solar Panel reaches a constant level towards the evening. On the LDR end, the voltage readings drop abruptly due to the lower surface area of the LDR as compared to the Solar Panel.

***Future Work Plan:***

In most of the electrified world, power is delivered to the point of use by an established generation, transmission and distribution network (called *the grid*), metered for consumption, the meter is read, then a bill is sent to the customer at regular intervals for the energy consumed. Unfortunately, much of the world is not approachable by the grid due to geographic issues, such as being on an isolated island, and/or a lack of economic viability where solar electric power distributed through mini grid plays an important role. The prepayment mode of electricity bill in such costly electricity generation and distribution system eliminates all issues including cost overhead related to manual bill collections, and a local payment infrastructure overhead supporting the collection mechanism.- where smart card based prepaid metering is a good workable solution. One of the key limitation of such ‘prepayment mode’ for bill payment needs some assurance of getting electricity to the consumers from power distribution authority prior to payment which is one of the main limitation for implementation of such system to an isolated solar electric grid as the duration of avail ability of solar power is uncertain in bad weather. The proposed research work will upgrade the current smart metering system through prediction of duration of availability of electricity using statistical model in real time - prior to consumption and will be able to control the power to a critical load more effectively. The future plan is to develop a proper ‘Inference Engine’- which will

able to predict the duration of availability of electricity and control load accordingly through the metering system automatically. This will ultimately help to upgrade the currently developed SMART CARD OPERATED PREPAID ENERGY METER WITH LOAD CONTROLLING FEATURE FOR SOLAR POWER APPLICATION.

***Graphical interpretation of LDR and Battery charging current with reference to time*** :

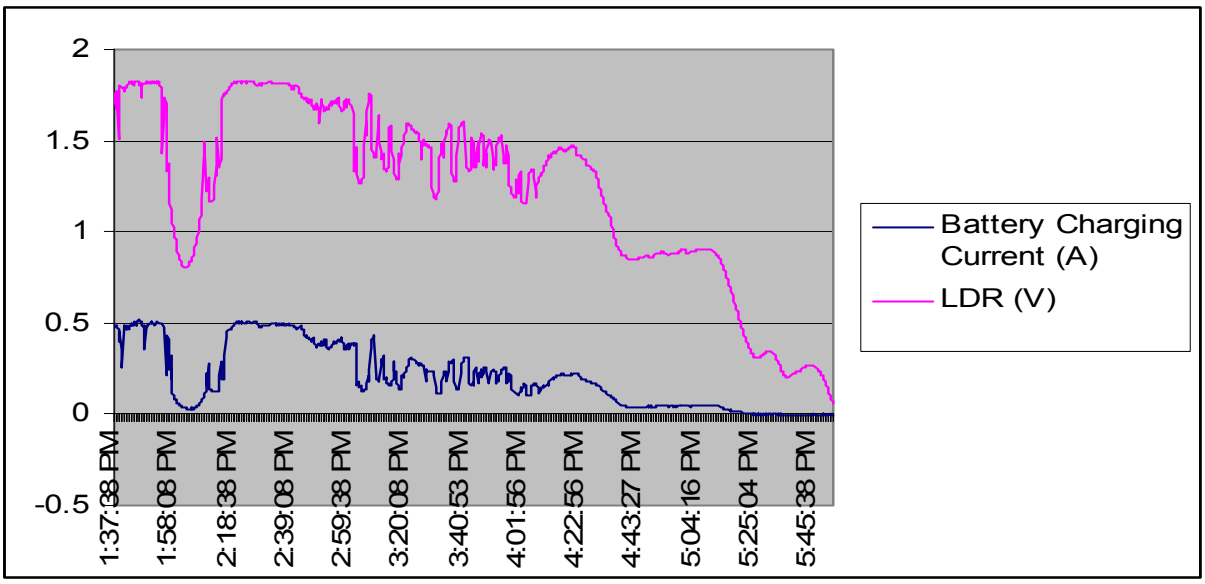


**Fig-1: Distance between LDR and the Solar Panel closed to each other in fluctuating weather.**

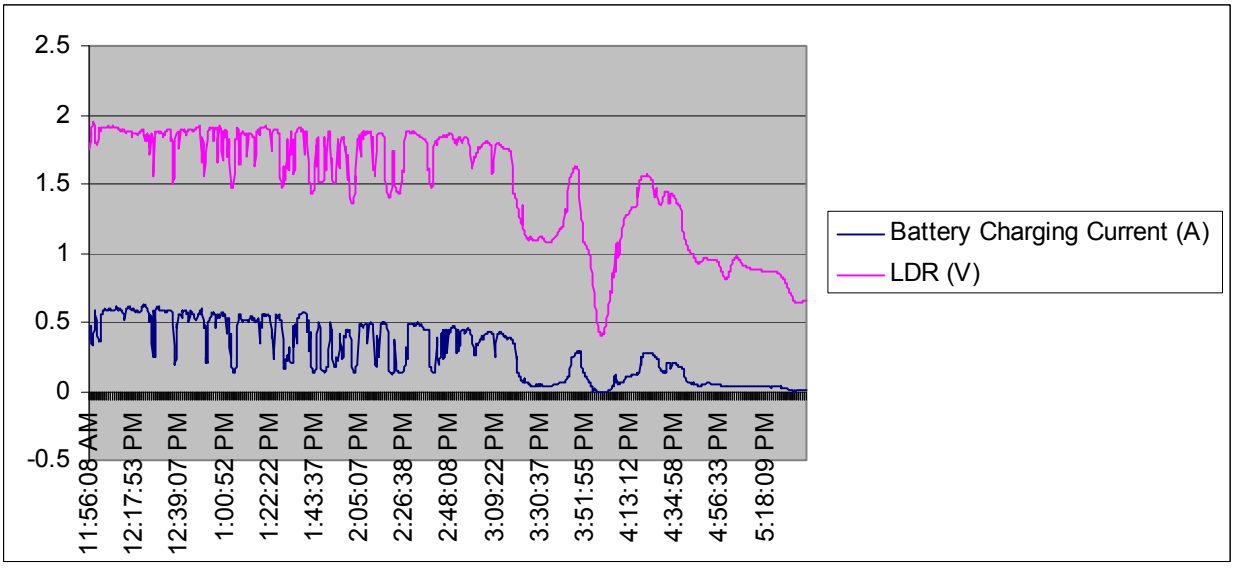


**Fig-2: LDR was at a distance 250 meter away from the Solar Panel in a fluctuating weather condition.**

**Brief CV**

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Education
Bsc(Hons) From Presidency College , Kolkata – Calcutta University.
B.Tech – Instrumentation and Electronics Engineering – From Jadavpur University, Kolkata
ME – Electronic Engineering with specialization in control Engineering – Jadavpur University, Kolkata..
PHD : Persuing at National Institute of Technology, Durgapur ,INDIA 2007.

**Professional Experience Summary:**

**Research and Development:**

Over 8 Years Industrial Experience in the field of Design , Development and Implementation of various Microprocessor processor based Industrial process control and automation related projects in Railways, Department of Telecommunication , in Private and Public Sector organizations.

**Academic Teaching and Research**

Over 17 Years Experience as Scientist in the field of Research and development at Central Mechanical Engineering Research Institute , Durgapur. And currently working as Scientist and Head - Embedded Systems Laboratory. , Central Mechanical Engineering Research Institute.
Current working field : Predictive embedded system , Low power embedded systems Design, Robotics and motion control, Reconfigurable hardware design etc.

**Honorary Appointments**

Adjunct Professor of Scholl of Mechatronics, Bengal Engineering and Science University,Kolkata.

**Award:**

Lock heed Martin (US) India Innovation Award 2007.
Listed in the upcoming edition of Who's Who in the world - 2010, Marquis Who's Who, USA..

**Research Grants Awarded from various Funding agency**:

Council of scientific and Industrial Research (INDIA) Department Science and Technology, India , West Bengal Renewable Energy Development Agency, Kolata ,Reputed Private Engineering Companies.

**Area of interest in research:**

*Predictive Embedded system for safety critical application.,*
*Low power energy efficient Hardware and software design on Embedded Plat form Robotics.*

**Recent Publication and Patents**

**a). *Current* l *publications, technical reports, books etc***

*1.Deign Methodology for Battery Powered Embedded Systems – in safety critical Application. - Joydeb Roy Chowdhury, Sayantica pattanayak and Dr.A.K.Bhattacharjee.*

*Published on February 2009 volume 31 - Computer Standards and Interfaces. Elsavier Publication.*

*2. Fuzzy Rule Based Intelligent Security and Fire Detection System –*

*J. Roychoudhury, T.P.Banerjee, and S.Das presented in 2nd International Workshop on Computational Intelligence in Security for Information Systems CISIS'09 Burgos, Spain ,September 23-26th, 2009,*

*Published by Springer in the a prestigious book on Advances in Soft Computing Series Lecture Notes in Computer Science 2009.*

*3. Design Methodology of a Fault Aware Controller Using an Incipient Fault Diagonizer - Joydeb Roychoudhury, Tribeni P. Banrerjee, A. K. Bhattacharjee and Ajith Abraham.- Proc. of the IEEE computer society , August 2009.IEEE conference on Hybrid Intelligent system 2009.China.*
*4.Design Methodology Internal Sub State Observer Using CPLD - Joydeb RoyChoudhury,Tribeni Prasad Banerjee,Aniket Nathvani, Rangeen Basu Roy Chowdhury, Dr. A. K Bhattacharya*
*World Congress on Nature and Biologically Inspired Computing (NaBIC'09) and to be published in the IEEE proceeding on computer society..*

***b) Patents:***

***1**.Sewing Machines for Automatic Decoratively stitching of a cricket ball*

*US patent (7308860) – on December 18 2007.Joydeb Roy Chowdhury, Hardyal Sigh,N.P Mukherjee, Uma dutta.*

***2**.A Prepaid Smart Card operated Electronic Energy Meter with Online Load Optimizer for Solar Power Application .patented in India National Patent with CSIR Application No. 2467/DEL/2006and applied for. International patent. Application Number :PCT/IN/000508.- Joydeb Roy Chowdhury*

***3.** Intelligent Early Fault Detection system using Embedded Processor -* 1)*ROY CHOWDHURY JOYDEB 2)SAHA MOUMITA Application No.1973/DEL/2007 A Publication Date : 24/04/2009*.

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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Research field keywords:

Modeling and Simulation
Education
Complex Systems
DEVS

**A creativity oriented pedagogic approach for active learning of System Theory and DEVS Simulation**

## 1. Research problem statement

The broader problem to be addressed is to recognize the multi disciplinary nature of Simulation and Modeling and explore innovative ways to cater to students with diverse educational backgrounds to employ modeling and simulation concepts and software tools in a generic trans-disciplinary manner that does not tie them down to a particular domain of application.

## 2. Significance and objectives

The study will involve innovative approaches to cater to minimally prepared students such as undergraduates or industry certificate-level workers, to acquire System Theory based D(iscrete) EV(ent) S(ystem) Specification concepts while promoting active learning in using the learned material. The long term effects of this research will help to improve understanding of how to convey a fundamental set of concepts and tools in order to facilitate creative use of such artifacts, uncover ways to address deep learning ( as opposed to surface learning) by adopting higher levels of the cognitive domain as characterized by Blooms taxonomy(Bloom 1956), encourage the introduction and usage of the software tools and methodology developed in this study as early as the 1st or 2nd year in a curriculum thereby effectively paving way to furthering the establishment of Modeling and Simulation (MS) education into multidisciplinary curriculums. In the proposed research, we hope to integrate a novel and creative approach to DEVS instruction into a curriculum that is derived from state-of-the-art conceptions on M&S education for undergraduate engineering.

