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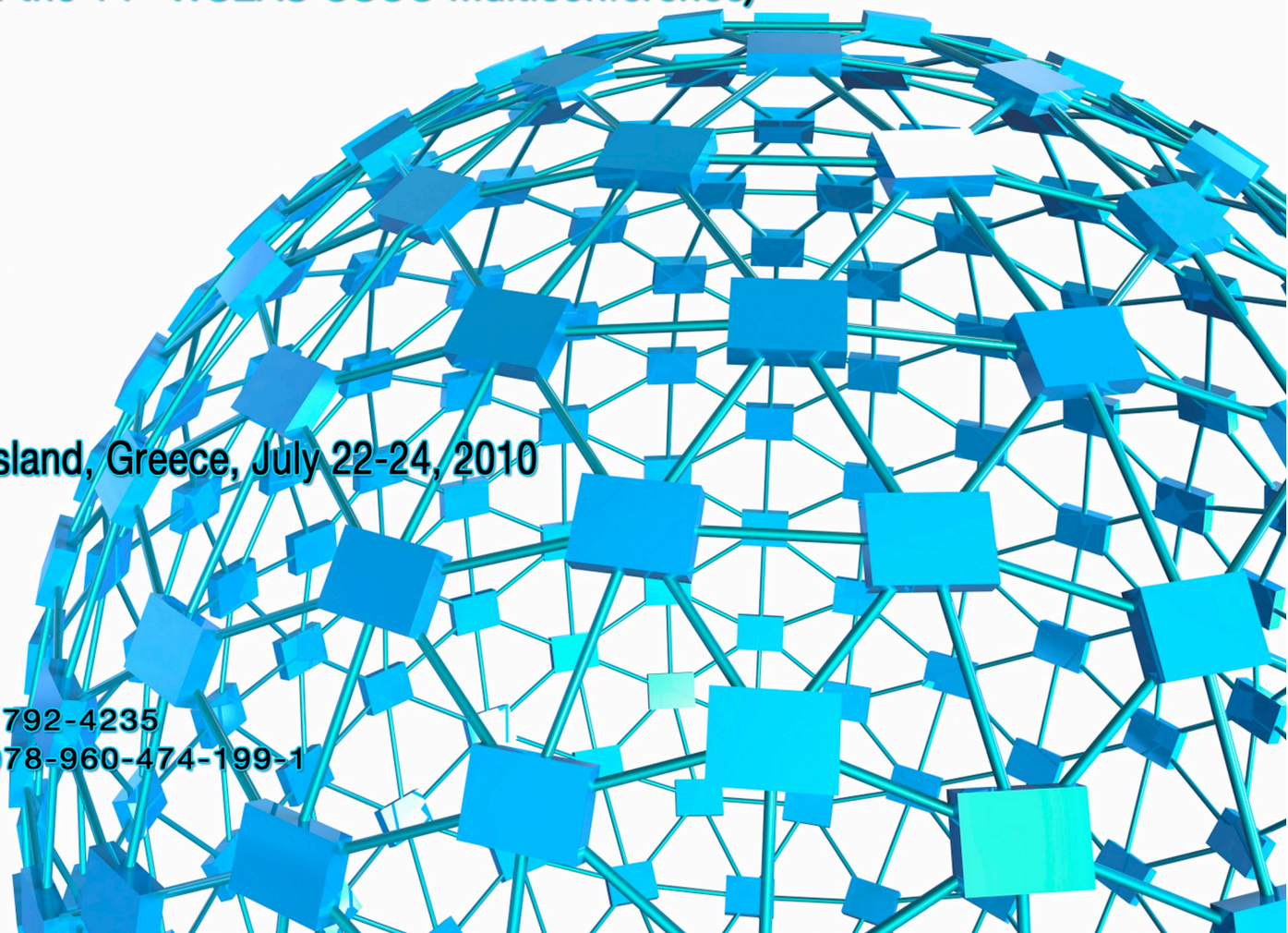
Latest Trends on Systems

VOLUME I

14th WSEAS International Conference on Systems
(Part of the 14th WSEAS CSCC Multiconference)



Corfu Island, Greece, July 22-24, 2010

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Preface

This year the 14th WSEAS International Conference on SYSTEMS (Part of the 14th WSEAS CSCC Multiconference) was held on Corfu Island, Greece, July 22-24, 2010. The conference remains faithful to its original idea of providing a platform to discuss systems theory, dynamical systems, control systems, robotics, artificial intelligence, genetic algorithms, aerospace systems, lightwave engineering, hybrid systems, speech and image processing systems, environmental modeling, sonar and underwater acoustic systems, space systems, wavelets, optimization, finite elements etc. with participants from all over the world, both from academia and from industry.

Its success is reflected in the papers received, with participants coming from several countries, allowing a real multinational multicultural exchange of experiences and ideas.

The accepted papers of this conference are published in this Book that will be indexed by ISI. Please, check it: www.worldses.org/indexes as well as in the CD-ROM Proceedings. They will be also available in the E-Library of the WSEAS. The best papers will be also promoted in many Journals for further evaluation.

A Conference such as this can only succeed as a team effort, so the Editors want to thank the International Scientific Committee and the Reviewers for their excellent work in reviewing the papers as well as their invaluable input and advice.

The Editors

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Keynote Lecture 1

Optimizing the Performance of Scientific Java Applications

Professor Kleanthis Psarris
Department of Computer Science
The University of Texas at San Antonio
San Antonio, TX 78249
USA
E-mail: psarris@cs.utsa.edu

Abstract: As part of its type-safety regime, the Java semantics require precise exception at runtime when programs attempt out-of-bound array accesses. In general, this requires a dynamic bounds check each time an array element is accessed, which limits the performance of array intensive scientific applications implemented in Java. However, if it can be proven that the array index is within the bounds of the array, the check can be eliminated. We present a new algorithm based on extended Static Single Assignment (eSSA) form that builds a constraint system representing control flow qualified, linear constraints among program variables derived from program statements. Our system then derives relationships among variables, and provides a verifiable proof of its conclusions. This proof can be verified by a runtime system to minimize the analysis' performance impact. Our system simultaneously considers both control flow and data flow when analyzing the constraint system, handles general linear inequalities instead of simple difference constraints, and provides verifiable proofs for its claims. We present experimental results demonstrating that this method eliminates more bounds checks than prior approaches with minimal overhead during JIT compilation. Furthermore our algorithm increased the speed at which the Java benchmarks executed by up to 16%.

