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A Letter From the Associate Editor in Chief

Ioan Dzitac

We are pleased pleased to inform all collaborators that our journal is covered in some Thomson Reuters/Scientific services starting with Vol. II, No.1, 2007. We would like to thank very much to Mr. Marian Hollingsworth for the following letter:

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June 4, 2008

Dr. Ioan Dzitac
CCC Publications
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Dear Dr. Ioan Dzitac,

I am pleased to inform you that ***International Journal of Computers Communications & Control*** has been selected for coverage in Thomson Reuters products and custom information services. Beginning with V. 2 (1) 2007, this publication will be indexed and abstracted in the following:

- Science Citation Index Expanded (also known as SciSearch®)
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If possible, please mention in the first few pages of the journal that it is covered in these Thomson Reuters services. I would greatly appreciate completion and return of the enclosed ***Journal Information Sheet*** at your earliest convenience.

In the future ***International Journal of Computers Communications & Control*** may be evaluated and included in additional Thomson Reuters products and information services to meet the needs of the scientific and scholarly research community.

Thank you very much.

Sincerely,

Marian Hollingsworth

Marian Hollingsworth
Director, Publisher Relations

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A Letter From the Associate Executive Editor

Ioan Buciu

1 Journal of Computers, Communications & Control Entered a New Era

As of the production of its third volume, issue 3, year 2008, the Journal of Computers, Communications & Control (IJCCC) entered a new era. I was pleasantly surprised when in March, 2008, a message arrived from Ioan Dzitac, the Associate Editor-in-Chief of IJCCC, notified me about the inclusion of this new periodical in the prestigious Master Journal List of Thomson Reuters Database. Two months later, more pleasant news came: IJCCC was covered in Science Citation Index Expanded (also known as SciSearch) as its quality figure of merit. This incredible achievement is emphasized by the journal's age. Started in 2006 as a quarterly peer-reviewed periodical, this almost new-born journal knew an increased interest ever since, due to its increasing quality over this short time period. To ensure high publication quality, all published manuscripts passed through a peer-review process. This process provides authors with valuable critiques of their work by at least three independent experts in the topic field of their manuscripts, helping the editors to assess the scientific and technical merit of the work described.

We are all aware of the Thomson Scientific Journal selection process and how selective this is. Several factors are considered and have to be fulfilled when evaluating journals for coverage, including the publication timeliness, editorial content, international diversity, citation analysis and, finally, the journal's electronic format. Out of these, the relative weakness of the IJCCC resides in the citation issue measured by its impact factor. However, as IJCC is a new journal, no citation history exists to date. For the future, a special attention shall be paid to this issue as its value is a strong indicator related to the journal's importance and popularity in its scientific field.

2 Journal of Computers, Communications and Control as E-Journal

We should stress the availability of the online version of the journal, fact which provides its accessibility worldwide. Currently, the submission process is carried out by asking the authors to send their manuscript via e-mail to the Editorial Office. We make efforts to improve the submission procedure by considering, in the future, a web-based online submission procedure to facilitate and ease the Author - Editorial Office - Reviewers communication. The authors will be able thus to check the status of their manuscript by logging on that website. This new system will greatly help us streamline the review process and improve its timeliness. Using this system the reviewers and editors are responsible for objective and timely assessment for the work submitted. After an initial quick check, the editors may return without review manuscripts submitted for publication that are poorly written or lack in quality and/or technical content, thus giving authors a chance to enhance their contribution and avoid undesired review loops.

3 New Members for Editorial Board

The last Editorial of the IJCCC is dated 2006, the year when its first issue was released. That time the Editorial Board included seventeen prestigious experts covering the scientific topics of the Journal. It is worth mentioning that the Journal started with a consistent Editorial Board even from the beginning, ready to managing the review and editorial process. As more and more manuscripts were submitted for publications the selection process faced difficult times. It was the time for the Editorial Board to be expanded by inviting new editors to join the club. Consequently, Răzvan Andonie joined the Editorial

Board as Executive Editor, while Ioan Dzitac stepped up from Executive Editor to Associate Editor-in-Chief. Shortly, Ioan Buciu was invited to serve as Associate Executive Editor. In addition, new eight members entered as Associate Editors, including Boldur E. Bărbat, Petre Dini, Xiao-Shan Gao, Ştefan I. Niţchi, Stephan Olariu, Dana Petcu, Radu Popescu Zeletin and Lotfi A. Zadeh. We look forward to their contributions to the Journal in their diverse fields of expertise. Horea Oros and Emma Valeanu act as Editorial Secretary. All together, in 2008, the Editorial Board sums 29 Members. With an enriched Editorial Board we hope to have better Journal Management and Manuscript Workflow.

4 Professor Lotfi A. Zadeh at International Conference on Computers, Communications & Control (ICCCC) - 2008

Between IJCCC and ICCCC there is a close relation. Firstly, because IJCCC was born in ICCCC. Secondly, both have the same founders: Ioan Dzitac, Florin Gheorghe Filip and Mişu-Jan Manolescu. Lately but not lastly, IJCCC publishes a supplementary issue every two years (in even years when ICCCC takes place) the proceedings of ICCCC. Once this issue is sent for coverage to Thomson Reuters, we will send for evaluation the two supplementary issues published so far, Vol.1 (2006) Supplementary issue-Proccedings of ICCCC 2006 and Vol.3 (2008) Supplementary issue-Proccedings of ICCCC 2008 (accessible online free of charge at http://www.journal.univagora.ro/?page=contents) with the hope that these issues will be recognized as ISI Proceedings.

The 2008 Edition of the International Conference on Computers, Communications & Control had a special guest as keynote speaker: Professor Lotfi A. Zadeh, professor at Berkley University of California. He created a new field of mathematics - Fuzzy Set Theory and Fuzzy Logic, which have found numerous applications in Artificial Intelligence, ranging from consumer electronics to medicine and natural languages. His current research is focused on fuzzy logic, soft computing and computing with words. Therefore, his presence was a great achievement and honor for the Conference and we were proud of having Zadeh at this event.

Also, it is a great honor for the whole team of IJCCC that professor Zadeh accepted at ICCCC 2008 to join the IJCCC board as an Associate Editor, a fact that certainly will contribute to the attractiveness and quality of our journal.

5 IJCCC for CrossRef and Digital Object Identification

In order to improve the cross references issue we are preparing to adhere to the CrossRef association. This organization provides a scalable linking system through which a researcher can click on a reference citation in a journal and access the cited article. By using the system, the work published in IJCCC will be linked out for a higher visibility to many other articles from thousands of publications. In other words, the system allows a researcher to link from a reference citation from the IJCCC directly to the cited content on another publisher's platform, subject to the target access control practices of the publisher. To avoid plagiarism and to protect the intellectual content of the material published in the IJCCC we will soon register to the Digital Object Identification (DOI) system. This way, the intellectual property will assess a better management through the use of persistent identifiers with metadata provided by the DOI system.

6 Microsoft Word Office Format

Typically, all the submitted manuscript for IJCCC should be written using the LaTeXtypesetting system, as it provides programmable publishing features and extensive facilities for automating most aspects of typesetting and desktop publishing, including numbering and cross-referencing, tables and figures, page layout and references. We encourage the authors to follow this professional system. However, for those authors not familiar with this document preparation system, we recently accepted documents prepared in Microsoft Word Office. The Journal Secretariat will convert the Word document to the LaTeXformat. In any case, the Microsoft Word format manuscript should follow the Journal format specifications, i.e. A4 paper, Times New Roman fonts, size 12, single column. Regarding figures, they should be sent as jpeg format to be subsequently included in the document. More details can be found on the Journal website.

Now, we reached our ISI objective. Through this Editorial we would like to take the opportunity expressing our deeply grateful and many thanks to the entire IJCCC Team (Editorial Board, Associate Editors, Technical Secretary, and the Agora Publishing House) and to all contributing authors who made this possible. The "battle" is not over yet and there is room for improvements in many technical and editorial aspects. From now on, standing on this prestigious position it's up to all of us.

We look forward to publishing your best scientific work in the IJCCC.

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Neuro-Fuzzy based Approach for Inverse Kinematics Solution of Industrial Robot Manipulators

Srinivasan Alavandar, M. J. Nigam

Abstract: Obtaining the joint variables that result in a desired position of the robot end-effector called as inverse kinematics is one of the most important problems in robot kinematics and control. As the complexity of robot increases, obtaining the inverse kinematics solution requires the solution of non linear equations having transcendental functions are difficult and computationally expensive. In this paper, using the ability of ANFIS (Adaptive Neuro-Fuzzy Inference System) to learn from training data, it is possible to create ANFIS, an implementation of a representative fuzzy inference system using a BP neural network-like structure, with limited mathematical representation of the system. Computer simulations conducted on 2 DOF and 3DOF robot manipulator shows the effectiveness of the approach.
Keywords: Neuro-Fuzzy, ANFIS, Robot manipulator, Inverse kinematics

1 Introduction

A robot manipulator is composed of a serial chain of rigid links connected to each other by revolute or prismatic joints. A revolute joint rotates about a motion axis and a prismatic joint slide along a motion axis. Each robot joint location is usually defined relative to neighboring joint. The relation between successive joints is described by 4×4 homogeneous transformation matrices that have orientation and position data of robots. The number of those transformation matrices determines the degrees of freedom of robots. The product of these transformation matrices produces final orientation and position data of a n degrees of freedom robot manipulator. Robot control actions are executed in the joint coordinates while robot motions are specified in the Cartesian coordinates. Conversion of the position and orientation of a robot manipulator end-effector from Cartesian space to joint space, called as inverse kinematics problem, which is of fundamental importance in calculating desired joint angles for robot manipulator design and control.

For a manipulator with n degree of freedom, at any instant of time joint variables is denoted by $\theta_i = \theta(t)$, $i = 1,2,3,...,n$ and position variables $x_j = x(t)$, $j = 1,2,3,...,m$. The relations between the end-effector position $x(t)$ and joint angle $\theta(t)$ can be represented by forward kinematic equation,

$$x(t) = f(\theta(t)) \tag{1}$$

where f is a nonlinear, continuous and differentiable function. On the other hand, with the given desired end effector position, the problem of finding the values of the joint variables is inverse kinematics, which can be solved by,

$$\theta(t) = f'(x(t)) \tag{2}$$

Solution of (2) is not unique due to nonlinear, uncertain and time varying nature of the governing equations. Figure 1 shows the schematic representation of forward and inverse kinematics. The different techniques used for solving inverse kinematics can be classified as algebraic [1], geometric [2] and iterative [3]. The algebraic methods do not guarantee closed form solutions. In case of geometric methods, closed form solutions for the first three joints of the manipulator must exist geometrically. The iterative methods converge to only a single solution depending on the starting point and will not work near singularities.

If the joints of the manipulator are more complex, the inverse kinematics solution by using these traditional methods is a time consuming. In other words, for a more generalized m degrees of freedom manipulator, traditional methods will become prohibitive due to the high complexity of mathematical structure of the formulation. To compound the problem further, robots have to work in the real world that cannot be modeled concisely using mathematical expressions. In recent years, there have been increasing

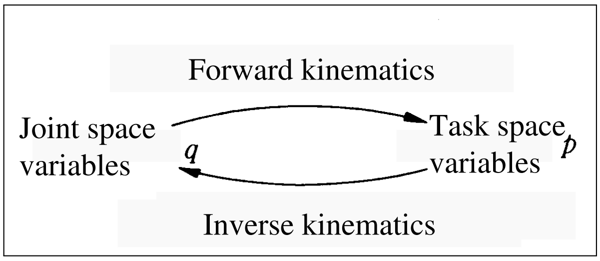

Figure 1: Schematic representation of forward and inverse kinematics

research interest of artificial neural networks and many efforts have been made on applications of neural networks to various control problems. The most significant features of neural networks are the extreme flexibility due to the learning ability and the capability of nonlinear functions approximations. This fact leads us to expect neural networks to be a excellent tool for solving the inverse kinematics problem in robot manipulators with overcoming the difficulties of algebraic, geometric and iterative methods.

Fuzzy Inference Systems are the most popular constituent of the soft computing area since they are able to represent human expertise in the form of IF antecedent THEN consequent statements. In this domain, the system behavior is modeled through the use of linguistic descriptions. Although the earliest work by Prof. Zadeh on fuzzy systems has not been paid as much attention as it deserved in early 1960s, since then the methodology has become a well-developed framework. The typical architectures of fuzzy inference systems are those introduced by Wang [4][5], Takagi and Sugeno [6] and Jang [7]. In [4], a fuzzy system having Gaussian membership functions, product inference rule and weighted average defuzzifier is constructed and has become the standard method in most applications. Takagi and Sugeno change the defuzzification procedure where dynamic systems are introduced as defuzzification subsystems. The potential advantage of the method is that under certain constraints, the stability of the system can be studied.

Utilization of Neural networks (NN) and Fuzzy logic for solving the inverse kinematics is much reported [8]-[13]. Li-Xin Wei et al [14]., and Rasit Koker et al [15]., proposed neural network based inverse kinematics solution of a robotic manipulator. There exist numerous possibilities for the fusion of neural networks and fuzzy logic technique so that both of them can overcome their individual drawbacks as well as benefit from each other's merits. Jang et al [16]., propose an Adaptive Neuro Fuzzy Inference System, in which a polynomial is used as the defuzzifier. This structure is commonly referred to as ANF1S. In this paper, neuro-fuzzy systems which provide fuzzy systems with automatic tuning using Neural network (ANFIS) is used to solve the inverse kinematics problem. The paper is organized as follows, in section 2, the structure of ANFIS used is presented. Section 3 describes simulation results and discussion. Conclusion and acknowledgment are followed in section 4 and 5 respectively.

2 ANFIS Architecture

This section introduces the basics of ANFIS network architecture and its hybrid learning rule. Inspired by the idea of basing the fuzzy logic inference procedure on a feedforward network structure, Jang [16] proposed a fuzzy neural network model - the Adaptive Neural Fuzzy Inference System or semantically equivalently, Adaptive Network-based Fuzzy Inference System (ANFIS), whose architecture is shown in Figure 2. He reported that the ANFIS architecture can be employed to model nonlinear functions, identify nonlinear components on-line in a control system, and predict a chaotic time series. It is a hybrid neuro-fuzzy technique that brings learning capabilities of neural networks to fuzzy inference systems. The learning algorithm tunes the membership functions of a Sugeno-type Fuzzy Inference System using the training input-output data. A detailed coverage of ANFIS can be found in [7],[16]-[17]. The ANFIS is, from the topology point of view, an implementation of a representative fuzzy inference

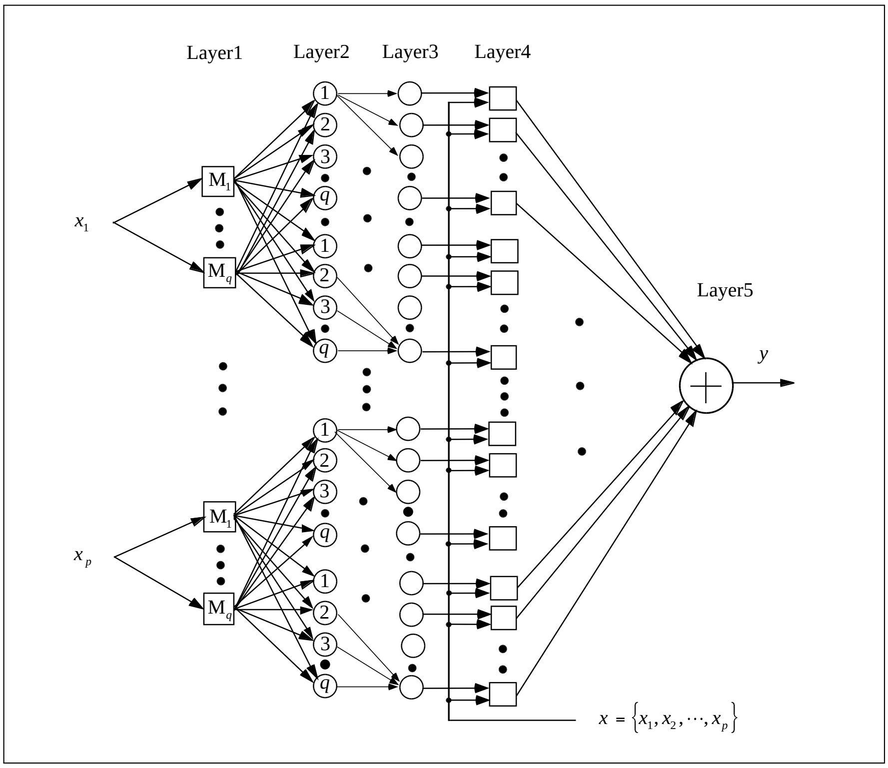

Figure 2: Structure of ANFIS

system using a BP neural network-like structure. It consists of five layers. The role of each layer is briefly presented as follows: let O_i^l denote the output of node i in layer l, and x_i is the i^{th} input of the ANFIS, $i = 1,2,...,p$. In layer 1, there is a node function M associated with every node:

$$O_i^1 = M_i(x_i) \tag{3}$$

The role of the node functions $M_1, M_2, ...M_q$ here is equal to that of the membership functions $\mu(x)$ used in the regular fuzzy systems, and q is the number of nodes for each input. Gaussian shape functions are the typical choices. The adjustable parameters that determine the positions and shapes of these node functions are referred to as the premise parameters. The output of every node in layer 2 is the product of all the incoming signals:

$$O_i^2 = M_l(x_l) AND M_j(x_j) \tag{4}$$

Each node output represents the firing strength of the reasoning rule. In layer 3, each of these firing strengths of the rules is compared with the sum of all the firing strengths. Therefore, the normalized firing strengths are computed in this layer as:

$$O_i^3 = \frac{O_i^2}{\sum_i O_i^2} \tag{5}$$

Layer 4 implements the Sugeno-type inference system, i.e., a linear combination of the input variables of ANFIS, $x_1, x_2, ...x_p$ plus a constant term, $c_1, c_2, ...c_p$, form the output of each $IF-THEN$ rule. The output of the node is a weighted sum of these intermediate outputs:

$$O_i^4 = O_i^3 \sum_{j=1}^{p} (P_j x_j + c_j) \tag{6}$$

where parameters $P_1, P_2, ..., P_p$ and $c_1, c_2, ..., c_p$, in this layer are referred to as the consequent parameters.The node in layer 5 produces the sum of its inputs, i.e., defuzzification process of fuzzy system (using weighted average method) is obtained:

$$O_i^5 = \sum_i O_i^4 \tag{7}$$

The flowchart of ANFIS procedure is shown in Figure 3. ANFIS distinguishes itself from normal fuzzy logic systems by the adaptive parameters, i.e., both the premise and consequent parameters are adjustable. The most remarkable feature of the ANFIS is its hybrid learning algorithm. The adaptation

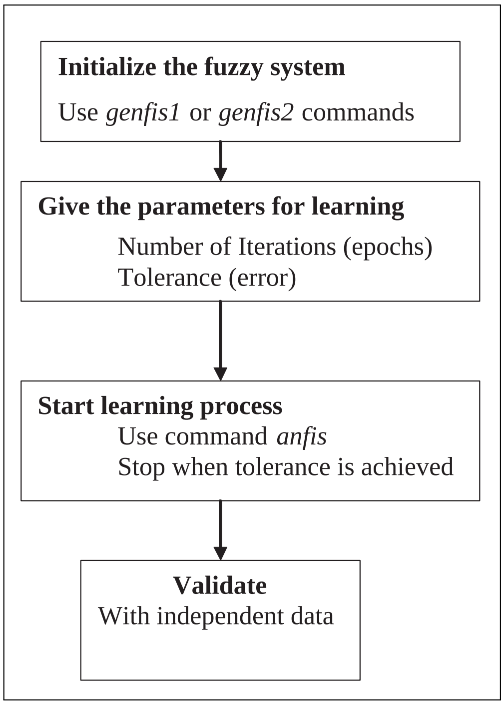

Figure 3: ANFIS procedure

process of the parameters of the ANFIS is divided into two steps. For the first step of the consequent parameters training, the Least Squares method (LS) is used, because the output of the ANFIS is a linear combination of the consequent parameters. The premise parameters are fixed at this step. After the consequent parameters have been adjusted, the approximation error is back-propagated through every layer to update the premise parameters as the second step. This part of the adaptation procedure is based on the gradient descent principle, which is the same as in the training of the BP neural network. The consequence parameters identified by the LS method are optimal in the sense of least squares under the condition that the premise parameters are fixed. Therefore, this hybrid learning algorithm is more effective than the pure gradient decent approach, because it reduces the search space dimensions of the original back propagation method. The pure BP learning process could easily be trapped into local minima. When compared with employing either one of the above two methods individually, the ANFIS converges with a smaller number of iteration steps with this hybrid learning algorithm.

This paper considers the ANFIS structure with first order Sugeno model containing 49 rules. Gaussian membership functions with product inference rule are used at the fuzzification level. Hybrid learning algorithm that combines least square method with gradient descent method is used to adjust the parameter of membership function.

3 Simulation and Results

Figure 4 and 5 shows the two degree of freedom (DOF) and three DOF planar manipulator arm which is simulated in this work.

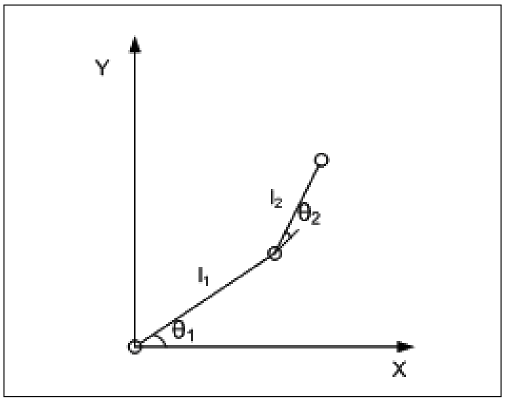

Figure 4: Two DOF manipulator

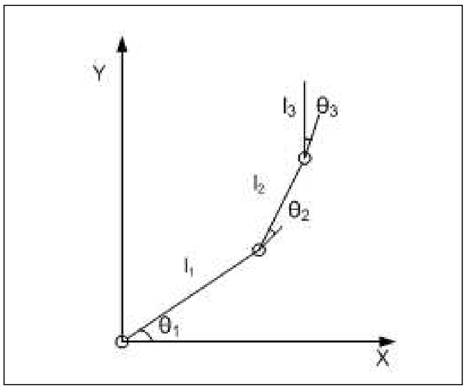

Figure 5: Three DOF manipulator

3.1 Two Degree of Freedom planar manipulator

For a 2 DOF planar manipulator having l_1 and l_2 as their link lengths and θ_1,θ_2 as joint angles with x, y as task coordinates the forward kinematic equations are,

$$x = l_1 cos(\theta_1) + l_2 cos(\theta_1 + \theta_2) \tag{8}$$

$$y = l_1 sin(\theta_1) + l_2 sin(\theta_1 + \theta_2) \tag{9}$$

and the inverse kinematics equations are,

$$\theta_1 = atan2(y,x) - atan2(k_2,k_1) \tag{10}$$

$$\theta_2 = atan2(sin\theta_2, cos\theta_2) \tag{11}$$

where, $k_1 = l_1 + l_2 cos\theta_2$, $k_2 = l_2 sin\theta_2$, $cos\theta_2 = \frac{(x^2+y^2-l_1^2-l_2^2)}{2l_1l_2}$ and $sin\theta_2 = \sqrt{\pm(1-cos^2\theta_2)}$.

Considering length of first arm l_1 = 10 and length of second arm l_2 = 7 along with joint angle constraints $0 < \theta_1 < \frac{\pi}{2}, 0 < \theta_2 < \pi$, the x and y coordinates of the arm are calculated for two joints using forward kinematics. Figure 6 shows the workspace for two link planar arm. The codes are written in MATLAB 7 Release 14.

The coordinates and the angles are used as training data to train ANFIS network with Gaussian membership function with hybrid learning algorithm. Figure 7 and Figure 8 shows the training data of two ANFIS networks for two joint angles. Figure 9 shows the difference in theta deduced analytically and the data predicted with ANFIS.

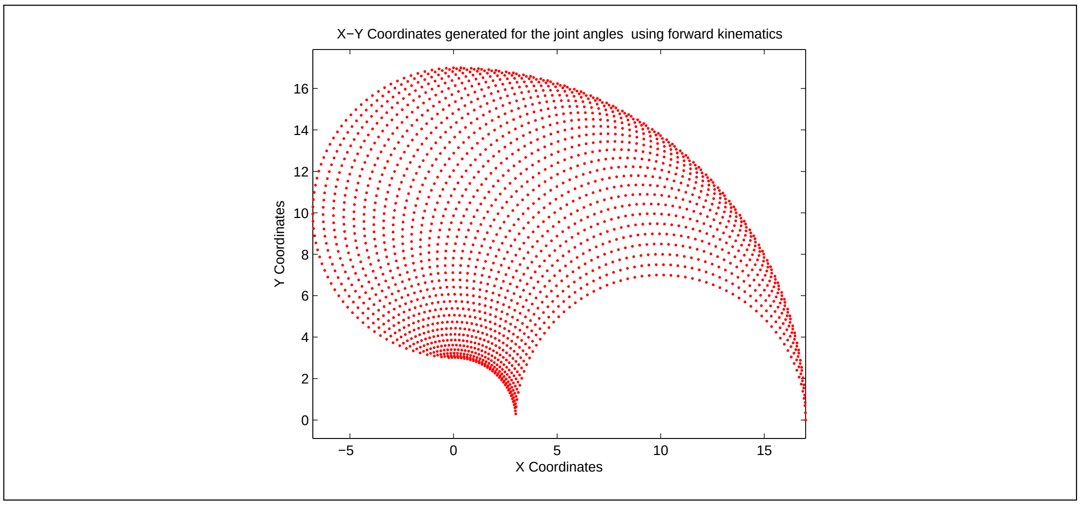

Figure 6: Workspace for two link planar arm

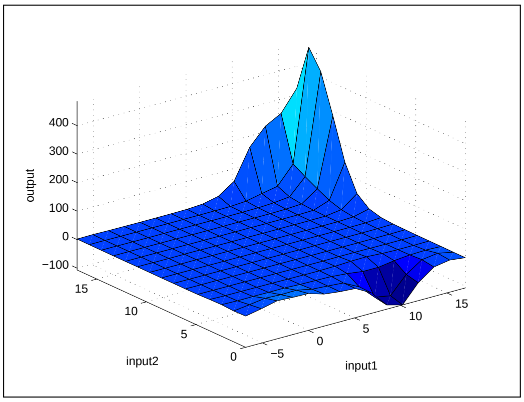

Figure 7: Training data of θ_1 for 2DOF manipulator

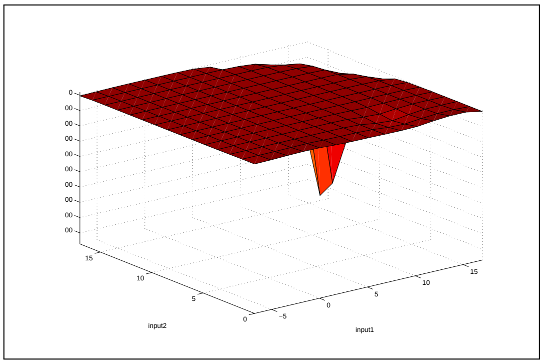

Figure 8: Training data of θ_2 for 2DOF manipulator

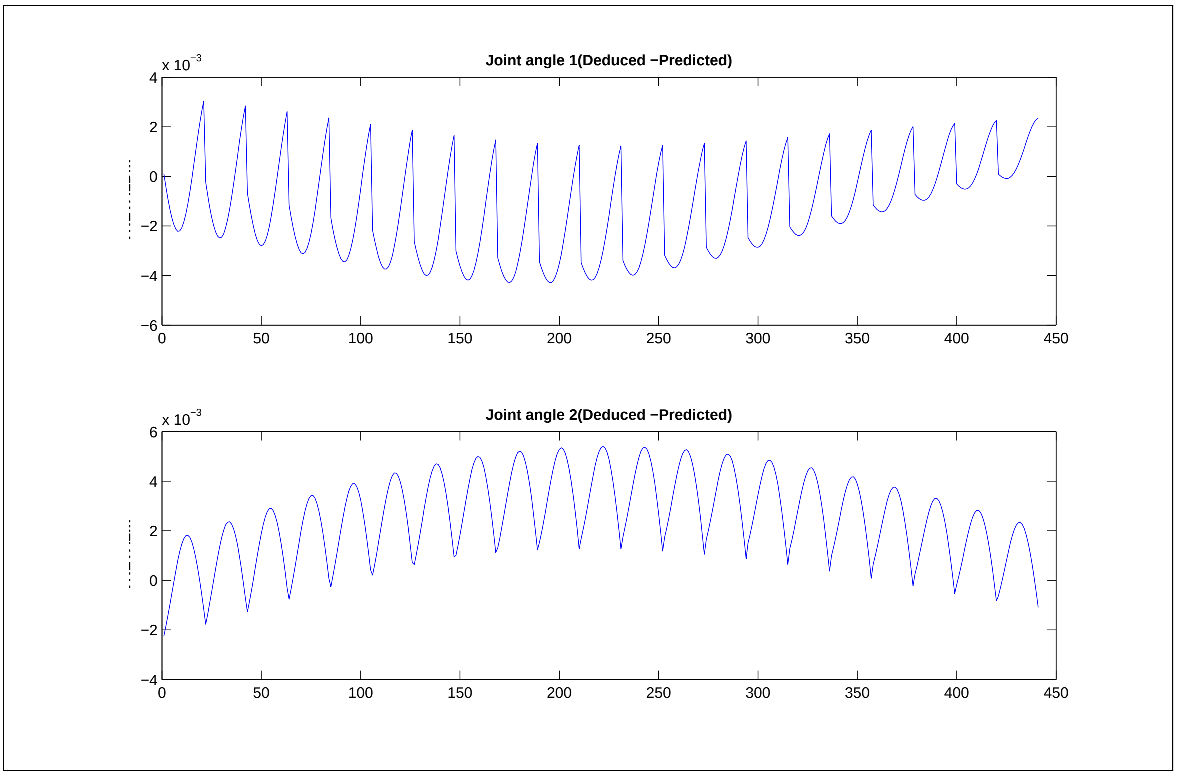

Figure 9: Difference in theta deduced and the data predicted with ANFIS trained for 2DOF manipulator

3.2 Three Degree of Freedom planar manipulator

For a 3 DOF planar redundant manipulator, the forward kinematic equations are,

$$x = l_1cos(\theta_1) + l_2cos(\theta_1 + \theta_2) + l_3cos(\theta_1 + \theta_2 + \theta 3) \tag{12}$$

$$y = l_1sin(\theta_1) + l_2sin(\theta_1 + \theta_2) + l_3sin(\theta_1 + \theta_2 + \theta 3) \tag{13}$$

$$\phi = \theta_1 + \theta_2 + \theta_3 \tag{14}$$

and the inverse kinematics equations are,

$$\theta_2 = atan2(sin\theta_2, cos\theta_2) \tag{15}$$

$$\theta_1 = atan2((k_1y_n - k_2x_n), (k_1x_n - k_2y_n) \tag{16}$$

$$\theta_3 = \phi - (\theta_1 + \theta_2) \tag{17}$$

where, $k_1 = l_1 + l_2cos\theta_2$, $k_2 = l_2sin\theta_2$, $cos\theta_2 = \frac{(x^2+y^2-l_1^2-l_2^2)}{2l_1l_2}$, $sin\theta_2 = \sqrt{\pm(1-cos^2\theta_2)}$, $x_n = x - l_3cos\phi$ and $y_n = y - l_3sin\phi$.