The potential and the broader impact of the research is further outlined as goals below.

- Recognize the multi-disciplinary nature of M&S to make it easier for students to grasp concepts of DEVS with minimal background in programming.

- Introduce creative methods to enhance the student learning in DEVS Systems-based concepts and tools while reducing the overheard time spent on learning the tools themselves.
    - A creation of a software environment based on defining DEVS models via an innovative easy-to-learn natural language format along with a unique environment for automatic model generation, testing and experimentation will be a highlight to the project.

- Bridge the gap between concept acquisition and creative use of the concepts. Sub goals are:
    - Characterize the skills and creativity needed to solve a taxonomy of systems problem types and develop metrics that distinguish skill attainment from level of creativity exhibited.
    - Foster “learning by experimenting” or “figuring out how the system works” to enhance a student’s acquisition of deep knowledge (Biggs 1995) about systems and models.
- Lower the semester at which System and DEVS-based M&S can be effectively

taught from the senior to the sophomore level. Similarly, enable effective training of those in the workforce who come with minimal preparation in the math, programming, or technical skills that are usually required for M&S training.

It should be also noted that the resulting methodologies uncovered by this research may be relevant and useful for teaching in other fields of study apart from Engineering and Computer Science.

## 3. Summary of the current state-of-the-art

System of Systems Engineering (SoSE) shows great potential for the advancement of technological innovations of the 21st century (Jamshidi 2008). System of Systems refers to complex systems that are made up components that are themselves complex systems. Such systems are increasing found in information technology applications to business, government and engineering and are at the root of this century's national/global challenges of economy, climate, and energy. Systems theory, especially as formulated by Wymore (92, 67), provides a conceptual basis for formulating the basic concepts of SoS. Systems are viewed as components to be coupled together to form a higher level system, the SoS. Components have input and output ports that allow couplings to be defined through which information can flow from output ports to input ports. The internationally recognized Discrete Event Systems Specification (DEVS) formalism (Zeigler 1976, Zeigler et al. 2000) based on Systems theory, provides a computational framework and tool set to support modeling and simulation (M&S) concepts in application to SoSE. Although DEVS is centered on discrete events, its connection with systems theory allows it to provide a computational representation of many other ways of specifying dynamic systems including differential equation and stochastic forms of model specification (Zeigler et al. 2000). A new textbook by Wainer (2009) provides numerous examples covering multi disciplinary domains in science, business, and industry.

The formal rigor and versatility of DEVS allows it to support development of a wide range of domain-specific models. Tag Gon Kim (Kim and Kim 2005) summarized a simulation modeling development methodology in there paper titled "DEVS Framework and Toolkits for Simulators Interoperation Using HLA/RTI". This methodology is supported by the AutoDEVS (Salas 2009) environment, an ontology-based tool set that automates the transformation of user-friendly FDDEVS (Finite Deterministic DEVS ) and system structure specifications into simulation models and experimental frames to test them.

As powerful as DEVS is, it presents a steep learning curve to many of the students and practitioners with regard to understanding the concepts, the mathematics behind it, and the implementation skills needed in programming to successfully tackle new problem sets. This creates opportunity for this research to explore innovative ways to teach Simulation and Modeling revolving around System Theory and DEVS to cater to a wider audience who might not be proficient in programming or mathematical skills.

The previously mentioned FDDEVS, which is a sub-class of DEVS, has properties that are very useful from the educational perspective. It is relatively simple and straightforward to provide an easy introduction to DEVS while still preserving the essential nature of the discrete event dynamic system properties such as events, timings, and model composition. It is amenable to automation in which a natural language model

description is transformed into a working DEVS model which can be manipulated in a simulation viewer. Although limited in its expressive power, FDDEVS models can serve as a skeletons from which to develop full-scale DEVS model by elaboration. An example would be to define an initial skeleton for a hierarchy based complex system using FDDEVS and then extend it to cater for randomness often involved in such systems. FDDEVS will serve as the mentor and backbone for software tool creation and development to meet the objectives of this study.

## 4. Proposed research methodology and plan

Our main inspiration is drawn from observing two trends emerging in the computer games space. Namely, the increasing interest in development of "serious" games that seek to teach traditional subjects rather than just entertain and the games that challenge players to figure out what the rules of the game are, rather than developing the skill to play a game with given rules. Can we learn from these trends to develop effective educational technology for DEVS and systems concepts and utilize "learning by experimenting" in a more deliberate way to combine with more traditional tutorials and exercises to achieve knowledge that has more depth and is more likely to result in greater creative application of learned concepts and skills?

Our approach in this research would be to employ simplified but generic DEVS forms to accelerate both learning and creative use of the learned material. To do so, we turn to a categorization of systems problems that will enable us to characterize the skills and creativity needed to solve a well-defined set of problem types. This categorization will also help to develop metrics that distinguish skill attainment from level of creativity exhibited.

### *Research Plan*

The plan for the proposed research is six fold, progressing from requirements formulation to implementation, application, and dissemination. The sequence is outlined below:

Task 1: Develop Requirements for Creativity-oriented Instruction of DEVS and Systems

Task 2: Develop GUI and Tool Set to Meet Requirements

Task 3: Employ Instructional Support Tools for Experimenting with, and Evaluating, Alternative Sequences

Task 4: Introduce to On-line and Live Engineering Class Room Instruction

Task 5: Formulate evaluation methods for On-line and Live Class Room environments.

Task 6: Disseminate Results and Education of Workforce

As an elaboration on task 1&2, we will start development requirements for a tool set and creativity-oriented instruction on DEVS and Systems from a table as below where a sequence of topics is developed to cover the material. The sequence need only be exemplary in order to get a handle on statements of student learning objectives, delivery support required, and tests of understanding, skill, and/or creativity that will be employed.

| Step in Sequence | Student Learning Objective | Instruction Delivery Support | Test of Understanding, Skill, Creativity |
|---|---|---|---|
| Finite DEVS Atomic model | Understand<br>• Ports: input, output<br>• States, including starting state<br>• Functions: time advance, internal transition, external transition, output | • Simple examples with explanations covering each of the aspects in detail<br>• To be developed | • Traditional exam<br>• Evaluating student response to systems analysis problem instances<br>• No test of creativity |
| Behavior of Finite DEVS | Understand and be able to:<br>• Inject inputs<br>• Observe state transitions, and outputs | • To be developed | • Evaluating student response to systems analysis and system synthesis problem instances<br>• No test of creativity |
| Coupled models (Compositions of Finite DEVS) | Understand<br>• Components<br>• Couplings (internal, external)<br>• automated port-matching coupling<br>Be able to create coupled models via port-matching | • To be developed | • Traditional exam<br>• Evaluating student response to systems synthesis problem instances<br>• test of creativity |
| Behavior of' Coupled Models | Understand<br>• Message exchange<br>• State trajectory<br>• Output trajectory | • To be developed | • Traditional exam<br>• Evaluating student response to systems analysis problem instances<br>• No test of creativity |
| Coupling of Finite DEVS and their Inverses | • Understand and be able to Produce inverses<br>• Be able to couple inverses to models | • To be developed | • Traditional exam<br>• Evaluating student response to systems analysis problem instances<br>• No test of creativity |
| Construction of Atomic FDDEVS | • To be developed | • To be developed | • Evaluating student response to systems synthesis and systems inverse problem instances<br>• test of creativity |
| Construction of Coupled DEVS using the System Entity Structure | • To be developed | • To be developed | • Evaluating student response to systems synthesis problem instances<br>• test of creativity |
| Construction of Coupled DEVS Families using the System Entity Structure | • To be developed | • To be developed | • Evaluating student response to systems synthesis problem instances<br>• test of creativity |

**Table 1 : Example Sequence of Topics in DEVS Instruction**

With reference to task 2 & 3 , a user interface as below will be used to allow students to define an FDDEVS atomic model using a succinct natural language. This input will be parsed and analyzed with results displayed for student inspection and correction. The validated input will then be used to automatically generate a DEVSJAVA implementation of the model with its visualized simulation execution. *A key innovation will be the accompanying auto-generation of a unique model set called "inverse models" which can be used for testing, verification and experimentation with a target model.*

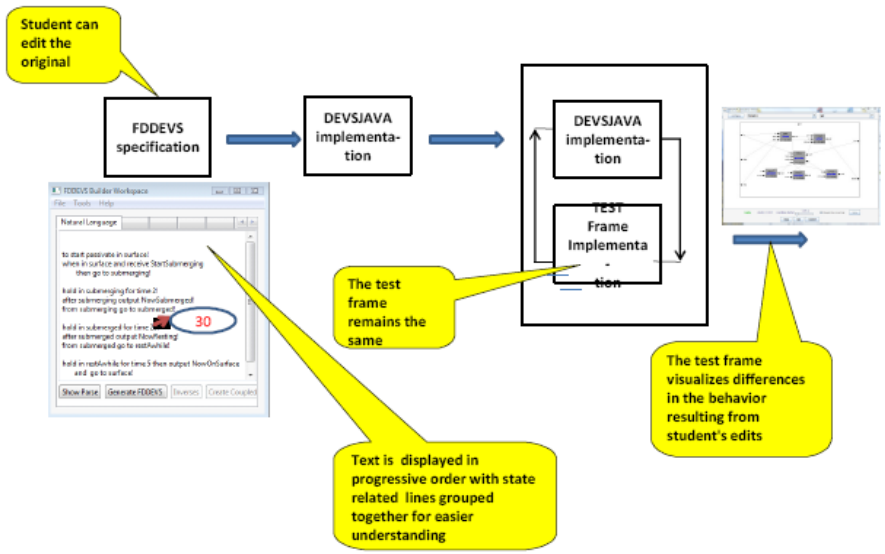


**Figure 1 Automating Feedback to a student experimenter**

## 5. Preliminary results

Fundamental and significant research is currently under way for tasks 1-4 and the novel software environment based on innovative and creative approaches mentioned before ( will address task 2 & 3 above) is in its early executable functionality.

An introduction to FDDEVS that represents an initial attempt to teach FDDEVS in a manner that is proposed here is provided at http://www.u.arizona.edu/~lahiru/.

From our initial experiences with tool-based instruction, several shortcomings with traditional MS instruction methods were identified and preliminary resolutions to them as below will be explored in detail as part of this study.

- *Difficulty in introducing theory*: help students in developing systems problem solving skills along with systems theory concepts – as facilitated by our DEVS/System Theory based approach.
- *Language and tool impediments:* design our tools to reduce the complexity of their use by novices.
- *Motivation:* Overcome lack of motivation by novel approaches such as supporting and incentivizing "figuring out how the system works"

- *Prior Preparation*: Design tools that automatically generate as much as possible from user input at the modeling level, reducing the need to be computer-savvy at the language and operating systems level.
- *Time Pressures*: maximize the efficiency with which material is presented by optimal choice of topics and sequencing; decompose material into atomic lessons that can be consumed in breaks between regular work; minimize the time spent in lessons by providing rapid responses with efficient software implementations.
- *Concept Learning Vs Concept Application* : from initial instruction attempts it became evident that students who has satisfactorily grasped an M&S concept still have difficulty in applying it to solve problems using corresponding tools. Hence concept introduction with practical experimentation which leads to deep learning needs to be explored.