Brief Biography of the Speaker:
Kleanthis Psarris is Professor and Chair of the Department of Computer Science at the University of Texas at San Antonio. He received his B.S. degree in Mathematics from the National University of Athens, Greece in 1984. He received his M.S. degree in Computer Science in 1987, his M.Eng. degree in Electrical Engineering in 1989 and his Ph.D. degree in Computer Science in 1991, all from Stevens Institute of Technology in Hoboken, New Jersey. His research interests are in the areas of Parallel and Distributed Systems, Programming Languages and Compilers, and High Performance Computing. He has designed and implemented state of the art program analysis and compiler optimization techniques and he developed compiler tools to increase program parallelization and improve execution performance on advanced computer architectures. He has published extensively in top journals and conferences in the field and his research has been funded by the National Science Foundation and Department of Defense agencies. He is an Editor of the Parallel Computing journal. He has served on the Program Committees of several international conferences including the ACM International Conference on Supercomputing (ICS) in 1995, 2000, 2006 and 2008, the IEEE International Conference on High Performance Computing and Communications (HPCC) in 2008, 2009, and 2010, and the ACM Symposium on Applied Computing (SAC) in 2003, 2004, 2005 and 2006.

Plenary Lecture 1

Turbulence and Quantum Mechanics from Cosmic to Planck Scales

Professor Siavash H. Sohrab
Robert McCormick School of Engineering and Applied Science
Department of Mechanical Engineering
Northwestern University, Evanston, Illinois 60208
USA
E-mail: s-sohrab@northwestern.edu

Abstract: A scale invariant model of statistical mechanics was recently applied to describe a modified statistical theory of turbulence and its quantum mechanical foundation. In the present study the implications of the results to a unified statistical theory of fields with applications to diverse physical systems in the fields of galacto-dynamics (cosmology), hydrodynamics, molecular-dynamics, electrodynamics, and quantum optics (dry-hydrodynamics) will be discussed. The comparisons between the predictions of the model and some of the available experimental observations over the entire range of spatial scales from cosmic to Planck will be examined. The connection between the cosmological constant and the vacuum energy and the concept of negative pressure will be discussed. In the field of optics, the implications of the important and central question: "Must the photon mass be zero?" asked by Bass and Schrodinger [Proc. Royal Soc. A 232, pp: 1-6 (1955)] will be further examined. Also, the implications of the invariant model of statistical mechanics to the classical theory of electrodynamics of Maxwell and Lorentz will be explored when the compressible nature of physical space, in accordance with Planck's compressible ether, is taken into account. In particular, the existence of longitudinal electromagnetic waves, L-waves, and their impact on the gravitational mass of photon will be discussed. Finally, the physical and quantum nature of time will be described and a scale-invariant definition of time will be presented and its physical significance to various systems as well as its relativistic behavior will be addressed.

Brief Biography of the Speaker:
Siavash H. Sohrab received his PhD in Engineering Physics in 1981 from University of California, San Diego, his MS degree in Mechanical Engineering from San Jose State University in 1975, and his BS degree in Mechanical Engineering from the University of California, Davis in 1973. He then joined Northwestern University in 1982 as postdoctoral research assistant and became Visiting Assistant Professor in 1983, Assistant Professor of Mechanical Engineering in 1984, and since 1990 he is Associate Professor of Mechanical Engineering at the Northwestern University. From 1975-1978 he worked as a scientist doing research on fire protection and turbulent combustion at NASA Ames research center in California. His research interests have been on combustion, fluid dynamics, thermodynamics, and statistical and quantum mechanics.

Plenary Lecture 2

Multiple Laplace-Z Transformation and Applications in the Study of Continuous - Discrete Systems

Professor Valeriu Prepelita
University Politehnica of Bucharest
Department of Mathematics-Informatics I
Splaiul Independentei 313, 060042 Bucharest
ROMANIA
E-mail: vprepelita@mathem.pub.ro

Abstract: The Operational Calculus as a distinct discipline has a history which has exceeded a century. But its roots can be found in the works of Leibniz, Bernoulli, Lagrange, Laplace, Euler, Fourier, Cauchy and others. Its importance is determined by its utility in solving complex problems in many domains such as Calculus, Number Theory, Special Functions, Ordinary Differential Equations, Mathematical Physics, Heat Transfer, Electronics, Automatics, etc.
In Systems and Control Theory the frequency domain methods, based on Laplace transformation in the continuous-time case or on Z transformation in the discrete-time case, play a very important role in the study of the "classical" 1D systems.
In the last two decades the study of two-dimensional (2D) systems (and more generally, of n-dimensional systems) developed as a distinct branch of Systems Theory, due to its applications in various domains as image processing, seismology and geophysics, control of multipass processes etc.
The two-dimensional (2D) systems were obtained from classical 1D linear dynamical systems by generalizing from a single time variable to two (space) variables. Different state space models for 2D systems have been proposed by Roesser, Fornasini and Marchesini, Attasi, Eising and others.
A subclass of 2D systems is represented by systems which are continuous with respect to one variable and discrete with respect to another one. The continuous-discrete models have applications in many problems like the iterative learning control synthesis, repetitive processes or in engineering problems such as metal rolling.
In order to extend the frequency domain methods to these multiple hybrid systems one needs a generalization of the Laplace and Z transformation.
The aim of this paper is to give a complete analysis of a suitable hybrid Laplace-Z type transformation and to emphasize its applications in the study of multidimensional continuous-discrete systems or for solving multiple hybrid equations.
In section 2 the continuous-discrete original functions are defined and it is shown that their set is a complex commutative linear algebra with unity. A multiple hybrid Laplace-Z transformation is defined as a linear operator defined on this algebra and taking values in the set of multivariable functions which are analytic over a suitable domain.
In section 3 the main properties of the multiple hybrid Laplace-Z transformation are stated and proved, including linearity, homothety, two time-delay theorems, translation, differentiation and difference of the original, differentiation of the image, integration and sum of the original, integration of the image, convolution, product of originals, initial and final values.
Section 4 is devoted to the inversion problem. Some formulas and methods for determining the original are given.
This hybrid transformation is employed in Section 5 to obtain transfer matrices for different classes of 2D (and more generally (q,r)-D) continuous-discrete linear control systems of Roesser-type, Fornasini-Marchesini-type and Attasi type models, including descriptor and delayed systems.
The realization problem is studied in Section 6. Two canonical controllable and observable realizations are provided. An algorithm is proposed which determines a minimal realization for separable (q,r)-D multi-input-multi-output (MIMO) systems. This method generalizes to (q,r)-D systems the celebrated Ho-Kalman algorithm. The proposed algorithm can also be used for MIMO separable nD discrete-time linear systems or for MIMO nD systems described by a class of hyperbolic partial differential equations.