For simulation, the length for three links are l_1 = 10, l_2 = 7 and l_3 = 5 with joint angle constraints $0 < \theta_1 < \frac{\pi}{3}, 0 < \theta_2 < \frac{\pi}{2}, 0 < \theta_3 < \pi$ coordinates of the arm are calculated for two joints using forward kinematics. Figure 10 shows the workspace for three link planar arm. The coordinates and the angles are used as training data to train ANFIS network with Gaussian membership function with hybrid learning algorithm. Figure 11, Figure 12 and Figure 13 shows the training data of three ANFIS networks for three joint angles. Figure 14 shows the difference in theta deduced analytically and the data predicted with ANFIS.

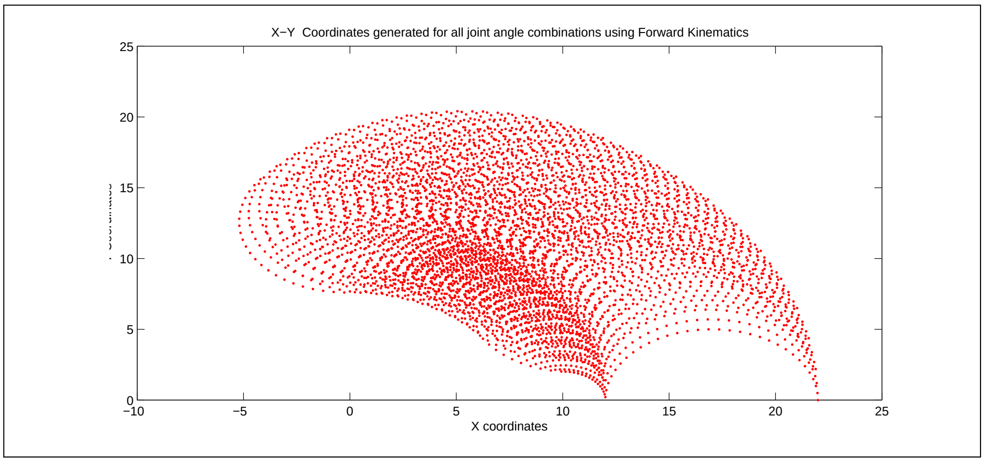

Figure 10: Workspace for three link planar arm

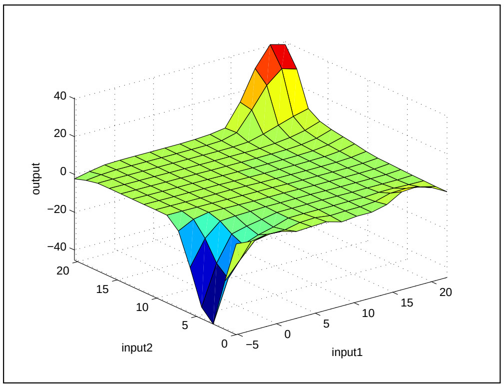

Figure 11: Training data of θ_1 for 3DOF manipulator

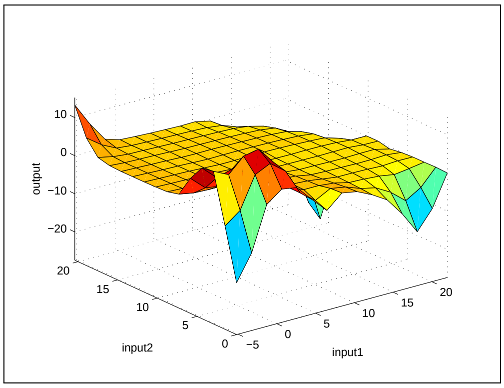

Figure 12: Training data of θ_2 for 3DOF manipulator

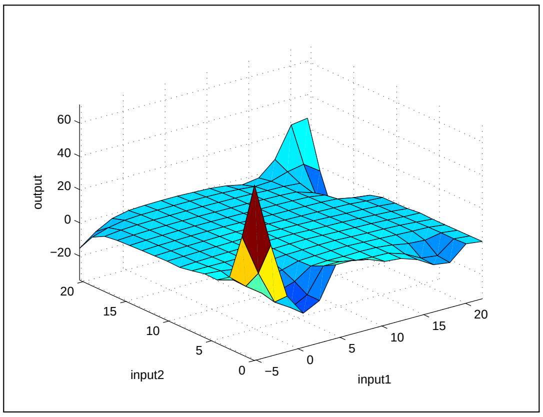

Figure 13: Training data of θ_3 for 3DOF manipulator

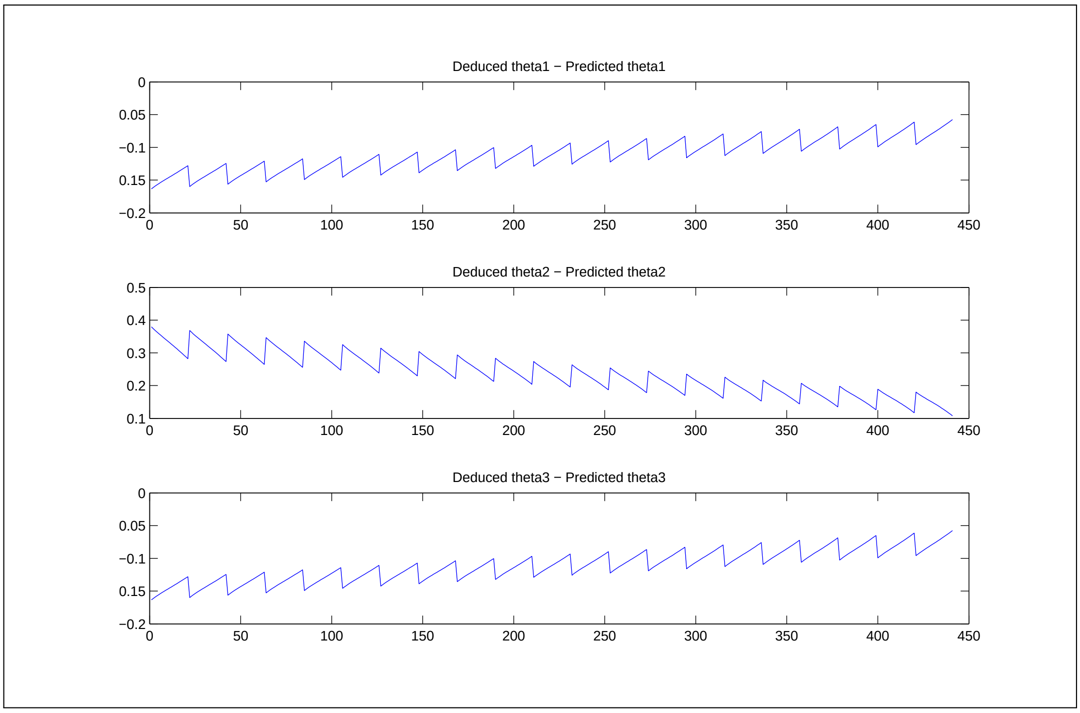

Figure 14: Difference in theta deduced and the data predicted with ANFIS trained for 3 DOF manipulator

4 Summary and Conclusions

The difference in theta deduced and the data predicted with ANFIS trained for two and three degree of freedom planar manipulator clearly depicts that the proposed method results in an acceptable error. Also the ANFIS converges with a smaller number of iteration steps with the hybrid learning algorithm. Hence trained ANFIS can be utilized to provide fast and acceptable solutions of the inverse kinematics thereby making ANFIS as an alternate approach to map the inverse kinematic solutions. Other techniques like input selection, tuning methods and alternate ways to model the problem may be explored for reducing the error further.

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Procedure for Cascade Control Systems Design: Choice of Suitable PID Tunings

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Abstract: This paper provides an approach for the application of PID controllers within a cascade control system configuration. Based on considerations about the expected operating modes of both controllers, the tuning of both inner and outer loop controllers are selected accordingly. This fact motivates the use of a tuning that, for the secondary controller, provides a balanced set-point / load-disturbance performance. A new approach is also provided for the assimilation of the inner closed-loop transfer function to a suitable form for tuning of the outer controller. Due to the fact that this inevitably introduces unmodelled dynamics into the design of the primary controller, a robust tuning is needed.

Keywords: PID Control, Cascade control systems, Performance Degradation

1 Introduction

Cascade control is one of the most popular *complex* control structures that can be found in the process industries, implemented in order to improve the disturbance rejection properties of the controlled system [1] [2]. The introduction and use of an additional sensor that allows for a separation of the fast and slow dynamics of the process results in a nested loop configuration as it is shown in figure (1). Each loop has associated its corresponding PID controller. The controller of the inner loop is called the secondary controller whereas the controller of the outer loop as the primary controller, being the output of the primary loop the variable of interest. The rationale behind this configuration is that the fast dynamics of the inner loop will provide faster disturbance attenuation and minimize the possible effect disturbance before they affect the primary output.

This set up involves two controllers. It is therefore needed to tune both PIDs. The usual approach involves the tuning of the secondary controller while setting the primary controller in manual mode. On a second step, the primary controller is tuned by considering the secondary controller acting on the inner loop. It is therefore a more complicated design procedure than that of a standard single-loop based PID control system.

Some existing studies provide approaches that help in the design of a cascade control system. In [3] a relay-feedback based autotuning method has been used. The procedure still needs of a sequential application of the usual relay based autotuning approach consuming. Other results provide tuning rules for the primary and secondary controller [4] [5] or suggest alternative control structures based on a modification of the conventional cascade configuration [6]. However there are no clear guidelines on how to automate the process and what should be the rationale behind both tunings.

In this paper a design issue that has not been addressed is considered: the *tradeoff* between the performance for set-point and load-disturbance response. When a load -disturbance occurs at the primary loop, the global load-disturbance depends on the set-point tracking performance of the secondary loop. In addition, good load-disturbance performance is expected for the secondary controller in order to attenuate disturbances that enter directly at the secondary loop. Also, it is well known that when the controller is optimally tuned for set-point response, the load-disturbance performance can be very poor [7]. Based on this observation this paper proposes the use of a balanced performance tuning [8] for the secondary loop. Furthermore, an approximation procedure is provided in order to assimilate the dynamics seen by the primary controller to a First-Order-Plus-Time-Delay model such that usual tuning rules for PID control can be applied. However here a robust tuning is suggested, because, the primary controller will need to face with unmodelled dynamics coming from the model approximation used for the secondary loop. Note that this kind of approximation is always needed if simple-model based tuning rules are to be applied. The present paper constitutes an extended version of [15]

The rest of the paper is organized as follows. Next section presents the cascade series control system configuration and control setup to be used. Section 3 provides a performance degradation analysis and how to find an intermediate tuning in terms of a *tradeoff* between both, servo and operation modes. Then, section 4 gives a procedure for cascade series control as the design approach involving tuning of the controllers and the models for those tunings. At section 5, it is addressed an approximation method to get the equivalent system for the inner loop. Section 6 presents an application example whereas section 7 ends with some conclusions and considerations.

2 Cascade Control

A typical configuration for cascade control is shown in figure (1), where an inner loop is originated from the introduction of an additional sensor in order to separate, as much as possible, the process fast and slow dynamics. As a result the control system configuration has an inner controller $C_2(s)$ with inner loop process $G_2(s)$ and outer loop controller $C_1(s)$ with outer loop process $G_1(s)$. Disturbance can enter at two possible distinct points: d_1 and d_2.

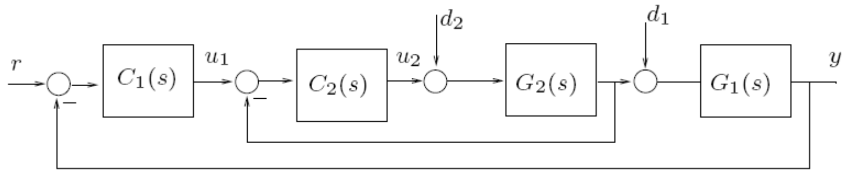

Figure 1: Cascade Control Configuration

The rationale behind this configuration is to be able to compensate for the best, possible disturbance d_2, before it is reflected to the outer loop output. In order to accomplish that purpose it is essential that the inner loop exhibits a faster dynamics that allows for such early compensation.

This motivates the design of the inner loop controller to act as a regulator (in order to reject d_2) but with as fast as possible dynamics. However, tracking capabilities are also of interest for this inner loop. When a disturbance, d_1, appears at the slow part of the plant the outer loop controller will react to it. This will introduce a variable set-point to be followed by the inner controller. On the other hand, the outer loop will be needed to compensate for disturbances not seen by the inner controller as well as to accommodate possible changes in the set-point input. It is therefore clear that in both cases (and specially for the inner loop) servo as well as regulatory performance is desired.

According to this, the overall process $G(s) = G_1(s)G_2(s)$ is split into the two parts $G_1(s)$ and $G_2(s)$ and associated controllers. The two controllers are standard feedback controllers that are assumed to take the usual ISA-PID form as:

$$C_1(s) = K_{p1}\left(1+\frac{1}{T_{i1}s}+\frac{T_{d1}s}{1+(T_{d1}/N_1)s}\right) \tag{1}$$

$$C_2(s) = K_{p2}\left(1+\frac{1}{T_{i2}s}+\frac{T_{d2}s}{1+(T_{d2}/N_2)s}\right) \tag{2}$$

where K_{p1} and K_{p2} are the proportional gains, T_{i1} and T_{i2} are the integral times, T_{d1} and T_{d2} are the derivative times and finally N_1 and N_2 are the derivative filter constants.

3 γ-tuning for balanced Servo/Regulation

This γ-tuning is based on the definition of a performance degradation index that takes into account how the response degrades with respect to the optimal one. As a controller will be optimal just for one of the situations (set-point or load-disturbance) the search for the suboptimal controller is performed on the basis of getting a *tradeoff* among the corresponding degradations with respect to both optimal controllers. See [7] and [8].

A general formulation of a quadratic performance, including a time weighting factor reads as:

$$J^n = \int_0^\infty (t^n e(t))^2 dt \tag{3}$$

However, in order to include operating mode issues it is rewritten as:

$$J_x^n(z) = \int_0^\infty (t^n e(t,x,z))^2 dt \tag{4}$$

where x denotes the *operating mode* of the control system and z the selected operating mode for tuning. Therefore the *tuning mode*. Will have $x \in [sp, ld]$ and $z \in [sp, ld]$. Obviously, for one specific process it has to be verified that:

$$\begin{aligned} J_{sp}^n(sp) &\leq J_{sp}^n(ld) \\ J_{ld}^n(ld) &\leq J_{ld}^n(sp) \end{aligned} \tag{5}$$

Performance Degradation, $PD_{om}(tm)$, will be associated to the *tuning mode* - tm - and tested on the, opposite, operating mode - om -. According to this, the performance degradation of the load-disturbance tuning, $PD_{sp}(ld)$, will be defined as:

$$PD_{sp}(ld) = \left|\frac{J_{sp}^n(ld) - J_{sp}^n(sp)}{J_{sp}^n(sp)}\right| \tag{6}$$

conversely, the performance degradation associated to the set-point tuning, $PD_{ld}(sp)$, will be:

$$PD_{ld}(sp) = \left|\frac{J_{ld}^n(sp) - J_{ld}^n(ld)}{J_{ld}^n(ld)}\right| \tag{7}$$

What is defined in [7] is the search for an intermediate controller that will be suboptimal with respect to both operating modes but will exhibit a balanced performance when both situations are likely to occur. On this basis we define a controller settings family parameterized in terms of a single parameter $\gamma \in [0,1]$. The set-point tuning will correspond to a contour constraint for $\gamma = 0$, whereas the load-disturbance tuning for $\gamma = 1$. Figure (2) graphically shows the procedure and the application for the three parameters of

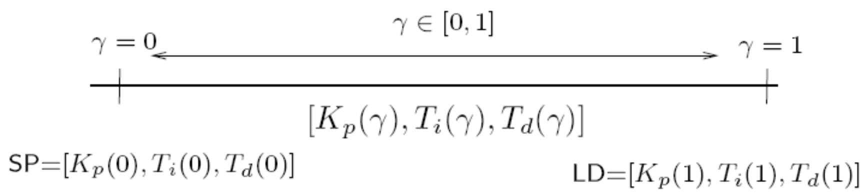

Figure 2: γ-tuning procedure for the search of the intermediate controller

the PID controller.

The controller settings family $[K_p(\gamma), T_i(\gamma), T_d(\gamma)]$ will be generated by a linear evolution for the parameters from the set-point tuning to the load-disturbance one and the other way around. Therefore:

$$\begin{aligned} K_p(\gamma) &= \gamma K_p^{ld} + (1-\gamma)K_p^{sp} \\ T_i(\gamma) &= \gamma T_i^{ld} + (1-\gamma)T_i^{sp} \\ T_d(\gamma) &= \gamma T_d^{ld} + (1-\gamma)T_d^{sp} \end{aligned} \tag{8}$$

with $\gamma \in [0,1]$ and $[K_p^{ld}, T_i^{ld}, T_d^{ld}]$ and $[K_p^{sp}, T_i^{sp}, T_d^{sp}]$ stand for the load-disturbance and set-point settings for $[K_p, T_i, T_d]$ respectively.

Now, in order to define a global performance degradation index, the previously defined terms as (6) and (7) need to be extended. Note the performance degradation was associated to the *tuned mode*. Therefore tested against the opposite operating mode. Now for every value of γ the performance degradation will need to be measured with respect to both operating modes (as the corresponding γ-tuning does not need to correspond to an operating mode).

- $PD_{sp}(\gamma)$ will represent the performance degradation of the γ-tuning on servo operating mode.

$$PD_{sp}(\gamma) = \left| \frac{J_{sp}^n(\gamma) - J_{sp}^n(sp)}{J_{sp}^n(sp)} \right| \tag{9}$$

- $PD_{ld}(\gamma)$ will represent the performance degradation of the γ-tuning on regulation operating mode.

$$PD_{ld}(\gamma) = \left| \frac{J_{ld}^n(\gamma) - J_{ld}^n(ld)}{J_{ld}^n(ld)} \right| \tag{10}$$

From these side performance degradation definitions, the overall performance degradation is introduced and interpreted as a function of γ: $PD(\gamma)$. There may be different ways of defining the $PD(\gamma)$ functional depending on the importance associated to every operating mode. However, every definition must satisfy the following contour constraints:

$$PD(0) = PD_{ld}(sp) \qquad PD(1) = PD_{sp}(ld) \tag{11}$$

The most simple definition would be to give:

$$PD(\gamma) = PD_{ld}(\gamma) + PD_{sp}(\gamma) \tag{12}$$

that can be extended by introducing weighting factors associated to each operating mode as:

$$PD(\gamma) = W_{ld}PD_{ld}(\gamma) + W_{sp}PD_{sp}(\gamma) \tag{13}$$

Those expressions represent a compromise, or a balance, between both losses of performance.

The intermediate tuning will be determined by proper selection of γ. This choice will correspond to the solution of the following optimization problem:

$$\gamma_{op} = arg\left[\min_{\gamma} PD(\gamma)\right] \tag{14}$$

The optimal value (γ_{op}) jointly with equations (8), give a tuning that provides a smaller performance than the optimal ones operating in the same way but, also a less degradation in the performance when the operation is different to the tuning mode.

The generation of the controller parameters family from the combined Servo/Regulation tuning, is a point that deserves more attention and a more deep analysis has to be done, specially regarding the stability of the resulting closed loop when γ varies from 0 to 1. An initial analysis can be found in [9]. Note however, that an unstable closed-loop would generate infinite Performance Degradation.

4 Approach for Cascade Control Design

The proposed approach for cascade control design is presented according to the different design stages needed in order to completely determine all the control system components.

4.1 Inner loop and outer loop process models

A description of the inner process is assumed to be available as a First-Order-Plus-Time-Delay (FOPTD) model. Well known procedures [10] can be applied in order to provide such approximation. Therefore $G_2(s)$ is assumed to obey to:

$$G_2(s) = \frac{K_2}{1+T_2 s} e^{-L_2 s} \tag{15}$$

Along similar lines, considering the output of $G_2(s)$ as the input to $G_1(s)$ a model of the same characteristics can be obtained for the slow dynamics part of the system as:

$$G_1(s) = \frac{K_1}{1+T_1 s} e^{-L_1 s} \tag{16}$$

The FOPTD process model is widely used and constitutes the starting point for many of the existing PID tuning procedures. It is simple and describes the dynamics of many industrial processes approximately [11].

4.2 Inner loop controller tuning

According to the role of $C_2(s)$ within the control system configuration it is important to bear in mind that a good disturbance rejection is expected for the inner loop (in order to accommodate the possible disturbance entering at d_2) as well as good set-point tracking capabilities. Effectively, when a disturbance enters at d_1 or when a reference change occurs, the outer loop controller $C_1(s)$ will generate the corresponding reference change for the inner loop controller $C_2(s)$. On the other side it is well known [7] that if we tune $C_2(s)$ for good disturbance rejection (set-point response) the set-point (load-disturbance) response can degrade considerably. Therefore, a balanced tuning, as the exposed in section 3, is needed for the inner loop controller where a *tradeoff* for both operation modes is considered.

The tuning of the secondary controller has been performed by application of the optimal ISE tuning rules [12]. The optimal settings presented below correspond to plants with a normalized dead time τ in the range 0.1-2.0. Numerical optimization followed by a curve fitting procedure is done for both operating modes. As a result of the curve fitting the controller settings distinguish between $\tau \in [0.1, 1.0]$ and $\tau \in [1.1, 2.0]$.

Set-point tuning settings

When determining the settings for optimal set-point response the optimization results are adjusted according to a formulae of the form [12] [13]:

$$K_p = \frac{a_1}{K}(\tau)^{b_1} \qquad T_i = \frac{T}{a_2 + b_2\tau} \qquad T_d = a_3 T(\tau)^{b_3} \tag{17}$$

with the values of a_i and b_i given in table (1) for the ISE, ISTE and IST^{2}E criterion.

τ range	**0.1 - 1.0**			**1.1 - 2.0**		
Criterion	ISE	ISTE	IST^{2}E	ISE	ISTE	IST^{2}E
a_1	1.048	1.042	0.968	1.154	1.142	1.061
b_1	-0.897	-0.897	-0.904	-0.567	-0.579	-0.583
a_2	1.195	0.987	0.977	1.047	0.919	0.892
b_2	-0.368	-0.238	-0.253	-0.220	-0.172	-0.165
a_3	0.489	0.385	0.316	0.490	0.384	0.315
b_3	0.888	0.906	0.892	0.708	0.839	0.832

Table 1: Optimal PID settings for set-point response

Load-disturbance tuning settings

When determining the optimal operation in regulation mode, the optimization is performed in similar terms as the set-point case. In this case the adjusted formulae that provides the controller settings obey to the following form:

$$K_p = \frac{a_1}{K}(\tau)^{b_1} \qquad \frac{1}{T_i} = \frac{a_2}{T}(\tau)^{b_2} \qquad T_d = a_3 T(\tau)^{b_3} \tag{18}$$

and the corresponding values of a_i and b_i, given in table (2), for the ISE, ISTE and IST^{2}E criterion.

4.3 Model for Outer loop tuning

Once the tuning of the secondary loop has been completed, the effective system, $G_e(s)$, seen by the outer loop can be determined as,

$$G_e(s) = H_2(s)G_1(s) = \frac{C_2(s)G_2(s)}{1 + C_2(s)G_2(s)}G_1(s) \tag{19}$$

τ **range**	**0.1 - 1.0**			**1.1 - 2.0**		
Criterion	ISE	ISTE	IST^{2}E	ISE	ISTE	IST^{2}E
a_1	1.473	1.468	1.531	1.524	1.515	1.592
b_1	-0.970	-0.970	-0.960	-0.735	-0.730	-0.705
a_2	1.115	0.942	0.971	1.130	0.957	0.957
b_2	-0.753	-0.725	-0.746	-0.641	-0.598	-0.597
a_3	0.550	0.443	0.413	0.552	0.444	0.414
b_3	0.948	0.939	0.933	0.851	0.847	0.850

Table 2: Optimal PID settings for load-disturbance response

The purpose here is to have an approximation to $G_e(s)$ on the basis of a FOPTD model to based on the design of the outer loop controller.

$$\tilde{G}_e(s) = \frac{K_e e^{-L_e s}}{T_e s + 1} \approx G_e(s) \tag{20}$$

Several approaches can be used for this purpose. In this paper we will use the one that is presented with more detail in section 5.

4.4 Outer loop controller tuning

Once the model for the effective process (20) is available we can proceed with the tuning of the outer loop controller. As the inner loop will provide compensation for local disturbances, we can think of the outer loop controller to be tuned in order to accommodate good performance for the set-point response. Bearing in mind that the process model used for design comes from an approximation of an higher order dynamics, aggressive tunings should be avoided. A very simple and FOPTD model based tuning rule that guarantees some degree of robustness is provided in [14]. On the basis of the effective model approximation, this tuning rule reads:

$$\begin{aligned} K_{p1} &= \frac{T_{i1}}{2.65 K_e L_e} \\ T_{i1} &= T_e + 0.03 L_e \\ \frac{T_{d1}}{N_1} &= 1.72 L_e \\ N_1 + 1 &= \frac{T_e}{T_{i1}} \end{aligned} \tag{21}$$

5 Equivalent model approximation

As we said before, once the tuning of the inner loop is ready, the outer controller sees an equivalent system as showed in equation (19).

The complete expression for $H_2(s)$ takes a general form like:

$$H_2(s) = \frac{p_2(s) e^{-L_2 s}}{p_1(s) + p_2(s) e^{-L_2 s}} \tag{22}$$

where, replacing the expressions for controller and model, we have that,

$$p_1(s) = (T_2 s + 1) T_{i2} s (\frac{T_{d2}}{N_2} s + 1) \tag{23}$$

$$p_2(s) = K_2 K_{p2} \left(1 + (T_{i2} + \frac{T_{d2}}{N_2}) s + \frac{T_{i2} T_{d2}}{N_2} (N_2 + 1) s^2 \right) \tag{24}$$

The presence in the denominator of the irrational term $e^{-L_2 s}$ difficultly the obtention of the effective process model $G_e(s)$ (and consequently $\tilde{G}_e(s)$) and posterior outer loop controller design.

In this communication, it is proposes to perform an approximation of the denominator of $H_2(s)$ (in a similar way to [16]) on the basis of a new polynomial $p(s)$ and delay term $e^{-\theta s}$ such that:

$$p_1(s) + p_2(s) e^{-L_2 s} \approx d(s) = p(s) e^{-\theta s} \tag{25}$$

First of all, the required order of $p(s)$ is determined. Note the effective transfer function $G_e(s)$ can be rewritten, assuming (25), as:

$$\begin{aligned} \widehat{G_e}(s) &= \frac{p_2(s) e^{-L_2 s}}{p(s) e^{-\theta s}} \frac{K_1 e^{-L_1 s}}{1 + T_1 s} \\ &= \frac{p_2(s)}{p(s)} \frac{K_1 e^{(-L_1 - L_2 + \theta) s}}{1 + T_1 s} \end{aligned} \tag{26}$$

The purpose here is to have an approximation, $\widehat{G_e}(s)$, to $G_e(s)$, that allows then to obtain a FOPTD model to facilitate the design of the primary loop controller.

Therefore, a second order polynomial $p(s)$ is needed. Note this way $G_e(s)$ will behave with a -20dB roll-off as a first order system. On the other hand the approximation with a first order system will make no sense. On this basis, the first step is to determine the coefficients of $p(s) = p_o + p_1 s + p_2 s^2$ and the value of θ. Note that $L_e = L_1 + L_2 - \theta$ and $K_e = K_1$ (integral action in the inner loop will assure $H_2(0) = 1$). Therefore it only rest to determine the vale of T_e.

The approximation (25) is performed according to the following procedure. First of all, the first three terms of the McLaurin expansions of both $p(s) e^{-\theta s}$ and $p_1(s) + p_2(s) e^{-L_2 s}$ are performed. Equating corresponding terms provide the following set of equations:

$$\underbrace{\begin{pmatrix} 1 & 0 & 0 \\ -\theta & 1 & 0 \\ \theta^2 & -2\theta & 2 \end{pmatrix}}_{A_\theta} \underbrace{\begin{pmatrix} p_0 \\ p_1 \\ p_2 \end{pmatrix}}_{\overrightarrow{p}} = \underbrace{\begin{pmatrix} b_0 \\ b_1 \\ b_2 \end{pmatrix}}_{\overrightarrow{b}} \tag{27}$$

with,

$$\begin{pmatrix} b_0 \\ b_1 \\ \\ b_2 \\ \\ \end{pmatrix} = \begin{pmatrix} K_2 K_{p2} \\ T_{i2} + K_2 K_{p2} (T_{i2} + T_{d2}/N_2 - L_2) \\ 2 T_{i2} T_{d2}/N_2 + 2 T_{i2} T_2 + \\ K_2 K_{p2} (L_2^2 - 2 L_2 (T_{i2} + T_{d2}/N_2) + \\ 2 T_{i2} T_{d2} (N_2 + 1)/N_2) \end{pmatrix} \tag{28}$$

Once a value for θ is provided, $\overrightarrow{p}$ can be determined by:

$$\overrightarrow{p} = A_\theta^{-1} \overrightarrow{b} \tag{29}$$

On the other hand, the value of θ will be determined in such a way that provides the better approximation (25) in the following sense:

$$\min_{\theta, \overrightarrow{p}=A_{\theta}^{-1}\overrightarrow{b}} \left\| p_1(s) + p_2(s)e^{-L_2 s} - p(s)e^{-\theta s} \right\|_{\infty} \tag{30}$$

When the values for θ and $\overrightarrow{p}$ are got, the determination of T_e in (20) is right straightforward.