## 6. Future plans

As mentioned above, though preliminary studies and implementations are already in effect, more significant research needs to be conducted for tasks 1-3 to make it consonant and effective to meet our objectives.

The novel conceptual framework for creating discrete event simulation models using constrained natural language and a set of user-friendly mapping, simulation, and visualization tools to implement the framework will need to be further developed to its full potential.

Task 4 needs to be carried out more formally and tasks 5-6 still needs to be researched and formulated as they as they are dependant on tasks 1-3.

It is also the intention of the researchers to test the developed concepts and tools in an introductory modeling and simulation course which will be a cornerstone of a new specialization in modeling and simulation of an electrical engineering undergraduate program at major university. Also steps will be taken to introduce and test the educational environment at industry level initially at RTSync a commercial spin off of the Arizona Center for Integrative Modeling and Simulation (ACIMS), a joint activity between two flagship Arizona universities (UA and ASU).Agreements and procedures will need to be formalized for this to come to reality.

Finally, it should be mentioned that this research will lead to innovative educational approaches in computer science and engineering with a strong possibility of its adoptation and extension to other fields of study. Also the methodologies uncovered by this research may be relevant and useful for teaching in other fields. The researchers will be involved in publications of the research results in journals, conferences and websites, including establishment of new conferences and dissemination venues where needed.

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Bloom, B. S., & Krathwohl, D. R. (1956). Taxonomy of educational objectives: The classification of educational goals by a committee of college and university examiners. Handbook 1. Cognitive domain. New York: Addison-Wesley.

Jamshidi, M. (2008) System of Systems – Innovations for the 21st Center, Wiley & Sons.

Kim Tag Gon and Kim Jaehyun. (2005) DEVS Framework and Toolkits for Simulators Interoperation Using HLA/RTI. Asia Simulation Conference 2005, Bejing, China. Pp.16 – 21.

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# Lahiru Ariyananda

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## HIGHER EDUCATION:

- **Candidate for Ph.D in Electrical and Computer Engineering**
  University of Arizona, USA, August 2008 – to present
- **M.S in Electrical and Computer Engineering**, University of Arizona, USA, May 2007
- **B.S in Computer Engineering with Minor in Mathematics**
  University of Arizona, USA, May 2001. *Honors and Magna Cum Laude*
- **Diploma in Computer Science** ,Institute of Technological Studies, Sri Lanka affiliated to University of Houston, Clear Lake, USA. 1997

## SELECTED WORK EXPERIENCE :

10/02 to date **Lecturer** University of Peradeniya, Dept of Computer Engineering, Sri Lanka.

- Lecturer in charge for 1st to 4th year undergraduate classes up to 360 students per class
- Has acted in the capacity
  - Course Coordinator and Course Moderator
  - Supervisor of Teaching Assistants up to groups of 5
  - Supervisor of Senior Capstone Projects
  - Coordinator of academic intramural activities,
  - Liaison between department and Industry and other Administrative duties

08/05 to date **Teaching Assistant** University of Arizona, Dept of ECE,USA

Team Lead for group of 3-5 personnel, Sp 07,Fa08 – Sp 10.
Have won several major awards for teaching**.** Taught large classes up to 180 first year students**.**

02/07 to 06/07 **Research Engineer** Arizona Center for Integrated Modeling and Simulation, University of
05/09 to 08/09 Arizona, USA

06/06 to 12/06 **Research Engineer** RTsync Corporation, Phoenix, USA

## PROFFESIONAL QUALIFICATIONS :

Followed a certificate course in **Teaching Methodology** at University of Peradeniya, Sri Lanka.

## SELECTED PAPERS/CONFERENCE :

U. Bulumulla, R. Navarathna, G. Munasinghe and L. Ariyananda**, "**Determining Capital Market Efficiency in the Colombo Stock Exchange (CSE) using Technical Analysis and the Artificial Neural Networks**"**, Second International Symposium at the University of Sabaragamuwa, July 2008, Sri Lanka.
**Won gold medal for the best project in students forum in engineering.** Supervised by myself.

## SELECTED PROJECTS/THESIS :

- **Graphical User Interface Representation and Generation Using System Entity Structures**, Summer 07. Adviser : Prof B.P Zeigler ( MS Thesis)
- **Evaluating Pricing Models for a Solar Power City using Distributed Multi Paradigm Simulation (** Using Matlab, Anylogic, Distributed Simulation concepts)
- **Simulation of a Flexible Manufacturing System.** Leader of a 3 Member team**.** ( Coded in C++)
- **Online Multimedia Database .** Team Leader of a 3 member Graduate Student group**,** Written in Java, JSP, Html, SQL.
- **GenetScope .** Member of Large professional team project **.** Developed for Defense Information Systems Agency**,** Joint Interoperability Test Command , Fort Huachuca, Arizona,USA**..** Written Java DEVSJava.

## SELECTED COURSEWORK :

Software Engineering , Artificial Intelligence, Distributed Multi-Paradigm Simulation Systems , Software Tools for Engineering Applications, Engineering for Computer Based Systems, Distributed Computing Systems, Probability & Random Processes, Micro Electronic Packaging Materials, Discrete Event Simulation, Computer Networks and Protocols, Circuit Theory, Circuit Analysis, Computer Aided Logic Design.

## EXPERIENCE IN PROGRAMMING LANGUAGES :

C/C++, Java, Perl, Visual Basic, Pascal, VHDL, Labview, Html with CGI, Post Script, Shell Scripting

## EXPERIENCE IN SPECIALIZED COMPUTER APPLICATIONS :

DEVSJAVA, ODEVS, FDDEVS, Arena, AnyLogic, Workview Office Suite, Leonardo Spectrum, PSpice, AutoCad,Adobe Photoshop, Flash , Rational Rose/Visual Paradism, MPI

## AWARDS/HONORS/ MEMBERSHIP :

Outstanding Graduate Teaching Assistant**,** College of Engineering, University of Arizona, Sp 09

Outstanding Graduate Teaching Assistant, Dept of ECE, University of Arizona, Sp 09

Graduate College Fellowship **,** University of Arizona, 2005-2006

Recipient of Arizona Board of Regents Scholarship, 1999 Jan –2001 May

National Society of Professional Engineers member, Golden Key National Honor Society member
Tau Beta Pi – Engineering Honor society member, Member of the Honors College, University of Arizona

## RELATED EXTRA-CURRICULAR ACTIVITIES& COMMUNITY SERVICE :

- Member of the Working committee of Industry day 2004 - Faculty of Eng, University of Peradeniya, Sri Lanka
- Host , Peradeniya University Research Sessions 2007
- Coordinator of the Eng-Faculty E-Souvenir CD for Industry Day 2004
- Actively involved in Social Welfare societies ( Sri Lanka)

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

Marco E. Rivera A.
PhD. Student since August 2008
Doctorate in Electronics Engineering
Area of research: Digital control applied to matrix converters.
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Avenida España 1680, Casilla 110-V Valparaíso, Chile.
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Power Converters, Power Systems, Predictive Control

# Research Proposal

## Predictive Control of an Indirect Matrix Converter

### (a) Research problem statement

The growing industrial development in Chile requires a higher amount of electrical energy available. As the energy is nowadays limited, the energetic efficiency of industrial processes is a topic highly relevant. In this sense, the role of power converters, as an interface between the mains and the mechanical actuator is crucial. Ideal power converters should operate with reduced losses, inject sinusoidal currents to the network and operate with unitary displacement factor. The regeneration capability is also a very important issue as the energy can be delivered back to the mains in braking processes. All these characteristics can be fulfilled by matrix converters.

The indirect matrix topology is similar to a conventional back-to-back inverter but without dc-link capacitor and with bidirectional switches in the front-end. Thank to this feature, modulation schemes used for the operation of conventional back-to-back inverters can be more or less directly applied, without the necessity of complex transformations as in conventional matrix topologies. Moreover, the capacitor-less DC-link permits to reduce the size of the converter and increase its reliability, as this component has the shortest lifetime compared to the other components. In addition, new topologies featuring a reduced number of semiconductors have been introduced. These topologies can be very competitive in those applications where the regeneration is not required.

Despite the apparent simplicity in the topology, it should be considered that this converter requires also a complex switching strategy that avoids the interruption of the load currents, in order to prevent over-voltages that could destroy the power semiconductors. These problems have been recently reported and solved in the literature. However, there are still some open issues for the operation of this inverter topology:

- The up to date presented modulation methods are complex and need a high computation effort of the controller, making this topology less attractive in comparison with the well known standard solutions.

- Matrix converters operate with a high switching frequency; therefore the efficiency of the converter is reduced due to the high losses during each switching transition. This aspect is especially critical in high power applications. On the other hand, the operation at low switching frequency adds the extra issue of resonances in the input filter.

- Almost all modulation schemes are based on the assumption that the input voltages are sinusoidal and balanced. This condition is not always met in the industry, where the voltages can be unbalanced and also distorted.

(b) Significance and objectives

The general objective of this work is to propose a simple and effective predictive control scheme for the indirect matrix converter that accomplish the standard requirements of other techniques such as unitary power factor operation, the control of the output currents and considers the following aspects:

- The scheme must be simple and allow the operation at low switching frequency to improve the overall efficiency, enabling at the same time the use of the standard topology in high power applications.
- Operation of the converter under abnormal input conditions. This aims to improve the process quality by reducing the effect in the output process of an abnormal condition in the mains.

The specific objectives of this work are:

- Development of a simple control strategy for the control of the indirect matrix converter. These control schemes must be capable to select the optimal switching state out of the information provided by the currents and the phase voltages. By means of a cost function, different aspects of the operation of the inverter can be optimized such as the control of the power factor and the reduction of the switching frequency.
- Operation of the converter under abnormal input conditions. In particular, some strategies for predictive control schemes will be evaluated in order to minimize the impact in the output currents.

The hypothesis for each specific objective are:

i. Simple control scheme: it has been reported that predictive control schemes permit in a simple way the control of standard matrix and back-to-back converter topologies featuring sinusoidal input currents, unitary power factor and sinusoidal output currents; comprising all usual units as modulators and PI-controllers in only one control block [18]. Therefore it should be easy to extend this idea for the control of indirect matrix converters.

ii. Operation at low switching frequency: By means of a cost function, the input currents and the dc link voltage can be controlled. As the control of the currents is decoupled from the control of the dc link voltage, resonances in the input filter caused by the dc link control loop will be avoided. Contrary to other standard modulation schemes, in this case the model of the input filter will be taken into account. This should enable the operation of the rectifier stage at a lower frequency without exciting resonances.

iii. Improved capability to withstand perturbations: The control scheme does work under the assumption of a good model of the input filter. Since the proposed scheme always chooses the best option out of the measured values of input current and voltages, an abnormal supply can be also considered in the calculation of the optimal switching state. In this way, the abnormal condition should not affect the control of the power factor and of the dc-link voltage.

## (c) Summary of the current state-of-the-art

### Indirect Matrix Topology

Matrix converters are forced-commutated converters which use an array of controlled bidirectional switches to synthesise a variable output voltage with unrestricted frequency [1]. This topology has recently attracted a great interest as it fulfils the most desirable characteristics in a converter: they are compact and allow the generation of a load voltage with arbitrary amplitude and frequency. Moreover, the operation with sinusoidal input currents and power factor equal to one is also possible. The capability of regeneration makes this topology especially attractive to drive loads that need to be braked, increasing the overall efficiency of a system.