Brief Biography of the Speaker:
Valeriu Prepelita graduated from the Faculty of Mathematics-Mechanics of the University of Bucharest in 1964. He obtained Ph.D. in Mathematics at the University of Bucharest in 1974. He is currently Professor at the Faculty of Applied Sciences, the University Politehnica of Bucharest, Head of the Department Mathematics-Informatics. His research and teaching activities have covered a large area of domains such as Systems Theory and Control, Multidimensional Systems, Functions of a Complex Variables, Linear and Multilinear Algebra, Special Functions, Ordinary Differential Equations, Partial Differential Equations, Operational Calculus, Probability Theory and Stochastic Processes, Operational Research, Mathematical Programming, Mathematics of Finance.
Professor Valeriu Prepelita is author of more than 100 published papers in refereed journals or conference proceedings and author or co-author of 12 books. He has participated in many national and international grants. He is member of the Editorial Board of some journals, member in the Organizing Committee and the Scientific Committee of several international conferences, keynote lecturer or chairman of some sections of these conferences. He is a reviewer for five international journals. He received the Award for Distinguished Didactic and Scientific Activity of the Ministry of Education and Instruction of Romania.

Plenary Lecture 3

Supercapacitors Application in Energy Hybrid Systems for Automotive

Dr. Carmen Mihaela Lungoci
Electrical Engineering and Computers Science Faculty
Electrical Engineering Department
Transilvania University of Brasov, Romania
E-mail: lungoci@unitbv.ro

Abstract: Energy hybrid systems are key elements in automotive, that meet the energy demands of traction engine, provide a convenient life and present a minimum weight and volume. Supercapacitors are devices able to meet specified demands, especially when they work together with the other energy sources, such as batteries.
Present research aims to develop an energy hybrid system for transport, using batteries and supercapacitors, in order to optimize it's energy management. To achieve this goal, several steps are taken in account.
Based on a synthetic analysis on superacapacitors, models are developed and determinations are carried out, to characterize and determine the type of supercapacitors pack to be used in the proposed applications.
Two architectures of hybrid energy systems are presented and their operating regimes are detailed. Mathematical modeling is carried out, models for the components and for the two hybrid systems being obtained.
The final part is intended to simulation and experimental tests, done for both traction applications proposed. Through the data results, supercapacitors contribution is underlined by a comparative analysis of main parameters provided by simulations and experiments too. The energy management is also presented, in a traditional system with batteries and in a hybrid system that contains supercapacitors and batteries.

Brief Biography of the Speaker:
Carmen Mihaela Lungoci received the B.Sc. in 1990 on the Automation for Industrial Control from Politehnica University, Bucharest and the M.S.E.E. degree in 2004 from Transilvania University of Brasov, Romania and Technology University of Belfort, France. In 2009 she received the Ph.D. degrees in Electrical Engineering from Transilvania University of Brasov, Romania. She is lecturer at this university, on the Electrical Engineering Department of the Electrical Engineering and Computers Science Faculty. Her current research interests includes supercapacitors, energy management in automotive systems and control strategies in hybrid systems.

Plenary Lecture 4

Work Directions and New Results in Electronic Travel Aids for Blind and Visually Impaired People

Professor Virgil Tiponut
Electronic and Telecommunication Faculty
POLITEHNICA University of Timisoara
Romania
E-mail: virgil.tiponut@etc.upt.ro

Abstract: There are approximately 45 million blind & visually impaired people world-wide according to the World Health Report. Vision loss limits the access of these individuals to the educational opportunities, social events, public transportation and leads to a higher rate of unemployment.
Many efforts have been invested in the last years, based on sensor technology and signal processing, to develop electronic travel aids (ETA) capable to improve the mobility of blind users in unknown or dynamically changing environment. In spite of these efforts, the already proposed ETAs do not meet the requirements of the blind community and the traditional tools (white cane and guiding dogs) are still the only used by visually impaired to navigate in their working and living environment.
In this paper, research efforts to improve the main two components of an ETA tool: the Obstacles Detection System (ODS) and the Man-machine Interface (MMI) are presented. Now, for the first time, the ODS under development is bioinspired from the visual system of insects, particularly from the Lobula Giant Motion Detector (LGMD) found in locusts. LGMD is a large neuron found in optical lobule of the locust, which mainly responds at the approaching objects. Starting from the mathematical model of the LGMD, known in the literature, it has been developed an ODS that can be used by visually impaired to navigate autonomously with obstacles avoidance. The already obtained results are very promising, but some improvements are also possible. We are developing now preprocessing algorithms for the visual information applied to the input of the LGMD neuron, in order to improve the response of the ODS. In the proposed solution, the position of the detected obstacles is correlated with the attitude parameters of the subject's head. In this way, the visually impaired person detects obstacles in a similar way as a subject with normal sight is looking for obstacles in front of him.
The man-machine interface developed in the present research exploits the remarkable abilities of the human hearing system in identifying sound source positions in 3D space. The proposed solution relies on the Acoustic Virtual Reality (AVR) concept, which can be considered as a substitute for the lost sight of blind and visually impaired individuals. According to the AVR concept, the presence of obstacles in the surrounding environment and the path to the target will be signalized to the subject by burst of sounds, whose virtual source position suggests the position of the real obstacles and the direction of movement, respectively. The practical implementation of this method encounters some difficulties due to the Head Related Transfer Functions (HRTF) which should be known for each individual and for a limited number of points in the 3D space. These functions can be determined using a quite complex procedure, which requires many experimental measurements. The proposed solution in our research avoids these difficulties by generating the HRTF's coefficients using an Artificial Neural Network (ANN). The ANN has been trained using a public data base, available for the whole scientific community and which contains HRTF's coefficients for a limited number of individuals and a limited number of points in 3D space for each individual.
The ODS and the MMI presented in the above have been implemented on a specific hardware build around an ARM-based microcontroller system. The obtained results and some conclusions are also presented.

Brief Biography of the Speaker:
Prof. Virgil TIPONUT received the M.Sc. in 1968, in Electrical Engineering/Computer Science, and the Ph.D. degree in Electronic Engineering and Telecommunications, in 1981, both at the POLITEHNICA University of Timisoara, Romania. Since graduation he is with POLITEHNICA University of Timisoara and curently he is a professor at Electronic and Telecommunication Faculty, responsable for teaching in embedded systems, smart transducers and neural networks.
His research interests include bioinspired systems, with application in mobile and rehabilitation robotics and some closed related areas: smart transducers, neural networks and fuzzy logic, biomedical engineering, embedded

systems. He has published more than 100 papers in national and international Journals and Conference Proceedings, authored 10 books and 10 text books, and holds 21 patents. He conducted more than 25 research and development projects, grants and contracts in the field of embedded systems, robotics and smart transducers.
Prof. Tiponut has been involved in setting up national and international conferences as a reviewer and/or member of organizing committee or board of sections. He was a visiting professor at universities from USA, Germany, Ireland and Schotland.
He is a member of the IEEE Society (CAS, EMB, RA), WSEAS Society, member of the Society of Electronic Engineers from Romania and corresponding member of the Academy of Technical Science from Romania.