6 Example

The presented approach is now exemplified by means of a simulation example. Consider the following definitions for the process models:

$$G_1(s) = \frac{1}{100s+1}e^{-40s} \qquad G_2(s) = \frac{5}{20s+1}e^{-4s} \tag{31}$$

The tuning of the secondary controller has been performed by application of the optimal ISE tuning rules [12] for set-point tracking and load-disturbance operation. Then, application of the *tradeoff* γ-tuning [7] with a weighting factor that gives a 25% extra weight to the load-disturbance performance degradation with respect to the set-point performance degradation ($W_{ld} = 1.25$ and $W_{sp} = 1$) provides a set of PID parameters. All these tunings are showed in table 3 and the value of the derivative filter constant is taken as $N_2 = 10$.

tuning	K_{p2}	T_{i2}	T_{d2}
set-point	0.89	17.83	2.34
load-disturbance	1.40	5.34	2.39
γ-tuning	1.15	11.59	2.37

Table 3: PID parameters for the inner loop

Consequently, for each one of the three secondary loops, an effective model approximation $\widehat{G}_e(s)$ and its respective model $\tilde{G}_e(s)$ can be obtained using the procedure exposed in section 5. As an example, figure 3 shows the outputs for the γ-tuning case where it can be seen that the approximation is very accurate. In table 4 are the FOPTD model parameters for the rest of tunings.

tuning	K_e	T_e	L_e
set-point	1.00	99.78	44.00
load-disturbance	1.00	96.58	44.00
γ-tuning	1.00	97.73	44.00

Table 4: FOPTD model approximation $\tilde{G}_e(s)$

Once again, for each of these model approximation, we can calculate the tuning for the outer loop controller using formulae given by [14]. Primary controller tuning parameters are in table 5.

Figure (1) shows the performance with respect to a step reference change is almost identical for the three scenarios. However, the disturbance attenuation to a load-disturbance entering at d_2 is clearly superior for the load disturbance optimally tuned secondary controller. Note for the γ-tuning the load-disturbance is also clearly better than that of the set-point tuning (without loosing performance with

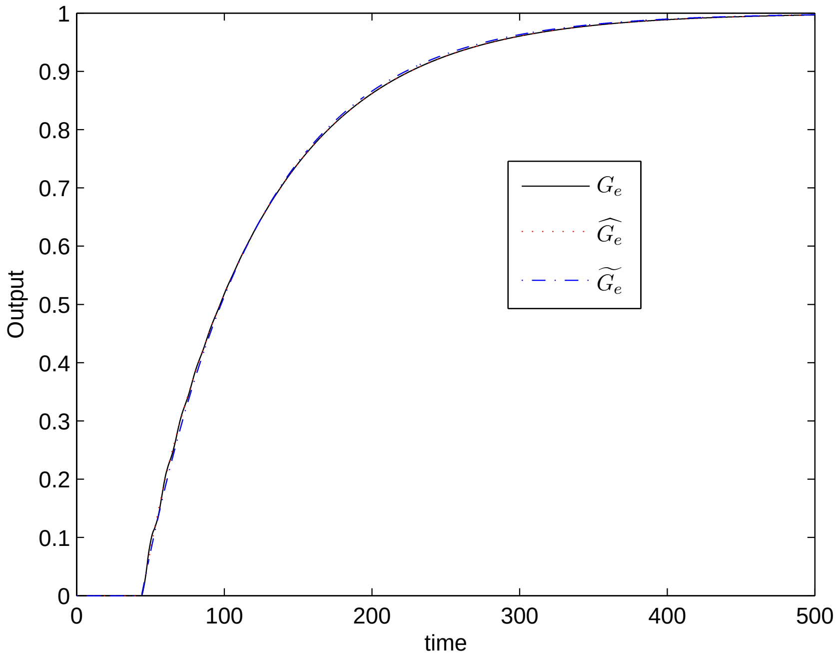

Figure 3: Model approximation validation for γ-tuning case

tuning	K_{p1}	T_{i1}	T_{d1}/N_1	N_1+1
set-point	0.87	101.10	99.00	0.99
load-disturbance	0.84	97.90	102.00	0.99
γ-tuning	0.85	99.05	101.00	0.99

Table 5: PID parameters for the outer loop

respect to a step change).

However, the noted lower robustness margins of the load-disturbance tuning generate a system that may be very sensitive to model errors [8] [9]. This can be noted if we take a look at the generated control signal u_2, shown in figure 2.

If we assume, for example, a 5% uncertainty in the secondary process time-constant the performance for the set-point and γ-tuning is maintained whereas for the load-disturbance the system is critically unstable as it is shown in figure (3).

7 Conclusions

This paper has addressed the problem of PID controller tuning choice within a cascade control system configuration. A procedure has been outlined that considers a balanced operation (set-point and load-disturbance) for the secondary controller and a robust tuning for the primary controller. In order to facilitate the design of the primary controller an approximation method has been provided that generates a FOPTD approximation suitable for PID tuning. The success of the approximation has been shown

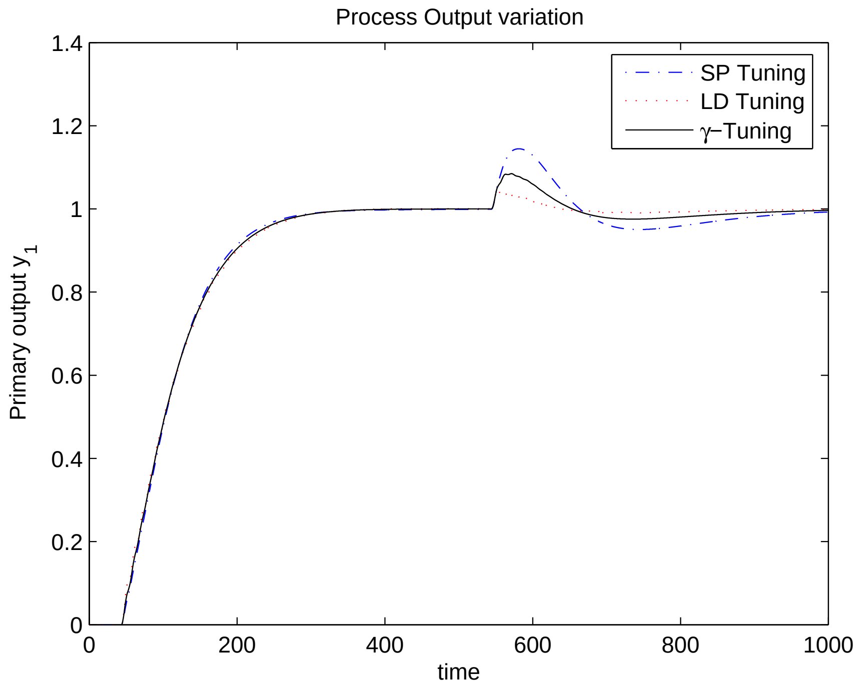

Figure 4: Primary output for a step in r and d_2

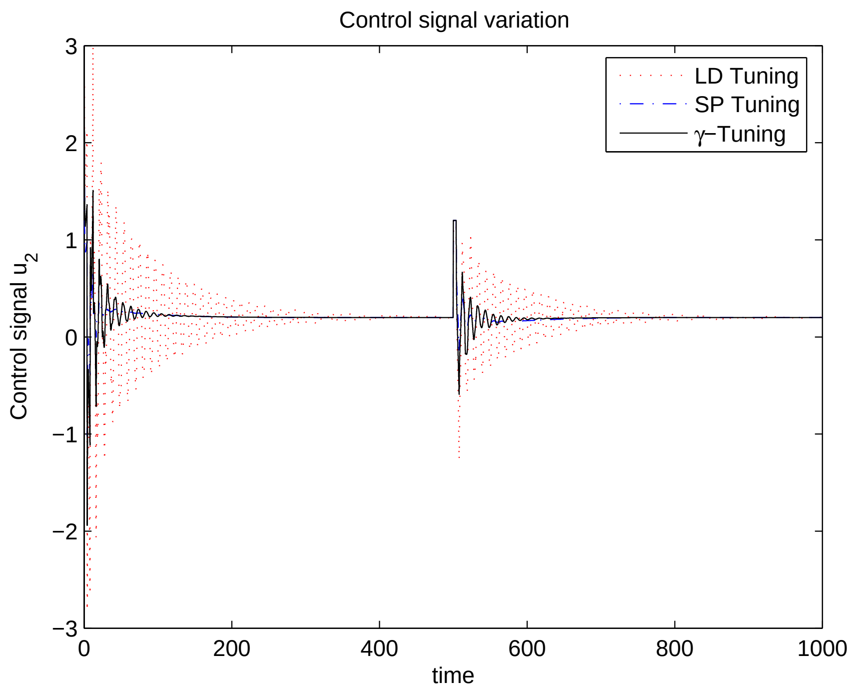

Figure 5: Control signal generated at u_2 for a step and load disturbance d_2

by means of an example. However a more deep analysis has to be done, specially with respect to the

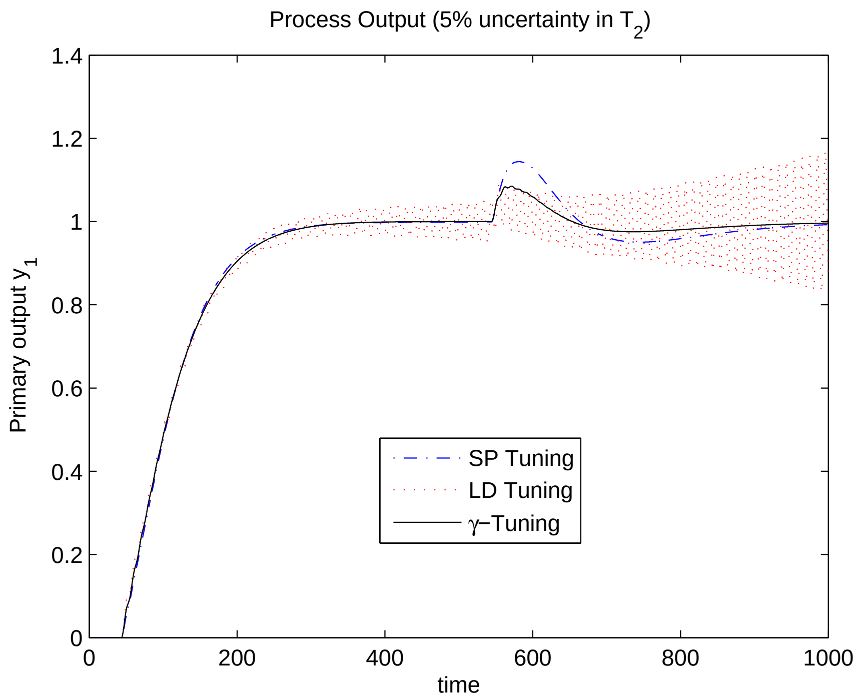

Figure 6: Primary output assuming a 5% uncertainty in T_2

obtention of concrete uncertainty bounds for the secondary loop modelling.

8 Acknowledgments

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A Hyper-Heuristic Approach for Efficient Resource Scheduling in Grid

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Abstract: Efficient execution of computations in grid can require mapping of tasks to processors whose performance is both irregular and time varying because of dynamic nature. The task of mapping jobs to the available computing nodes or scheduling of the jobs on the grid is a NP complete problem. The NP-hard problem is often solved using heuristics techniques. Heuristic and metaheuristic approaches tend to be knowledge rich, requiring substantial expertise in both the problem domain and appropriate heuristics techniques. To alleviate this problem the concept of Hyper-heuristic was introduced. They operate on the search space of heuristics instead of candidate solutions and can be applied to any optimization problem. This paper emphasizes the use of Hyper-heuristics built on top of hybridized Metaheuristics to efficiently and effectively schedule jobs onto available resources in a grid environment thus resulting in an optimal schedule with minimum makespan.
Keywords: grid, hyper-heuristics, scheduling

1 Introduction

As the number of networked computers worldwide increases complex computations are distributed over multiple computer to improve the utilization of the computers and to meet the increasing computational requirements of scientific research. Grid computing which is an extension of distributed computing is a highly dynamic one, in which the resources join and leave the grid in an unpredictable fashion. The grid operates in a peer-to-peer fashion where resources join or leave without any pre-arranged schedule. The true computational capability is also hard to obtain at any instance of time as these computational resources can go offline regardless of the job state allocated.

The Resource management system (RMS)[6] of the grid has to select the appropriate resource and to provide best QOS. Foster [8] defines the responsibilities of the RMS on the grid as the discovery of available resources to the application, mapping the resources to the application subject to some performance goals and scheduling policies and loading the application to the resource in accordance with the best available schedule. The task of mapping jobs to the available computing nodes or scheduling of the jobs on the grid is a NP complete problem. The schedule strategies can have a significant impact on the performance characteristics. The NP-hard problem is often solved using heuristics techniques. Heuristics are intended to gain computational performance or conceptual simplicity, potentially at the cost of accuracy or precision. Simple heuristics methods may not find an optimal solution, since they perform moves that lead to a final solution, which is a local optimum. To escape from the local optima traps, metaheuristic [2] is used. A metaheuristic is an iterative master process that guides and modifies the operations of subordinate heuristics in order to efficiently produce high quality solutions. Metaheuristics operate at a higher level, over heuristics, guiding them to an optimal solution. Common metaheuristics are local search, simulated annealing, ant colony optimization, tabu search, genetic algorithms, and swarm intelligence. Many variants and hybrids of these techniques exist and can be applied in various real world applications.

Heuristic and metaheuristic approaches tend to be knowledge rich, requiring substantial expertise in both the problem domain and appropriate heuristics techniques. To alleviate this problem the concept of Hyper-heuristic [7, 13] was introduced. It is a heuristic that operates at a higher level of abstraction than the current metaheuristics approaches.

Metaheuristics are problem-specific solution methods, which require knowledge and experience about the problem domain and properties and require fine-tuning of parameters. They provide state-of-the art solutions. Hyper-heuristics, on the other hand are developed to be general optimization methods, which can be applied to any optimization problem easily. They operate on the search space of heuristics instead of candidate solutions. Thus unlike metaheuristics, Hyper-heuristic methods deploy a set of simple heuristics and use only nonproblem-specific data, such as, fitness change or heuristic execution time. Hyper-heuristic approach is used to solve the various scheduling problems like Sales Summit problem, personnel scheduling, nurse rostering problem, course and timetabling problem. Hyper-heuristics algorithms are more adaptive to the Grid scenarios where both resources and applications are highly diverse and dynamic in nature. In this paper, we use the hyperheuristic approach to schedule the independent jobs in a grid environment.

2 Related Work

Tremendous amount of research has been going to devise efficient algorithms to schedule resources efficiently in dynamic work environments. Rafael A. Moreno [1] addresses the issues that the resource broker has to tackle like resource discovery and selection, job scheduling, job monitoring and migration etc. Lingyun Yang [14]proposed a conservative scheduling policy that uses information about expected future variance in resource capabilities to produce more efficient data mapping decisions. David Beasley,Marek Mika and Grzegorz Waligora[2] formulated the scheduling problem as a linear programming problem and proposed local search metaheuristic to schedule workflow jobs on a Grid. Tracy D. Braun[4] compares eleven static heuristics for mapping a class of independent tasks onto heterogeneous distributed computing systems. Ajith Abraham, Rajkumar Buyya[3]hybridized nature's heuristics namely GA, TS and SA and used the hybrid heuristics for job scheduling in a Grid.
Peter Kowling[7]applied hyper heuristics to a real world problem of Personnel Scheduling occurring at a UK academic institution. The hyper heuristics was found to produce results of much higher quality than those obtained by other naïve approaches. Edmund Burke and Yuri Bykov[13]proposed the use of hyper heuristic technique for course time tabling problems. Gonzalez[15]proposed a scheduling method which uses hyperheuristic to schedule independent jobs in computational grid. They considered two modes namely immediate mode and batch mode. The hyperheuristic uses a set of parameters for decision making like the Job heterogeneity, resource heterogeneity and the objective functions makespan, flow time and the resource utilization. Fidanova[16]compared the simulated annealing approach with the ant algorithm for scheduling jobs in Grid.

3 Grid Scheduling

The execution of a job in a dynamic environment like Grid often calls for efficient algorithms to schedule the resources required for successful execution of the jobs. These resources may themselves be dynamic and may enter or leave the system at any point of time or fail and can be idle. So a scheduling strategy is required to generate schedules, which seek to minimize the total execution time of jobs and also adapt to the heterogeneity and the dynamism of the environment. Allocation of a resource to a job, involves three basic steps.

1. Resource Discovery :

   Identifying the resources that are currently free (without being allocated to any job) in the system.

2. Resource Selection :

   Choosing one of the free resources based on some underlying algorithm to schedule it to a job on the ready queue.

3. Job Execution :

   Allocating the chosen resource to a job and executing the job.

The scheduling of Grid jobs can be done using no time characteristics where the resource broker have to make decision based on resource management policies or in the presence of time characteristics derived from the prediction mechanisms. In our work, we consider that the time characteristics are available. The resource providers provide offers based on their local policies and the grid resource broker is responsible for resource discovery, deciding allocation of a job to a particular resource, binding of user applications, initiate computations adapt to changes in grid resources and present the grid to the user as a single unified resource.

3.1 Metaheuristics scheduling

The Grid scheduling problem is a NP complete problem. Various metaheuristics methods are used to solve the scheduling in Grid.

Genetic Algorithm (GA)

GA is the most popular and successful among the metaheuristic that has been used with increasing frequency in the context of scheduling problems. GA is adaptive methods that can be used to solve optimization problems, based on the genetic process of biological organisms. By mimicking this process GA is able to evolve solutions to real world problems if they have been suitably encoded. Much work has been done on using GA for grid scheduling[9, 10, 11, 12] where schedules generated are near optimal. GA uses a direct analogy of natural behavior. They work with a population of individuals each representing a possible solution (partial solution) to a given problem. Each individual is assigned a fitness score according to how good a solution to a problem it is. The highly fit individuals are given opportunities to reproduce by cross-breeding with other individuals in the population. This process is known as mutation and cross-over in technical terms. This produces new individuals as offspring which shares some features of its parents. Thus, by favoring the mating of more fit individuals, the most promising areas of search space are explored. If GA is designed well, the population will converge to an optimal solution of the problem.
The performance of GA depends on the reproduction phase. Here, the chromosomes of the chosen parents are recombined using mechanisms of mutation and crossover. The crossover takes a pair of chromosomes and cuts it at a random position to form two head portions and two tail portions. The tail portions are then swapped to get a new chromosome. Thus the two offsprings get some genes from each of its parent. Mutation is nothing but altering each gene with a randomly chosen small probability value.

Local Search (LS)

LS algorithms use the notion of neighborhood. A neighborhood is a set of solutions possible to generate from the current solution according to a defined neighborhood generation mechanism. These algorithms start from a chosen initial solution and move from one solution to another solution by searching successive neighborhoods to get a solution as close to optimum as possible. The idea of LS (or neighborhood search) has been in existence for a long time and has been used for getting good solutions of the traveling salesman problem. The LS strategy is also used for finding solutions to hard combinatorial optimization problems. One disadvantage LS is that, there are chances of a LS algorithm getting stuck in a Local Maxima or Local Minima.

Simulated Annealing (SA)

SA is a well known metaheuristic that belongs to a class of threshold algorithms. SA exploits the analogy between the way in which a metal cools and freezes into a minimum energy crystalline structure (the annealing process) and the search for a minimum in a more general system. SA works by searching the set of all feasible solutions, and reducing the chance of getting stuck in a poor local optimum by allowing moves to inferior solutions under control of a randomized scheme. Specifically if a move from solution x to a neighboring inferior solution x' results in a change in objective function value by Δc then the move is still accepted if exp(-Δc/T_p)≥Random where T_p (Temperature) is a control parameter and Random ∈ [0:1] is a uniform random number. The value of T_p is initially high, allowing many inferior moves to be accepted but is gradually brought down to lower the acceptance of inferior moves. Determining the initial value of control parameter and the method of decreasing its value are important considerations in this scheme.

Tabu Search (TS)

TS is a metaheuristic strategy based on neighborhood search with overcoming local optimality. Unlike SA it works in a deterministic way trying to model human memory processes. Memory is implemented by the implicit recording of previously seen solutions, using simple but effective data structures. This approach focuses on the creation of a Tabu list of moves that have been performed recently and are forbidden to be performed for a certain number of iterations, thereby helping to avoid cycling and promoting search in a diversified space. At each iteration, TS moves to the best solution that is not forbidden and thus independent of local optima.

3.2 Hybrid Metaheuristics

To obtain better results, GA is hybridized with other metaheuristics. In our work, GA is hybridized with Local search, Simulated Annealing and Tabu search.

GA-LS

The GA-LS hybrid performs mutations on all the chromosomes, accepting mutated solutions only if they have a better fitness value than the current chromosome that was mutated. This process is repeated for a random number of times, or until a termination condition is met, creating a generation per execution of the process. The population in each generation is sorted according to fitness function and this generation is used as input for the next.

GA-SA

In GA-SA, for every mutation of a given chromosome in the population, a parameter 'temperature' is decreased by a random value. If the mutated solution is better than the current solution, then it is accepted with a probability 1. If the mutated solution is inferior to the current solution, it is accepted with a probability of $e^{-\Delta cost/temperature}$. When the temperature becomes 0(threshold), it is re-initialized to 1. The acceptance of solutions creates a new population. The population in each generation is sorted according to fitness function and this generation is used as input for the next.

GA-TS

GA-TS hybrid maintains a tabu list. Each time a new chromosome is generated by mutating a chromosome from the input population, it is checked to see whether it is present in the tabu list. If it is present, it is rejected, irrespective of its quality with respect to the current solution. If it is not present, the new solution is added to the tabu list and then checked for quality. If it is better than the current solution, it is accepted. This hybrid thus ensures that previously visited solutions are not visited, thus saving running time by avoiding solutions that are already 'seen'.

3.3 Hyper-Heuristics

Metaheuristics are problem-specific solution methods, which require knowledge and experience about the problem domain and properties and require fine-tuning of parameters. Since different metaheuristics have different strengths and weaknesses, it makes sense to see whether they can be combined in some way so that each makes up for the weaknesses of another. A simplistic way of doing this would be as shown below:

If (ProblemType(P) = P1) Apply (heuristic1, P)

Else if (ProblemType(P) = P2) Apply(heuristic2,P)

Else . . .

One logical extreme of the above approach would be an algorithm containing infinite switch statements enumerating all finite problems and applying the best-known heuristic for each which is certainly not a good approach. A better approach is to associate each heuristic under the problem condition under which each flourishes and hence apply different heuristics to different phases or parts of the solution process.
Hyper-heuristic describes a set of strategies that are used to choose a heuristic from a set of low level heuristics. It can be described as a supervisor, which controls the choice of which local search neighborhood to choose while constructing a solution/schedule. A local search neighbor, also known as a low-level heuristic, is a rule or a simple method that generally yields a small change in the schedule. The strategies used can be very simple or metaheuristics and the hyper-heuristic can also be a metaheuristics. Figure 1 represents the general framework for hyper-heuristic approach.

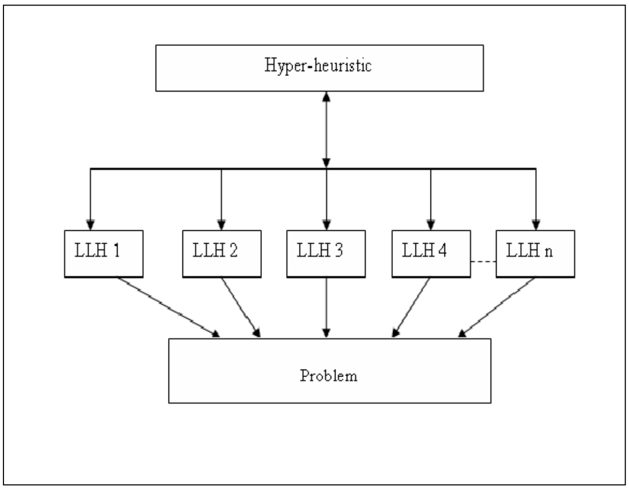

Figure 1: General Framework of Hyper-heuristic approach

A single iteration of a hyperheuristic method can be decomposed in two stages, heuristic selection and movement acceptance. The selection methods can be simple which randomly select the low level heuristics. Greedy hyperheuristics chooses the best performing heuristic at each iteration. Choice function keeps track of previous performance of each heuristic and makes a choice via a choice function. The movement acceptance can be deterministic or nondeterministic. One of the nondeterministic acceptance criteria is the great deluge algorithm. The Hyper-heuristic algorithm used is based on the extended Great

Deluge algorithm. It uses the Greedy selection heuristic to select the best heuristic. The basic concept of the Extended Great Deluge Hyper-heuristic Algorithm is as shown below.
Step 1: Initialization

1. Initialize population.
2. Set the total iterations N;
3. Evaluate fitness function f(s)
4. Initial level B_0 = f(s)
5. Specify input parameter B
6. Set i = 1;

Step 2: Process ith chromosome
While not stopping condition do

1. Select the candidate solution s^* by applying the selection heuristic
2. Evaluate fitness function for s^*
3. If f(s^*) $\leq$ B then accept s^*; f(s) = f(s^*);
4. B = B-Δ B;

During the initialization step, the fitness function f(s_o) is set level B. This is slowly reduced by ΔB at each iteration. The performance of the algorithm is dependent upon the choice of theΔB parameter and is dependent on the number of iterations and initial fitness function.

4 Scheduling Model

Each job to be scheduled for processing has a unique id and an associated processing resource requirement like the number of processing cycles required. The jobs are indivisible, independent of all other jobs. The arrivals of jobs are random and are placed in a queue of unscheduled jobs. Available processing resources vary over time, a exponential smoothing function, A (i) = (1-v) A (i-1) + v a (i-1) is used to smooth out the fluctuations where v is the control parameter chosen between 0 and 1 and the sequential arrival of the processes are given by a(i). The smoothing is done by allowing the recent values to exert more influence than the older values. Batches of jobs from the queue are scheduled on processors during each invocation of scheduler.
At any instant of time, when the number of jobs that have to be scheduled are greater than the number of resources available, then a suitable mapping of jobs to resources have to be found. We follow the following allocation mechanism, in such a case. If R resources and J jobs are available at a time instant(J>R), then a balanced randomized initial population is generated using the most - into - least (MIL) list scheduling heuristics which has been successfully used in GA schedulers. A random number of tasks are assigned to resources in a round robin fashion. The remaining tasks are then sorted and the job requiring the maximum number of cycles (Longest Job) to complete is chosen and is allocated to the resource with the greatest speed (Fastest Resource). The fastest resource is chosen from the list of resources that become available first. This scheduling policy is referred to as the Longest-Job-Fastest-Resource (LJFR) heuristic. Once a job is allocated by the LJFR heuristic, the next job is allocated on similar lines, but using the SJFR (Shortest-Job-Fastest-Resource) heuristic. Thus, the LJFR-SJFR heuristic is applied

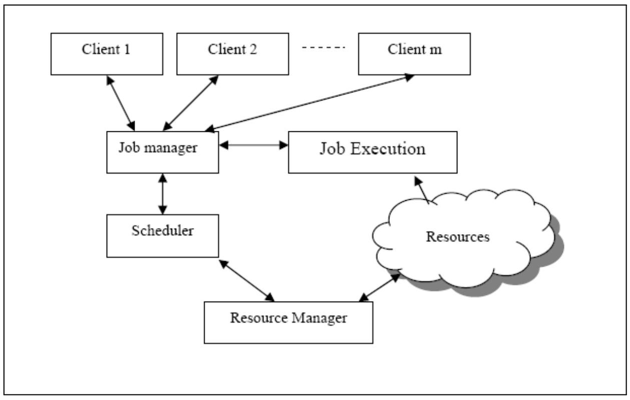

Figure 2: Representation of chromosome

alternatively to the sequence of jobs and resources. This method of allocation is represented by a 'chromosome' as shown in figure 2. Each 'sequence' represents a mini-allocation table, allocating R jobs to R resources. The Expected Time to Compute matrix [4] is formed from the time characteristics of the jobs and stored the ETC matrix of size J×R. The fitness function is based on the makespan of the schedule. It is calculated as min_s max $\{C_i$, i = 1,. . . J$\}$

where C_i is the finishing time of latest job and s is the schedule.

5 Experimental Results

The scheduling experiment was performed for several test cases and the results obtained are graphically represented. For each test case, the experiment was executed at an average of 50 times to measure the performance of the heuristics. The graph in figure 3, 4 and 5 show the comparison of GA-LS, GA-SA, GA-TS and Hyper-heuristic for 50 runs of the sample test cases.

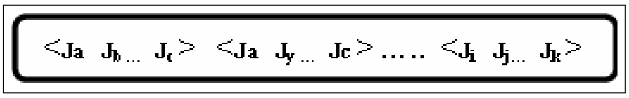

Figure 3: Makespan comparison for scheduling 200 jobs on 20 resources

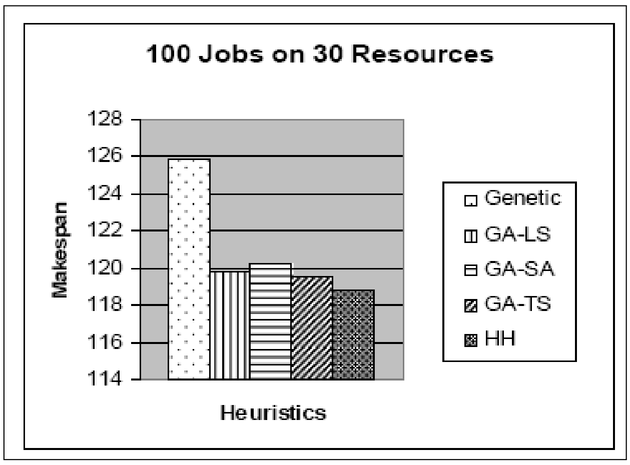

Figure 4: Makespan comparison for scheduling 100 jobs on 30 resources

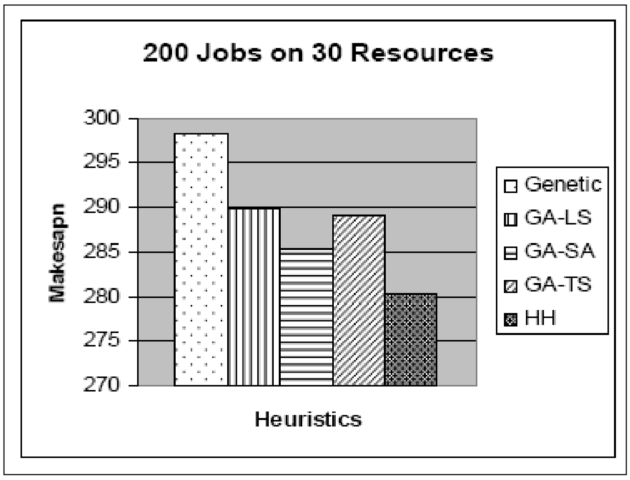

Figure 5: Makespan comparison for scheduling 400 jobs on 250 resources

6 Conclusion

In this paper, we attempted to use hyper heuristics on top of three hybrid Meta heuristics built using four known heuristics, namely GA, TS, SA and LS for scheduling jobs in a grid environment. The hyper heuristic built on top of the hybridized metaheuristics is experimentally shown to give better results than the individual hybrid heuristics in all the test cases.