The development of matrix converters starts with the works presented in [2,3], where the name “matrix inverter” was coined and the topology was described using bidirectional power switches. These authors also present a method to generate the output voltages by using a transfer function applied to the input voltages. A rather different concept was presented in [4]. In this work the idea of a fictitious dc-link was introduced: the switching states are arranged in such a way that the input phase with most positive value and the input phase with most negative value are always selected. This concept is known as indirect transfer function [5], as an intermediate stage is used for the synthesis of the output voltages. The physical implementation of this mathematical concept gives rise to the indirect matrix topology, where a six-switch bidirectional bridge corresponds to the rectifier, followed by a capacitor-less dc-link stage connected with a conventional 6-switch unidirectional inverter [6] (Fig. 1).

This topology has the same performance as the conventional matrix converter in terms of voltage transfer ratio, four quadrant operation, unity power factor and sine waveforms with only high harmonics content in the input and output side. However, due to the topological similarity between this converter and standards inverters, well known space vector modulation methods can be applied, simplifying the implementation of control schemes. In addition, it allows the reduction of the number of switches under certain conditions and the clamp capacitor can be greatly simplified as one diode and one capacitor [7]. Due to these advantages, indirect matrix topologies have received considerably attention in the last few years and several contributions have been made in the form of new modulation methods, the control of reactive power in the input currents, the analysis of the operation with distorted power supply as well as new topologies with reduced number of switches, also known as sparse matrix converters [8,9].

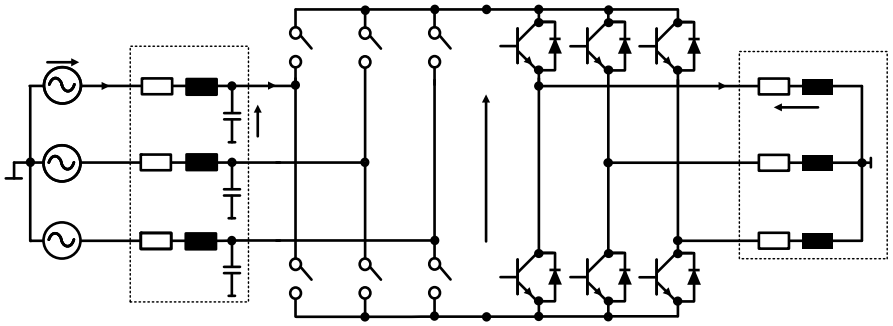

Fig. 1. Indirect matrix converter power topology.

In [10,11] a space phasor modulation scheme is presented that achieves the theoretical maximum output voltage of this inverter topology. In [12], a modulation method is presented that distributes the zero space phasors of the inverter stage in order to achieve a zero dc-link current commutation of the rectifier, obtaining in this way a soft-switching operation. Thanks to this characteristic, the switching losses at the side of the rectifier are significantly reduced [6]. In [9], the efficiency of a sparse matrix inverter is improved by employing the lowest and the second largest phase voltage for the generation of the DC-link voltage. Even though, all these schemes feature a high switching frequency, therefore high semiconductor losses can be expected in the side of the inverter despite of the aforementioned improvements. Even though the recent advances in semiconductor technology permit a reduction of the losses by using reverse blocking IGBTs [13], the operation at a lower frequency is still an interesting issue. In this case, the resonances of the input filter play an important role that has to be taken into account. It should be pointed out that most modulation strategies do not consider the filter in the input side for the generation of sinusoidal currents [8,9,14].

Almost all the existing modulation schemes assume symmetrical sinusoidal voltages for the operation the converter. It has been suggested in [15] that the current controllers are unable to eliminate the distortion in output currents, in this case those strategies that measure the input voltages generate output voltages of higher quality. In [16] it has been proposed a hybrid topology to make the matrix topology immune to a voltage unbalance in the inputs, however, this approach includes the addition of extra switches and a small dc-link, adding extra complexity to the topology. The problem has been more or less extensively studied for conventional matrix topologies, however there is almost no papers reporting the problem in indirect matrix topologies. The importance of this issue is clear, as it can directly affect the quality of the process in which the converter is involved.

A proof of the interest that shows the scientific community in matrix converters topologies is the tutorial “Matrix Converters” presented in APEC2007, one of the most prestigious conferences in the area of power electronics [17].

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[14] Kolar, J.W.; Schafmeister, F.; "Novel modulation schemes for conventional and sparse matrix converters facilitating reactive power transfer independent of active power flow" in proceedings of The 35th Annual Power Electronics Specialists Conference, 2004. PESC 04. CD-ROM.
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[19] M. Rivera, R. Vargas, J. Espinoza, J. Rodriguez, "Behavior of the Predictive DTC based Matrix Converter under Unbalanced AC Supply," to be presented in IAS2007.

## (d) Proposed research methodology and plan

The work will be organized in several phases:

i. First, the proposed ideas will be verified using a model of the converter created with Matlab Simulink. The size of the filter will be theoretically estimated and its behaviour evaluated through simulations.
ii. In order to compare the performance of the proposed control scheme, a standard control scheme will be also simulated.
iii. One converter prototype will be built for the purpose of testing the proposed ideas. The converter will use discrete elements to permit an easy and fast replacement of the parts in case of failure.
iv. Tests will be carried out with different switching frequencies and sizes of the input filter. The size of the filter will be modified for operation at lower frequency. For this test, multiple values of the filter capacitor or of the inductance have to be available.

v. The performance of the control scheme will be analyzed under abnormal conditions in the mains. This part of the work will be carried out using a programmable power supply available in the University of Concepcion.

(e) Preliminary results

Most of the preliminary results have been published as indicated:

| | Publications | |
|---|---|---|
| **2009** | **Predictive Control of an Indirect Matrix Converter**<br>P. Correa, J. Rodriguez, **M. Rivera**, J. Espinoza, J. Kolar<br>IEEE Transactions on Industrial Electronics, Vol. 56 Nº 6, pp. 1847-1853; June 2009 | Published |
| **2009** | **Predictive Control of the Indirect Matrix Converter with Active Damping**<br>**M. Rivera**, P. Correa, J. Rodriguez, I. Lizama, J. Espinoza<br>6th International Power Electronics and Motion Control Conference, IPEMC 2009, 17 to 20, May, Wuhan, China. | Published |
| **2009** | Predictive Control for Current Source Rectifiers Operating at Low Switching Frequency<br>I. lizama, J. Rodriguez, B. Wu, P. Correa, M. Rivera, M. Perez<br>6th International Power Electronics and Motion Control Conference, IPEMC 2009, 17 to 20, May, Wuhan, China. | Published |
| **2009** | **Predictive Control of the Indirect Matrix Converter with Active Damping**<br>**M. Rivera**, P. Correa, J. Rodriguez, I. Lizama, J. Espinoza, C. Rojas<br>Energy Conversion Congress and Expo, ECCE 2009, 20 to 24, Sept., California, USA. | Published |
| **2009** | Predictive Current Control with Resonance Mitigation in a Direct Matrix Converter<br>J. Rodriguez, P. Wheeler, B. Wu, J. Espinoza, **M. Rivera**, C. Rojas, I. Lizama<br>IEEE Transactions on Power Electronics, Submitted. | Under Review |
| **2009** | **Predictive Control of Source and Load Currents in a Direct Matrix Converter**<br>J. Rodriguez, J. Espinoza, **M. Rivera**, F. Villarroel, C. Rojas<br>IEEE International Conference on Industrial Technology, ICIT 2010.. | Published |
| **2009** | **Predictive Torque and Flux Control of an Induction Machine fed by an Indirect Matrix Converter**<br>J. Rodriguez, J. Kolar, J. Espinoza, M. Rivera, C. Rojas<br>IEEE International Conference on Industrial Technology, ICIT 2010. | Published |
| **2009** | **Predictive Current Control with Reactive Power Minimization in an Indirect Matrix Converter**<br>J. Rodriguez, J. Kolar, J. Espinoza, M. Rivera, C. Rojas<br>IEEE International Conference on Industrial Technology, ICIT 2010. | Published |
| **2009** | **Predictive Control of a Direct Matrix Converter Operating under an Unbalanced AC Source**<br>J. Rodriguez, J. Kolar, J. Espinoza, M. Rivera, C. Rojas<br>IEEE International Symposium on Industrial Electronics, ISIE 2010. Submitted. | Accepted |
| **2009** | **Predictive Torque and Flux Control of an Induction Machine fed by an Indirect Matrix Converter with Reactive Power Minimization**<br>J. Rodriguez, J. Kolar, J. Espinoza, M. Rivera, C. Rojas, ISIE 2010, | Accepted |

Submitted.

## (f) Future plans

Future plans are the experimental implementation of the research developed during 2008 and 2009 to publish the results in journal papers.

# Marco E. Rivera A.

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## Education

**Universidad Federico Santa María USM** **Valparaíso, CHILE**
*Working as PhD Student in Electronics Engineering, today*
CONICYT Scholarship for Doctoral Studies in Chile

**Universidad de Concepción UdeC** **Concepción, CHILE**
*Master of Science in Engineering with a major in Electrical Engineering, Jan. 2008*
Undergraduate Scholarship Facultad de Ingeniería

**Universidad de Concepción UdeC** **Concepción, CHILE**
*Electronics Civil Engineering, Mar, 2007*
Juan Gomez Millas Scholarship
Crédito con Garantía del Estado

**Universidad de Concepción UdeC** **Concepción, CHILE**
*Bachelor of Science in Engineering, Dec. 2004*
Juan Gomez Millas Scholarship
Crédito con Garantía del Estado

## Experiencie

**Tecnológico de Monterrey TEC** **Monterrey, CHILE**
*Feb. 2010*
Visiting PhD. Student, invited by Prof. Manuel Macias and Osvaldo Micheloud
Worked on power electronics (Indirect Matrix Converter), advanced controls (SVM and Predictive control), computer simulation (MatLab) and digital/hardware implementation (DSP 6713, HPI and FPGA Xilinx S400)

**Ryerson University** **Toronto, CANADA**
*Jan. 2010 – Mar. 2010*
Visiting PhD. Student, invited by Prof. Bin Wu
Worked on power electronics (Four Leg Inverters), advanced controls (predictive control), computer simulation (MatLab) and digital/hardware implementation (dSPACE 1103 and FPGA Altera)

**Universidad Federico Santa María USM** **Valparaíso, CHILE**
*Aug. 2008 – Oct. 2009*
Part time professor about Digital Signals Process and Design of Electronics Devices.
Designed and built an indirect matrix converter of 7.5 kW based on dSPACE and FPGA.
Research and experimental implementation of new control strategies applied to static power converters, particularly indirect matrix converters and four-leg converters. Fondecyt 1080059 Project.

**University College Cork – Power Electronics Research Laboratories** **Cork, IRELAND**
*Feb. – Aug. 2008*
Awarded with a scholarship of the Marie Curie Host Fellowships for Early Stage Research Training in Electrical Energy Conversion and Conditioning Technology at the University College Cork, Ireland, where worked in research related to static power converters, predictive control and digital control for high power drives and the development of high performance control platforms based on FPGAs.