Plenary Lecture 5

Video and Audio Mobile Robot Systems

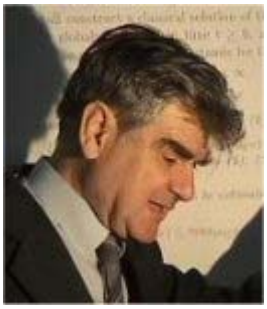
Associate Professor Alexander Bekiarski
Department of Telecommunications
Technical University Kliment Ohridski
Sofia, Bulgaria
E-mail: aabbv@tu-sofia.bg

Abstract: Video and audio mobile robot systems are a coarse model of the human visual and hearing systems. They consist of video and audio sensors mounted on the mobile robot platform and a specific hardware and software for image and sound processing. The visual sensors are usually a single video camera or a pair of two cameras giving mono or stereo images, respectively. The audio sensors also can be mono or stereo, if the number of microphones are one or two, but more frequently as audio sensors in mobile robot are used microphone arrays with two or more number of microphones arranged in a linear, circular or matrix structure to achieve an effective sound direction of arrival or determination or sound localization in the situations, when a person speak to the robot. The visual images and audio signals, received with each of these sensors, can be process to extract the necessary information for the right orientation and moving control of the mobile robot in one indoor or outdoor area of observation. The area of the research in the visual and audio robot systems are the advanced methods and algorithms for image and sound signals analysis, feature extraction, objects or human body separation and tracking, face recognition from images and speech recognition and identification, scene analysis etc., suitable for mobile robot applications. The information calculated separately from each of video and audio robot system can be combined together to improve the precision of objects, persons or speakers tracking form the mobile robot.
The goal of this article is to give a brief review of the topics in the area of image and sound processing methods and algorithms for mobile robots and to present some concrete results of the research in the area of visual and audio mobile robot systems achieved from the group in Technical University of Sofia with the author of this article of the head.

Brief Biography of the Speaker:
Born in 1944, Plovdiv, Bulgaria. He received M.S. degree in Communications in 1969 in Technical University, Sofia. Ph. D in Television and Image Processing in 1975, Assoc. Prof. since 1987 in the same University. Vice-Dean of Faculty on Life-Long Learning Center since 2005, Vice-Dean of French Language Faculty of Electrical Engineering since 2006. The author over 180 research papers in Image Processing Systems, Pattern Recognitions, Neural Networks etc. Currently the leader of courses in Basic of Television, Television Systems, Theory of Coding, Digital Signal Processors etc. His scientific iterests encompass Video and Audio Processing, Digital TV, Neural Networks, Artificial Intelligence in Video and Audio, Artificial Intelligence Programming Languages Lisp Prolog, Expert Systems, Robotics Camera Eye and Microphone Arrays, Signal Processors, Embedded Systems, Microcontrollers, Programming Languages C++, Java, Matlab etc.

Plenary Lecture 6

Nonlinear Waves



Professor Petar Popivanov
Institute of Mathematics and Informatics
Bulgarian Academy of Sciences
Sofia, Bulgaria
E-mail: popivano@math.bas.bg

Abstract: This talk deals with several equations of Mathematical Physics as mKdV, Camassa-Holm and its generalizations, Hunter-Saxton, Burgers, systems of conservation laws, sin-Gordon, semilinear wave equations, etc. They originate from Physics, but we propose here their investigation via purely mathematical methods in the frames of the University courses (Lebesgue integral, Fourier transform, Schwartz distributions). Therefore, the talk is addresses to a broader audience including graduate students, Ph.D. students, mathematicians, physicists, engineers and specialists in the domain of PDE. Certainly, there are monographs on the subject based on rather complicated and difficult methods that make the readers acceptance hard-especially for beginners or non specialists. We propose a short survey on Jacobi's and Legendre elliptic functions and illustrate them by traveling wave solutions and their interaction. We discuss some examples from physics – interaction of fluxons and antifluxons. By using the appropriate modifications of the method of characteristics we study the generalized Cauchy problem for the Hunter-Saxton equation and for the conservation laws equation (existence, uniqueness). We estimate the life span of the continuous generalized solutions and prove that in some cases they are Lipschitz. Moreover, in some cases we construct a-shocks avoiding Colombeau algebras and the parabolic regularization.

Brief Biography of the Speaker:
P. Popivanov graduated at the Faculty of Mathematics of the Sofia University "St. Kliment Ohridski" in 1969. In the period 1970-1973 he was PhD student at the Moscow State University "Lomonosov" to the Russian mathematician Yu.V.Egorov – eminent specialist in PDE. He defended his PhD thesis in Moscow in 1973 and his second doctor degree at the Sofia University "St. Kliment Ohridski" in 1986. Since 1969 he works at the Institute of Mathematics and Informatics of BAS: Assoc. Prof. (1979), Full Prof. (1988), Corresponding Member of BAS (1995), Full Member of BAS (2003). He is head of Differential Equations Section at the Institute of Mathematics and Informatics since 1989. He was Chairman of the Scientific Council of the same Institute in the period 1995-2008; and since 2004 he is member of the Board of BAS. P. Popivanov is actively working in the domain of Partial Differential Equations. He is the author of more than 126 scientific papers, 46 of them published in journals having IF; 46 referee reports in Bulgaria, Italy and Germany for PhD and Doctoral theses, habilitations, etc.; 3 monographs – 1 published in Akademie Verlag, Berlin (jointly with D. Palagachev), 1 published in Wiley-VCH (jointly with T. Gramchev), and one in Bulgaria as well as two manuals on Differential Equations. He has been invited as Visiting Professor, for giving seminars and for participation in congresses and conferences in the following scientific centres: Universite Paris-11 (Orsay), Ecole Polytechnique (Paris), Universite Paul Sabatier (Toulouse), Universite de Rennes - France; the Universities of Bologna, Trieste, Torino, Pisa, Ferrara, Bari, Cagliari, Catania, Messina – Italy; Warsaw University – Poland; Moscow State University "Lomonosov", "Steklov" Institute (Moscow) – Russia; Institute "Weierstrass" – Berlin and the Universities in Potsdam, Kemnitz, Holzhau, Clausthal – Germany; the Universities of Lund, Vaxjo, Linkoping – Sweden; the Universities of Chow, Tsukuba, Tokyo, Hiroshima, Kyoto, Nagoya, Osaka – Japan; Weizmann Institute, Technion and Ariel Universities – Israel; Belgrade University – Serbia, Ioannina University – Greece, etc. P. Popivanov is Doctor Honoris Causae of Rousse University "Angel Kanchev".