Global optimization algorithms attract considerable computational effort. In a dynamic environment like Grid, the main emphasis would be to generate schedules in a minimum amount of time. The performance of the scheduler can be improved by using parallel GA. The scheduler in our work is designed for a single objective. Since the resource scheduling problem in grid is a multiobjective one, a Pareto based multiobjective genetic algorithm may be used to generate the schedule sequence.

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An Intelligent Supervising System for the Operation of an Underground Mine

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Abstract: This paper presents a conceptual model for an Intelligent System built to support the scheduling for an underground mine in order to supervise its operation. The system is composed by a Simulation Model linked to a Knowledge Based System designed by means of hierarchical, colored and temporal Petri Nets. Simulation Model allows simulating the operation of the production, reduction and transport levels in the mine. Knowledge Based System is activated by events produced in daily operations and yields the results of registered events and the actions taken to solve the problem, generating operation rules. The proposed model allows different types of mine operations and scenarios providing data for decision-making. The system helps to evaluate different policies for programming the activities in the mine thus seeking to enlarge the equipment productivity. The model also allows the feasibility assessment of the Daily Master Plan based on the input data of the simulation model.
Keywords: Intelligent System, Discrete Event System Modelling, Cognition and Control, Knowledge Based System, Petri Nets.

1 Introduction

The main operations of underground mining industry over the last decade of the twentieth century have been designed to automate the extractive processes withdrawing operators from contaminated and unsafe places inside the mine. In order to achieve this objectives tele-operation and robotisation of equipment were introduced in underground mine operations [1, 2]. The optimization of operation management has been obtained by moving from a push to a pull system approach or by using heuristics to produce an optimal schedule. In this way, pseudo intelligent simulation models can be used to generate policies to re-schedule the activities in real time [1, 11].

During daily operations of Codelco's underground mine Teniente 4 SUR (Chile) there are continuous events being generated which alter the normal work cycle of the mine, affecting its activities in their diverse levels or resources [1, 11]. Observation and analysis of their behaviour and the effects of these events thereafter in daily mine operations is of the most importance, as shown in other applications [6]. In this context, it is necessary to simulate the behaviour of the underground mine, whose continually functioning does not allow it to be available for its study, thus providing in this way new alternatives to improve its productivity, its efficiency and efficacy.

Nowadays, Petri Networks are an important alternative to model production systems, emulating parallel and concurrent systems, without the need of building a simulation model for each system. Petri Nets allow modelling the production process of the mine because it is possible to build various independant modules and then to produce a given configuration as a combination of those modules [3, 4, 7]. Petri Networks are being used for modeling dynamic operation of discrete systems in different domains [5], mainly in manufacture [4, 8, 9]. They are also utilized like a very useful tool for modelling, to analyze, to simulate and to control production systems [10, 12]. In this way, a number of basic networks representing different elements of the mine are built and then they are combined to represent the whole system. Hierarchical and temporal Petri Nets have allowed the construction of a simulation model with a knowledge based system built in, which is parametric, scalable and adaptable to various configurations of underground mines. In Petri Nets, each element represents a characteristic feature that is present in any system to be modeled and operations are based on three basic elements: places, transitions and tokens.

A Petri Net is defined by a 7-tupla (L, T, V, I, O, M, m_0), where:

$L : l_1, l_2, l_3, l_4, \ldots, l_n.$, finite set of places non-empty, $n >= 0$.

$T : t_1, t_2, t_3, t_4, \ldots_m$, finite set of transitions not empty, $m >= 0$; $V : Values\{0,1\}$

I: Binary function used to determine connections from places to transitions.

$So, I : L \times T \rightarrow V$, and if $I(l,t) = 1$,the place l is connected to transition t, otherwise there is no connection.

S: Binary function used to determine which transitions are connected to which places,

So, $S : T \times L \rightarrow V$and if it exists a connection from transition t to the place l if and only if $S(t,l) = 1$

M: Set of Tokens: $(0, 1, 2, 3, ...m\}$

m_0 : Initial token function, $m_o : L \rightarrow N$

$L \cap T = \varnothing; I, O : T \rightarrow L$

Places define different conditions about the state of resources and transitions define the events required to change the state of the resources.

2 Mine processing cycle and the Production System

In the "El Teniente" mine processing cycle, the rocks in higher levels are reduced in size. However, the transition from secondary rock to primary rock creates a problem of inefficiency causing a fall of productivity up to 10 %. This situation forced the company to use a mechanized method of exploitation called "Block Caving" which is shown in Figure 1 . The production system consists basically of three main levels:

Production level: in this level the chunks of material are taken 18 meters down the ground level until the collector shafts called ore-passes. Then, the material is loaded from ore-passes, transported and dumped into pits. This part is done by Load-Haul-Dump (LHD) vehicles.

Reduction level: this level is located 35 meters under the production level, where the mineral falls into the chopping/crushing chamber (rock breaker chambers). Here a rock breaker reduces its granulation to less than a cubic meter and then it follows its gravitational movement. The reduction is necessary because some chunks of mineral, which are too big, can cause a bog inside the transport chimneys, and they can also damage the train wagons of the inferior level.

Transportation level: here, the mineral that comes down from the chopping chambers is loaded into mailboxes and finally into trains wagons and it's taken by trains (crossed) to the processing areas where copper is detached from barren material.

The company has a Production Master Plan that works in a push mode. That plan does not take into consideration the supervision and effective coordination of the levels previously described. This situation influences, from top to bottom levels, the productivity and performance in both the technical and operational aspects. This means that each level processes the material as soon as it comes from the level immediately above. The coordination of activities among levels is done through radio communication from the highest to the lowest level (one by one), taking into account the availability of equipment in each level, without any visual information of them.

The Daily Master Plan (CARTIR) defines the operations for each available resource according to the production goals, also indicates the extraction points, tonnage to be extracted and availability of pits and ore-passes. Simulated scenarios allow the simulation of a working shift in the mine under operational conditions without reprogramming. The system provides recommendations regarding actions to be taken, whenever some unexpected event happened. Reports will reflect a summary of the outcomes and falls which occurred, also recommendations delivered by the system and the final actions taken in the process. Reprogramming orders will be executed whenever a major outcome is registered and the needs to reprogram activities to achieve the daily goals are detected. Generation of new operational rules is activated when some outcome is registered revealing no final solution. Events or outcomes that perturb the established working program can force to modify it to achieve the production goals.

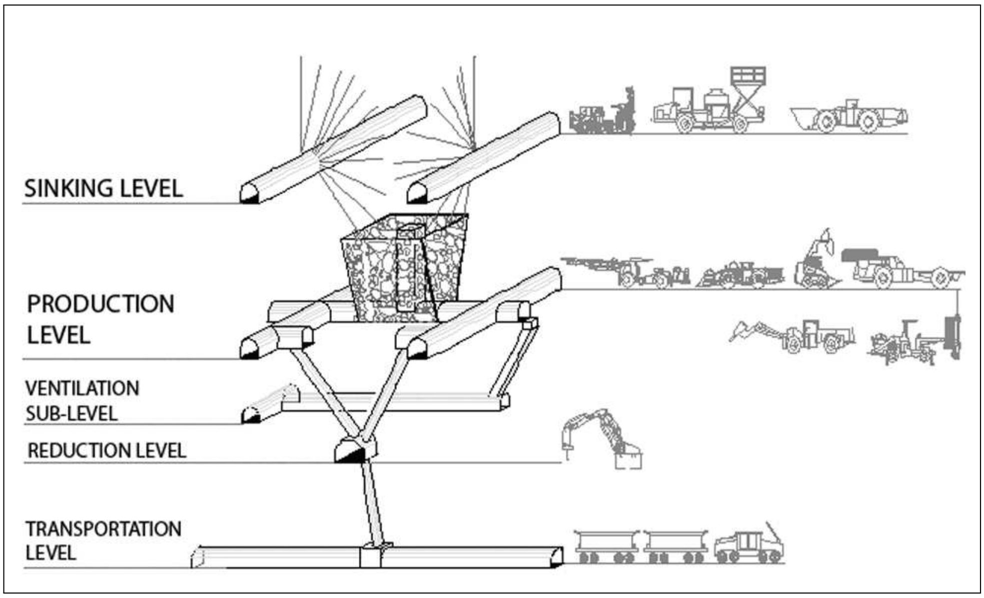

Figure 1: Block Caving Exploitation Method.

The main variables involved in the generation of the CARTIR are: a) copper law searching attractive exploitation areas, b) arsenic law that restricts the production to a drainage channel for the LHD operators, c) extraction speed rate: is determined by the LHD capacities, d) Monthly tons. to be extracted, e) availability of infrastructure at all levels, f) failure of any equipment at the subsequent level will affect the actual level of operation, g) time schedule of the daily program CARTIR not including non scheduled events which could results in failing the expected extraction.

3 The Intelligent Supervising System

The Intelligent Supervising System for the operation of the mine is composed by a Simulation Model (SM) and a Knowledge Based System model (KBS) integrated in a single model. The simulator, which is being fed by the Daily Master Plan, allows processing and simulation of the different scenarios that may take place during daily mine operations, utilizing as a basis the historical data of the different shifts. The Knowledge Based System provides the knowledge acquired by experts on the operation of all resources that participate in the productive process, as well as the possible failures of those resources. This allows generating events, solutions, and new operating rules for the system identifying critical failures for the production, reduction and transport levels. The architecture of the Intelligent Supervising System is presented in Figure 2.

The operation, inputs and results of the Intelligent Supervising System are detailed as follows:

Daily Master Plan (CARTIR): it is a set of rules which define the number of bucket mineral operations for each available resource (workers and teams), also indicates the extraction points, tons. to be extracted, availability of draining channels, emptying points and the Copper Law within the sector. These rules are established according to the annual production goals which are defined by the mine itself.

Events or outcomes: an outcome is defined as an event which perturbs the established working program which can force to modify it to achieve the production goals. There are a variety of events which can be associated to a working level within the mine or an event within a working team. Whatever the paralyzed resource will be, the expected operation of the mine will be affected demanding the intervention of some expert which then will define what action should be taken to carry on with the planned production program.

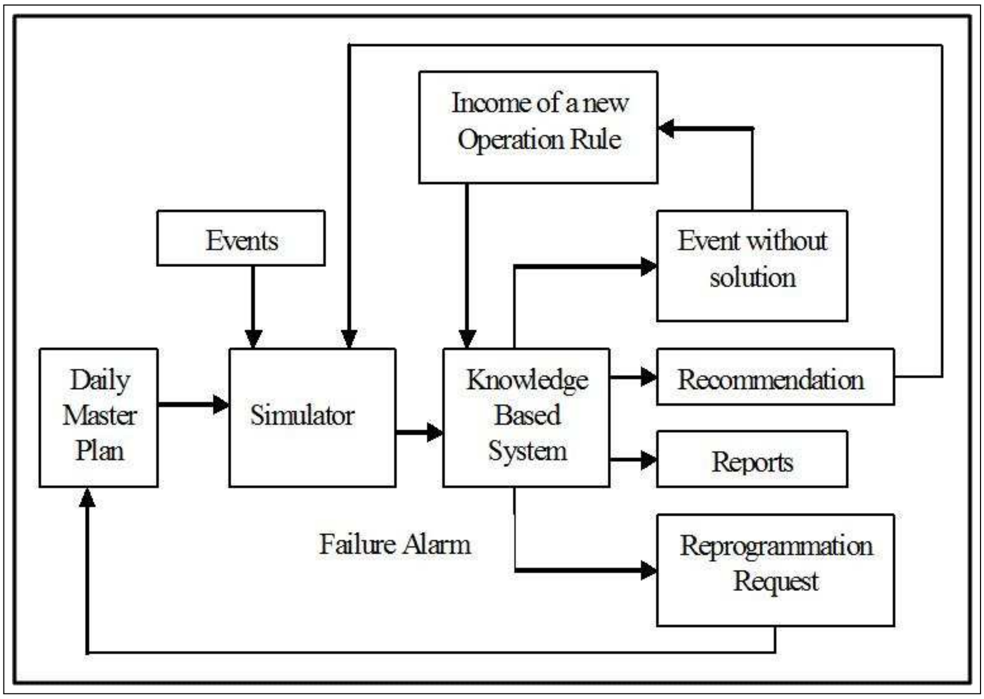

Figure 2: Architecture of Intelligent Supervising System.

Simulated Scenarios: corresponds to the simulation of a working shift in the mine under normal operational conditions without reprogramming, step which is executed by introducing the Cartir information to the simulation module.

Outcome without solution: outcome which does not generate a recommendation or solution defined in the knowledge base of the KBS consequently yielding the storage of a new outcome as a case, adding new knowledge or a solution which generates new operational rules.

Recommendation: advisability regarding actions to be taken, whenever some unexpected event happened within the mine. The knowledge stored in the KBS yields the appropriate indication to be followed.

Reports: these reports will reflect a summary of the outcomes and flaws which occurred, recommendations delivered by the system and the final actions taken in the process.

Reprogramming orders: these orders will be executed whenever a major outcome is registered and the needs to reprogram activities to achieve the daily goals are detected.

Generation of new operational rules: this step is activated when some outcome is registered revealing no final solution. It will be stored in the KBS which by means of interactions with the simulation module will yield a new operational rule which can then resolve the event.

3.1 The Simulation Model (SM)

The proposed model describes the operation of load-haul-dump vehicles (LHDs) at the production level, also the operation of rock-breakers equipment at the reduction level from the beginning of a shift up to its end. LHDs vehicles moves through the tunnels inside the mine according to a given schedule, which will be affected by different events such as own breakdowns, rock-breakers breakdowns, etc. It is comprised of three sub-modules: production, reduction and transport. The Production Level Module shown in 3 initiates itself with the place denominated Generator LHD, from which tokens are activated which represent the LHD resources that contain the start up attributes of the simulation, yielded by the Daily Master Plan. Arriving to the street module, the token must identify the action that it will realize (entering or leaving street) once the token has continued on the indicated route, it must enter the first physical resource fixed in the mine and of the level of production denominated Street (C1R to C15R, C1L to C15 L).

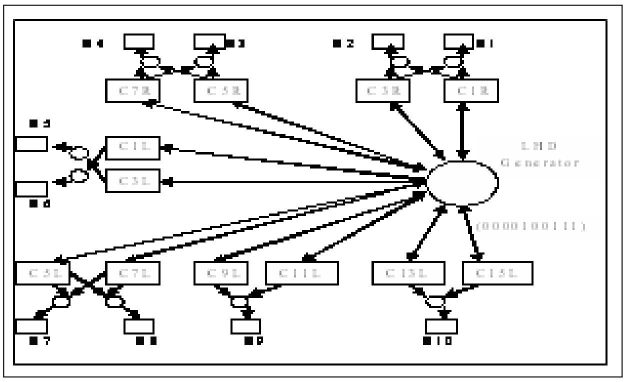

Figure 3: Production Level Module.

The Street module is composed by three modular and flexible structures, which are combinable between them and are representative of each street: Ore-pass Module, Two Ore-pass Module and Two Ore-pass -Pit Module, which communicate with the rest by means of a fourth, more complex structure denominated Routing Tree. Figure 4 shows in particular, the design of the Two Ore-pass -Pit Module which adds new attributes to the initial module, which allow for the routing of the LHD through the totality of the module. Next, the internal design of each one of the ore-passes is realized (Z12, Z13) and the pit (P2) respectively.

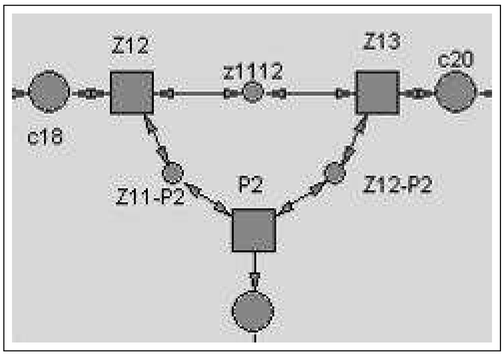

Figure 4: Two Ore-passes -pit Module.

In Figure 5 it is possible to observe the configuration of one street. Each module represented by Z_i presents a pair of parallel points of extraction, while each module P_i represents an emptying pit. The module denominated Routing corresponds to the routing structure of the model, and contains both the joints between modules and trees as well as the routing trees themselves.

The Routing Tree Module of the LHD has the function of directing the token or LHD through each one of the modules previously defined, by means of various alternative roads in order to comply with the tasks assignment of the Master Daily Plan. This one assigns to each token that enters and leaves the Master Daily Plan a unique vector of nine attributes (a b c d s e nb ca l) which contain a unique combination representing a unique movement to be followed by the LHD vehicle through those modules.

Ore-pass Module attributes:

a: Attribute which determines the events of loading or passing through the module.

b: Attribute which determines the output sense of LHD. Two Ore-pass Module attributes:

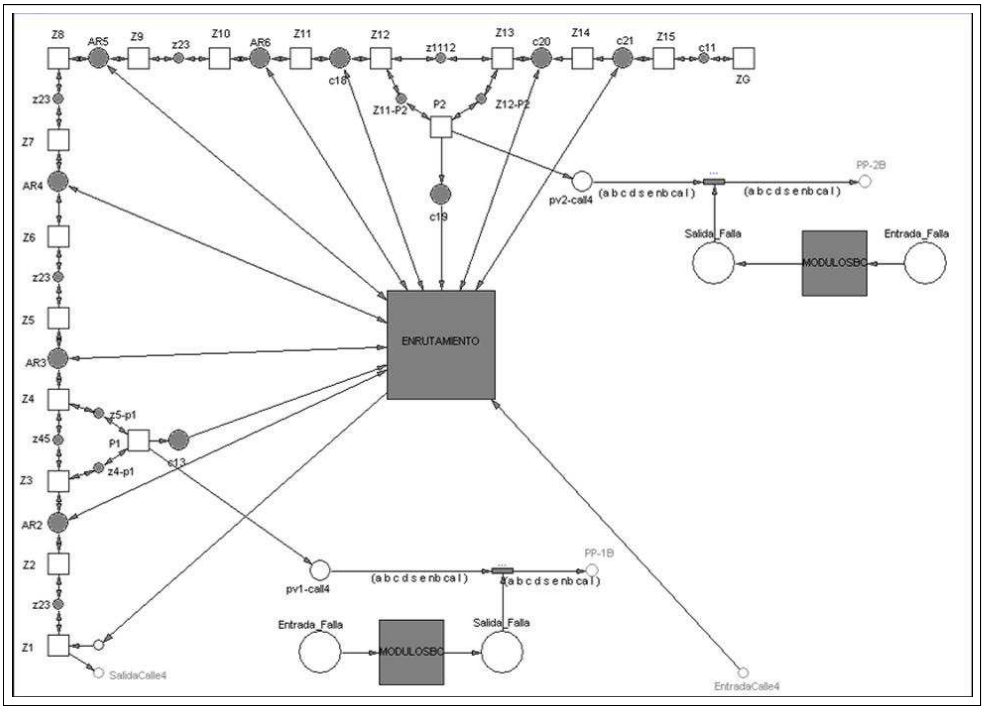

Figure 5: Street Module.

c: Attribute which determines the events of loading or passing from Two Ore-pass Module.

d: Attribute which determines the output sense of LHD from Two Ore-pass Module.

Two Ore-pass-Pit Module attributes:

a: attribute which determines the events of loading or passing from ore-pass 1 of ZPZ.

b: attribute which determines the output sense of LHD from ore-pass 1 of ZPZ.

c: attribute which determines the events of loading or passing from ore-pas 2 of ZPZ.

d: attribute which determines the output sense of LHD from ore-pas 2 of ZPZ.

e: attribute which determines the output sense of LHD from pit module.

nb: Number of bucket pending from the current instruction.

Routing Tree Module:

It corresponds to the attributes determining the movement of LHD vehicle in the mine according to the routing tree.

s: attribute giving the sense of movement for LHD vehicle.

ca: this attribute keeps the street number in where the LHD vehicle is running when it is passing through the tree.

l: is a binary attribute. When $b = 1$, the LDH vehicle must continue running by the street until the turning zone, then it must return to the ore-pass for loading.

The resources at the Reduction Level are the Rock-breaker and the Rock-breaker operator. These resources are shared by a pair of streets and a design of the connection of reduction/reduction level is done. At this level the size reduction of material and minerals is realized which will be then transported and later processed at the plant. The resources that are present at this level are the Rock-breaker and the Rock-breaker Operator, both resources are in charge of the comminuting of the material extracted at the production level and which must be taken to the transport level. The resources present at this level are shared by a pair of streets and a design of the connection level of reduction/level of production is done. This design repeats itself in all the streets of the model.

The material coming from the comminuting level is loaded and kept in the Mailbox, until it reaches its limit of storage capacity (280 tons.). Once this limit is reached, it opens its gates freeing the material to the Crossed resource, which in turn transports the material out of the mine for its later processing. In case the resource Mailbox presents any failure, the Mailbox Operators must aid and repair the Mailbox, so that it continues with its normal operation. In the model, each one of the LHD bucket represents a token therefore if a Mailbox concentrates 40 tokens, a new token will be generated in the Crossed. Figure 6 shows the Reduction-Transport Module.

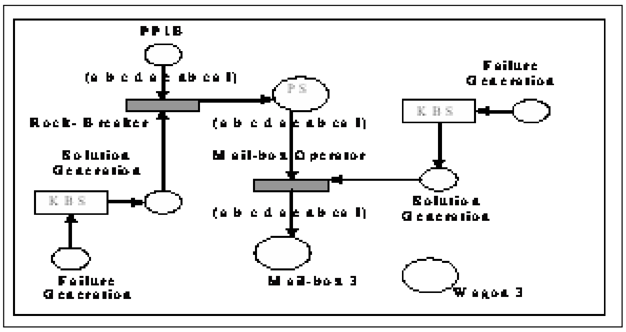

Figure 6: Reduction-Transport Module.

3.2 The Knowledge Based System (KBS)

KBS is the engine of knowledge which allows the simulation module to include solutions to the failures that might have happened at each level. The KBS module consists of a modular structure which by means of a routing chart allows identification of the events or failures which happen at each level. Its solution to the occurring problem at the expected production level has to represent the best solution to successfully continue any operation scheduled by the system. The KBS module consists of four basis structures which correspond to the Production, Reduction, Transport and Human Resources (HH RR) levels allowing separation of failures that will happen as operations go along. The Human Resource Module has been structured as an autonomous entity since it will affect the entire operation of the mine.

The activation of this module occurs when the initial transition KBS module generates some token with numerical attributes allowing the association of a token to some particular failure. All token activated have some specific attribute “z” which describes the characteristics of the event. This token generation was defined as a uniform probability which helps modelling the events or failures. Once the event has been identified together with its solution, it will leave the KBS giving recommendations related to one of fifty six (56) failures that have been modelled. The events that happen at each level are associated to it frequency of occurrence per shift. According to this frequency a numerical interval is associated to each level, resource or failure. Each token generated in the initial transition of the model is characterized by numerical values.

The KBS module is connected with the three level modules and with the Human Resource module by means of an entry called Failure Entry. Once it has looked over each branch of the knowledge system and once the event has been identified together with its solution, it will leaves the operational tree at the place called Failure Exit. The modelling at different levels was achieved by means of hierarchical Petri networks. The coloured ones allow representation and differentiation of events which call for a significant stopping of all operations.

The design of the knowledge tree shown in Figure 7 solving a failure step is considering only one entry place which corresponds to the generated failure and only one exit which corresponds to the solution of the failure and its repercussion at the production level. This procedure is identical for each failure.

In order to determine the level to which the failure has to be attributed, four probability intervals associated to the frequency occurrence of each failure at each level were defined. The first interval corresponds to failures at the production level, the second one corresponds to failure at the reduction level, the third one failures occurring at the transportation level and the fourth one keeps track of failures occurring at the level of human resources. If a failure token is activated and its numerical value falls within one of these intervals, the failure will be directed to only one of these modules. The connections of the internal KBS design need to define the attributes which determine if the token taken this particular path has effectively the characteristics needed to enter a particular module and additionally allow activation of the system failure token. In the case of the connectors shown in Figure 7, the defined attribute corresponds to the variable "z". Four connections start at the Event Input level and each one communicate with one of the modules assigned to the different levels. Four key transitions identifying the activated token are identified between the Event Input point and the place which is connected with the modular structure of the defined levels. These transitions filter the token which are trying to pass through due to the defined conditions. Only those tokens which possess the attributes which exactly correspond to those defined by conditions of a particular transition will be able to follow their route through the tree. For example let us assume that the activation transition of the model generates a token whose value (determined by some probability) is equal to 0.2 and the midway transition between Event Input point and Production Level point is characterized by the condition that only tokens whose values is less or equal to 0.4. Since the token is lower than 0.4, it will only pass through this transition since it corresponds to a failure which happened and is fixed only at the production level and hence follows its way through this branch.

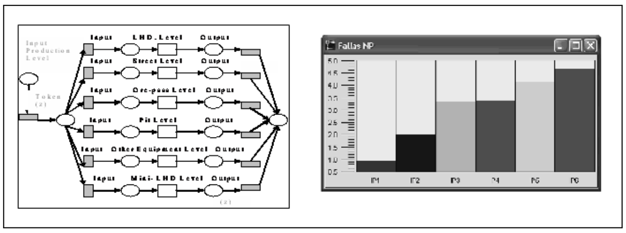

Figure 7: KBS Production Module and corresponding failure histogram.

A first evaluation identifies the level affected by the input event at the production, reduction, transport and human resource level. A second evaluation identifies the resources affected by the event at each level. Six modules have been built at the production level (LHD, Street, Pit, Ore-pass, mini LHD). A third evaluation at the production level identifies the failure associated to specific resources. The LHD is a production level resource which is continuously exposed to faults. The potential events which have been defined for this resource shown in Figure 8 are: repair, major failure, minor flaw and oil supply. This design also includes a module which considers all possible resource failures at the reduction level and at the transport level which affects the system operations. The resources considered are: rock-breaker equipment and rock-breaker operator, mailbox, mailbox operators and crossed (trains).

The Human Resource module is very important in the modelling process since its events are those who generate the most important delays or interruptions during operations in the mine. Originally it was thought building the model of the human resource as an independent resource for each level. However after inspection of the shift functioning, it was noticed that the personnel of the mine are rotating between

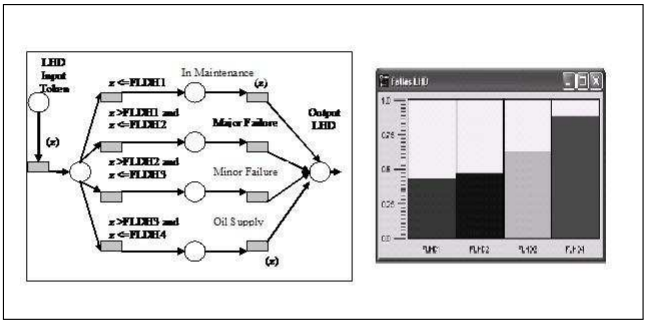

Figure 8: KBS LHD Module.

the different levels according to the requirements and the state of each level. This was the reason to modify the construction of the system, modelling the human resource as another module of equal importance than the production, reduction and transport levels. On the other hand as human resources becomes one single unique module it is possible to integrate the availability of all personnel that is participating in operational activities and optimally assign these resources for the operation.

4 Results

The Intelligent Supervising System (SM-KBS) was implemented using Pace Petri Nets tool. Different scenarios have been proposed in an 8 hours shift in order to evaluate the operation. In initial scenario for testing, in 6 streets modeled without stochastic events, the programmed production and the real one agree. Next, several iterations were done generating between 8 and 13 random failures which affect the different levels and resources of the system, altering the programmed initial operation.

The failures detected in this scenario were: a) at the production level, 5 dirty street failures affecting streets 1, 4 and 5 with a failure probability of 18%; b) at the reduction level, 6 failures affecting rock-breakers, for example: chamber with disconnection of chains affecting street 6 with a failure probability of 1.2%; c) at the Transport level, one failure was detected in the Mail Box with pit pump; d) at the Human Resource Level, one failure related to delay in the “Operator assignment” with a delay of 60 minutes of no availability of the resource and a failure probability of 18%.

The first validity step was done at the moment of checking that the solutions given by the system for each failure was correct. When checking this information, it was confirmed that the system gave the scheduled recommendations as outcome variable; therefore, in this first point the right working of the system was established. In the case of dirty street the system recommends calling to LHD equipment to work in cleaning the street with its bucket or using a small LHD vehicle which make the cleaning of the place. In the case of closed ore-pass the system recommends to stop the extraction in ore-pass because of low copper law or by fulfilling the programs and to reprogram. In the case of rock breakers with disconnection of chains the system suggest that the chains must be connected after waiting that the pit is full and put signals in the Transport level. In the case a minor failure happened in the rock breakers, the system recommends that mechanicals must be called to repair in situ, where they can take the bad spare out to a special place for its reparation or be repaired in situ. It must be continued loading if there is any space. In the case of the system recommends that the train lines must be cleaned, iron wagons, box and repair any damage in the facilities caused by the fallen material fallen violently from the pit, then it is necessary to reprogram the activities.

It was observed that the increase in the number of failures leads to the decrease in the efficiency and at the same time to the decrease in the real tonnage of the streets. In spite of that the box resource is not something that affect directly to the programming production of a street, the global effect of this stop affects in a cross way the use of the resources operation that could be used.

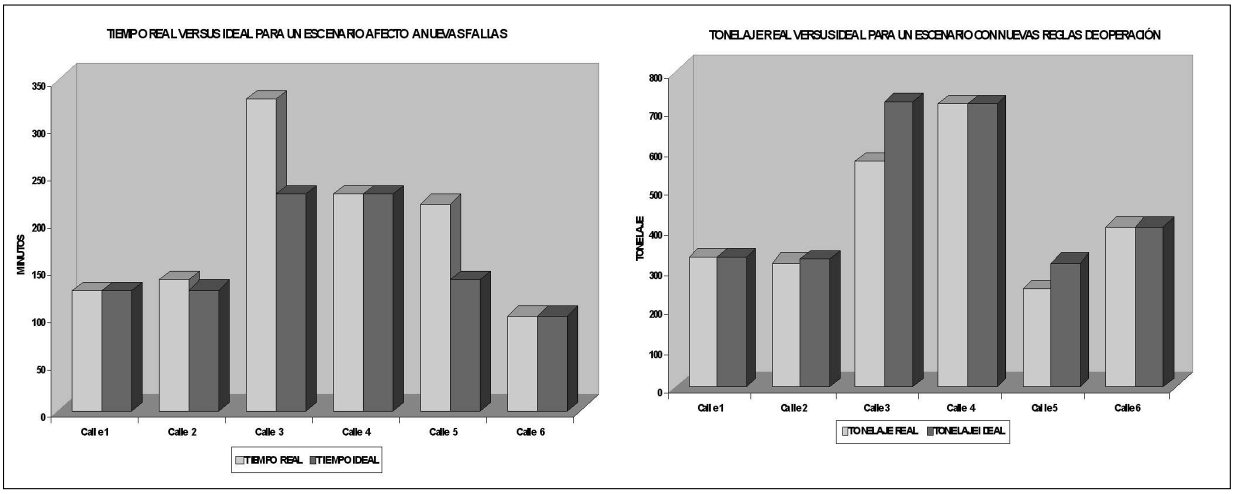

Figure 9: Real time versus the programmed time and tonnage

In this simulated scenario composed by 13 random failures, only 11 of them were recognized by the system. When an undetermined failure is found, identifying the level or levels affected, its frequency, the resources involved, and the estimated time for its solution, as a result of this, a new operation rule is added to the KBS.