**Núcleo Milenio Electrónica Industrial y Mecatrónica (NEIM)** **Valparaíso CHILE**
**Universidad Santa María.**
*Apr. – Dec. 2007*

Research and experimental implementation of new control strategies applied to static power converters, particularly matrix converters. Fondecyt 1060424 Project.

**Área Técnica Coyhaique, Subgerencia de Operaciones y Mantenimiento de Redes de Telefónica Móvil** **Coyhaique, CHILE**
*Jan. – Feb. 2005*

Software application development consulting SQL databases - Oracle OSS System Nokia, which allow measurement analysis of GSM service in field, very useful for the assistant manager.

---

**Personal**

Intensive English Course in Instituto Chileno Norteamericano de Cultura, scholarship form CORFO Chilean Goberment. **Valparaíso, CHILE**

Conversational basic in French, French Course Scholarship in the Service of Cooperation Linguistics and Education of the French Embassy, Alliance Francaise of Concepción and Dirección de Asuntos Internacionales e Institucionales UdeC. **Concepción, CHILE**

Native Spanish.

Part of the Handball team of UdeC participating in different local and national champions and Musician, playing saxophone, participating in different local, national and international presentations with Orquesta Espectáculo ETP. **Concepción, CHILE**

# Doctoral Consortium

## 2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)

**April 11 – 13, 2010**
**Chicago, IL, USA**

**Samy El-Tawab**

Department of Computer Science
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Computer Networks: (Vehicular Networks, VANET: Vehicular Ad-hoc Networks and Wireless Communications)

## A Research Proposal of a Framework for Intelligent Road Monitoring System Using Smart Sensors

### A.1 Introduction:

*Vehicular Networks* is one of the hot research areas these days. Two combinations of communication have been used in the Vehicle Ad-hoc Networks (VANET) field, Vehicle-to-Vehicle (V2V) and Vehicle-to-infrastructure (V2I). The main focus of researcher is to invent a new technology without any expensive changes in the infrastructure. In the United States, motor vehicle traffic crashes are the leading cause of death for all Americans betweens two and thirty four years of age [6]. In 2006, the National Highway Traffic Safety Administration reports that 42,642 people were killed in motor vehicle traffic crashes [3]. Among all these accidents, each year, approximately 7,000 highway deaths and 800,000 injuries are associated with about 1.2 million weather-related accidents. The estimated annual cost from these weather-related crashes (deaths, injures and property) amounts to nearly $42 billion [4]. To alert drivers with weather conditions including heavy rain, snow, sleet, fog, smoke, dust, ice and black ice can reduce the risks of accidents and improve the safety and efficiency of the roads. Vehicular Network research targets a solution to these problems to help notifying the drivers with bad weather or road conditions.

### A.2 Problem Statement:

*Investigate the integrating between the wireless sensing technology and the vehicle technology to provide safer, reliable and comfortable road systems. As a result of this integration, we try to study the routing techniques, sensing techniques, power consumption, communications, security, information propagation and applications.*

### B.1 Significance of the Study:

The research study could provide information on the issues of Vehicular Networks technology particularly on the integrity, vulnerability and security of VANET. Further, our study would also be a review on the VANET Technology present and future. This study would be beneficial to vehicle manufactures, transportation authority and application developers (software companies). To the future researchers, this study can provide baseline information on the recent status of VANET technology.

### B.2 Objectives of the Study:

*This study aimed to determine the issues on the integrity, vulnerability, and security of communication between vehicles and infra-structure. It is designed to identify the possible types of attacks and threats on VANET Technology and its measures.*

This study would specially persuade the following objectives:

1. *To invent new model for communication between vehicles and infra-structures.*
2. *To determine the types of attacks and threats.*
3. *To measure the performance of our new model over different mobility.*
4. *To realize awareness on VANET services and issues to the future users.*

## C. Summary of the Current State-of-the-art:

**Cat's eyes** - which are built in the road as reflectors that can help drivers to see the road in the fog condition or at night - can be used in the VANET technology. We add sensing capability to each node of Cat's eye in order to create Ad-hoc Network that won't suffer from any network disconnection problem [4]. As traffic incidents are considered one of the major factors leading to traffic jams; there is a crucial need to develop a system that helps reduces those road incidents. The proposed system will notify the drivers as early as possible of any risk or danger ahead. That gives the ability and the sufficient data to make balanced and intelligent decision about these risks [2]. Numerous architectures require an unrealistically expensive deployment and maintenance cost or cannot be converted to Highways [1].

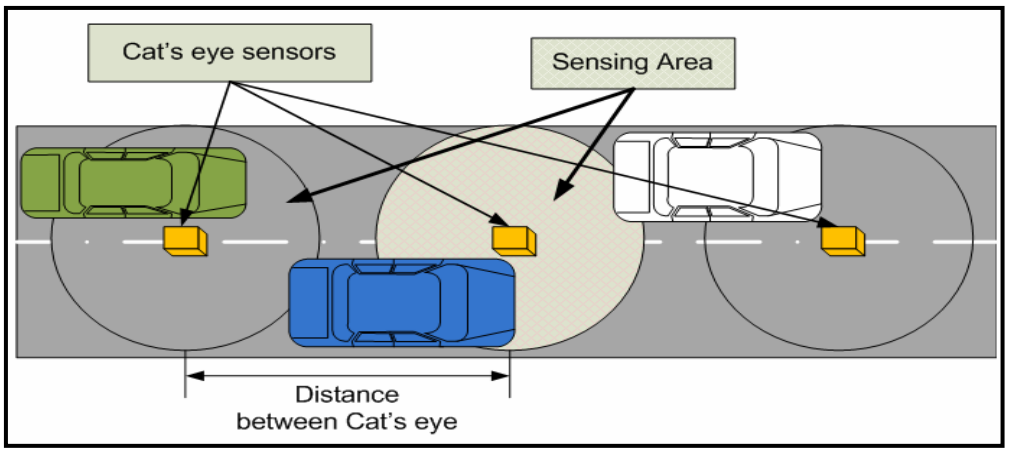


***Figure 1:*** A Group of sensors on the highway. Cars are detected in the sensing areas. (Figure is not drawn to scale).

On highways, Cat's eyes are placed along the road on both sides. A metal detector sensor is placed inside each cat's eye. These nodes (the cat's eye) form a network to disseminate the information about average speed and density (number of vehicles per time period) to the other nodes of the network. The information will be forwarded (backwards) to the other nodes on the road. There are three benefits of using the cat's eye. First, they already exist on the highways and periodically maintained. Second, the uniformly placement of the cat's eye gives the advantage of sensing the highway completely and, third, information captured from nodes can monitor the car

density on the highway; detect an incident, forward emergency information or alert weather conditions on the highways to drivers.

## D. Methodology and Plan:

Not only our goal is to monitor the road but also to notify drivers of any accident or bad weather conditions. Our idea depends on the nodes placed on the road that allows propagating data (backward and forward). We assume that each node contains a metal detector sensor that measures the existence of metal in the surrounding area [9]. The metal detector is a waterproof detector that can use radio direction-finding technology to detect the existence of a metal. Any node in our system can report its own readings and measurement. These nodes can report such information such as geographic position, the period a vehicle spent in its sensing area, intensity of metal (small vehicle, Truck, trailer, etc). Over a period of time T, sensor $S_i$ has stored data about the average number of vehicles $A_i$ and the average speed $V_i$.

### D.1 Locality of nodes:

Let $S_1$, $S_2$, $S_3$ ... $S_i$..., $S_n$ group of consecutive nodes on the highway. The distance between two consecutive nodes on the highway is known as *d*. This distance is pre-defined in each state- in Virginia, USA it is (80 feet) 24.3 meters [8]. Each node is sensing the area around it with radius of 4 meters which covers a circle around the node. We define the locality of nodes as recording the same parameters or data over a given distance. In case of normal density traffic or sparse with no incidents, sensors from $S_1$ to $S_j$ where j < i record the same value of average speed and average number of vehicles which we call locality of nodes.

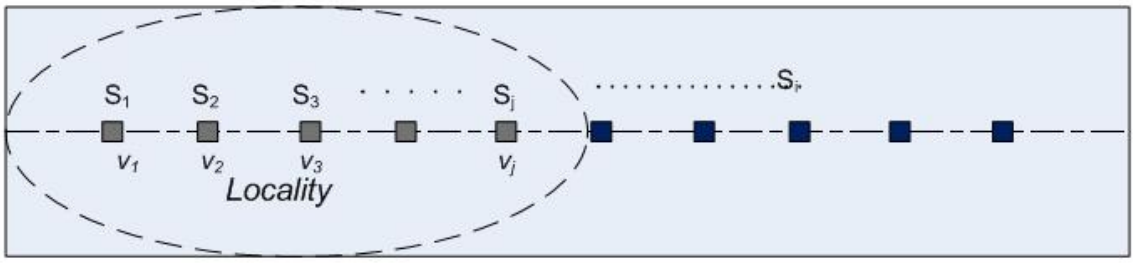


***Figure 2:*** A group of sensors $S_1$, $S_2$, $S_3$ ... Sj with the same average speed and density is gathered in same cluster

## D.2 Information Propagation

We have two aims for information propagation. First, we aim to prevent Secondary Accidents. Second, we notify drivers far away from the accident of an expected delay that gives them the option to continue or exit before reaching the incident location. Our idea is divided into two stages. Stage I: focus on the first goal which notifying vehicles close in distance to accident. Stage II: A new mechanism to track the source of the incident while notifying drivers away from the accident.

Our idea of information propagation depends on two main factors (density of the highway) and (time spent by the accident). The more time the incident stay, the further the information need to be propagated. Furthermore, the more density on the highway, the faster it will backup. In high density highways, an incident may form a backup of vehicles faster than low density highways. In order to satisfy this point, we need to propagate information as a function of density and time.

## D.3 Queue-end Warning System on Highways

We estimate the length of the backup at the entrance of a tunnel in order to notify coming drivers with the expected delay and to prevent any accident from coming vehicles. We model our system as a G-queue system which is m interconnected queues of type M/M/1 queue; vehicles are Poisson arrivals where ’positive’ vehicles (customers) are those who obey the service and routing disciplines present the vehicles that stay in the lane (queue) until entering the tunnel or the exit. The ’negative’ vehicles (customers) present the vehicles who change their lane or impatient to wait in the queue. Our queue network of m interconnected queues present a highway with m lanes. Our idea of estimating the queuing length then propagation of information depends on two main factors (estimated length of the queue) and (average density).

## E. Preliminary Results, Simulation & Evaluation:

We evaluate our frame work using ONE simulator, which is the Opportunistic Network Environment simulator that used to generate node movement using different movement models, route messages between nodes with various routing algorithms and sender and receiver types [7]. It allows visualizing both mobility and message passing in real time in its graphical user interface. In the simulation, our model uses a two lane highway of size 11 miles which describes a part of the Highway US-13 that goes beside the East coast from Virginia to New York. We generate vehicles randomly from the start points. The model assume a fixed stations between the two lanes which represents our nodes (Cat eye's) along the highway, we call them (Group I fixed nodes). These stations are 24.384 meters (80 feet) apart from each other [8]. Each vehicle - we call it (Group II moving

nodes) broadcast a packet every 2 seconds in the range of a circle with radius 12.192 meters (40 feet). Our model calculates the cluster size in different cases.