Plenary Lecture 7

The Origin of Life: Information Theory Perspective

Professor Krzysztof Cyran
Vice Head of Institute of Informatics
Silesian University of Technology
Gliwice, Poland
E-mail: Krzysztof.Cyran@polsl.pl

Abstract: The Life on Earth can be considered as one of the most complex systems that the science tries to understand. In particular the beginning of Life is still an unsolved problem having many implications to the theory of systems Current theories concerning the origin of life fall into two groups defined by Dyson in his famous book Origins of Life. The first group assumes that the transition form abiotic to biotic world occurred with the emergence of self-replicating RNA molecules and is referred to as RNA-world hypothesis. This most commonly accepted hypothesis requires the existence of the RNA-replicase ribozyme the search of which is described by McGinness and Joyce in 2003. The evolution of new genes after appearance of the RNA-replicase is challenged by instability of Eigen's hypercycles composed of many genes supporting cyclically their replication. An alternative approach, proposed by Niesert as a compartment model with random segregation of genes, proved to be stable for very limited number of genes. Significant advance in the RNA-world theory has been done in 2007 by Ma et al. who performed intensive computer simulations demonstrating the emergence of the auto-catalytic and self-replicating activity of RNA oligonucleotides. Another relevant computer simulation-based study was reported in 2007 by Baaske et al. who observed the extreme accumulation of nucleotides in simulated hydrothermal pores. The second group of hypotheses derives life from the biochemistry of amino acids and their polymers, proteins. This group encompasses such theories like Dyson's theory of double origin which requires at least 8-10 types of monomers for emergence of the first auto-catalysing protocells and therefore excludes from this role nucleotides, or theories described in 2007 by Rode et al. assuming that salt-induced peptide formation (SIPF) reaction could have been the crucial step from chemistry towards biology. In the lecture these theories will be reviewed as well as models of early stages of RNA-world will be presented. The latter methodology will be based on intensive computer simulations of the package model with random segregation of genetic material. The improvement proposed here is modeling the environmental changes of the evolving population by stochastic fluctuation of the number of replicating molecules (NORM) in the compartment. This stochasticity can be the sole source of variation or it can be added to the cell-to-cell stochasticity originally proposed by Niesert. Further enhancement relying on BP extinction conditions applied to simulated population of RNA protocells will also be proposed. The aim is to model the evolution of the early RNA-world before the appearance of chromosomal architecture of genomes. Finally, the comparison of the single-strand and the compartment models will be carried out from the information processing perspective using the Shannon information theory. The potential of models for preserving the genetic information will be studied for the compartment and the single strand models with the complexity threshold estimated in Demetrius-Kimmel BP model supplemented with possibility of phosphodiester bond break. The advantage of this latter model lies in its potential for obtaining reliable estimates of its parameters. Since the probability of the break of a phosphodiester bond between two nucleotides can be experimentally received for feasible conditions of the early Earth, the model can be more accurate than models based on information balance between mutation and natural selection. Advantageous in the proposed comparison is also the use of information amount as a measure of evolutionary capacity of hypothetical models of the RNA-world. In this context it should be noticed that the problem of error catastrophe is equally important for both groups of theories concerning the origin of life, although for each of them the acceptable value of complexity threshold is different Therefore, the reliable estimate of this threshold based on methodology proposed could favor one or the other group, or at least predict the limits for the length of newly arisen genomes and in that matter contribute to revealing the mystery of Life.

Brief Biography of the Speaker:
Krzysztof A. Cyran was born in Cracow, Poland, in 1968. He received MSc degree in computer science (1992) and PhD degree (with honours) in technical sciences with specialty in computer science (2000) from the Silesian University of Technology SUT, Gliwice, Poland. His PhD dissertation addresses the problem of image recognition with the use of computer generated holograms applied as ring-wedge detectors.

He has been an author and co-author of more than 80 technical papers in journals (several of them indexed by Thomson Scientific) and conference proceedings. These include scientific articles like: K. A. Cyran and A. Mrozek, “Rough sets in hybrid methods for pattern recognition,” Int. J. Intel. Syst., vol. 16, 2001, pp. 149-168, and K. A. Cyran and M. Kimmel, “Interactions of Neanderthals and modern humans: what can be inferred from mitochondrial DNA?” Math. Biosci. Eng., vol. 2, 2005, pp. 487-498, as well as a monograph: U. Stanczyk, K. Cyran, and B. Pochopien, Theory of Logic Circuits, vol 1 and 2, Gliwice: Publishers of the Silesian University of Technology, 2007. Dr. Cyran (in 2003-2004) was a Visiting Scholar in Department of Statistics at Rice University in Houston, US. He is currently the Assistant Professor and the Vice Head of the Institute of Informatics at Silesian University of Technology, Gliwice, Poland. Since 2009 He is also a Coordinator of postgraduate studies in the Civil Aviation Personnel Education Center of Central and Eastern Europe. His current research interests are in image recognition and processing, artificial intelligence, digital circuits, decision support systems, rough sets, aviation and aeronautics, computational population genetics and bioinformatics, including Human evolution and Origin of Life.

Dr. Cyran has been involved in numerous statutory projects led at the Institute of Informatics and some scientific grants awarded by the State Committee for Scientific Research. He also has received several awards of the Rector of the Silesian University of Technology for his scientific achievements. In 2004-2005 he was a member of International Society for Computational Biology. Currently he is a member of the Editorial Board of Journal of Biological Systems (indexed by ISI) and a member of Scientific Committee of the Seventh International Conference on Rough Sets and Current Trends in Computing (proceedings published by Springer). In past he was a member of the Scientific Program Committees of WSEAS international conferences in Malta (ECC’08), Rodos (AIC’08, ISCGAV’08, ISTASC’08) and multiconference in Crete (CSCC’08) as well as member of the Scientific Committee and Vice-Chair of the Organizing Committee of the International Conference on Man-Machine Interactions with proceedings published by Springer. He is also a reviewer for Studia Informatica and such journals indexed by Thompson Scientific as: Optoelectronic Review, Mathematical Biosciences and Engineering, and Journal of Biological Systems.

Plenary Lecture 8

Gradient Theory Across the Scale Spectrum: Examples from Astroscales and Above to Nanoscales and Below

Professor Elias C. Aifantis
Laboratory of Mechanics and Materials
Polytechnic School
Aristotle University of Thessaloniki, Thessaloniki GR-54124, GREECE
and
Center for Mechanics of Material Instabilities and Manufacturing Processes
College of Engineering
Michigan Tech University
Houghton, MI 49931, USA
E-Mail: mom@mom.gen.auth.gr

Abstract: Gradient theory has been succesful in interpreting a variety of physical processes ranging from diffusion and chemical reactions to deformation and fracture phenomena. The theories of spinodal decomposition, dislocation patterning, gradient elasticity and gradient plasticity are special examples. After reviewing these advances, the extensions of gradient theory to model other phenomena across the scale spectrum are discussed. These include examples ranging from nanoscales and below to astroscales and beyond.