5 Summary and Conclusions

The Intelligent Supervising System designed, composed by a Simulator linked to Knowledge Based System allows the study of the real operation of an underground mine, including the generation of events affecting it. The design covers the three operational levels of the mine, including human resource events. The use of hierarchical, colored and temporized Petri Nets in the design gave more flexibility to the model and allowed a hierarchy of the levels with their resources. In order to identify the failures or critical events that take place in the operation of the mine, the colored Petri Nets were used, tool that helped to give the aspect of critical that they have in the real operation. The programming considers 56 types of failures and it is possible to modify the probability of occurrence of one of them. Regarding the results obtained, the model was utilized to investigate the impact of the different types of failures. It was found that, in order of importance, that the events that affect the production most are the blocking of a secondary ore-pass, a minor breakdown of a rock breaker and a major breakdown of a LHD vehicle. The effect of human resource failure is global and it affects directly the amount of production for the shift. When failures occurred, the KBS System gave the correct solution that was programmed. The delay that was originated for each failure was scheduled according to the information given by experts in terms of the time consumed in each case. The incorporation of critical failures in the modelling process is another innovative characteristic which represents in a realistic way the operation of the mine. For outcomes which do not generate a recommendation or solution defined in the KBS, a new outcome as a case is generated, adding new knowledge or a solution which generates new operational rules. These results are useful to the managers, because they know now in which resources to pay attention and improve the maintenance of those resources.

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Disassembly Line Scheduling with Genetic Algorithms

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Abstract: Disassembly is part of the demanufacturing and it is meant to obtain components and materials from end-of-life products. An essential performance objective of a disassembly process is the benefits it brings, that is the revenue brought by the retrieved parts and material, diminished by the cost of their retrieval operations. A decision must be taken to balance an automatic disassembly line. A well balanced line will decrease the cost of disassembly operations. An evolutionary (genetic) algorithm is used to deal with the multi-criteria optimization problem of the disassembly scheduling.
Keywords: control, scheduling algorithms, evolutionary programming, genetic algorithms

1 Introduction

In the second half of the 20^{th} century, the people and governments started to become aware that the "take - make - waste" system, which resulted from the industrial revolution, is not sustainable. The assumptions on infinite material "sources" of raw materials and "sinks" to absorbe industrial and domestic wastes could not hold any longer because of the exponential growth of world population and accelerated widespreding of industry and consumption.

In their inspiring book on system engineering, Blanchard and Fabrycky [1, p.555] state that "Green manufacturing should be an objective adopted by producers to reduce the environmental impact of their products and production operation continuously. Real environmental improvement requires a system life-cycle approach to guide design decisions and operational policies". Several driving factors such as: a) competitive differentiation, b) customer consciousness, c) legal regulations, and d) fight for improving profitability have led to this new way of thinking and even to new standards such as ISO 14,000 series.

A new science of sustainability called "Industrial Ecology" was born [2,Frasch], [3, Graedel, Allenby]. Within it, research directions such as "design for environment" (with a proactive character), and "environmental management" (a reactive, remedial aproach) compose a new design trend called "environmentally conscious design and manufacturing" [1, Blanchard and Fabrycky, p. 558].

At present, both designers and manufacturers show an increasing tendency to consider product and system entire life-cycle starting with perceiving customers needs, and continuing with design and development, manufacturing, product utilization, maintenance, phase-out, and disposal. In this context, the term "remanufacturing" includes the set of planning and processing activities (such as checking in, disassembling, cleaning, inspection and sorting, reconditioning, reassembling, testing and packaging) for recycling obsolete products. The first steps of remanufacturing process can be grouped under the name "demanufacturing". A new industry for demanufacturing has shown up to provide with new usage of expensive modules, components and materials and, at the same time, to prevent excessive wastes. Also industrial producers tend to add their demanufacturing departments to existing manufacturing facilities. Sometimes, chains of firms show up to implement new paradigms such as "extended", "networked", and "virtual" enterprise [3, Filip, Bărbat].

This paper aims at proposing the usage of genetic algorithms for optimal scheduling of disassembly lines. The remaining part of this paper is organised as it follows. First, the main concepts and research directions in modelling, optimization and control in disassembly processes are reviewed. Then, the optimal scheduling problem of a disassembly line is formulated. A short description of genetic algorithms is given next. Experimental results on solving the optimal disassembly problem by a genetic algorithm are given before presenting the paper conclusions.

2 Disassembly- A Main Stage in Recycling

Several types of recycling of end-of-life manufactured goods are possible such as : a) reusing of components and modules of high value, b) refurbishing and partial reconstruction of a good returned from the market, c) recovery of the raw material or energy by incineration and melting. Disposal, which is the last solution to resort to, is done only if the other alternatives are not possible. The choice between these different types determines the recycling process and allow for defining the *end-of-life destinations* for components of manufactured goods.

Different recycling loops are different approaches of the process. The simplest approach is that of dismantling a product. By applying dismantling operations, a discarded good can be broken down faster and with small costs. In this case more pure fractions can be obtained with less efforts. This simple approach exploits only the value of the raw material. It does not take into account the functional value of the product or of its components.

The regain of the functional values needs a recycling process that minimizes the destroying effects on the product. This means to reuse, refurbish and capitalize the components of the used product in order to remanufacture a new one. Remanufacturing is a superior form of reusing, since its objective is to maximize the value of repaired parts and to minimize the disposal quantity. Central to remanufacturing is the *disassembly process* that decomposes a product into parts and/or subassemblies. Disassembling is a non-destructive technique and implies the extraction of the desired components and/or materials. If the parts are not reusable after reconditioning, partial or total destructive operations are to be applied: drilling, cutting, wrenching, and shearing. These techniques are used in view of the material or energetically recovery.

There are several research directions in relation with disassembly processes such as: modeling, planning, and control. The chapter 16 on "design for produceability and disposability" of the book on system engineering of Blanchard and Fabrycky [1] contains an excellent introduction to product and system design to facilitate remanufacturing.

Since disassembly processes can be viewed as *discrete, event - driven systems* [5, Cassandras, Lafortune], Petri nets can be a natural solution. There are lots of reported results. For example, Moore, Gungor and Gupta [6] propose Disassembly *Petri nets* to take into account operation precedence constraints in planning aplications. Penev and Ron [7] proposed *Disassembly graphs*. Kuo, Zhang and Huang [8] describe Disassembly trees which associate for each branch the direction of the disassembly operation by adapting the *Assembly trees* proposed by Henrioud [9]. The usage of *object oriented Petri nets* proposed by Lakos [10], to model disassembly processes is analysed by Duta, Filip and Henrioud [11].

For balancing the operation of the disassembly line, Duta, Filip and Henrioud [12] utilize the method of *equal piles approach* proposed Rekiek [13]. To model products associated with incomplete, imprecise, and, sometimes, wrong information, *Fuzzy reasoning Petri nets* are proposed by Gao and Zhou [14] to make real-time disassembly scheduling decisions possible.

A review of state-of-art implementations of control structures for disassembly line is given by Duta and Filip [15].

3 Problem formulation

Disassembly of manufactured products induces both disassembly costs and revenues from the parts saved by the process. Thus, at the planning stage a good trade-off has to be found that depends, both on the "depth" of the disassembly, and on the sequence of operations. The optimization of the ratio between gain and cost can be accomplished by using an appropriate distribution of the disassembly tasks on workstations, an assignment that provides a maximal value for the total profit. The optimization problem depends upon the structure of the disassembly system: if it is made up of a single workstation, the costs depend mainly upon the process duration. If the system is a line, the costs depend mainly upon the line balancing, all the more if it is highly manual. Another problem that occurs during a disassembly process is how deep the disassembly sequence must go so as to maximize the outcome of this process. In [11, Duta, Filip and Henrioud], [16, Duta, Henrioud and Caciula] it was shown that an incomplete disassembly sequence can be more profitable than a complete one. Destructive and dismantling operations have to be taken into consideration, as well.

Hence, we have to deal with a multi-criteria optimization problem of a disassembly process: maximizing the benefit it brings deciding how deep the disassembly sequence can go and minimizing the costs using an optimal scheduling along the line. A decision in a scheduling problem upon many criteria is a NP-hard to solve problem [17, Filip]. Stochastic algorithms have already been used to fulfill a multi-criteria optimization problem in [18, Minzu and Henrioud].

In this paper we consider that the line structure was given and propose an algorithm which will allow finding a disassembly sequence and its assignment on workstations that optimizes a very simple function which integrates the income from the parts and the cycle time of the disassembly line.

In this paper we address the case of disassembly lines where the cycle-time is not merely the sum of all operative and logistic times but it also depends strongly upon the line balancing. The objective is to find the most profitable disassembly sequence taking into account, on one hand - the end-of-life options for each part or subassembly of a given product, and on the other hand - the operational times for a given assignment of the tasks on the disassembly workstations.

A cost function which combines both disassembly costs and revenues was proposed in [19, Duta, Filip and Henrioud].

$$f = \frac{r}{t_{cy}} \tag{1}$$

where r is revenue associated to each disassembled part and t_{cy} is the cycle time.

The global revenue is the sum of partial revenues obtained according to the end-of-life destinations of the disassembled parts. These partial revenues are established by experts after repeated disassembly processes.

$$r = \sum_k r_k,\ k = \overline{1..nc} \tag{2}$$

where nc is the number of final components or the number of subassemblies obtained after the disassembly process.

The cycle time can be defined like the operational time of the slowest workstation on the line

$$t_{cy} = \max_{W_i} \sum_{j \in (tasks\ on\ W_i)} t_j \tag{3}$$

where W_i is the workstation i, and j is one disassembly operation and t_j the operational times.

We make the *following assumptions*:

- The disassembly line is linear (flow-shop type);
- End-of-life revenues of the subassemblies are known;
- Operational costs are included in the final incomes;
- The criterion of maximizing the outcome depending of the success rate of disassembly operations has been taken into consideration;
- The failure of the disassembly process is an event that can also occur since certain parts of the product could be deformed and impossible to separate without destroying;

- The disassembly line is not starving; it works in a continuous flow.

Evaluating the function from equation (1) reveals the profit on a time unit, which is an important indicator for the productivity of the disassembly system. This function also takes into account the value of the cycle time obtained for a well-balanced line. The optimization can be made both for the manual and automatic disassembly lines.

4 Genetic algorithms

Genetic algorithms are optimization solvers used in many areas due to their capacity to reduce the combinatorial complexity of NP-complete problems. They do not give the global optimal solution, but a local optimal one by exploiting a defined search space. A genetic algorithm starts with a set of randomly generated possible solutions called initial population. Each member of a population is encoded as a chromosome. Chromosomes are represented by a combination of numbers or characters which contain information about the solution. A score named fitness coefficient is assigned to each chromosome based on the viability of the solution. Chromosomes with high scores are chosen as parents to create a new population. The objective is to obtain children with better scores. To avoid the uniformity of the population and to increase the space of research, at each step of creation, two processes may occur namely: crossover and mutation. Crossover combines the features of two or more parents into one child chromosome. Mutation generates a child similar with his parent with one or more genes altered. These operations ensure the diversity of the new generated population [20, Goldenberg].

Once established the initial population and defined the three types of operations (reproduction, crossover, mutation), a genetic algorithm provides new members of population until a stop condition is fulfilled. Usually, this criterion is given by a maximal/minimal value of the objective function obtained after a number of iterations of the genetic algorithm.

5 Example

To test the genetic algorithm, consider the example of the disassembly of a Motorola radio set described by Salomonski and Zussman, [21]. The corresponding Disassembly Petri Net is given in the figure 1.

The disassembly process is represented four distinct possible sequences of transitions:
$\{t_1 \rightarrow t_3 \rightarrow t_5 \rightarrow t_7\}$, $\{t_1 \rightarrow t_3 \rightarrow t_6 \rightarrow t_8\}$, $\{t_2 \rightarrow t_4 \rightarrow t_5 \rightarrow t_7\}$ and $\{t_2 \rightarrow t_4 \rightarrow t_6 \rightarrow t_8\}$.

To take into account additional destructive disassembly methods, in the correspondent Petri Net there are three alternative tasks represented by transitions $\{t_{1,1}, t_{4,1}, t_{6,1}\}$.

For the present study we considered that there are three workstations on the line. An alternative destructive task is done only on a station that can perform both destructive and non-destructive operations. We say that this kind of workstation is a "mixed" one. Thus, workstations 2 and 3 are considered mixed. In other words, when a task is moved from one station to another, the type of the operation is changed together with its operational time.

We supposed that the tasks t_1 and t_4 can be performed in a non-destructive way on the first workstation and in a destructive way on the second one. For the task t_6 a destructive disassembly is done on the third station and a non-destructive disassembly is performed on the second workstation.

According to the Petri Net given in figure 1 the correspondent operational times on the initial partition of the tasks on the workstations are:

$$T_i = \{0.92, 0.07, 0.07, 0.12, 0.95, 0.75, 0.75, 0.95\}$$

Taking into consideration the times for the alternative destructive operations the set above becomes:

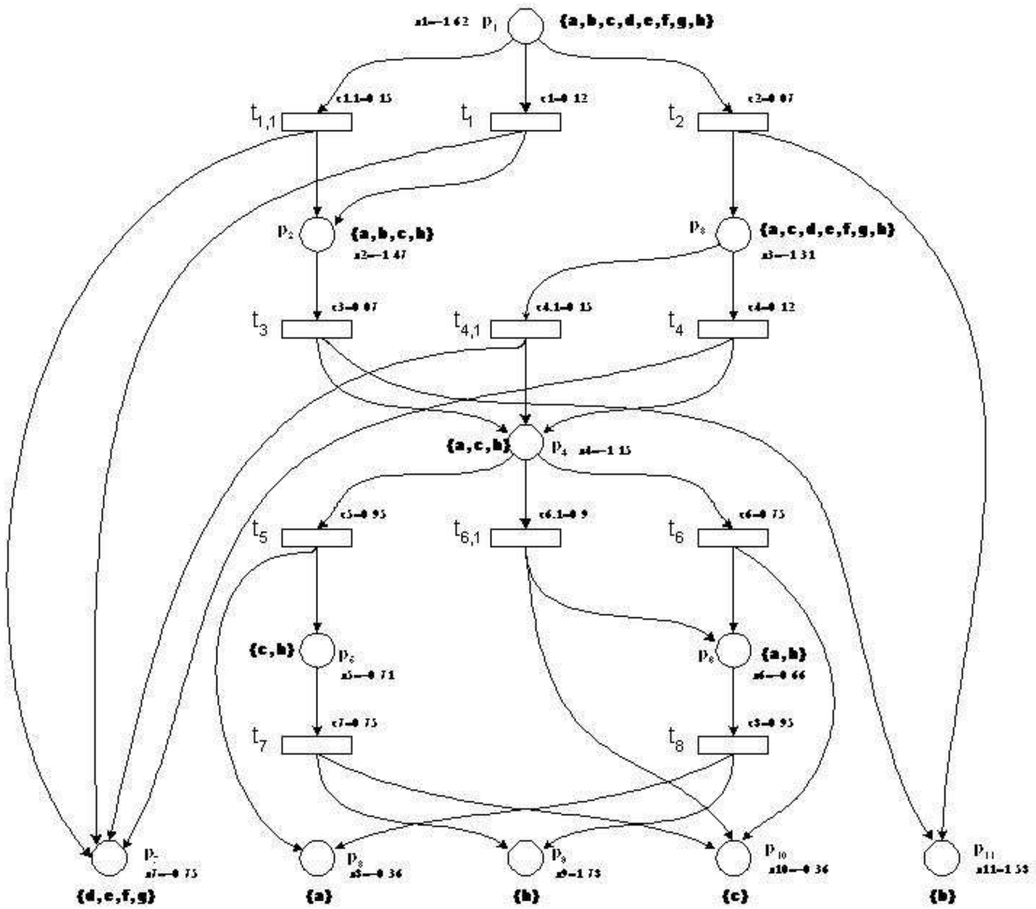

Figure 1: Disassembly Petri Net of a radio set

$$T_f = \{0.95, 0.07, 0.07, 0.15, 0.95, 0.90, 0.75, 0.95\}$$

The final revenues are calculated with the method proposed in [11, Duta, Filip and Henrioud] by using the data from the Petri Net given in the figure 1. The corresponding sets of revenue values are:

$$R_i = \{-1.36, 0.27, 0.54, 0.54, 0.62, 0.67, 2.75, 2.75\}$$

$$R_f = \{-1.32, 0.27, 0.54, 0.50, 0.62, 0.60, 2.75, 2.75\}$$

The objective is to maximize the value of the function from the equation (1) by finding the sequence that maximize the final revenue and in the same time ensuring a well-balance of the disassembly line (e.g. minimizing the cycle time).

In our problem, a chromosome is represented by the possible tasks assignment matrix S which elements are:

$$s_{ij} = \begin{cases} 1\; if\ the\ task\ j\ can\ be\ assigned\ to\ the\ workstation\ i \\ 0\; if\ the\ task\ j\ can't\ be\ assigned\ to\ the\ workstation\ i \end{cases}$$

$i = \overline{1..n}$ and $j = \overline{1..m}$ (n is the number of workstations and m - the number of disassembly operations).

One S matrix can be the solution of our optimization problem only if it satisfies the following constraints:

1. The **non-divisibility constraint** that does not allow a task to be assigned to more than one station.

$$s_{ij} \in \{0, 1\} \tag{4}$$

2. The **assignment constraint** that it requires that each task be assigned to *exactly* one station.

$$\sum_i s_{ij} = 1 \tag{5}$$

3. The **precedence constraint** that invokes technological order so that if task i is to be done before task j ($i<j$), then i cannot be assigned to a station downstream from task j

$$\sum_{k=1}^{n} k \cdot s_{ki} - \sum_{k=1}^{n} k \cdot s_{kj} \leq 0 \tag{6}$$

The steps of the genetic algorithm are:

Step 1 *Generating the initial population.*

There are three workstations and eight operations (tasks). The matrix of the possible task assignment is:

$$M = \begin{pmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{pmatrix}$$

We generated 24 matrices S that fulfill the constraints (4)- (6) by using the method presented in [19, Duta, Filip, and Henrioud]. We randomly chose three of them as shown bellow:

$$S_1 = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{pmatrix} \quad S_2 = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \end{pmatrix} \quad S_3 = \begin{pmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \end{pmatrix}$$

We observe that the three matrices can be obtained by moving an operation from one workstation to the next workstation.

The repartition of tasks on the workstations is represented in the figure 2.

Step 2 *Evaluating by the value of the objective function.*

The fitness coefficients f1 and f2 are defined by calculating the value of the objective function from the equation (1) for each complete disassembly sequence of the radio set given in the Figure 1.

Table 1: Evaluation of the initial population

	f1	*f2*	***fitness*** *(f1+f2)/2*	***strength*** *fitness %*	***average***
S1	0.5	0.6	0.55	33%	1
S2	0.5	0.43	0.46	27%	0.80
S3	0.75	0.6	0.675	40%	1.20
sum			1.685	100%	
average			0.5616	33%	

Step 3 *Selection.*

The selection of the individuals is made after their robustness so as to generate a more robust and healthy population.

We can not utilize the roulette method of selection because it generates non valid individuals (that don't respect the three constraints specified before). Matrices S_1 and S_3 are the strongest.

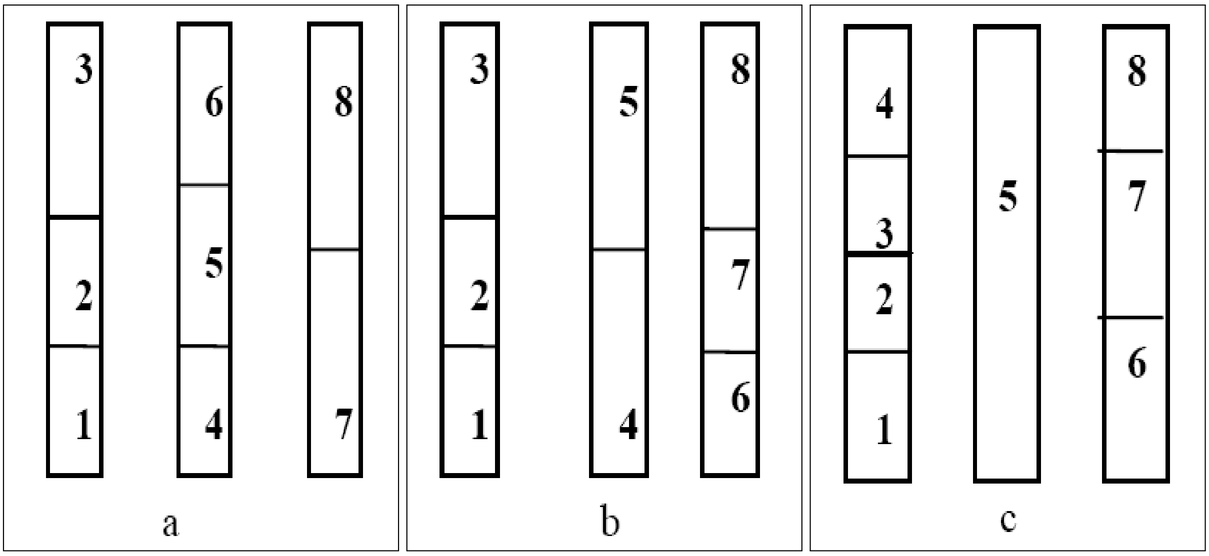

Figure 2: Assignment of tasks on the three stations for the initial population

Step 4 *Crossover*

If we have two matrices A and B of the same dimensions

$$A = \{a_{ij}\}\ i = \overline{1..n},\ j = \overline{1..m}$$
$$B = \{b_{ij}\}\ i = \overline{1..n},\ j = \overline{1..m}$$

The crossover operator $\oplus$ is defined as

$$a_{ij} \oplus b_{ij} = \begin{cases} 0\ if\,(a_{ij} = 0\ and\ b_{ij} = 0)\ or\ if\ (a_{ij} = 1\ and\ b_{ij} = 1) \\ 1\ if\,(a_{ij} = 1\ and\ b_{ij} = 0)\ or\ if\ (a_{ij} = 0\ and\ b_{ij} = 1) \end{cases}$$

We also define a special matrix called *mask matrix*

$$MSK = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

Calculating $S_1 \oplus MSK$ and $S_3 \oplus MSK$ we obtained two chromosomes that have two genes crossed: a new chromosome and a copy of chromosome S_2:

$$S_4(=S_2) = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \end{pmatrix}$$

$$S_5 = \begin{pmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{pmatrix}$$

Step 5 *Mutation*

A mutation can be made by the movement of one task between two neighboring stations. A new individual is obtained from S_4

$$S_5 = \begin{pmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Step 6 *Replacing the initial population*

Performances of the new population are represented in the table 2.

Table 2: Evaluation of the new population

	f1	*f2*	***fitness*** *(f1+f2)/2*	***strength*** *fitness %*	***average***
S3	0.75	0.6	0.675	31%	0.92
S5	0.95	0.75	0.85	38%	1.16
S6	0.75	0.6	0.675	31%	0.92
sum			2.20	100%	
average			0.73	33%	

Step 7 *Iteration*

As a result the genetic algorithm is iterated until a stop condition is accomplished. After 20 iterations the maximal value of the objective function remains 0.95. So the optimal assignment of tasks is given by the matrix S_5. The value of the function from the equation (1) is given in euro/second.

6 Conclusions

A new computation method in the problem of the optimization of the disassembly sequences is proposed in this paper. The method used has the advantage that it takes into account the operational durations, as well as the profit achieved after a disassembly process from the valorization of the obtained components or subassemblies. In a balanced disassembly line, the cycle time has the lowest value so the operational costs are minimized. The algorithm does not optimize the balance of the disassembly line, but give a solution that improves this balance.

Applying an evolutionary algorithm some undetectable solutions of the problem can be taken into account. However, using genetic algorithms implies a lot of information. The result is obviously faster obtained than using the backtracking method. In the disassembly process a local and fast solution for the optimal disassembly sequence is preferred to the complex and slower algorithms.

In the future work evolutionary programming will be applied to disassembly more complex industrial products.

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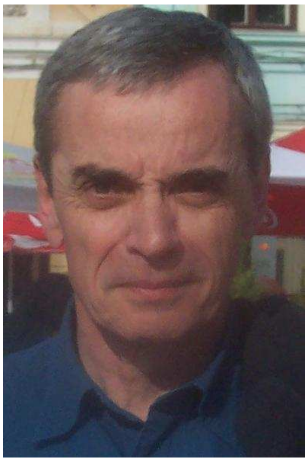

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Integration of Traffic Management and Traveller Information Systems: Basic Principles and Case Study in Intermodal Transport System Management

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Abstract: As they involve many interacting agents behaving in numerous ways that are extremely difficult to predict, urban transportation systems are complex in nature. The development of intermodal passenger transportation solutions to address the mobility issues constitutes a major thrust area of urban transport policies. But, to offer citizens comprehensive seamless mobility, intermodal transportation system management (ITSM) requires the integration of two major components. The traffic regulation support system, to help the operator responsible for the regulation tasks: coordination of timetables, synchronising arrival and departure times between the different transportation modes, and the traveller information system, giving customers access to information and using a comprehensive set of information tools. In this paper, a generic model of a transport management system, integrating these two components is proposed. This generic model is then used to elaborate a traffic regulation system in the case of a bimodal transportation system (tram-bus). The traffic regulation support system, based on the decision model of an operator, and the traveler information system are described.
Keywords: intermodal transportation systems, traffic regulation, travellers information system, management support system.

1 Introduction

Urban networks were, for years, only designed and built to carry flows of passengers to and from workplaces and their role was limited to their transport function. They did not take into consideration passenger expectations and the integration of the system in its environment. This period is definitely behind us, and a high transport capacity is no longer the sole criteria for assessing urban transportation system efficiency. Mobility patterns are hence changing as cities, with their large sprawling populations and are generating greater and more diverse mobility demands. Today, due to the growing service-oriented economy, people require a broad and flexible spread of transport services to choose from. Citizens are demanding greater mobility - more frequent and more widespread - and a higher quality mobility.

Most existing public transport systems were built at a time when the majority of journeys were fixed and routinely made. Therefore, they must now fundamentally change their approach. Public transport must take an increasingly flexible and competitive approach to meet the needs of today's travelling public and become more service-oriented. It must increase its quality, punctuality, frequency, attractiveness and comfort because all of which have an impact on its productivity. Indeed, urban networks have been transformed from just being a transport system into being an urban achievement around which the city and its mobility system are structured and developed. It is therefore crucial that an optimisation of interchange and transfer points between modes occurs for making them functional and pleasant. As well, there is no interest in setting up an efficient transport system if passengers do not know how to use it. So, another important aspect is the provision of high quality information. These two aspects, minimising waiting times and giving a real-time information to guide the travellers efficiently, are two essential points for the design of an intermodal transportation system.

The intermodal transportation systems approach is briefly described in the section II and a generic model of a traffic management system, integrating a traveller information system and a traffic regulation support system is proposed in the section III. The section IV shows how this model was used to develop a traffic regulation system, based on the decision model of an operator in the case of a bimodal transportation system (tram-bus). The travellers information system used by the operators is also explained. This system provides the operator with the information she/he needs to identify the disturbances and evaluate potential corrective actions to be carried out according to the regulation strategy she/he has selected. This paper is an extended variant of the work [15].

2 Towards intermodal transportation systems

Intermodality is both a technical term for a specific type of journey including several modes of transport and a policy principle. Intermodality describes coordinated interchanges between two or more transportation modes to complete a movement. In this light, intermodal movements involve either the physical transfer of people or individual items from one mode to another, or the transfer of one loaded transport vehicle or container from one mode to another to continue the journey. Numerous studies have been carried out on advantages (mainly quality of service) and disadvantages (costs, technical problems) of intermodal transportation systems. These are a number of barriers which prevent the advancement of intermodal passenger transportation (institutional, system integration, interoperability requirements) [20, 10]. Nevertheless, the development of intermodal transportation solutions constitutes a main thrust area of urban transport policies and the role of intermodal transportation systems has become increasingly important. The intermodal approach involves looking at how individual modes can be connected and managed as a seamless and sustainable transportation system. That is, the fundamental objective of intermodalism is to integrate all the modes into an optimal, sustainable, and ethical system. Such a system should support efficiency, safety, mobility, economic growth, protection of the natural environment.

Any person departing from any of the available modes of transportation (train, bus, plane, metro, Ě) may get on the intermodal system additional services to reach its final destination. The comfort and the attractiveness of passenger transport systems depend largely upon the quality of the transfers at interchanges between public transport modes themselves and with the car. So, a crucial element of a successful intermodal transport system is the coordination of timetables, synchronising arrival and departure times between modes as much as possible to minimise passenger travel and waiting time. Here the impressive advances made in both computer technology, telecommunications and decision support tools and methods are playing a crucial role in the promotion of public transport: informing the travellers about existing transport possibilities in order to allow them to define and plan their movement, giving access to information and quality infrastructure to find out what mode of transport is available. In addition, parks and ride also contribute to a successful intermodal transport system, encouraging car drivers to leave their car in a car-park at the outskirts of the city and to travel by metro, tram or a bus on a route which is free of traffic difficulties.

The previous description shows that intermodal transport systems are customer-oriented that makes them really attractive. But, to offer citizens comprehensive seamless mobility, they require advanced management systems combining different decision and informational support, especially to help the operator, responsible for the traffic regulation.

3 Generic model of a passenger traffic regulation support system

The planning process of an urban transport system consists first in calculating a theoretical planning [1] and different timetables describe trips according to lines, frequencies, transport demand and travel times in the transport network. But, random events occur (vehicle's breakdown, strike, traffic congestion...) that cause disturbances and make the predictive scheduling to be modified. Therefore, for reducing the effects of disturbances, regulation tasks must be carried out to adapt the predictive scheduling to the real state of the network. This process consists in creating new schedules resulting from the decisions the regulator takes and depending on several parameters (the location, the type of disturbance, the time the disturbance occurs, ...).