## F. Future Plans:

We have presented a new frame work for monitoring the highway and forwarding information using the deployed nodes on the highway. Our simulation calculated the cluster size (number of nodes with the same cluster). Our primary results show that the more vehicles with different speed on the highway, the less cluster size needed for communication and fast update. We also provide the update-status algorithm for the vehicles on the highway. This information can help in monitoring the highways. Also, we describe communication timing between nodes. Our future work, we would like to merge the vehicle-to-vehicle communication to our system which will allow forwarding information in case of dead clusters in the middle of the highway. Moreover, our plan is to develop a weather notification system on the highway by using our frame work and adding some other sensors that record more information about the weather around the nodes.

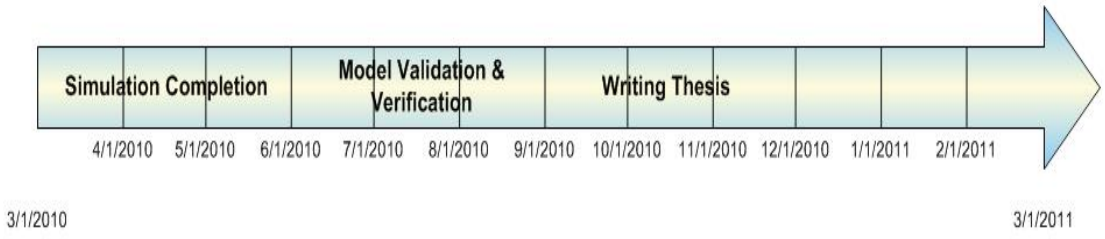


***Figure 3:*** Future Work

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- ✓ **Computer Science:** Modeling and analysis of Quality-of-Service, Simulation, Multimedia communication, Algorithms, Numerical Analysis, Graph Algorithms, Graph theory and Algorithm Complexity.

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- **Computer Science & Automatic Control Department, Alexandria University** Alexandria, Egypt
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**Jan 2003 - May 2006**
Masters level course-work and research projects.

- **Web Developer** Alexandria, Egypt **Jan 2005 - May 2006**
Participated in designing and developing the official web-site of the Faculty of Engineering, Alexandria University. (http://www.alexeng.edu.eg/)

- **Unilever Mashreq Company** Alexandria, Egypt
Application Developer- Dept. of Information Technology **Aug 2002 - Jan 2003**

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- ❖ A prize for Excellence in Scholarship in The College of William and Mary's 8th Annual Graduate Research Symposium, Williamsburg, Virginia, USA. Mar 2009

- ❖ Award and certificate of Leadership, Old Dominion University, Norfolk, Virginia, USA April 2007

- ❖ Alexandria University fellowship for M.Sc. Degree. Alexandria University, Alexandria, Egypt Jan 2003 - Jun 2006

# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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Research field: Nonlinear systems; Robust control; Operator theory;
Robust right coprime factorization

# Research Proposal

## Operator based robust nonlinear control for MIMO nonlinear systems

### Section 1. Research problem statement

Coprime factorization is an effective method in dealing with nonlinear systems. Factorization approach was introduced into control system analysis and synthesis by the factorization of transfer matrices since 1980s, which was used for discussing system analysis, design, stabilization, and control. Especially, Chen and Han (IEEE AC, 1998) investigated right coprime factorization of a nonlinear plant in a fairly general operator-theoretic setting, where, the operator can be linear or nonlinear, continuous-time or discrete time, finite-dimensional or infinite-dimensional, and can be either in the frequency domain or in the time domain. In Deng et al. (IEEE AC 2006), a new condition about operator based robust right coprime factorization for nonlinear systems with unknown bounded perturbation was derived. Based on the derived condition, the stability was guaranteed and output tracking problem with different spaces of reference input and output was discussed. Recently, robust right coprime factorization approach has been used to consider flexible arm experimental system with uncertainties, networked nonlinear control design for aluminum plate thermal process with time-delays and so on. This approach has been proved effective in theoretical studies and practical application on nonlinear SISO systems. However, robust nonlinear control system design for operator based multi-input multi-output (MIMO) nonlinear plants has seldom been studied due to the difficulties in dealing with coupling effects.

### Section 2. Significance and objectives

Operator based coprime factorization approach uses the input-output time function model given by basic physical rules from the real system, that is, approximation of the real system is avoided. Robust stability can be guaranteed by using a Bezout identity. Moreover, as for the system with perturbation, the effects from the perturbation cannot be transmitted back to error signal. As has been stated, this approach provides a convenient framework for the nonlinear control system design, including the case where the given plant $P$ is unstable.

In this work, robust nonlinear control system design for multi-input multi-output (MIMO) nonlinear perturbed plants is considered by using operator based robust right coprime factorization approach. In details, robust stability and output tracking design scheme for MIMO nonlinear perturbed system are considered.

### Section 3. Summary of the current state-of-the-art

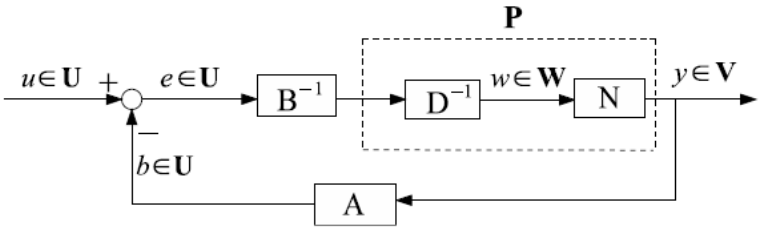


Fig. 1. A nonlinear feedback system

A normal nonlinear feedback control system is shown in Fig.1. Let $U$ and $V$ be the input and output spaces of a given plant operator $P$, i.e., $P: U \to V$. The given plant $P$ is said to have a right factorization, if there exist a linear space $W$ and two stable operators $D: W \to U$ and $N: W \to V$ such that $D$ is invertible and $P = ND^{-1}$ on $U$. The space $W$ is called a quasi-state space of $P$. The factorization is said to be coprime, or $P$ is said to have a right coprime factorization, if there exist two stable operators $A: V \to U$ and $B: U \to U$, satisfying the following Bezout identity

$$AN + BD = M, \quad M \in u(W,U) \tag{1}$$

where $B$ is invertible, $M$ is called unimodular operator, namely, $M$ is stable and $M^{-1}$ is stable under the note of bounded-input bounded-output stable, and $u(W,U)$ is the set of unimodular operators. The stability of the system has been proved under the condition that the Bezout identity is satisfied (see Chen and Han, IEEE AC, 1998).

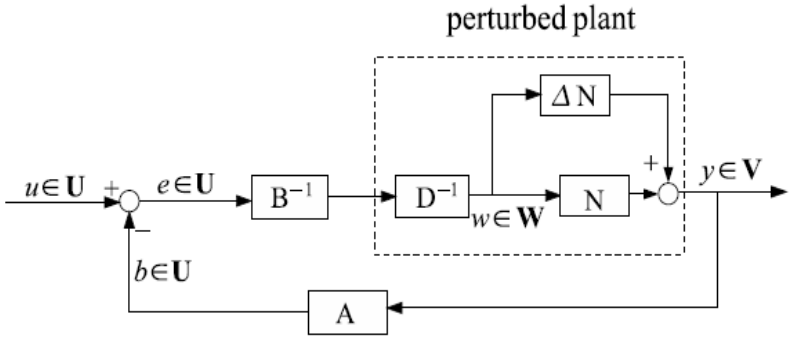


Fig. 2. Nonlinear system with perturbation

A nonlinear feedback control system with plant perturbation shown in Fig. 2 was studied in Deng et al. (IEEE AC 2006), where, the perturbation is concerning with the unmodelled uncertainties of the controlled plant. Let the nominal plant and the plant perturbation be $P$ and $\Delta P$, respectively, and the overall plant $\tilde{P}$ is given as $\tilde{P} = P + \Delta P$. The right factorization of the nominal plant and the overall plant are

$$P = ND^{-1}, \quad \tilde{P} = (N + \Delta N)D^{-1} \tag{2}$$

where $N, \Delta N$ and $D$ are stable operators, $D$ is invertible, $\Delta N$ is unknown but the upper and lower bounds are known. Then the stability of the system can be guaranteed provided that (1) and the following condition are satisfied.

$$\left\| (A(N + \Delta N) - AN)M^{-1} \right\| < 1 \tag{3}$$

By using (3), fault detection in a thermal process control system with input constraints was considered in Deng et al. (IMechE 2007), a flexible arm experimental system with uncertainties was analyzed in Deng et al. (IJMechS 2008), networked non-linear control for an aluminum plate thermal process with time-delays was considered in Deng and Inoue (IJSS 2008) and so on.

Section 4. Proposed research methodology and plan

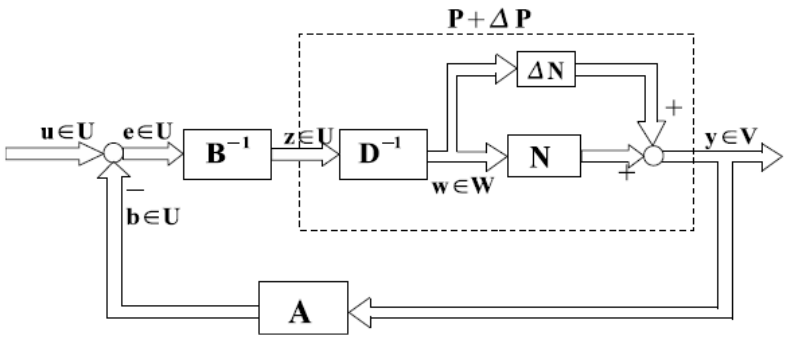


Fig. 3. The perturbed nonlinear systems

Based on the research on SISO perturbed plant, multi-input multi-output (MIMO) nonlinear perturbed system is designed as Fig.3, where, **P**=(*P1,*···*,Pn*) and **ΔP**=(*ΔP1,*···*,ΔPn*) are given nominal nonlinear plant and perturbation such that $P_i = N_i D_i^{-1}$ and $\Delta P_i = \Delta N_i D_i^{-1}$. Let input space, out space, quasi-state space be U, V, W, and the signals of input, error, control input, quasi-state and plant output be **u**=($u_1,\cdots,u_n$)∈U, **e**=($e_1,\cdots,e_n$)∈U, **z**=($z_1,\cdots,z_n$)∈U, **w**=($w_1,\cdots,w_n$)∈W and **y**=($y_1,\cdots,y_n$)∈V respectively. **A**=($A_1,\cdots,A_n$) and **B**=($B_1,\cdots,B_n$) are controllers to be designed. If there exist no coupling effects in the system, then the system is robustly stable provided that

$$A_i N_i + B_i D_i = M_i, \quad M_i \in u(W,U) \tag{4}$$

$$\left\| (A_i(N_i + \Delta N_i) - A_i N_i) M_i^{-1} \right\| < 1 \tag{5}$$

Generally speaking, there exist coupling effects between the plants $P_i$. In order to demonstrate the coupling effects more details, we suppose that there exist *n(n-1)* internal operators $G_{ij}$ $(i \neq j, i, j = 1,\cdots,n)$ concerning with the coupling effects. Assume that output of operator $B_i^{-1}$ is $x_i$, namely, $x_i(t) = B_i^{-1} e_i(t)$, thus the control input is $z_i(t) = x_i(t) + \sum_{\substack{j=1 \\ j \neq i}}^{n} G_{ij} x_j(t)$, where, $G_{ij} : U_j \to U_i$ is the internal operator concerning with coupling effects from the input of the plant $P_j$ to plant $P_i$, and $z_i(t)$ is the control input of ith-subsystem $(i = 1,\cdots,n)$. Then the quasi-state signal is $w_i(t) = D_i^{-1} z_i(t)$, plant output signal is $y_i(t) = N_i w_i(t)$, thus the system is indeed MIMO system.