Brief Biography of the Speaker:
E.C. Aifantis is a Professor of Mechanics at the Aristotle University of Thessaloniki, Hellas, and a Distinguished Research Professor of Engineering at Michigan Technological University, USA. For the last 10 years he has been coordinating a European Research/Training Network, sequence on Material Instabilities in Deformation and Fracture involving a number of leading European Laboratories (e.g. Cambridge, Delft and 5 more) with a total of about $5 Million. Most recently a European Research Council (ERC) Starting Grant recipient (K. Aifantis) funded with 1.13 Million Euros decided to conduct her research in his laboratory (Physics Today - April 2008 issue, p.30-31, BBC; Science Careers. Moreover, two EU International Incoming Fellowships of 200 kEuros each were awarded (A. Romanov/Ioffe Physicotechnical Institute, Russia, and N. Kioussis/California State University, USA). He is also a co-PI of a NIRT NSF Program on Nanomechanics of Polymeric and Biological Nanofibers with a total budget exceeding $1 Million. He has published over 450 papers with over 5300 citations, edited 12 books, organized numerous international conferences, and has been invited as keynote speaker on various occasions. He is an Editor of the Journal of Mechanical Behavior of Materials, Honorary Editor of Computer and Experimental Simulations in Engineering and Science, on the Advisory/Editorial board of Numerical and Analytical Methods in Geomechanics, Open Mechanics Journal, Journal of Nano Research, Reviews on Advanced Materials Science, Acta Mechanica Solida Sinica, Materials Physics and Mechanics, Acta Mechanica (formerly), Mechanics of Cohesive-Frictional Materials (formerly). In June 2005 in the joint ASME/ASCE/SES Mechanics and Materials Conference in Baton Rouge, a Symposium was held honoring his contributions in gradient theory, dislocation patterning and material instabilities.

Plenary Lecture 9

Nonlinear Models of Interactions Among Two or Three Species : Symbiosis, Prey-Predator, Competition

Professor Daniele Fournier-Prunaret
Professor INSA
Director of LATTIS
DGEI-INSA
Toulouse, France
E-mail : daniele.fournier@insa-toulouse.fr

Abstract: Interactions among two or three different species can be modeled using nonlinear discrete maps based upon logistic map.
The considered interactions can be of mutual benefits (symbiosis), competition or predator-prey type. The strength of the interaction depends upon real coupling parameters. The study is done by considering classical tools of nonlinear discrete dynamical systems (singularities, stability, attractors, basin, bifurcations, critical manifolds...). The different kinds of interactions give rise to many various and complex phenomena, depending upon the strength of the coupling parameter. Multistability can be obtained with fractal basin boundaries, chaotic attractors can be observed. The evolution of the attractors and their basin under parameter variation can be explained using bifurcation analysis and critical manifold study.
Such studies can give rise to applications in Ecology, Biology or Economics.
All these works have been done in collaboration with R. Lopez-Ruiz, from University of Zaragoza, Spain.

Brief Biography of the Speaker:
Daniele Fournier-Prunaret obtained a Ph.D. under the supervision of Pr. C. Mira, eminent specialist of Nonlinear Dynamical Systems, then a Doctorat d'Etat at the University Paul Sabatier of Toulouse, France, respectively in 1981 and 1987. She is currently Professor at the National Institute of Applied Sciences (INSA) in Toulouse, France and the Head of the LATTIS (Toulouse Laboratory of Technology and System Engineering). Her research and teaching activities concern Modelisation and Analysis of Nonlinear Dynamical Systems, focusing more particularly on the study of Chaos and Applications to Telecommunications, Secure Transmissions and Biology. She is the author of around 100 papers in international journals and conferences related to the study of Nonlinear Maps.

Plenary Lecture 10

Accelerate your Favorite Numerical Integrator with Two Lines of Code

Assistant Professor Houman Owhadi
California Institute of Technology
Pasadena, CA
USA
E-Mail: owhadi@caltech.edu

Abstract: Dynamical systems (possibly stochastic) with multiple time scales pose a major problem in simulations because the small time steps required for stable integration of the fast motions lead to large numbers of time steps required for the observation of slow degrees of freedom. A general belief has been that with a nonlinear relation between original and slow variables, averaging integrators should not work "if the slow variables are not explicitly identified and made use of". Furthermore, in recent years, a great deal of attention has been focused on the following challenges: How to accelerate a legacy code (used as black box) for stiff ODEs or SDEs while, at the same time, preserving all of its nice properties? How to obtain explicit structure/symmetry-preserving integrators for (possibly stochastic) mechanical (molecular) systems with non quadratic stiff-potentials? etc...
In this talk, we show that these problems have a surprisingly simple common solution: turning on and off large coefficients in the legacy code. This a joint work with J. Marsden and M. Tao.

Brief Biography of the Speaker:
Houman Owhadi PhD is an assistant professor of Applied and Computational Mathematics and Control and Dynamical Systems at California Institute of Technology. His research interests are in homogenization and multiscale analysis, probability theory, stochastic mechanics, molecular dynamics and uncertainty quantification. He is the head of the uncertainty quantification group of the Caltech Predictive Science Academic Alliance Program.

Plenary Lecture 11

Logarithmic Number Systems

Professor Mark Arnold
Lehigh University
Bethlehem, PA
USA
E-mail: maab@lehigh.edu

Abstract: The Logarithmic Number System (LNS) represents real numbers using a finite precision logarithm. Like any finite representation, the number of bits chosen determines the resolution of the system and therefore the application performance. LNS offers better performance and lower cost for "easy" real operations such as multiplication, division, roots and powers compared to fixed- and floating-point number systems where such operations are thought to be hard. The problems with LNS are that addition and especially subtraction are increasingly expensive when performed with extreme accuracy, because these operations involve table lookup and possibly interpolation. Also, conversion to and from conventional representations can be similarly expensive. Another inconvenience is the fact the logarithm of zero is undefined. This talk will consider how certain special-purpose applications have overcome these problems to exploit LNS advantages, giving hardware that is faster, cheaper and consumes less power than those based on traditional arithmetic.

Examples of special-purpose systems that have adopted LNS successfully include neural networks, multimedia encoders/decoders, control systems, speech recognition and N-body simulators. In each of these applications, designers have reformulated the algorithm to avoid certain LNS weaknesses. LNS works for such applications because they have a large share of "easy" operations and they tolerate lower-precision results. Traditionally, LNS sum and difference calculation have carried out with enough accuracy to be faithful to the number of bits of precision required for the application, however this can be relaxed in some cases. To minimize the cost of the LNS, simulative studies determine the minimum number of bits for in the LNS representation for the application to operate successfully.