The real-time regulation of an urban collective transport network is a very complex problem, especially in case of simultaneous disturbances, that frequently overload the regulator with numerous information. Taking efficient decisions requires: to have a global and significant overview of the network, to access rapidly to the available information related to the disturbances, to analyse the characteristics of the disturbances in order to identify the most appropriate corrective actions, to evaluate and compare the impact of these actions to decide which one must be selected. Our purpose here is to assist the regulators (decision-makers) and to propose them effective solutions taking account their preferences and uncertainties related to these preferences.

The generic model of a transport regulation support system (TRSS) is shown in figure 1. The role of each software package as a component of the integrated architecture can be identified as follows:

- the Exploitation Assistance System is the main information system of the TRSS, interfacing TRSS with all the network information sources (sensors, GPS, phone, radio-locator...).
- the Decision Assistance System (DAS) is composed of three components: (i) the regulation data base containing all the information required for regulation (location of disturbances, line, bus number, Ě),), (ii) the regulation models composed of all regulation methods the regulator can use and/or combine to elaborate a coercive action: algorithms, meatheuristics,.. (iii) the RSS monitor which supports data manipulation, allows an interactive navigation through the regulation system, and allows the regulator to manage the regulation process by choosing the regulation models he wants to find out a solution.
- the Information Assistance System: it is used by the operators to send relevant information to the users of the network.
- the Geographical Information System (GIS): this module stores cartographic information about the network (streets and transportation networks, measurement locations, contour lines, etc.) and descriptive data (streets names, measurements, statistics, Ě).). It can help the regulator by providing a spatial view of the network, locating and displaying the disturbances areas.

4 Application

The validation of our approach occurred within the framework of a project involving an industrial partner, the TRANSVILLES company, as well as several research laboratories (LAGIS, LAMIH and INRETS). TRANSVILLES is the company which actually runs the urban transport network (tramway and bus) in the town of Valenciennes. This project is sponsored by the Nord/Pas-de-Calais regional authorities and by the FEDER (Fonds Européen de Développement Régional - European Fund for Regional Development). Our research work consists in the specification, design and evaluation of (1) a human-computer supervision interface (referred to later as the Information Assistance System or IAS), and (2) a Decision Assistance System (DAS). The IAS is intended for human regulators working on passenger information on the transport system in Valenciennes.

The transport network includes information screens (or display units) intended for the passengers. These screens are found both in the stations and in the vehicles; they show information on the schedules and on the connections. These information are calculated automatically by an exploitation assistance system (EAS) in which the position and state of each vehicle are stored.

In conclusion, the regulation system is made up of three sub-systems: an Information Assistance System (IAS), an Exploitation Assistance System (EAS), a Decision Assistance System (DAS), (see Figure 1).

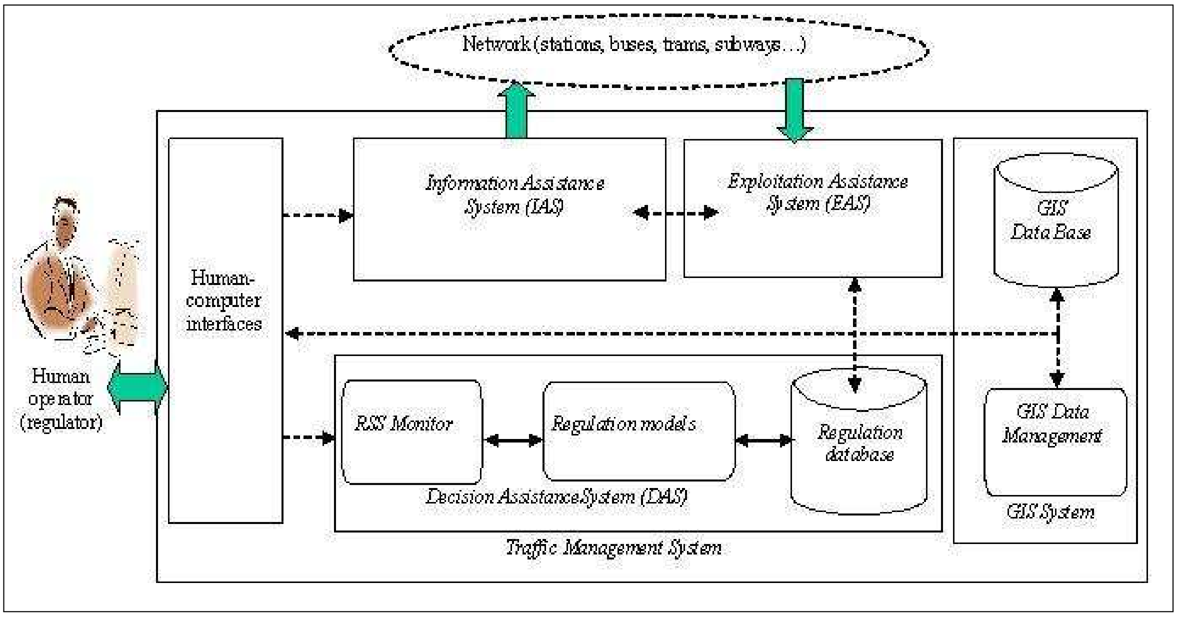

Figure 1: Generic model of an urban transport regulation support system

Each of the three sub-systems plays a particular role. Indeed, the EAS has to centralise the information regarding exploitation of vehicles (alerts, vehicles ahead of time, messages, schedules, delays,...), and make it possible to manage these elements. The DAS is intended to create, evaluate and suggest regulation strategies to the human regulator using the information provided by the EAS. In this way, the regulator has less work to do, which should help to improve the quality of regulation and thus the quality of the overall service. The DAS is not intended to replace the human regulator, but it must provide assistance in decision-making [8]. The IAS is intended to present information to the regulators and make it possible to send relevant information to the passengers [3, 4].

A simulation system has been developped to simulate the behaviour of the multimodal network in Valenciennes. This simulator is described in the next section. The DAS and the IAS, which are objects of our researches, are more detailed in the two next sections.

5 The Simulator

The software QUEST (Queuing Event Simulation Tool), developed by Delmia, was chosen to build the simulation model. QUEST is a powerful discrete event simulation tool that allows very complex systems to be modelled. We used it to model the transportation network of our industrial partner. This multimodal network is composed of buses, trams and trains. The simulation system takes both the normal behaviour and the disturbances into account. The topology of the transportation system consists in a road network principally used by buses and a rail network which incorporates both tram and train networks. This type of network is sometimes supported by a road network, in which case bus and tram interaction must be taken into consideration. Crossings are modelled to avoid collisions between buses or between buses and trams. Intersections between roads or between roads and rail lines are supervised. Trams always have priority in road-rail intersections. Overtaking is restricted: only stationary buses may be overtaken by moving buses. An overtaking manoeuvre on the rail network can only be accomplished by using a specific procedure, such as following parallel tracks or shunting tracks, which, strictly speaking, is traffic diversion, not overtaking. Rolling equipment can be divided into three categories: train, tram or bus. Buses can be further divided into standard buses, articulated buses or minibuses. Their dimensions, kinematic characteristics and capacities are modelled. Macroscopic passenger flow simulation is used to track passenger movements; the model does not track individual passengers. Passenger flow is considered at simple stop areas, at interchanges, and within the vehicles. Stop area arrival patterns are modelled using a Poisson law. The mean arrival rate per time unit varies according to timeband (period of the day) and type of day (weekday, weekend, school holidays Ě).). Stop areas are divided into simple stop areas and interchange stop areas. A stop area is simple if passengers can board or disembark without any possiblity of connecting to other lines while an interchange stop area combines multimodal transportation vehicles and may be very complex. In our application, the interchanges are divided into two types:

- interchanges between bus and tram: a tram drops passengers off, and when a bus reaches the stop area, it takes passengers on board and leaves, unless the bus driver sees an approaching tram. In this case, the bus waits for the tram. In any case, the tram drops its passengers off, regardless of whether there is an interchange or not,
- interchanges between bus and bus: the interchange is organized around an arriving bus, which brings passengers into the interchange, and a waiting bus, which takes waiting passengers out of the interchange.

Two types of disturbances may occur and disrupt the transportation network:

- alarms detected by the vehicle or its driver (failures, emergency calls) or detected by the controller (operational threshold exceeded Ě))
- unforeseen events resulting from an accident, traffic jam, passenger behaviour, driver illness ... .

In our application, perturbations are generated by the user of the simulation system. Vehicle perturbations include delays, early arrivals, unscheduled stops, and network perturbations refers to the unavailability of some part of the network. The regulation action that will compensate for the dysfunction is defined by the user with the help of the Decision Assistance System and is then simulated. In this instance, QUEST's ability to communicate with external softwares via a socket-based mechanism that allows it to send or receive any type of information is clearly an advantage.

6 The Decision Assistance System

6.1 Global modelling approach chosen concerning the decision-making process of the regulator

DSS design is a very rich research and development field [21]. Most of the decision-making systems developed in the field of regulation are based on automatic methods. Several authors (see for instance [12]) have contributed to the use of artificial intelligence in the field of transportation system regulation using fuzzy models. Balbo [2] adopts a multi-agent approach for offer planning, and Laichour [8] uses the same type of approach to regulate transfers. Fayech Chaar [5] combines a multi-agent approach with a generic algorithm. However, none of these approaches consider the integration of the method in an interactive environment. In parallel, three main modelling approaches have been proposed and used to model a human operator:

- the oldest is the "human factor" approach (1940-1955), which models the observable elements of operator behavior during task execution [6].
- then, the "human/automatic" approach (1955-1980), which is based on physics theory, has tried to model the human operator. Information Theory, the Optimal Control Model and model of the regulation of human activity proposed by [9], are all based on this modelling approach.

- the third approach is the "Cognitive engineering" approach, which holds that the role of human operators in system operations is supervision and decision-making. Thus, problems that this approach seeks to resolve are related to the decision-making involved in system control, management, monitoring and reconfiguration.

As we consider that the regulator is part of all supervision and decision-making tasks, our application falls into the "cognitive engineering" approach. Our proposed model is inspired by the ones introduced by Hoc [11] and [7] (see Figure 2). This model integrates the regulator in the decision process and allows conflicts between the user and the system to be avoided.

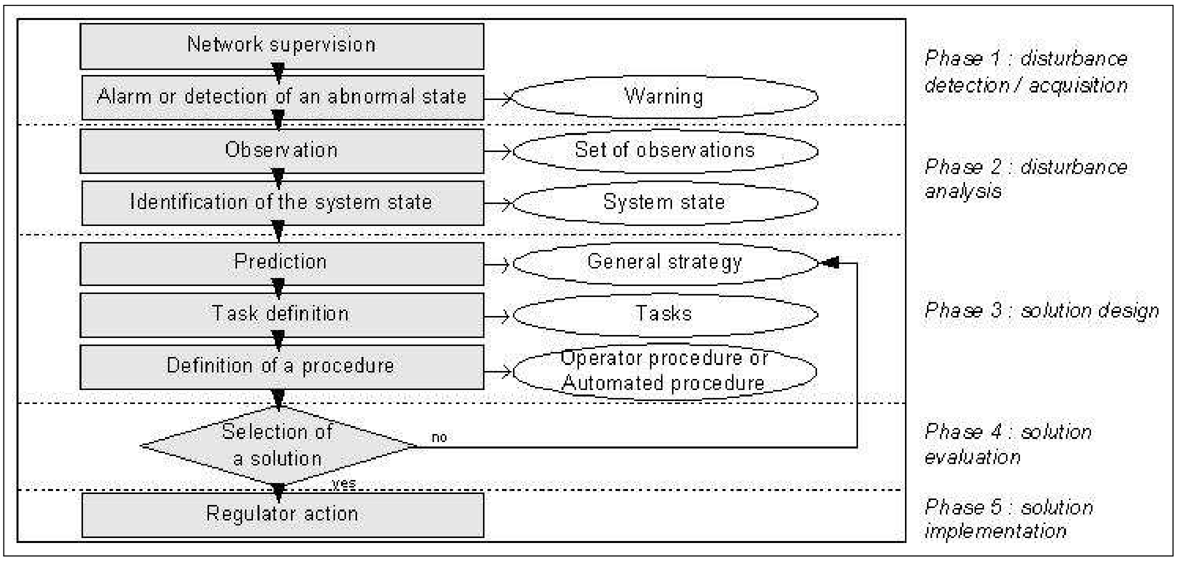

Figure 2: The decision model of the regulator

6.2 Functional model for the regulation of a transportation system

Figure 2 shows the functional diagram of the decision model described above. It is composed of five phases: disturbance detection and acquisition, disturbance analysis, solution design, solution evaluation and solution implementation. They are all described below.

- Phase 1: Disturbance detection/acquisition. Three detection methods are possible: (1) the automatic vehicle-monitoring system can provide relevant information about disturbances; (2) vehicle drivers can call in by radio; (3) the regulator can anticipate disturbances based on his experience in supervising a transportation network. The third case is the most common.

- Phase 2: Disturbance analysis. Descriptive data of a disturbance are numerous. Since there are often several simultaneous disturbances, the assistance system provides a disturbance analysis to avoid information overload at the level of the regulator. It provides a synthetic representation of relevant network data for each disturbance, a description of the specific information available (e.g., passenger flow at vehicle stops, number of passengers in the vehicles, characteristics of the line). Current disturbances are ranked according to significant criteria defined with the help of the industrial partner.

- Phase 3: Solution design. Three methods are proposed to the regulator for choosing or designing a solution. These methods complement approaches mentioned above [2] [5] [8]. They increase interactivity and allow the regulator to adapt to the varying complexity of the disturbances:

  - a manual method: all available basic and combined regulation actions are listed in a typology provided by the system and are proposed to the regulator [8].
  - a semi-automatic method: the regulator chooses among the different regulation logics. He can focus on respect for punctuality or respect for transfers. The system can then filter acceptable actions and proposes a list of possible actions .
  - an automatic method: the regulator chooses one of the suitable solutions automatically proposed by the system.

- Phase 4: Solution evaluation. All solutions are evaluated according to indicators computed by the system. These indicators allow the efficiency of the solution to be verified. These indicators are classified according to their importance: (1) “essential” indicators evaluate the service offered to passengers (e.g., regularity, punctuality, respect of transfer times); (2) “important” indicators evaluate the additional consequences of a disturbance (e.g., delays); (3) "secondary" indicators simply provide information to the regulator but have no influence on the decision (e.g., the lines and transfers that are affected by the solution). The regulator chooses the best solution according to these indicators.

- Phase 5: Solution implementation. The chosen solution is implemented by creating a new timetable.

6.3 System components

System implementation is based on an architecture including the following modules:

- The “acquisition tool” evaluates the complexity of the disturbances and classifies them based on local and network parameters and traffic management criteria (e.g., type of vehicle, geographical location, time, number of passengers in the vehicle and waiting at the next stop).

- The “regulation environment” manages three modules according to the method chosen by the regulator:

  - the “manual tool module” is used if the regulator builds his own solution manually. This module contains a set of mathematical algorithms specifically developed for the project. Each algorithm models a specific regulation action such as “U-turn with vehicles and drivers exchange”. These algorithms have been enhanced by a filtering procedure, which enables or disables the algorithms depending on which logic is chosen. The filter is based entirely on specifications defined by the industrial partner TRANSVILLES. For example “respect for transfer” logic will disable “U-turn with vehicles and drivers exchange”.
  - the “case-based reasoning module” uses the traditional CBR approach [19]. Its principle is based on the use of previous experience to solve problems. This approach can be used because TRANSVILLES has compiled a database of incidents and strategies applied to resolve them. This database is enriched with the activities resulting from manual regulation or those generated automatically by the system.
  - the “expert system” uses a knowledge base that exploits the expertise of our industrial partner (TRANSVILLES). It is used if no solution can be found using the CBR module.

7 The information assistance system

7.1 Architecture chosen for the human-computer interface

Several architecture models of interactive systems have been put forward by researchers over the past twenty years. Two main types of architecture can be distinguished: architectures with functional components (Language, Seeheim and ARCH) and architectures with structural components (PAC, PAC-Amodeus, MVCĚ);); several of these models have also variations [13]. The classic models distinguish three essential functions (presentation, control and application). Some models (such as the Seeheim and ARCH models) consider these three functions as being distinct functional units. Other approaches using structural components, and in particular those said to be distributed or agent approaches, suggest grouping the three functions together into one unit, the agent. The agents are then organised in a hierarchical manner according to principles of composition or communication (for example PAC, MVC). Our approach could be considered as being intermediate as it borrows elements for its principles from both types of model given above: we suggest using a division into three functional components which we have called respectively: interface with the application (connected to the application), dialogue controller, and presentation (this component is directly linked to the user). These three components group together agents [14].

The *application agents* handle the field concepts and cannot be directly accessed by the user; one of their roles is to ensure the correct functioning of the application and the real time dispatch of the information necessary for the other agents to perform their task. The *interactive agents* (or i*nterface agents*) are in direct contact with the user; they co-ordinate between themselves in order to intercept the user commands and to form a presentation which allows the user to gain an overall understanding of the current state of the application. In this way, a window may be considered as being an interactive agent in its own right; its specification describes its presentation and the services it is to perform. The *dialogue control agents* provide services for both the application and the user; they are intended to guarantee coherency in the exchanges emanating from the application towards the user, and vice versa.

7.2 Agent oriented specification and design of the human-machine interface

An agent oriented architecture is used for the human-computer interface. The *application agents* are intended to manage the passenger information in the vehicles and stations and to calculate the information to be displayed (delays, timetable and route modifications, etc.). According to the traffic context, each agent possesses rules enabling it to act correctly in its environment. Concerning the specification of the *interface agents*, we have identified six types of interface agent responsible for direct interaction with the human regulator.These agents are represented in the form of interactive windows. The regulator can interact with these agents via the various functions possible in the windows, for example: the buttons, the edition zones, the pictures, etc. These agents are: The State of traffic agent, The State of the line agent, The Station agent, The Vehicle agent, The Message agent, The Overall view agent. It should be remembered that the aim of the IAS is to enable the regulator to visualise, edit, create and transmit information intended for the passengers in the stations and/or vehicles. In order to perform his/her task of regulation correctly, the regulator interacts with these different interface agents. For instance, the *State of the traffic* interface agent gives a synthetic representation of all the delays concerning mobile units travelling on the network. Thus, with the help of the network support system, it ensures the real time surveillance of vehicle delays on the network supervised. The *State of the line* interface agent is made up of graphic elements such as stations, route sections, vehicles, Ě ((see figure 3a). A click on a vehicle directly displays the view (window) of the *vehicle interface* agent which will deal with any further interaction with the regulator (see figure 3b). The principle is the same when the operator click on a station (see figure 3c). Explanations about the other types of interface agents can be found in [14] or [18].

8 Evaluation

We are evaluating and validating the global approach; preliminary results are available in [18]. In parallel with technical tests, evaluation with regulators using the different interactive systems in normal

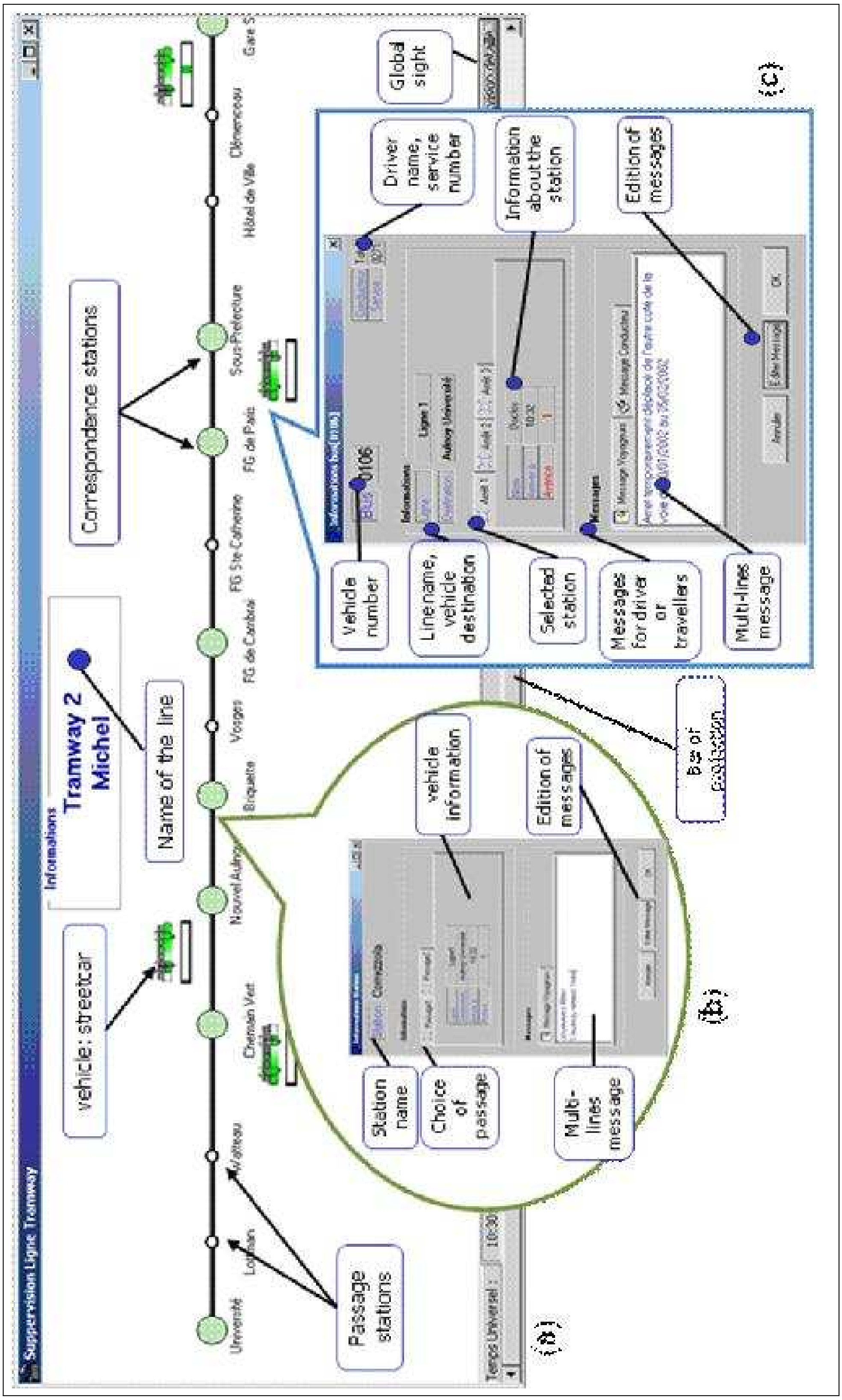

Figure 3: (a) view of the state of the line interface agent, (b) view of a vehicle interface agent, (c) view of a station interface agent

and abnormal situations are under development. The evaluation of interactive system consists in ensuring that the users are able to carry out their task by using it; it must therefore meet their needs. The methods for evaluating interactive systems are as varied as they are numerous. In [16, 17] the emphasis is placed on two global evaluation criteria: utility and usability. Indeed, evaluation consists in verifying and confirming the interactive system, whatever the domain of application. If it meets advanced criteria, it is then accepted and validated. Otherwise it has to be reorganized for a new evaluation.

8.1 Data Collection using an electronic informer for the evaluation of agent oriented interactive system used in regulation room

An "electronic informer" is a software tool which ensures the automatic collection, in a real situation, of users' actions and their repercussions on the system. The collection of information is done in a discreet and transparent way for the user, who must not at any time feel hampered by the presence of the informer. Our evaluation method is divided into two closely dependent phases [15]: the first will be dedicated to the acquisition of the data related to the interaction between the user and the agent-based interactive system; the second phase ensures the classification and the analysis of the recovered data.

The parameters to be acquired correspond to the various interactions between the user and the interactive system. They must contribute to the judgement to give on the quality of the system and make it possible to the designers to plan improvements to be brought to it. These parameters allow the identification of the: reactions of the interface further to the actions of the user, reactions of the user further to the actions of the interface, time response of the system, duration of the human tasks, user errors, uses of the help, displayed and not used information, and so on. The acquisition of all these parameters is ensured by the various informer agents. Their tasks will consist in perceiving the actions/reactions of the corresponding interface agent and the user, and to record them. Indeed, we equipped these agents with a rather simple architecture (see Figure 4). This architecture consists of (1) a perception module, ensuring the acquisition of the data provided by the user and the agent presentation, (2) an interpretation

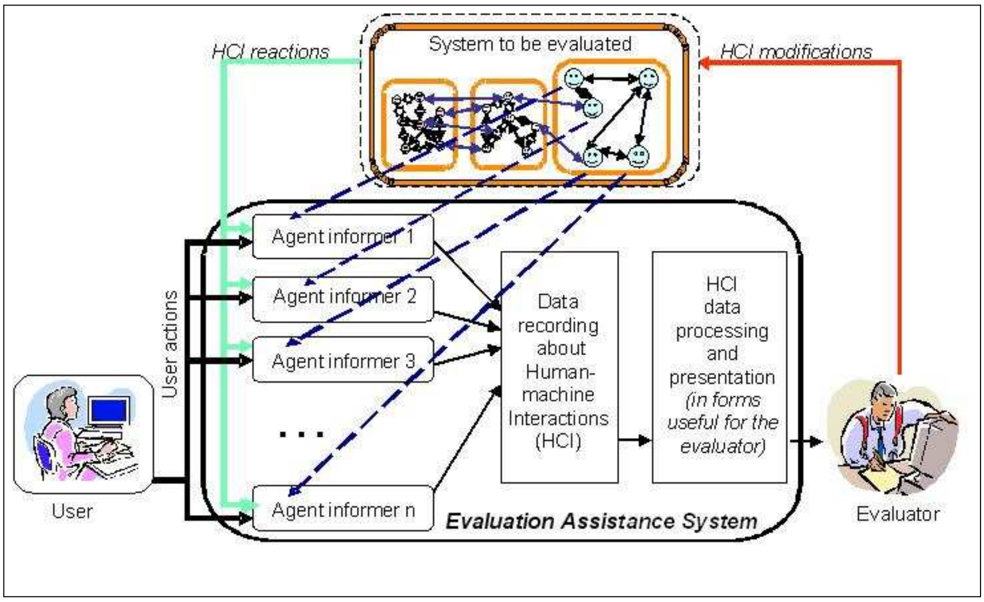

Figure 4: Using the electronic informer for the evaluation of agent oriented interactive system.

and classification module ensuring a sorting of the collected data, and (3) a recording module ensuring the data storage in a database. The acquisition of information via the various tools and techniques of evaluation is not the most difficult task during the evaluation phase of a system. Indeed, the interpretation of the gathered data as their analysis is a more delicate task.

8.2 Analysis of the data collected

The second phase is dedicated to the analysis of the recovered data. In order to facilitate the work of the evaluator, we equipped our electronic informer with an analysis data module. The evaluator can thus consult the various data according to the categories already quoted above. With each appearance of a sight (i.e. the visible part of an interface agent), we engage a stopwatch. It stops at the time of its disappearance or its setting behind plane. The output value represents the duration of the visualization of a sight. We attach importance to the duration of appearance of the sights. Indeed, it can exist a close connection between the duration of consultation of a sight and the strategies implemented by the users. The interaction of the user with the system is carried out via the interface agents; so an agent informer is assigned to each interface agent. In parallel, the integration of a mouse agent and of a Keyboard agent have been done; when collaborating with the other agent informers, the Keyboard and Mouse agents have to allow the recording of different actions/reactions from the interface (interface agents) and from the user. Such principles are more detailed in [18].

9 Summary and Conclusions

For economical and ecological reasons, the role of intermodal transportation systems has become increasingly important. It is now crucial to provide the human operators in regulation rooms with systems for making easier their management. A generic model of a traffic regulation support system has been proposed. We are validating the global approach during a project concerning the urban transport network in the town of Valenciennes, France. The article was focused on the decision assistance system and the information assistance system. For the evaluation, an electronic informer for the evaluation of agent oriented interactive system has been realized; its basic principles have been also explained. The proposed approach and the resulting architecture are promising because they are centred on the human activities in regulation room during the different normal and abnormal real situations. Research perspectives concern experimentations in abnormal situations combining different types of dysfunctionnings.

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Tissue P Systems with Cell Division

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Abstract: In tissue P systems several cells (elementary membranes) communicate through symport/antiport rules, thus carrying out a computation. We add to such systems the basic feature of (cell–like) P systems with active membranes – the possibility to divide cells. As expected (as it is the case for P systems with active membranes), in this way we get the possibility to solve computationally hard problems in polynomial time; we illustrate this possibility with SAT problem.
Keywords: Tissue-like P systems, cell division rule, SAT problem, NP-complete problem

1 Introduction

In membrane computing, there are two main classes of P systems: with the membranes arranged hierarchically, inspired from the structure of the cell, and with the membranes placed in the nodes of a graph, all of them at the same level, inspired from the cell inter-communication in tissues. A particularly interesting sub-class of the first class are the systems with active membranes, where the membrane division can be used in order to solve hard problems, e.g., **NP**-complete problems, in polynomial or even linear time, by a space-time trade-off. In the tissue P systems, the communication among cells is performed by means of symport/antiport rules, well-known in biology. Details can be found in [8], [10], as well as in the comprehensive page from the web address `http://ppage.psystems.eu`).

In this paper we combine the two definitions, and consider tissue P systems (with the communication done through symport/antiport rules) with cell division rules of the same form as in P systems with active membranes, but without using polarizations. The rules are used in the non-deterministic maximally parallel way, with the restriction that if a division rule is used for dividing a cell, then this cell does not participate in any other rule, for division or communication (the intuition is that when dividing, the interaction of the cell with other cells or with the environment is blocked); the cells obtained by division have the same labels as the mother cell, hence the rules to be used for evolving them or their objects are inherited (the label precisely identifies the available rules).

This natural extension of tissue P systems provides the possibility of solving SAT problem in polynomial time (with respect to the number of variables and of clauses), in a confluent way: at precise times, one of the objects yes or no is sent to the environment, giving the answer to the question whether the input propositional formula is satisfiable. The construction is uniform: in a polynomial time, a family of recognizing tissue P systems with cell division is constructed, which, receiving as inputs encodings of instances of SAT, tells us whether or not these instances are satisfiable.

2 Tissue P Systems with Cell Division

We assume the reader to be familiar with basic elements of membrane computing and we directly define the class of P systems which is investigated in this paper.