To study the MIMO nonlinear plants, the coupling effects need to be considered. One of the research methods is to regard the coupling effects as the effects from

uncertainties of $D_i$, which is denoted by $\Delta D_i$ such that $D_i + \Delta D_i$ is invertible. That is, $x_i(t) + \sum_{\substack{j=1 \\ j \neq i}}^{n} G_{ij} x_j(t) = (D_i + \Delta D_i) w_i(t)$. Then, based on the results of Deng et al. (IEEE AC, 2006), the stability can be guaranteed if

$$\left\| [A_i(N_i + \Delta N_i) - A_i N_i + B_i(D_i + \Delta D_i) - B_i D_i] M_i^{-1} \right\| < 1 \quad (6)$$

However, $D_i + \Delta D_i$ is not invertible in some cases. In order to avoid that, robust control of MIMO nonlinear system with perturbation is considered in more detail.

## Section 5. Preliminary results

*Theorem 1.* Assume that the MIMO nonlinear feedback control systems shown in Fig.3 is well-posed, and the nominal plant $P_i$ has right coprime factorization as (4). If the internal operator $G_{ij}$ can be stabilized by $B_j^{-1}$ in the sense that $G_{ij} B_j^{-1}$ is stable. Then the system is stable provided that (5) is satisfied.

Then, as for the stabilizing system, the output tracking performance can be realized by the system given in Fig. 4, where, stable nonlinear tracking filter **C**=(*C1,· · ·,Cn*) is designed to make the output **y**=(*y1,· · ·,yn*) track to the reference input **r**=(*r1,· · ·,rn*).

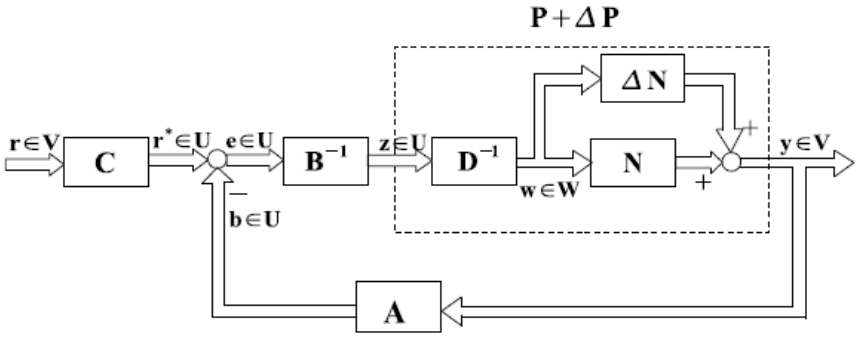


Fig. 4. Tracking design for perturbed nonlinear systems

*Theorem 2.* Concerning the stabilizing perturbed MIMO nonlinear systems shown in Fig.4, if

$$(N_i + \Delta N_i) M_i^{-1} C_i = I, \quad i = 1, \cdots, n \quad (7)$$

Where, *I* is the identity operator, then the output tracks to the reference inputs.

## Section 6. Future plans

Based on the current result, the sufficient condition for guaranteeing the robust stability and realizing output tracking performance of the perturbed MIMO nonlinear system has been derived. However, the fact that perturbation is unknown generates difficulties in the control design process. Also, this problem still exists in SISO nonlinear systems. Then, how to design controllers in detail to obtain the desired performance is the future work.

## ----RESUME----

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# Doctoral Consortium

**2010 IEEE International Conference on Networking, Sensing and Control (ICNSC 2010)**

**April 11 – 13, 2010**
**Chicago, IL, USA**

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## A Probability Collectives Approach for Distributed Optimization of Complex Systems

(Probability Collectives, Multi-Agent System, Collective Intelligence, Distributed Optimization, Multiple Traveling Salesmen Problem)

**(a) Research problem statement**

Complex systems generally have many components and it is difficult to understand the whole system only by knowing each component and its individual behavior. This is because any move by a component affects the further decisions/moves by other components and so on. Traditionally, such systems were seen as centralized systems, but as the number of components grows, complexity may grow exponentially, it become necessary to handle the systems using distributed and decentralized optimization approach. This makes the entire system to be seen as a collection of sub-systems or a Multi-Agent System (MAS). The major challenge is to make these agents work in a coordinated way, optimizing their local goals and eventually the global system objective. Furthermore, although the population based algorithms such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Wasp Colony System, Swarm-bot, etc. have been used solving complex problems, as the complexity grew these problems become quite tedious to be handled using these algorithms.

One of the frameworks through which such distributed, decentralized and cooperative approach can be implemented is COllective INtelligence (COIN) using the method of Probability Collectives (PC) which has deep connections to Game Theory, Statistical Physics, and Optimization [1]. It was first proposed by Dr. David H. Wolpert in 1999 in a Technical Report presented to NASA [2]. PC is found to be an obvious tool that can deal with the increasing complexity because of its ability to treat the problem by decomposing it into sub-problems and further deal with a variety of large problems [3-9] more efficiently and in a more simplified way.

The author of this report notices the challenging area of the Multiple Traveling Salesmen Problem (MTSP) where PC can be quite useful and show its potential. This is because the MTSP is a NP-hard combinatorial optimization problem although easy to understand, remains a challenge for the researchers over the years. Furthermore, scientific researchers from the defense industry in Singapore were interested to solve path planning problems for multiple UAVs by modeling them as MTSPs, with a possible extension towards a decentralized optimization and control of these autonomous vehicles. This motivated the author of this report to solve the MTSP by applying PC as a distributed and decentralized optimization methodology.

In addition, the control of urban traffic system is a complex task because of the dynamic nature of the traffic as well as large number of possible interactive and conflicting objectives involved [10, 11]. This complexity and ever growing traffic volume in urban areas is leading to serious congestion problem as well as posing the intersections as bottlenecks. Such system is difficult to be set up, maintain in a centralized way and demand significant computing power [2, 10-12]. This suggests decomposing the entire traffic network into its various components such as sub-networks/intersections, phases, etc. to control them individually.

The discussion on the comparison between PC and the other evolutionary algorithms such as PSO, ACO, GA, Artificial Neural Network (ANN), etc. can be found in author's recent publication [13].

**(b) Significance and objectives**

Following are the objectives of the current research work.

1. Extend the PC approach further in order to exploit the key benefits of being a distributed, decentralized and cooperative approach. This includes modifying the PC approach to make it more efficient and faster. Furthermore, it also includes the development of more general and powerful approach of PC by incorporating necessary constraint handling techniques so as to make it solve a variety of practical constrained problems.
2. Solve the MTSP using PC. As PC is a distributed, decentralized approach, it can potentially be applied to the path planning of Multiple UAVs (MUAVs). This further involves applying PC on the real distributed, decentralized platform with separate workstations for each agent.
3. Solve the urban traffic control problem in a distributed and decentralized way using PC. This involves allowing every intersection in the traffic network independently and dynamically optimize the decision variables such as green signal durations, cycle time, phase sequence, etc. in order to optimize the performance of local traffic. This may further result in optimum performance of the entire traffic network. This further involves applying PC on the real distributed, decentralized platform with separate workstation for each agent.

**(c) Summary of the current state-of-the-art**

As PC is used on the distributed and decentralized platform, it is applied to variegated areas such as wireless sensor networks, scheduling, logistics, mechanical design, etc. where it is found to be superior over the other tools.

The joint optimization of the routing and resource allocation in wireless networks was solved in [14, 15]. In all these works, as the concave utility functions were difficult to solve using traditional optimization techniques, they were assumed to be monotonically increasing, strictly convex, positive and differentiable. On the other hand, the PC approach implemented in [3, 4] played an important role by turning the original problem into convex optimization over a probability distribution. In case of mobile wireless networks, choosing the optimal number of nodes for a cluster and a cluster head is a NP-hard problem. The use of PC was demonstrated in [5] for the optimum selection of the cluster heads using the weighted clustering algorithm.

In a complex system such as airplane fleet assignment with 129 variables and 184 constraints, the minimization of the number of flights was achieved using PC [16]. Applying a centralized approach to this problem may increase the communication, computational load and further may add latency in the system. The potential of PC in mechanical design was demonstrated for deciding the cross-sections of the individual bars and individual segments of a 10 bar truss [6] and a segmented beam [7], respectively. The 10 bar truss problem in [6] was solved as a discrete constrained optimization problem, while the segmented beam problem in [7] was solved as an unconstrained continuous optimization problem. It is worth to mention here that the constrained handling technique is not explicitly mentioned in [6].

Benchmark problems such as Schaffer's function, Rosenbrock function, Ackley Path function and Michalewicz Epistatic function were solved using GA and PC to test the important characteristics such as multimodality, nonlinearity and non-separability [8]. The results indicated the superiority of PC in the rate of descent, trapping in false minima and long term optimization.

PC was evaluated in [9] using centralized and decentralized architectures solving the 8-Queens problem. The comparison between the two architectures underlined the average superiority of the decentralized approach including the computational cost. This was because of the distributed sample generation and updating of the probabilities in the latter approach.

The above discussion shows that although PC is versatile and applicable to variegated areas, it is not yet implemented to solve the combinatorial optimization problem such as MTSP as well as no approach is developed handling the constraints. The PC is modified solving the test cases of the Multiple Depot MTSP (MDMTSP) [13] as well as the Single Depot (SDMTSP) [17] by the author of this report. The PC solution to the MDMTSP is discussed in the following subsections of this report. The author of this report also notices the traffic control problem as a possible practical application where PC can be very useful as the computations and communication will be reduced to local level and may help to respond faster.

**(d) Proposed research methodology and plan**

The thorough literature review on PC is done to understand the basic concepts of PC. The PC is modified and formulated. The modifications are done to increase the efficiency as well as performance. Necessary heuristic techniques are also developed and incorporated.

The problem such as unconstrained Segmented Beam problem is solved to get the preliminary results [7]. The Rosenbrock Function (with limited number of variables) is solved to validate the modified PC [18]. The modified PC is applied to two specially developed test problems (with limited number of nodes and vehicles) for the MDMTSP. To validate the performance and efficiency of the approach the results are compared with some of the algorithms solving the MTSP with approximately same number of nodes and vehicles. The necessary techniques needed to assist the PC algorithm are developed [13].

The constrained PC approach will be developed and validated optimizing the most suitable benchmark functions and comparing the results with the other methods. In this PC solution, the variables of test functions will be considered as agents selecting their own strategies.

The modified PC approach will be applied to urban traffic control problem. A network of traffic intersections will be considered in which the individual intersections will be represented as agents. A suitable traffic simulator will be used to set up a dynamic traffic scenario. The necessary parameters such as flow rate, etc. representing the traffic condition will be measured and used further by PC algorithm to optimize the variables associated with the individual intersections. The optimized variables will be fed back to the simulated traffic intersections to check the individual intersection as well as entire network

performance. This is to validate the ability of the PC approach solving the real life problem such as traffic control. Moreover, similar to [13] if needed in the due course of the implementation of the traffic control problem appropriate techniques will be developed.