This talk will explore many LNS techniques. These include interpolation methods, cotransformation of difficult subtractions into easier additions, elimination of subtractions through redundancy, bit-serial arithmetic and ROM-less approximations. Also, this talk will consider recent implementations that generalize LNS, such as for complex values.

Brief Biography of the Speaker:
Mark G. Arnold received the BS and MS from the University of Wyoming (USA), and the PhD from the University of Manchester (UK) Institute of Science and Technology (UMIST). From 1982 to 2000, he was on the faculty of the University of Wyoming. From 2000 to 2002, he was a lecturer at UMIST. In 2002, he joined the faculty of Lehigh University (USA). In 1976, he co-developed SCELBAL, the first open-source floating-point high-level language for personal computers. In 1997, he received the best paper award from Open Verilog International for describing the Verilog Implicit To One-hot (VITO) tool he co-developed. In 2007, he received the best paper award from the Application-specific Systems, Architectures and Processors (ASAP) conference for a paper describing novel cotransformations for Logarithmic Number Systems (LNS). He is the author of over one hundred technical papers (the majority on LNS) and the book Verilog Digital Computer Design. His research interests include computer arithmetic, hardware description languages, microrobotics and embedded, control, multimedia and application-specific systems.

Plenary Lecture 12

Glocal Control: Realization of Global Functions by Local Actions

Professor Shinji Hara
Department of Information Physics and Computing
The University of Tokyo
Japan
E-mail: shinji_hara@ipc.i.u-tokyo.ac.jp

Abstract: Recently, systems to be treated in various fields of engineering including control have became large and complex, and more high level control such as adaptation against changes of environments for open systems is required. One of the distinguished features in such large scale dynamical systems is that our available actions of measurement and control are restricted locally although our main purpose is to achieve the desired global behaviors. This motivates us to develop a new research direction so called "Glocal Control," which means that the global purpose is achieved by only local actions. At the beginning of this talk the idea of glocal control is explained through real world requirements in meteorological phenomena and biomedical systems. We then introduce a new framework for hierarchical multi-agent networked dynamical systems and show some fundamental results on stability and cooperative stabilization. Theoretical analysis for periodic oscilation phenomena in gene regulatory netwoks is also presented as an application.

Brief Biography of the Speaker:
Shinji Hara was born in Izumo, Japan, in 1952. He received the B.S., M.S., and Ph.D. degrees in engineering all from Tokyo Institute of Technology, Tokyo, Japan, in 1974, 1976, and 1981, respectively. In 1984, he joined Tokyo Institute of Technology as an Associate Professor and has served as a Full Professor for ten years. Since 2002 he has been a Full Professor of the Department of Information Physics and Computing, The University of Tokyo. His current research interests are in robust control, sampled-data control, decentralized cooperative control for multi-agent dynamical systems, glocal control and computational aspects of control system design. Dr. Hara received the George S. Axelby Outstanding Paper Award from the IEEE Control System Society in 2006 and Best Paper Awards from The Society of Instrumentation and Control Engineers, Japan (SICE) several times. He was the General Chair of the CCA04, the Program Co-Chair of the 17th IFAC World Congress in Seoul, and Associate Editor of several international journals including IEEE Trans. on Automatic Control and Automatica. He was the President of SICE last year, and he is currently the Vice-President of the IEEE CSS, and Fellow of IEEE and SICE.

Towards Multi-robot Independent Visual SLAM

MONICA BALLESTA, ARTURO GIL, ÓSCAR REINOSO, LUIS PAYÁ and LUIS M. JIMÉNEZ
Miguel Hernández University
Department of Industrial Systems Engineering
Avda. de la universidad s/n, 03202, Elche
SPAIN
$m.ballesta||arturo.gil||o.reinoso||lpaya||luis.jimenez@umh.es$

Abstract: This paper focuses on the study on the map fusion problem as one of the steps towards the independent multi-robot map building. The situation proposed considers a set of several robots performing map building tasks. Each robot builds its own local map using its observations and estimates its path independently. As a result, there will be a set of local maps that can be fused into a global one. This is the case when the map fusion takes importance. Particularly, we focus our experiments on landmark-based maps constructed using visual information and by means of a particle filter.

Key–Words: SLAM, map fusion, visual landmarks, particle filter

1 Introduction

Map building is one of the fundamental tasks that has to be accomplished by a robot to be considered as autonomous. The capability of building a map of the environment while simultaneously the robot localizes in it is known as SLAM (Simultaneous Localization and Mapping) and has received great attention over the last years [10].

A single robot is able to carry out the construction of a map. However, this task will be more efficiently performed if there is a team of robots that cooperate in the consecution of this objective [8, 9]. In this case the map building will be performed more quickly and robustly than with a single robot [11]. However, the trajectories of several robots have to be estimated meanwhile information from different entities is fused to estimate a single map. As a consequence, the dimensionality of the problem is higher.

Regarding the sensors used to extract information from the environment, some authors employ range sensors such as LASER [14, 15] or SONAR [17]. However, there is an increasing interest on using cameras as sensors. This approach is denoted as visual SLAM [16]. These devices obtain a higher amount of information from the environment and are less expensive than other sensors such as LASER. Moreover, 3D information can be directly obtained when using stereo vision [4]. Finally, in order to build the maps, a recent proposal is the FastSLAM algorithm [12]. The main idea of this algorithm is the use of a particle set that represents the uncertainty in the pose of the robot. Each particle is an hypothesis of the real path followed by the robot and has an associated map of the environment. The SLAM problem is seen as the sum of two fundamental aspects: the estimate of the pose of the robot and the estimate of the map. Although these aspects are intrinsically related, they can be considered separately. That is to say, if the robot's path is known, then the estimate of the map would be trivial. In a similar way, if the map is known, it would be easy to localize the robot in it. The FastSLAM algorithm divides the SLAM problem into a localization problem and several individual estimates of the map. This algorithm can be summarized in the following steps:

1. New particle set generation.
2. Landmark estimation.
3. Assigning a weight to each particle.
4. Importance reampling.

These steps are repeated successively during the SLAM process.

Our work focuses towards the approach in which there is a team of robots that colaborates in the construction of a map of the environment. In this approach the map and the trajectories are not built jointly such as in other multi-robot proposals [3]. On the contrary, we propose an alternative solution in which the robots initiate the SLAM process independently, i.e., they have no knowledge about other robots' poses and observations. The map building can be performed without knowing the relative positions of the robots. The SLAM problem is therefore solved by means of

several independent particle filters. After a while, each robot will have built a local map with its own reference system. In order to obtain a global map, the set of local maps have to be fused into a single one. In this paper, we focus on this step. First, it is necessary to estimate the relative position in order to find a common reference system for the local maps. This is denoted as map alignment and consist in computing the tranformation that relates two reference systems. This is done by establishing correspondences between the local maps. Finally the global map is obtained in the map merging step, in which the data is fused. The study of the map alignment and map merging, tackled in this paper, is a necessary preliminary step in order to achieve an independent multi-robot SLAM platform.