A *tissue P system with cell division* of degree $m \geq 1$ is a construct

$$\Pi = (O, E, w_1, \ldots, w_m, R, i_o),$$

where:

1. $m \geq 1$ (the initial degree of the system; the system contains m cells, labeled with $1,2,\ldots,m$; we will use 0 to refer to the environment);
2. O is the alphabet of *objects*;
3. $w_1,\ldots,w_m$ are strings over O, describing the *multisets of objects* placed in the m cells of the system at the beginning of the computation;
4. $E \subseteq O$ is the set of objects present in the environment in arbitrarily many copies each;
5. R is a finite set of *evolution rules*, of the following forms:
   (a) $(i,x/y,j)$, for $i,j \in \{0,1,2,\ldots,m\}, i \neq j$, and $x,y \in O^*$;
   communication rules; $1,2,\ldots,m$ identify the cells of the system, 0 is the environment; when applying a rule $(i,x/y,j)$, the objects of the multiset represented by x are sent from region i to region j and simultaneously the objects of the multiset y are sent from region j to region i;
   (b) $[\, a\,]_i \rightarrow [\, b\,]_i [\, c\,]_i$, where $i \in \{1,2,\ldots,m\}$ and $a,b,c \in O$;
   division rules; under the influence of object a, the cell with label i is divided in two cells with the same label; in the first copy the object a is replaced by b, in the second copy the object a is replaced by c; all other objects are replicated and copies of them are placed in the two new cells.
6. $i_o \in \{1,2,\ldots,m\}$ is the output cell.

Therefore, we use antiport rules for communication (for a rule $(i,x/y,j)$ we say that the maximum of the lengths of x and y is the *weight* of the rule), and division rules as in P systems with active membranes.

The rules of a system as above are used in the non-deterministic maximally parallel manner as customary in membrane computing. In each step, all cells which can evolve must evolve in a maximally parallel way (in each step we apply a multiset of rules which is maximal, no further rule can be added), with the following important mentioning: if a cell is divided, then the division rule is the only one which is applied for that cell in that step, its objects do not evolve by means of communication rules. This is like saying that a cell which divides first cuts all its communication channels with the other cells and with the environment; the dotter cells will participate to the interaction with other cells or with the environment only in the next step – providing that they are not divided once again. Their label precisely identify the rules which can be applied to them.

The computation starts from the initial configuration and proceeds as defined above; only halting computations give a result, and the result is the number of objects present in the halting configuration in cell i_o; the set of numbers computed in this way by the various halting computations in Π is denoted by $N(\Pi)$.

In the present paper we are not interested in the computing power of systems as above – already systems without membrane division are known to be Turing complete (see [8], [6], etc.), but in their computing efficiency. That is why we introduce a variant of tissue P systems with membrane division, namely *recognizing systems with input* following the definitions of complexity classes in terms of membrane computing (see [9]). Such a system has the form $\Pi = (O,\Sigma,E,w_1,\ldots,w_m,R,i_{in})$, where:

- $(O,E,w_1,\ldots,w_m,R,0)$ is a tissue P system with cell division of initial degree $m \geq 1$ (as defined in the previous section, but with the environment, indicated by taking $i_o = 0$, used for reading the output of a computation), and $w_1,\ldots,w_m$ are strings over $O-\Sigma$.

- The working alphabet O has two distinguished objects `yes` and `no`, present in at least one copy in some initial multisets w_1, ..., w_m, but not present in $\mathcal{E}$.

- Σ is an (input) alphabet strictly contained in O.

- $i_{in} \in \{1,\ldots,m\}$ is the input cell.

- All computations halt.

- If $\mathcal{C}$ is a computation of Π, then either the object yes or the object no (but not both) must have been released into the environment, and only in the last step of the computation.

The computations of the system Π with input $w \in \Sigma^*$ start from a configuration of the form $(w_1, w_2, \ldots, w_{i_{in}} w, \ldots, w_m; E)$, that is, after adding the multiset w to the contents of the input cell i_{in}. We say that the multiset w is *recognized* by Π if and only if the object yes is sent to the environment, in the last step of the corresponding computation. We say that $\mathcal{C}$ is an accepting computation (respectively, rejecting computation) if the object yes (respectively, no) appears in the environment associated with the corresponding halting configuration of $\mathcal{C}$.

Definition 1. We say that a decision problem $X = (I_X, \theta_X)$ is solvable in polynomial time by a family $\Pi = \{\Pi(n) \mid n \in \mathbf{N}\}$ of recognizer tissue-like P systems with cell division if the following holds:

- The family Π is *polynomially uniform* by Turing machines, that is, there exists a deterministic Turing machine working in polynomial time which constructs the system $\Pi(n)$ from $n \in \mathbf{N}$.

- There exists a pair (cod, s) of polynomial-time computable functions over I_X (called a polynomial encoding of I_X in Π) such that:

  – for each instance $u \in I_X$, $s(u)$ is a natural number and $cod(u)$ is an input multiset of the system $\Pi(s(u))$;
  – the family Π is *polynomially bounded* with regard to (X, cod, s), that is, there exists a polynomial function p, such that for each $u \in I_X$ every computation of $\Pi(s(u))$ with input $cod(u)$ is halting and, moreover, it performs at most $p(|u|)$ steps;
  – the family Π is *sound* with regard to (X, cod, s), that is, for each $u \in I_X$, if there exists an accepting computation of $\Pi(s(u))$ with input $cod(u)$, then $\theta_X(u) = 1$;
  – the family Π is *complete* with regard to (X, cod, s), that is, for each $u \in I_X$, if $\theta_X(u) = 1$, then every computation of $\Pi(s(u))$ with input $cod(u)$ is an accepting one.

We denote by $\mathbf{PMC}_{TD}$ the set of all decision problems which can be solved by means of recognizer tissue-like P systems with cell division in polynomial time. This class is closed under polynomial–time reduction and under complement.

We close this section with an important remark about the previous way of solving decision problems. Specifically, we have said nothing about the way the computations proceed; in particular, they can be non-deterministic, as standard in membrane computing. It is important however that the systems always stop and always they send out an object which is the correct answer to the input problem. From the soundness and completeness conditions above we deduce that every P system $\Pi(n)$ is *confluent*, in the following sense: every computation of a system with the *same* input multiset must always give the *same* answer.

3 Solving SAT in Polynomial Time

As expected, the possibility to divide cells means the possibility to create an exponential space in a linear time, and this space can be used in order to obtain fast solutions to computationally hard problems.

Theorem 1. *Tissue P systems with active membranes can solve* SAT *in polynomial time. (Otherwise stated,* SAT $\in \mathbf{PMC}_{TD}$*.)*

Proof. Let us consider a propositional formula $\gamma = C_1 \wedge \cdots \wedge C_m$, consisting of m clauses $C_j = y_{j,1} \vee \cdots \vee y_{j,k_j}$, $1 \leq j \leq m$, where $y_{j,i} \in \{x_l, \neg x_l \mid 1 \leq l \leq n\}$, $1 \leq i \leq k_j$ (there are used n variables). Without loss of generality, we may assume that no clause contains two occurrences of some x_i or two occurrences of some $\neg x_i$ (the formula is not redundant at the level of clauses), or both x_i and $\neg x_i$ (otherwise such a clause is trivially satisfiable, hence can be removed).

We codify γ, which is an instance of SAT with size parameters n and m, by the multiset

$$\begin{aligned} cod(\gamma) &= \{s_{i,j} \mid y_{j,r} = x_i,\ 1 \leq i \leq n, 1 \leq j \leq m, 1 \leq r \leq k_j\} \\ &\cup \{s'_{i,j} \mid y_{j,r} = \neg x_i,\ 1 \leq i \leq n, 1 \leq j \leq m, 1 \leq r \leq k_j\}. \end{aligned}$$

(We replace each variable x_i from each clause C_j with $s_{i,j}$ and each negated variable $\neg x_i$ from each clause C_j with $s'_{i,j}$, then we remove all parentheses and connectives. In this way we pass from γ to $cod(\gamma)$ in a number of steps which is linear with respect to $n \cdot m$.)

The instance γ will be processed by the tissue P system $\Pi(s(\gamma))$ with input $cod(\gamma)$, where $s(\gamma) = \langle n,m \rangle = \frac{(n+m)\cdot(n+m+1)}{2} + n$. We construct the recognizing tissue P system (of degree 2) with input

$$\Pi(\langle n,m \rangle) = (O, \Sigma, E, w_1, w_2, R, 2),$$

with the following components:

$$\begin{aligned} O &= \Sigma \cup \{a_i, t_i, f_i \mid 1 \leq i \leq n\} \cup \{r_i \mid 1 \leq i \leq m\} \\ &\cup \{T_i, F_i \mid 1 \leq i \leq n\} \cup \{T_{i,j}, F_{i,j} \mid 1 \leq i \leq n, 1 \leq j \leq m+1\} \\ &\cup \{b_i \mid 1 \leq i \leq 3n+m+1\} \cup \{c_i \mid 1 \leq i \leq n+1\} \\ &\cup \{d_i \mid 1 \leq i \leq 3n+nm+m+2\} \cup \{e_i \mid 1 \leq i \leq 3n+nm+m+4\} \\ &\cup \{f, g, \texttt{yes}, \texttt{no}\}, \\ \Sigma &= \{s_{i,j}, s'_{ij} \mid 1 \leq i \leq n,\ 1 \leq j \leq m\}, \\ E &= O - \{\texttt{yes}, \texttt{no}\}, \\ w_1 &= \texttt{yes}\ \texttt{no}\ b_1\ c_1\ d_1\ e_1, \\ w_2 &= f\ g\ a_1\ a_2\ \ldots\ a_n, \end{aligned}$$

and the following rules.

1. **Division rules:**

   $[\, a_i \,]_2 \to [\, T_i \,]_2 [\, F_i \,]_2$, for all $i = 1, 2, \ldots, n$.

   (Membrane 2 is repeatedly divided, each time expanding one object a_i, corresponding to a variable x_i, into T_i and F_i, corresponding to the values *true* and *false* which this variable may assume. In this way, in n steps, we get 2^n cells with label 2, each one containing one of the 2^n truth-assignments possible for the n variables. The objects f, g are duplicated, hence a copy of each of them will appear in each cell.)

2. **Communication rules:**

   $(1, b_i/b_{i+1}^2, 0)$, for all $i = 1, 2, \ldots, n+1$,
   $(1, c_i/c_{i+1}^2, 0)$, for all $i = 1, 2, \ldots, n+1$,
   $(1, d_i/d_{i+1}^2, 0)$, for all $i = 1, 2, \ldots, n+1$,
   $(1, e_i/e_{i+1}, 0)$, for all $i = 1, 2, \ldots, 3n+nm+m+3$.

   (In parallel with the operation of dividing cell 2, the counters b_i, c_i, d_i, e_i from cell 1 grow their subscripts. In each step, the number of copies of objects of the first three types is doubled, hence after n steps we get 2^n copies of b_{n+1}, c_{n+1}, and d_{n+1}. Objects b_i will check which clauses are satisfied by a given truth-assignment, objects c_i are used in order to multiply the number of copies of t_i, f_i as we will see immediately, d_i are used to check whether there is at least one truth-assignment which satisfies all clauses, and e_i will be used in order to produce the object no, if this will be the case, in the end of the computation.)

$(1, b_{n+1}c_{n+1}/f, 2)$,
$(1, d_{n+1}/g, 2)$.

(In step $n+1$, the counters $b_{n+1}, c_{n+1}, d_{n+1}$ are brought in cells with label 2, in exchange of f and g. Because we have 2^n copies of each object of these types and 2^n cells 2, each one containing exactly one copy of f and one of g, due to the maximality of the parallelism of using the rules, each cell 2 gets precisely one copy of each of $b_{n+1}, c_{n+1}, d_{n+1}$. Note that cells 2 cannot divide any more, because the objects a_i were exhausted.)

$(2, c_{n+1}T_i/c_{n+1}T_{i,1}, 0)$,
$(2, c_{n+1}F_i/c_{n+1}F_{i,1}, 0)$, for each $i = 1, 2, \ldots, n$,
$(2, T_{i,j}/t_iT_{i,j+1}, 0)$,
$(2, F_{i,j}/f_iF_{i,j+1}, 0)$, for each $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$.

(In the presence of c_{n+1}, the objects T_i, F_i introduce the objects $T_{i,1}$ and $F_{i,1}$, respectively, which initiates the possibility of introducing m copies of each t_i and f_i in each cell 2. The idea is that because we have m clauses, in order to check their values for a given truth-assignment of variables, it is possible to need one value for each variable for each clause. Note that this phase needs $2n$ steps for introducing the double-subscripted objects $T_{i,1}, F_{i,1}$ – for each one we need one step, because we have only one copy of c_{n+1} available – then further m steps are necessary for each $T_{i,1}, F_{i,1}$ to grow its second subscript; all these steps are done in parallel, but for the last introduced $T_{i,1}, F_{i,1}$ we have to continue m steps after the $2n$ necessary for priming. In total, we perform $2n+m$ steps.)

$(2, b_i/b_{i+1}, 0)$,
$(2, d_i/d_{i+1}, 0)$, for all $i = n+1, \ldots, (n+1)+(2n+m)-1$.

(In parallel with the previous operations, the counters b_i and d_i increase their subscripts, until reaching the value $3n+m+1$. This is done in all cells 2 at the same time. Simultaneously, e_i increases its subscript in cell 1.)

$(2, b_{3n+m+1}t_is_{i,j}/b_{3n+m+1}r_j, 0)$,
$(2, b_{3n+m+1}f_is'_{i,j}/b_{3n+m+1}r_j, 0)$, for all $1 \le i \le n$ and $1 \le j \le m$,
$(2, d_i/d_{i+1}, 0)$, for all $i = 3n+m+1, \ldots, (3n+m+1)+nm-1$.

(In the presence of b_{3n+m+1} – and not before – we check the values assumed by clauses for the truth-assignments from each cell 2. We have only one copy of b_{3n+m+1} in each cell, hence we need at most nm steps for this: each clause contains at most n literals, and we have m clauses. In parallel, d increases the subscript, until reaching the value $3n+nm+m+1$.)

$(2, d_{3n+nm+m+i}r_i/d_{3n+nm+m+i+1}, 0)$, for all $i = 1, 2, \ldots, m$.

(In each cell with label 2 we check whether or not all clauses are satisfied by the corresponding truth-assignment. For each clause which is satisfied, we increase by one the subscript of d, hence the subscript reaches the value $3n+nm+2m+1$ if and only if all clauses are satisfied.)

$(2, d_{3n+nm+2m+1}/f\ \texttt{yes}, 1)$.

(If one of the truth-assignments from a cell 2 has satisfied all clauses, then we reach $d_{3n+nm+2m+1}$, which is sent to cell 1 in exchange of the objects yes and f.)

$(2, \texttt{yes}/\lambda, 0)$.

(In the next step, the object yes leaves the system, signaling the fact that the formula is satisfiable. In cell 1, the counter e will increase one more step its subscript, but after that it will remain unchanged – it can leave cell 1 only in the presence of f, but this object was already moved to cell 2.)

$(1, e_{3n+nm+2m+2} f\ \texttt{no}/\lambda, 2)$,
$(2, \texttt{no}/\lambda, 0)$.

(If the counter e reaches the subscript $3n+nm+2m+2$ and the object f is still in cell 1, then the object no can be moved to a cell 2, randomly chosen, and from here it exits the system, signaling that the formula is not satisfiable.)

In order to show that the family $\Pi = \{\Pi(\langle n,m\rangle) \mid n,m \in \mathbf{N}\}$ is polynomially uniform by deterministic Turing machines we first note that the sets of rules associated with the system $\Pi(\langle n,m\rangle)$ are recursive. Hence, it is enough to note that the amount of necessary resources for defining each system is quadratic in $\max\{n,m\}$, and this is indeed the case, since those resources are the following:

1. Size of the alphabet: $6nm+17n+4m+12 \in \Theta(nm)$.
2. Initial number of cells: $2 \in \Theta(1)$.
3. Initial number of objects: $n+8 \in \Theta(n)$.
4. Number of rules: $4nm+10n+3m+16 \in \Theta(nm)$.
5. Upper bound for the length of the rules: $3 \in \Theta(1)$

From the previous explanations, one can see that, starting with the multiset $cod(\gamma)$ added to cell 2, which is the input cell, the system correctly answers the question whether or not γ is satisfiable. The duration of the computation is polynomial in terms of n and m: the answer yes is sent out in step $3n+nm+2m+2$, while the answer no is sent out in step $3n+nm+2m+4$. This concludes the proof. □

The antiport rules from the previous construction are of weight at most 3, but the weight can be reduced to two, at the expense of some slowdown of the system. For instance, instead of the rule $(1, e_{3n+nm+2m+2} f\ \texttt{no}/\lambda, 2)$ we can consider the rules $(1, e_{3n+nm+2m+2} f/h, 0)$, $(1, h\ \texttt{no}/\lambda, 2)$, where h is a new object. We can proceed in the same way with the rules $(2, b_{3n+m+1} t_i s_{i,j}/b_{3n+m+1} r_j, 0)$, $(2, b_{3n+m+1} f_i s'_{i,j}/b_{3n+m+1} r_j, 0)$, for $1 \le i \le n$ and $1 \le j \le m$, but in this way instead of at most nm steps for finding the satisfied clauses we will need at most $2nm$ steps. The details are left to the reader.

Taking into account that SAT is an **NP**–complete problem and the class $\mathbf{PMC}_{TD}$ is closed under polynomial–time reduction and under complement, we have:

Corollary 2. $\mathbf{NP} \cup \mathbf{co\text{-}NP} \subseteq \mathbf{PMC}_{TD}$

4 Final Remarks

We have proven that by adding the membrane division feature to tissue P systems (with the communication done by antiport rules of a small weight) we can solve **NP**-complete problems in polynomial time. We exemplify this possibility with SAT problem.

It remains as a research topic to consider the same extension for other types of systems, for instance, for cell P systems with symport/antiport rules, or for neural P systems (with states associated with cells and multiset rewriting rules for processing the objects. The difficulty in the case of cell P systems with symport/antiport comes from the fact that only the skin membrane can communicate with the environment; on the other hand, the skin membrane cannot be divided, hence we need exponentially many objects for communication with inner membranes, and such objects should be brought in from the environment. In turn, neural P systems with the maximal use of rules and replicated communication are already known to be able to solve **NP**-complete problems in polynomial time; the challenge now is not to use replication). In spite of these difficulties, we expect results similar to the above one also in these cases.

Another problem which remains open is to consider tissue P systems with the communication using only symport rules.

A previous version of the present paper was circulated in the volume of the Second Brainstorming Week on Membrane Computing, held in Sevilla, in February 2004, and in the meantime several papers have considered tissue-like P systems with cell division as a framework for devising polynomial solutions to **NP**-complete problems. For instance, [2] deals with the Subset Sum problem, [3] deals with the Partition problem, [5] deals with the Vertex Cover problem, and [4] considers the 3–coloring problem. What is not yet investigated is the possibility to also solve **PSPACE** problems, as it is the case, for instance, for cell-like P systems with division of non-elementary membranes (see [11]) or with membrane creation (see [7]). This last possibility for producing working space, cell creation rules, has been only recently considered for tissue P systems [1]. Let us recall that this kind of rules does not perform replication of objects, as it happens with cell-division rules, and it is an open question whether tissue P systems with communication and membrane creation rules can solve efficiently computationally hard problems.

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Surface Roughness Image Analysis using Quasi-Fractal Characteristics and Fuzzy Clustering Methods

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Abstract: In this paper the authors describe the results of experiments for surface roughness image acquisition and processing in order to develop an automated roughness control system. This implies the finding of a characteristic roughness parameter (for example Ra) on the bases of information contained in the image of the surface. To achieve this goal we use quasi-fractal characteristics and fuzzy clustering methods.
Keywords: image processing, surface roughness, quasi- fractal parameters, fuzzy clustering.

1 Introduction

Surface roughness of manufactured products is defined in SR ISO 4287/2001 standard and other international standards. Simple and complex characterization parameters are explained in works like [1], which are considering the use of stylus devices to measure roughness after a linear or curved path [3, 7, 7, 12]. Although these devices had been continuously upgraded in order to increase measuring precision [3], they are not efficient enough used in automated measuring systems, due to the fact that the stylus must make contact with the measured surface and also due to the very long time of measurement. A newer technique in surface roughness measurement is the employment of digital image acquisition and processing [4, 6]. In this case the camera is coupled to a microscope (bellow a magnification of x100) and the acquisitioned images are processed with specially designed computer programs. So one image of 24 mm^2, corresponds to 100 stylus scanning.

In the paper [10] a method of summit and directionality identification of textured images is defined using surface image analysis. In [2] there is shown that surfaces obtained by turning, milling and grinding presents a high complexity when they are analyzed by optical, electron microscopes or AFM (Atomic Force Microscope). Isotropic surfaces obtained by machining can be characterized by the Mandelbrot-Weierstrass function using fractal methods. For the characterization of anisotropic surfaces some authors are proposing methods based on the two dimensional FFT algorithm. This method had been used for characterization of grinded surface.

The basic idea in [11] is to decompose the surface roughness (described in terms of amplitude, wave length and direction) in convex elements (summits) and then analyze these structures with morphologic trees. The authors claim that clear correlations can be obtained between the obtained morphologic tress and the tribologic proprieties of the surfaces.

In [4] the correspondence between surface roughness obtained with a certain manufacturing method and its image had been studied based on functional dependence between roughness height and the grey level values of the image. The authors had studied these correspondences with the help of polynomial nets, trained with experimental results, which has as inputs cutting speed, feed and cutting depth and also the mean values of image grey levels. The polynomial net is capable to estimate the surface roughness with an acceptable accuracy, which had been validated with a series of experimental measurements. The advantage of this method is the possibility to apply it to online roughness estimation in turning processes.

The paper [9] proposes a new method to analyze and characterize the surface roughness. On the basis of an algorithm in three steps the classification of textured images of some manufactured surfaces is made, surfaces obtained by casting, milling and grinding. In the first step the image is processed by a frequency normalized wavelet transform, obtaining a set of images at different scales and phases. In the second step characteristic parameter values are extracted and in the third step the image classification is obtained using the set of extracted features.

From the synthesis of presented works, it can be concluded that the method of surface image processing is better than the methods using the stylus type measurement, because it is faster and there is no contact between the measuring instrument and the surface. It also has been shown that there is a correlation between the height of the roughness and the image grey levels and the estimation of surface roughness can be done in similar ways as texture analysis.

2 Acquisition and Preprocessing of Surface Images

For image acquisition purposes several manufactured roughness probes with known roughness parameters were used (STALÎ DOVODCA - GOST 9378-80 E15718) obtained by manufacturing operations as: cylindrical milling, plane milling, shaping, frontal grinding, plane grinding and polishing. In this paper only surface roughness images representing shaping, plane grinding and polishing will be analyzed, because these images are more similar to each other and harder to classify. Four non-overlapping images, of every probe's surface were taken using a CCD camera mounted on a CITIVAL microscope at magnifications of x10 and x25. The resolution of the images was 640x480 pixel. The correlation between surface roughness and surface image had been studied in a large number of papers [4] showing a certain functional dependency between asperity height and image intensity. During experiments however, we observed that this correlation is more complex and depends in a very high degree on the illumination conditions of the probe. Usual image processing phases, of non-object representation images are presented in [14].

After the image acquisition, a number of preprocessing operations had to be made in order to obtain better image quality. The used preprocessing steps were as follows:

- *filtering* - eliminate inherent image noises;
- *establishing region of interest* - keep only high information regions of the image;
- *uneven illumination effects elimination* - eliminate effects of higher intensity in the middle of the image, which is characteristic for images taken with microscopes (figure 1 and 2) ;
- *correction of probe rotation and position variations* - as the images are anisotropic, rotation of the probe can alter the analysis results. Here 2D Fast Fourier Transforms described in [2] or oriented Gabor filters described in [5], can be used. The authors had tested several automatic image rotation algorithms and finally a 1D FFT method was used.

On the base of tested preprocessing methods a program module had been developed, which can perform al preprocessing steps automatically and which can be eventually included in an automated quality control system. After preprocessing, the image quality was fair enough to perform the next step of image processing. Studying recent researches in texture analysis and image processing a number of statistical methods (co-occurrence, statistical moments) and frequency domain methods (Gabor filters, wavelet analysis), had been tested in order to obtain automated recognition of surface roughness parameters, but these methods didn't yield the wanted results. So we focused our research on fractal methods.

3 Fractal Image Processing Characterization

Considering the goal of our research, computation of fractal dimension is less important from a practical point of view. It is more important to use fractal or pseudo-fractal parameters in order to discriminate surfaces with different roughness characteristics. Fractal dimension computation of rough

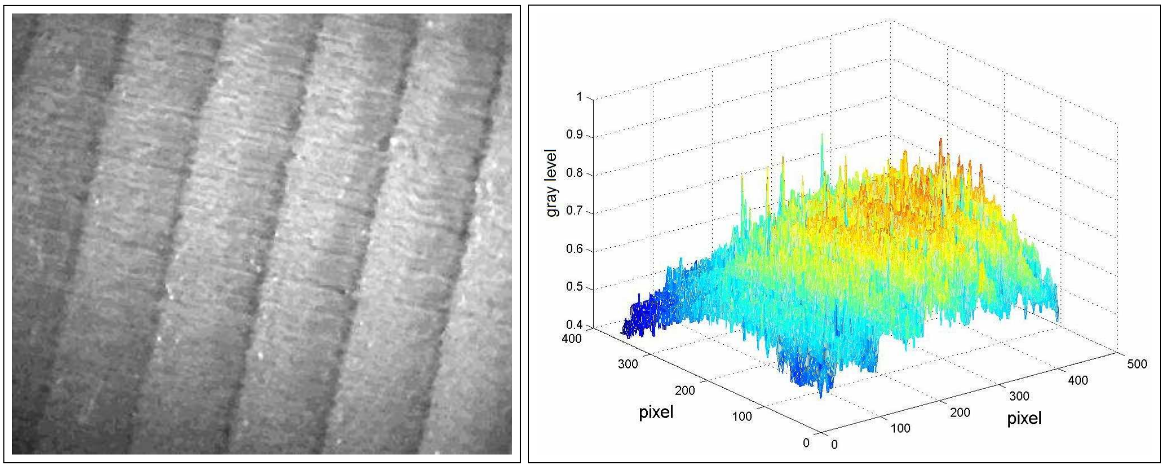

Figure 1: Surface image with higher center intensity.

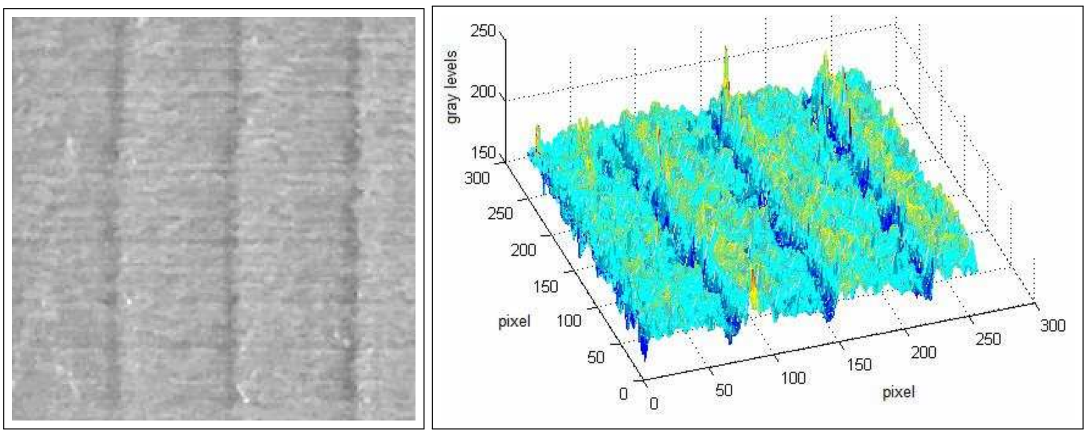

Figure 2: Image after preprocessing (uneven lighting and rotation has been eliminated).

surfaces using the Weierstrass-Mandelbrot function is described in [2] and others. When this function is correlated to power spectral density, the fractal dimension is correlated to the slope of the spectrum represented in logarithmic scale. The Weierstrass-Mandelbrot function is difficult to apply in practice. That is why we had to use methods, which are easier to implement as computer algorithms. These methods are the box counting method (BC) and the frequency domain fractal parameter (using power spectral density diagrams). Both methods had been tested on the roughness probes images. The box counting method (BC) had been derived from the "compass dimension" and is closely related to fractal dimension as it has been stated by Mandelbrot with the relation:

$$D = \frac{\log N}{\log(1/r)} \tag{1}$$

The compass dimension is obtained measuring a curve (which can represent a section through a surface) with decreasing measuring units ($r_i, i = k...1$) and storing the number of measures N_i for each r_i. The diagram of $log(N_i)$ as function of $log(1/r_i)$ is drawn obtaining a so called Richardson plot. If the Richardson plot is a straight line then the measured object is fractal and the slope of the plot is it's compass dimension. The BC method uses rectangular boxes of decreasing edges instead the linear measure r_i. Fractal dimension can also be computed on the bases of power spectral density (PSD), as it is stated in [1]. If the PSD amplitude is represented as a function of spatial frequency (f) in a logarithmic diagram then the fractal parameter can be considered as the slope (p'_1) of the log(PSD) approximation line and the (p_2') as the intersection of this line with the ordinate axis.

$$\log(PSD) = p'_1 \log(f) + p'_2 \tag{2}$$

First we have developed a 2D box counting algorithm and then a 3D algorithm (which uses 3D boxes on 3D matrix as shown in figure 2) both yielding satisfactory results. Although the obtained results show that the analyzed images do not have true fractal behavior (the resulted Richardson plot is not a rigorously straight line), the goal is to find correlations between obtained parameters on one hand and the surface roughness on the other hand.

In this research we had used the BC3D (3 dimensional box counting) method, but in the Richardson plot, instead of using only linear approximation in order to define parameters, we also used second and third degree polynomials. If we denote $y = \log(N_i)$ and $x = \log(1/r_i)$, we will have the following relations:

$$y = p_1 x + p_2 \tag{3}$$
$$y = p_3 x^2 + p_4 x + p_5 \tag{4}$$
$$y = p_6 x^3 + p_7 x^2 + p_8 x + p_9 \tag{5}$$

Examples of curve fitting for relations (3), (4), (5) are given in figures 3, 4 and 5.

We had considered then to use coefficients p1Ěp9 to characterize the roughness of the studied manufactured surfaces. These coefficients had been named by us "quasi fractal parameters" (QFP, meaning fractal-like parameters) highlighting the fact that they are not rigorously correlated to fractal dimension.

In order to study the possibilities to classify images representing rough surfaces, with the above defined parameters, we have made two dimensional representations that we denoted as QFP diagrams (Quasi Fractal Parameter Diagrams). Each of these diagrams represents a bi-dimensional space having as dimensions two of the QFPs defined above.