Although PC is a distributed and decentralized approach, similar to [7, 13, 18] all the computations and simulations solving the traffic control problem will be conducted on a single workstation. Furthermore, the PC method will be coded in MATLAB 7.4.0 (R2007A) on Windows platform with Pentium IV processor, 512MB RAM and 3GHz processor speed.

**(e) Preliminary results**

The PC approach is tested on a variety of problems including, Rosenbrock function, and test cases of the MDMTSP. These are discussed below in detail.

***Solution to Rosenbrock Function Using PC***

There are a number of benchmark test functions for contemporary optimization algorithms like GAs and evolutionary computation. The Rosenbrock function is an example of a non-linear function having strongly coupled variables and is a real challenge for any optimization algorithm because of its slow convergence for most optimization methods. The Rosenbrock function with $N$ number of variables is given by

$$f(\mathbf{x}) = \sum_{i=1}^{N-1}\left[100\left(x_i^2 - x_{i+1}\right)^2 + \left(1 - x_i\right)^2\right] \tag{1}$$

where $\mathbf{x} = [x_1 \quad x_2 \quad \ldots \quad x_N]$, $\text{lower limit} \le x_i \le \text{upper limit}$ and the global minimum is at $f(\mathbf{x}^*) = 0$, $\mathbf{x}^* = [1 \quad 1 \quad \ldots \quad 1]$. A difficulty arises from the fact that the optimum is located in a deep and narrow parabolic valley with a flat bottom. Also, gradient based methods may have to spend a large number of iterations to reach the global minimum. The Rosenbrock function with 5 variables ($N = 5$) was solved using PC [13, 18]. Although the optimal value of each and every

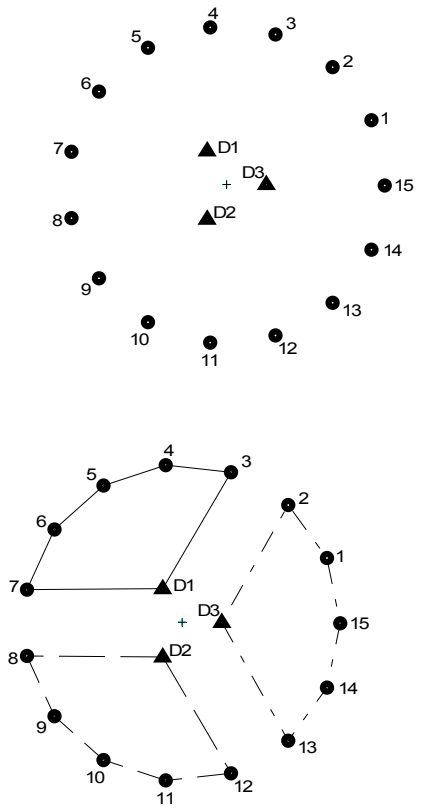
**Table 1. Performance Using PC Approach**

| Agents/ (Variables) | Strategy Values Selected with Maximum Probability | | | | | |
|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Range of Values |
| Agent 1 | 1 | 0.9999 | 1.0002 | 1.0001 | 0.9997 | -1.0 to 1.0 |
| Agent 2 | 1 | 0.9998 | 1.0001 | 1.0001 | 0.9994 | -5.0 to 5.0 |
| Agent 3 | 1.0001 | 0.9998 | 1 | 0.9999 | 0.9986 | -3.0 to 3.0 |
| Agent 4 | 0.9998 | 0.9998 | 0.9998 | 0.9995 | 0.9967 | -3.0 to 8.0 |
| Agent 5 | 0.9998 | 0.9999 | 0.9998 | 0.9992 | 0.9937 | 1.0 to 10.0 |
| Fun. Value | $2 \times 10^{-5}$ | $1 \times 10^{-5}$ | $2 \times 10^{-5}$ | $2 \times 10^{-5}$ | $5 \times 10^{-5}$ | |
| Fun. Eval. | 288100 | 223600 | 359050 | 204750 | 249500 | |

variable $x_i$ is 1, the allowable range for each variable (agent) was intentionally assigned to be different. The results of 5 trials are shown in Table 1. The corresponding comparison between PC and the other algorithms solving the Rosenbrock function can be found in [13, 18].

***Test Cases of the Multi Depot MTSP (MDMTSP)***

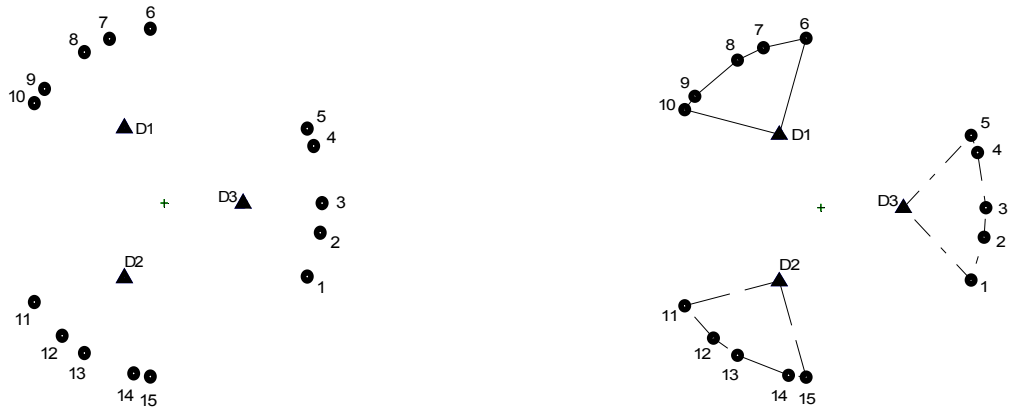
PC accompanied with the specially developed insertion, elimination and swapping heuristic techniques [13] was applied to two test cases of the MDMTSP. Case 1 is presented in Figure 1(a). Three depots (D1, D2 and D3) are placed 120º apart from one another on the periphery of an inner circle. Fifteen equidistant nodes are placed on the outer circle. The angle between the nodes is 24º. The diameters of the inner and outer circle are 10 and 40 units, respectively. One traveling vehicle is assigned per depot. The vehicles start their journeys from their assigned depots and return to their corresponding depots. A total of 50 runs of PC were conducted for Case 1. The true optimum solution was achieved in every run is plotted in Figure 1(b).




**(a) Case 1** **(b) Solution to Case 1**

**Figure 1. Test Case 1**

Case 2 is presented in Figure 2(a) where three depots are placed 120º apart from one another on the periphery of an inner circle. Fifteen nodes are placed on the outer circle. These nodes are arranged in three clusters. In every cluster, the nodes are intentionally placed at uneven angles apart. The diameters of the inner and outer circle are 5 and 10 units, respectively. Similar to Case 1, one vehicle is assigned per depot. A total of 50 runs were conducted for Case 2. The true optimum solution achieved in ever run is plotted in Figure 2(b).




**(a) Case 2** **(b) Solution to Case 2**

**Figure 2. Test Case 2**

**Table 2. Performance Comparison of Various Algorithms solving the MTSP**

| Method | Nodes | Vehicles | Avg. CPU Time (Minutes) | % deviation from Avg. Sol. |
|---|---|---|---|---|
| MTSP to standard TSP [19] | 20 | 2 | 2.05 | -- |
| | 20 | 3 | 2.47 | |
| | 20 | 4 | 2.95 | |
| Cutting Plane [20] | 20 | 2 | 1.71 | -- |
| | 20 | 3 | 1.50 | -- |
| | 20 | 4 | 1.44 | |
| Elastic Net [21] | 22 | 2 | 12.03 | 28.71 |
| | 22 | 3 | 13.10 | 74.18 |
| | 22 | 4 | 12.73 | 33.33 |
| Branch on an Arc with Lower Bound-0 [22] | 15 | 3 | 0.56 | -- |
| Branch on an Arc with Lower Bound-2 [22] | 15 | 3 | 1.01 | -- |
| | 20 | 4 | 2.32 | |
| Branch on a Route with Lower Bound-0 [22] | 15 | 3 | 0.44 | -- |
| **Proposed PC (MDMTSP)** | **15 (Case 1)** | **3** | **2.09** | **0.00** |
| | **15 (Case 2)** | **3** | **1.27** | **0.00** |
| **Proposed PC (SDMTSP) [17]** | **15** | **3** | **3.34** | **2.94** |

The above solution using PC indicates that it can successfully be used to solve the Multi-Agent Combinatorial Optimization problems such as the MDMTSP. As shown in Table 2, the results are compared with some of the other methods solving the Single Depot MTSP with problem sizes close to the specially developed test cases solved here. For further details refer to author's recent publication [13]. For details of the PC solution to SDMTSP refer to [17].

***Comparison and Discussion***

It is worth to mention some of the key differences of the PC approach presented here and the original PC approach [1, 2, 6, 16]. The convergence criterion in the present PC approach is no change in the final goal value for a considerable number of iterations or maximum predefined number of iterations. On the other hand, the convergence criterion in the PC approach originally presented in [1, 2, 6, 16] and also by the author of this report in their previous work presented in [7] was the number of iterations for which there is no change in the highest probability value of the most recent favorable strategy. In the present PC approach very few number of samples are drawn from the uniform distribution of the individual agent's sampling range or sampling space. On the contrary, in the

original PC approach Monte Carlo sampling method was used, which was computationally expensive and slower as the number of samples needed was in thousands or even millions. In addition, the regression (necessary in the original PC approach to fit the individual utility inside the individual range domain) is completely avoided in the present PC approach, making the modified approach computationally less expensive. Most significantly, in the present PC approach, the sampling range of individual variables (agents) is narrowed down with every iteration ensuring faster convergence and an improvement in efficiency over the original PC approach [13, 17, 18]. For the MDMTSP solution, the neighboring radius is narrowed down iteratively exploiting the same benefits. For further details refer to [13].

**(f) Future plans**

The literature on PC and the problems solved underlines that the PC has potential role in a variety of areas such as machine shop scheduling, mechanical design, clustering, vehicle routing, etc. Furthermore, it is noticed that no generic constraint handling approaches have been developed for incorporating into the overall PC framework. Some efforts are taken in the current work solving the MDMTSP, in which the basic constraints of the MTSP are treated using the repair work i.e. using various heuristic techniques. This approach may be workable but is not an elegant option. If complexity of the problem and related constraints increase, the repair work may become more tedious. In this regard, author of this report intend to develop a generic constraint handling technique that can be incorporated into PC solving a variety of realistic problems with practical constraints.

Moreover, the PC approach can be implemented on truly distributed and decentralized platform with possible application to UAVs working collectively to complete the assigned tasks. Such applications can be seen in the fields of military surveillance, fire-fighting, exploring alien territory, etc. Similarly, PC can also be tested physically for the traffic control problem by assigning separate workstation to each traffic intersection optimizing the performance of the entire traffic network.

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## Resume

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## Publications

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- ✓ **Kulkarni A.J.** and Tai K. (2010) "Probability Collectives: A Distributed Optimization Approach for Constrained Problems", IEEE World Congress on Computational Intelligence (WCCI 2010), Barcelona, Spain, 18-23 July 2010 (Accepted for Publication)
- ✓ **Kulkarni A.J.** and Mayorga R.V. (2010) "Artificial Neural Network Optimization using Layer Partition and Genetic Algorithms along with Statistical Analysis", Computational Intelligence Research, 6 (1), pp. 77-87
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***National and others***

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