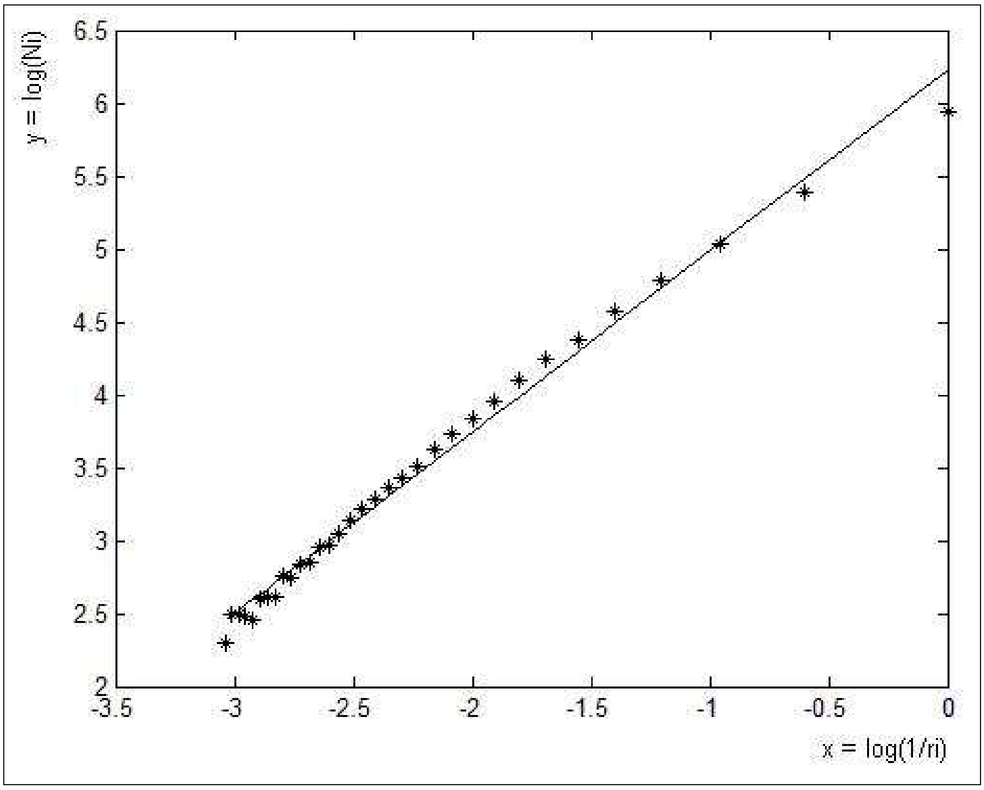

Figure 3: Linear curve fitting for points obtained with the BC3D algorithm applied on an image of shaped surface.

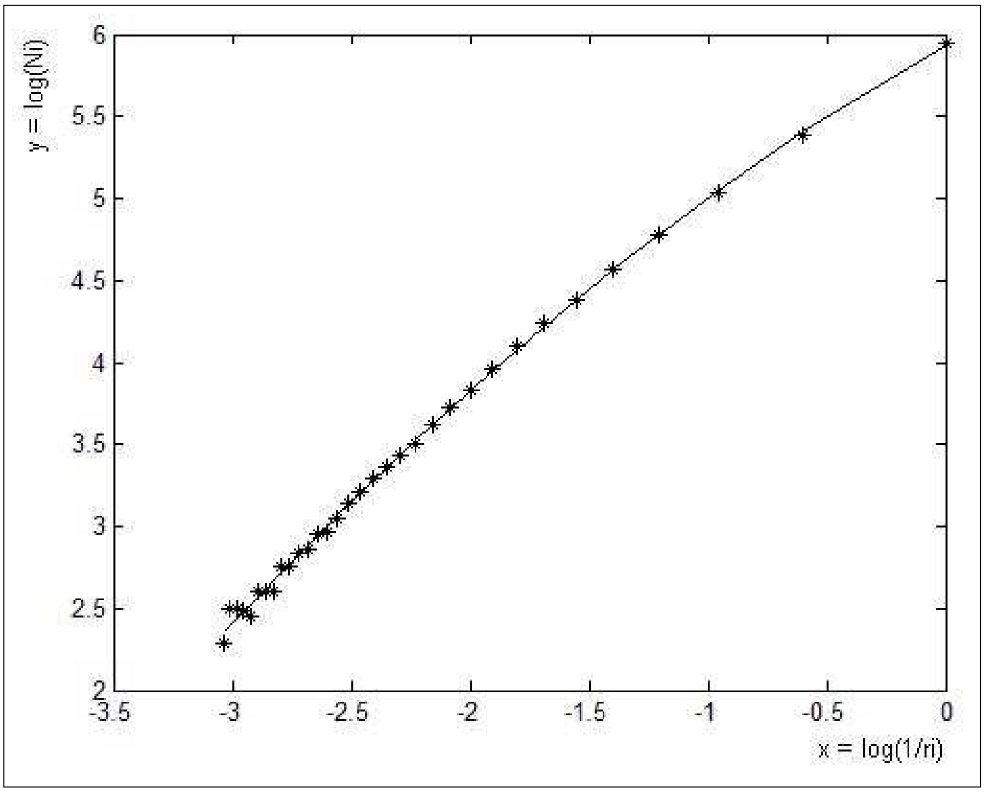

Figure 4: Second order polynomial curve fitting for points obtained with the BC3D algorithm applied on an image of shaped surface.

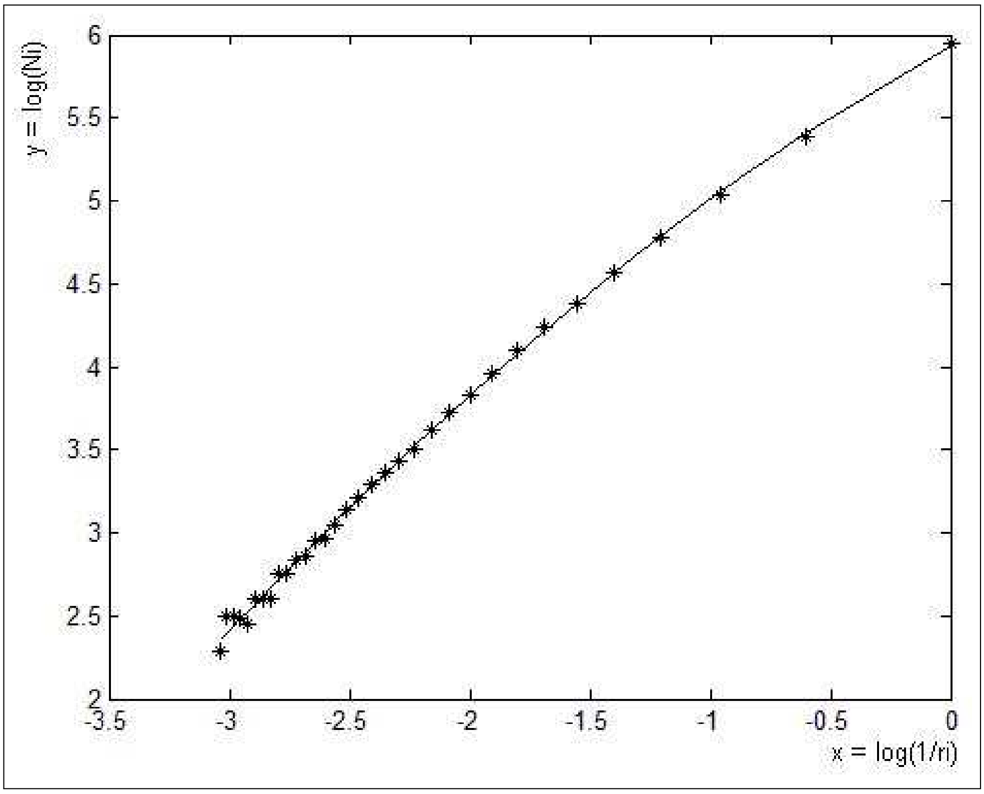

Figure 5: Third order polynomial curve fitting for points obtained with the BC3D algorithm applied on an image of shaped surface.

4 Experimental Considerations

In order to establish how QFPs can characterize surface roughness we had acquired and processed four different images from each surface roughness probe, for three types of cutting operations: shaping with 4 different roughness values, grinding with four different roughness values and polishing with three different roughness values. Table 1 shows sample categories, roughness values, sample codes and diagram symbols. In diagram symbols the color represents the operation and the symbol represents a specific roughness value.

Some examples of analyzed images are shown in figure 6.

There had been also acquired images for magnification of x25. For both magnifications, the images had been studied using QFP diagrams. Two examples of such diagrams are shown in figure 6.a and 6.b.

Comparing diagrams in figures 6.a. and 6.b., it can be observed that some of the same studied samples have different locations in the parameter space. For example the black squares (representing S4 samples) have one location for x10 magnification and other location for x25 magnification. This shows that p1 and p2 parameters are not “true fractal” parameters because they do not exhibit an invariance to scale, but this also shows that if in x10 magnification we can not really distinguish the S4 samples from the G group samples, at x25 magnification the S4 samples are well distinguishable. This lead to the conclusion that acquiring and analyzing sample images at different magnifications can help to better discriminate the samples. The selection of optimum magnifications to be used needs to be experimented for large sets of images. In this paper we will present discrimination algorithms only for samples with magnification of x10. The establishing of box dimension range is also an issue, but this can be also solved with experiments on large sets of calibration images. The authors plan to present algorithms for these issues in a future work. We had mentioned before that there is a closed link between fractal dimension

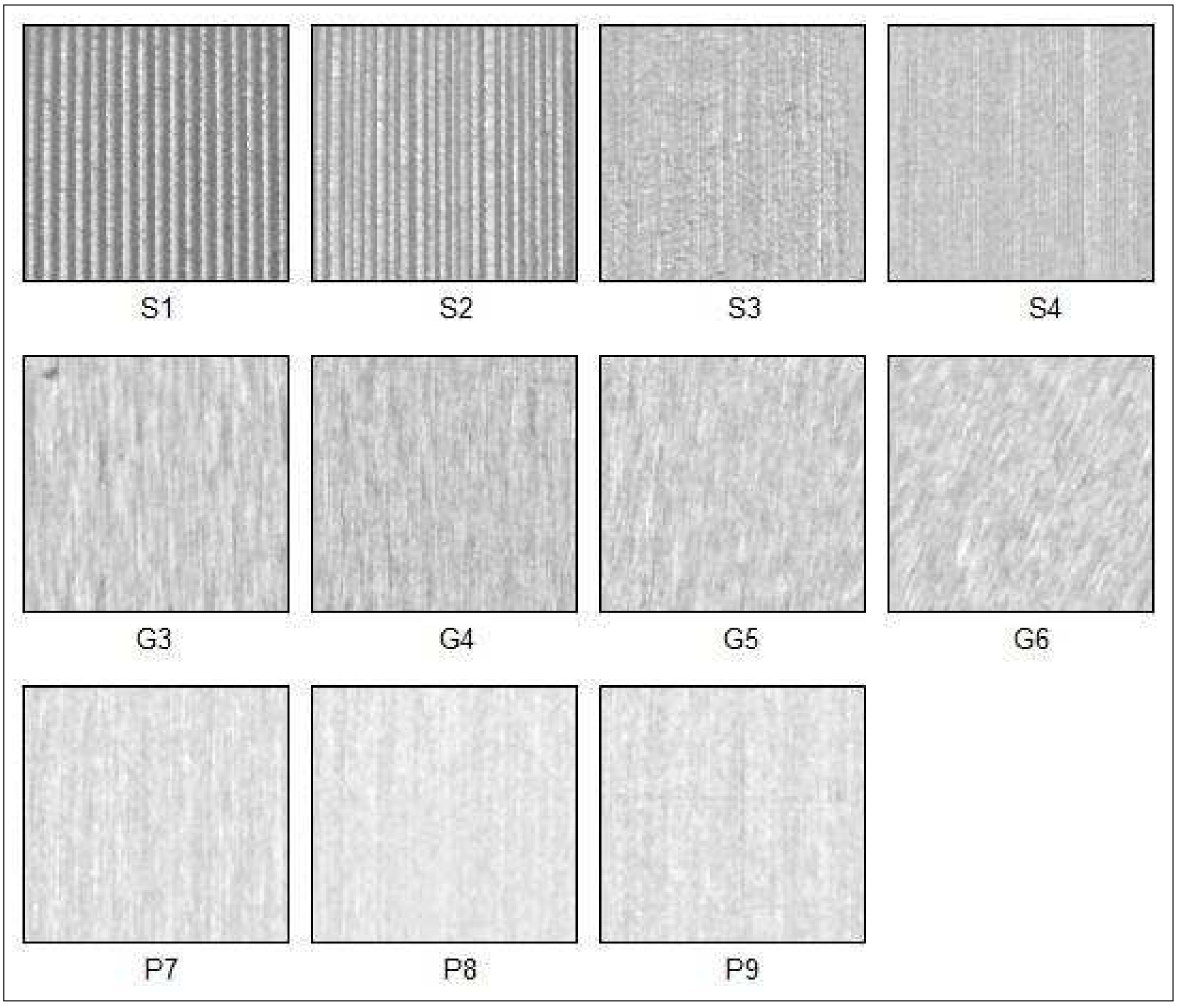

Figure 6: Examples of studied images (magnification x10, coding as stated in Table 1).

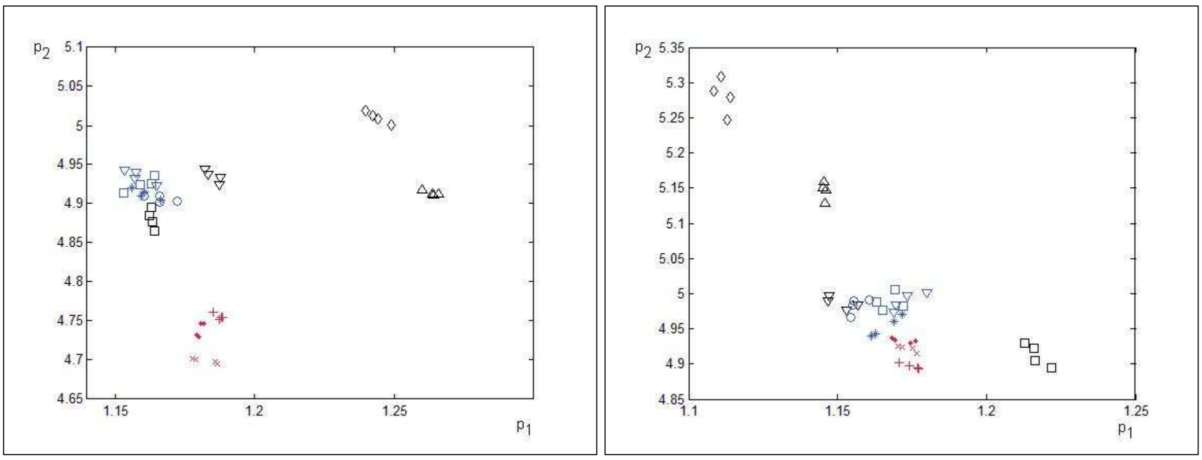

Figure 7: QFP diagrams for parameters $p_1 - p_2$, a. magnification x10; b. magnification x25.

Table 1:

Machining operation	Roughness (Ra)	Code	Diagram symbol
Shaping	12.5 – 6.3	S1	Black diamond
	6.3 – 3.2	S2	Black up pointing triangle
	3.2 – 1.6	S3	Black down pointing triangle
	1.6-0.8	S4	Black square
Grinding	3.2 – 1.6	G3	Blue down pointing triangle
	1.6 – 0.8	G4	Blue square
	0.8 – 0.4	G5	Blue circle
	0.4 – 0.2	G6	Blue star
Polishing	0.2 – 0.1	P7	Red plus sign
	0.1 – 0.05	P8	Red x
	0.05 – 0.025	P9	Red dot

and power spectral density parameters, obtained with FFT methods [1] and [2]. The authors had made experiments with the PSD method too, in order to compare the two methods. For the PSD method the same probes were used as in the first case. The obtained results were very close to results obtained with the box counting method. Here an issue to solve is the automated selection of the analysis frequency range. Establishing samples discrimination can be made automatically by a series of clustering methods, like fuzzy c-means or artificial neural networks. The goal of applying clustering methods is to find the cluster center for each sample with known roughness parameter (training phase). After finding the cluster central point this will be used to classify unknown roughness samples (recognition phase). In this phase we will discuss only the training phase.

Regardless what kind of clustering method we use, a good practice is to make the discrimination in successive steps:

1. plot the QFP diagrams for combinations of quasi-fractal parameters taken by two (it is also possible to use higher order QFP spaces, but these can not be properly represented in diagrams);
2. apply a clustering algorithm and find cluster centers;
3. observe which samples are well discriminated, store the cluster centers for these samples and eliminate them from the data set;
4. restart from step 1. with the remaining samples, until all the samples are discriminated.

5 Fuzzy C-Means Clustering of Quasi-Fractal Parameters

In order to perform sample discrimination, we choose to use the fuzzy c-means clustering method, which has been implemented in some programming environments as for example in MATLAB. This method does not need large sets of data for training and was suitable for our purpose. In this method each sample is considered to be a part of a cluster, in some degree, defined by a membership degree. This method has been introduced in [13], as an enhancement of existing clustering methods. The method solves the problem of clustering by grouping data sets in multi-dimensional spaces in a number of specified clusters. The method starts with an estimation of the cluster centers marking the central value of each cluster. In the same time, for each sample is assigned a membership degree, which reflects the belonging of that sample to certain cluster. The initial cluster center is then successively modified in order to achieve the minimum of an objective function which is the distance of a sample to the center, weighted by the samples membership degree.

We are presenting in the followings the results obtained applying the fuzzy c-means clustering method to the QFP spaces of the described samples. Final clustering is achieved in 4 phases.

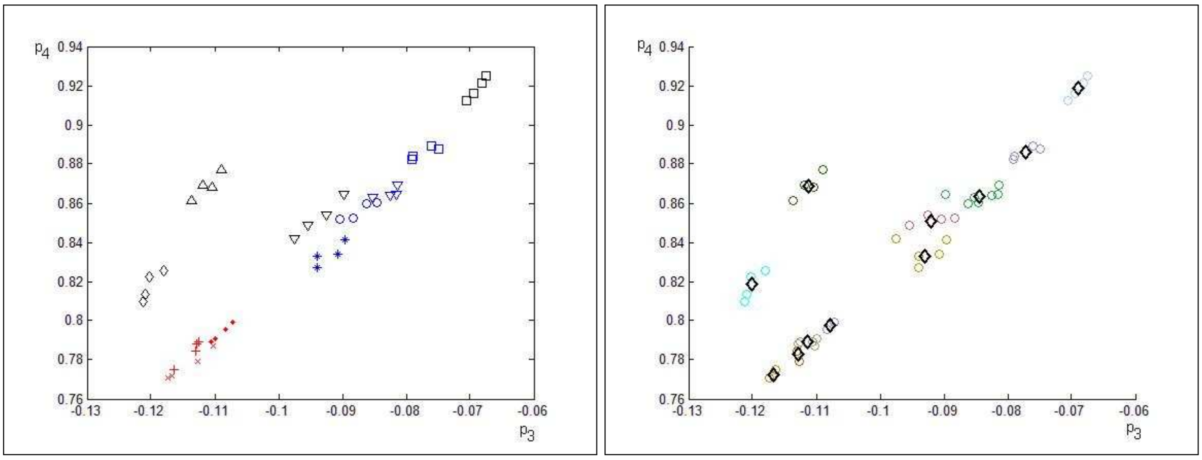

Figure 8: QFP diagram (a) and clustering (b) for phase 1.

The black diamond markers in (b) represent the cluster center and each color represents one cluster.

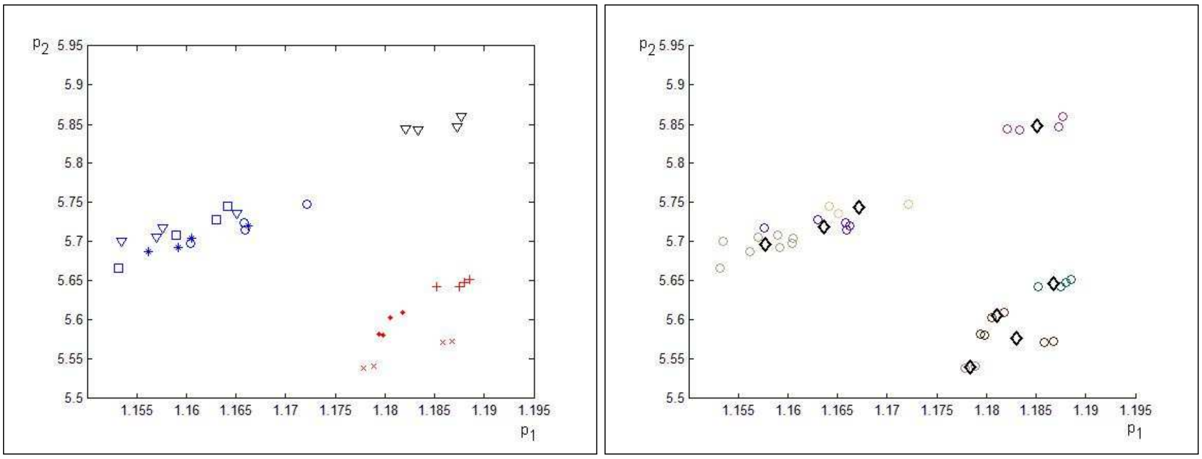

Figure 9: QFP diagram (a) and clustering (b) for phase 2.

The black diamond markers in (b) represent the cluster center.

In the first phase (figure 8) we could find a well discriminated clustering of samples S1, S3, S4, in the second phase (figure 9) we discriminate S2, in the third (figure 10) P1, P2, P3 and G6 and eventually in phase four (figure 11) G3, G4, G5. The found cluster centers will serve to classify any unknown sample later on. In order to increase clustering precision, a combination of different diagrams can also be used.

6 Conclusions

In this paper new quasi-fractal parameters ($p_1 \dots p_9$) were defined and a new type of diagram (QFP diagram) was proposed to achieve roughness image recognition.

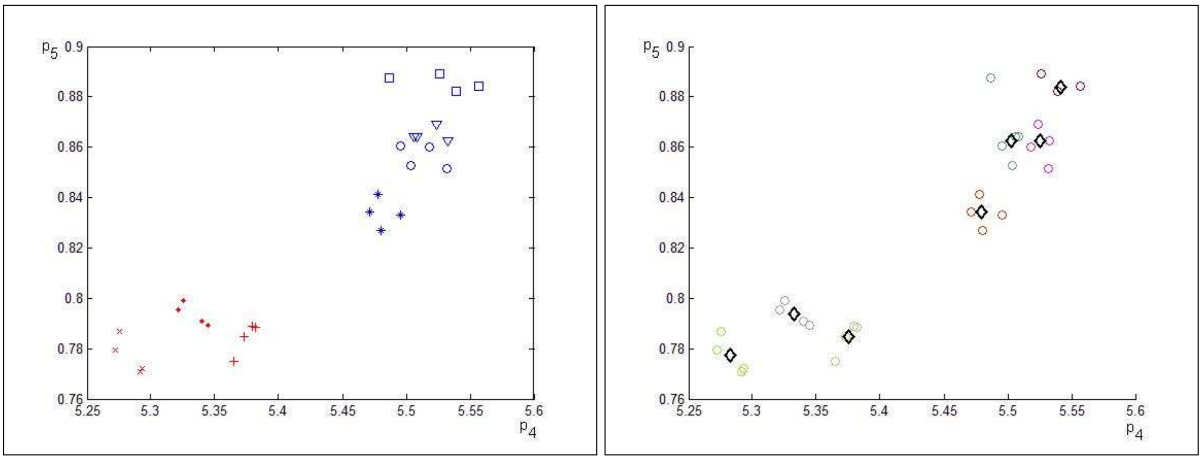

Figure 10: QFP diagram (a) and clustering (b) for phase 3.

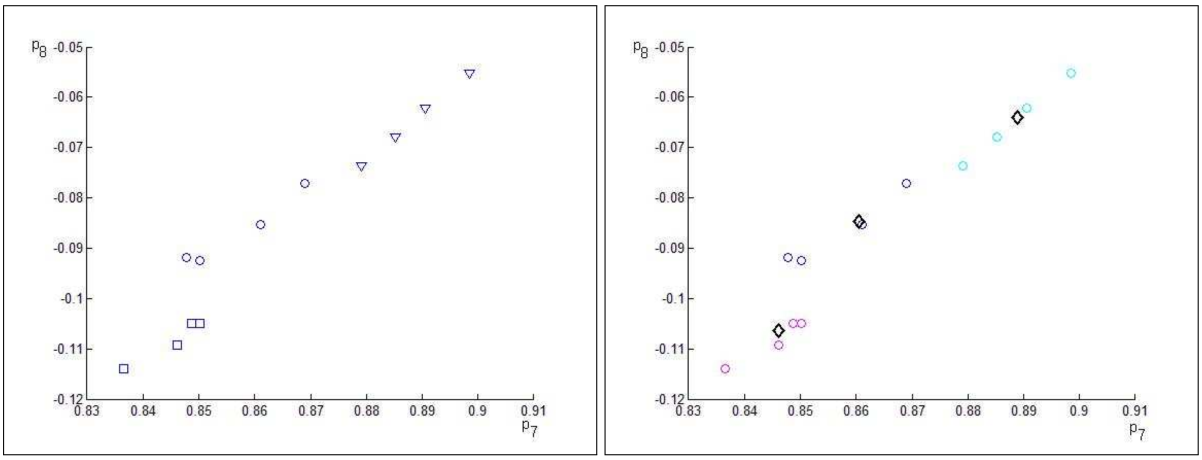

Figure 11: QFP diagram (a) and clustering (b) for phase 4.

The presented method is not an optimal one since the selection of parameters for the different phases was made by hand, but this selection is needed to be done only once for a group of roughness samples obtained with certain manufacturing methods. The algorithms must also be tested on larger sets of images.

As further developments the selection of box dimension range for BC3D method and frequency range for PSD method will be studied. We will also study the influence of magnification on quasi-fractal parameter discrimination, and a method to find optimal parameter selection.

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Book review

Florin Gheorghe Filip

INTRODUCTION TO DISCRETE EVENT SYSTEMS
by Christos G. Cassandras and Stèphane Lafortune,
2008, Springer Science + Business Media LLC, XXIV + 776 p.,
ISBN: 978-0-387-33332-8.

Discrete event systems (DES) represent a class of dynamic, discrete - time systems whose states can take values only in a discrete-value space and can change only as a result of asynchronous occurrences of planned or spontaneous events. At present, there are ever more numerous subclasses of discrete event systems. Queuing systems, computer and communication systems, manufacturing and traffic systems are only a few examples of DES which are described in the book.

This is a second revised and added edition of a book written by professors Cassandras of Boston University and Lafortune of the University of Michigan. It builds upon the Cassandras' book entitled "Discrete Event Systems: Modelling and Performance Analysis", which was published in 1993 by Irwin and Aksen Associates and received in 1999 the "Harold Chesnut" prize of IFAC (International Federation of Automatic Control) for the best text book in control engineering.

The necessity of the book was perceived by the authors as a consequence of remarking several facts as it follows. There are more and more various complex real-life technical objects, which can be viewed as instances of DES class. They are to be understood, their operations are to be controlled and, if it is possible, optimized. The traditional methods, which are based on differential or difference equations, though have been proved effective in controlling many systems which show a continuous in time function to represent the state trajectories, are not adequate for the DES, whose sample paths (state trajectories) are described by piece-wise constant functions of time. Consequently, there is a need to develop new modelling frameworks, analysis techniques, design tools, testing methods, and systematic control, and optimization procedures for this new generation of highly complex systems. To fulfil their objective the authors adopt a multidisciplinary approach by building on control theory ("for performance optimization via feed back control"), computer science ("for modelling and verification of event-driven processes"), and operations research ("for analysis and simulation of stochastic DES"). Also the authors propose modelling frameworks and describe new analysis and control methods which are specific for DES and introduce new paradigms to allow combining mathematical tools with processing experimental data. In the Preface, the authors emphasize the critical role of the electronic computer in performing various activities such as system analysis, design, and control.

The authors are well aware of the existence of numerous books and papers addressing various subclasses of DES such as: language and automata theory, Petri nets , queuing models, Markov chains, discrete time simulation, perturbation analysis and so on , all using specific representations of the objects studied. The authors aim at proposing in the book a unified modelling framework with a view to enabling a coherent and systematic study of the objects which belong to almost all DES subclasses mentioned above. Consequently, two discrete event modeling formalisms are utilized throughout the book to represent the state transition structures: automata and, to a lesser extent, Petri nets. In section 1.3.3, the authors introduce three *levels of abstraction* in the study of DES (*untimed, or logical, timed, and stochastic*) to describe sequences of events. The levels of abstraction are used to gradually refine the presentation of the notions and methods contained in the book.

The *first chapter* of the book contains an introduction to system concepts and parallel presentations of the main concepts of continuous variable dynamic systems, (CDS) and discrete event - driven systems. It also introduces hybrid systems; which most of the time be have as CDS, but in certain time moments when discrete events cause discontinuities in the state trajectory.

Chapter 2, 3 and *4* contain a study of DES at the *logical (or untimed)* level of abstraction. Language models of DES and the representation of languages by automata are described in *Chapter 2*. Software tools for analysis of DSS are presented too. Supervisory control issues are studied in *Chapter 3*, which contains also a detailed presentation of decentralized control. In *Chapter 4*, Petri nets concepts are addressed.

Chapter 5 refines the models presented in chapter 2 (automata) and 4 (Petri nets) to include time through the *clock mechanism* and gives an introduction to *hybrid systems*.

Chapters 6-11 utilise the third (*stochastic*) level of abstraction. The first three chapters (7, 8, and 9) contain aspects which are presented in the "traditional" manner of stochastic models based on probability theory. Markov chains, and classical queuing theory models are presented in chapters 7 and 8, respectively. Control and decision models based on Markov chains are described in *Chapter 9*.

Chapters 10 and *11* presents several concepts and techniques which heavily rely on the use of computer and do not require adopting the assumptions which were necessary when using classical stochastic models. *Chapter 10* contains an introduction to discrete - event simulation including a presentation of languages and corresponding software products (in section 10.4.). *Chapter 11* presents sensitivity analysis and concurrent estimation methods, including the new “Infinitesimal Perturbation Analysis” (IPA).

The book contains also auxiliary material such as: a) a review of Probability theory, and b) a description of IPA estimator. A web site (http://vita.bu.edu/cgc/Book), which is continuously maintained, can help the reader in his/her study.

This is a high quality book, rich in content, up-to-date, and well written. The presentation style utilized throughout the book is a formal one. Various examples presented and references made to relevant web sites increase value and usability of the book.

The book can be of great value for various categories of senior undergraduate and postgraduate students and of the people which are interested in control, communications, computer science as well as in manufacturing and industrial engineering. Therefore, I warmly recommend it to the readers of the *International Journal of Computers, Communications, and Control* (IJCCC).

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