2 Related work

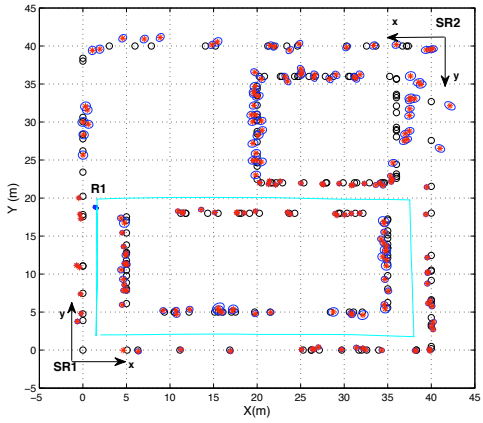
Different solutions to the multi-robot SLAM problem have emerged so far. These solutions can be classified into two different groups:

1. Solutions in which the estimate of the map and the robot trajectories is performed jointly. In this case, the construction of a single map is centralized using the observations of all the robots, updating the trajectories and the map jointly ([14, 3, 6, 8]). The problem is that the intial relative position of the robots should be known which is something that may not be possible in practice.

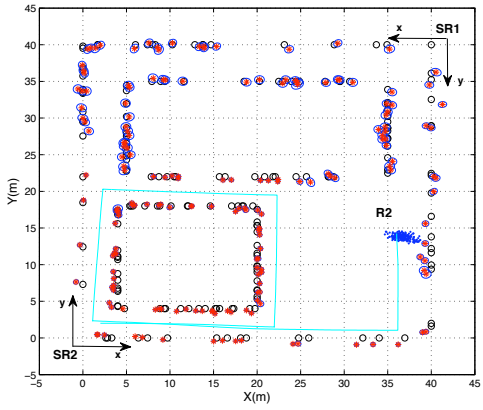
2. Solutions in which each robot estimates an own individual map using its observations independently ([9, 18]). In this case, new observations should only be compared with a limited number of landmarks in the local maps. Additionally, the construction of the local maps can be carried out even if the relative poses of the robots are not known. This is an advantage over the previous case. However, the map fusion step is troubled since the data association should be solved between the local maps.

In this paper, we focus on the latter approach. i.e., the robots start from different positions and build local maps independently. Then, the fusion of these local maps may be required. As a consequence, the trasformation between the different reference systems should be known. In this situation, most approaches try to find the relative position of the robots. In this sense, the easiest case can be seen in [14], where the relative position of the robots is supposed to be known. Nevertheless, more difficult approaches are [9] and [18]. In these cases, the robots try to establish a meeting point in order to measure their relative positions. In many approaches the transformation between maps is performed with the matching of landmarks [13].

3 Map building



(a)



(b)

Figure 1: Example of map building using FastSLAM. Two robots share the same space ($R1$ and $R2$), but the map building is performed independently.

In this work, we use Pioneer-P3AT robots, provided with a laser sensor and a STH-MDCS2 stereo head from Videre Design. This stereo camera is used to extract visual information from the environment. Concretely, we use the Harris corner detector [7] to obtain distinctive points of the scene. Moreover, these points are characterized by a visual descriptor known as U-SURF [2]. The selection of this combination detector/descriptor is the result of a previous work [5].

Figure 1 shows an example of the map building using the FastSLAM algorithm. Two robots share the

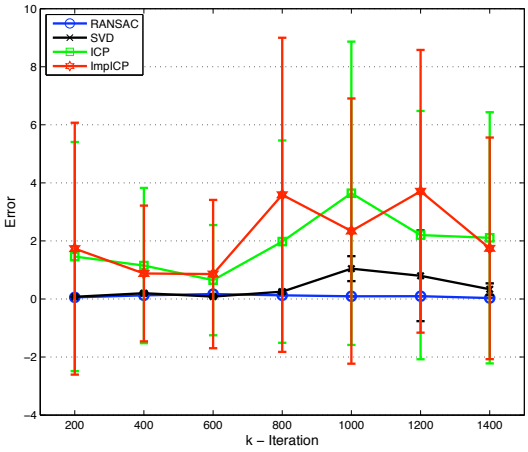


Figure 2: Traslation error.

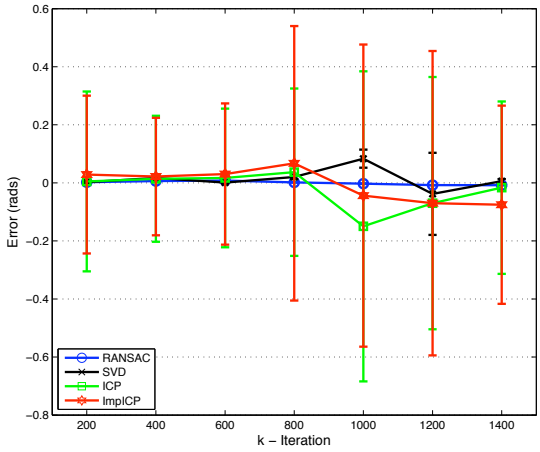


Figure 3: Rotation error.

same scenario although they do not have any knowledge about the other robot's existence. Each robot perfoms an independent particle filter. In the figure, we can see the reference system of each robot (SR_1 and SR_1). Figure 1(b) presents the same scene of Figure 1 (a), but rotated as SR_2. The reference systems are located at the (0,0,0) position of the respective robots. In the figure, we apreciate how the pose of each robot is represented by a particle set. $R1$ (Figure 1(a)) has a lower uncertainty in the pose since the robot has already closed a loop (revisits an area). On the contrary, in Figure 1(b), we observe that the uncertainty in the pose of $R2$ is higher since the particle set is more disperse. Additionally, the path of the robots is also represented. For clarity reasons, we present only the path of the most probable particle, which is the best estimate at that moment. Regarding the map estimated, it can be observed that the estimate of the landmarks has more or less uncertainty depending on how many times are these landmarks seen by the robots or the distance from which they are observed. The uncertainty is represented by an ellipse.

In the experiments presented in this paper, the map alignment is evaluated at different stages of the SLAM process. These experiments have been carried out using 200 particles per robot.

4 Map Aligment

This section studies the aligment of landmark-based maps. Concretely, the maps built are made of visual landmarks. Aligning two maps means establishing a common reference system for these maps. This is done by computing the transformation between the reference systems of the different local maps.

In this framework, our aim is to find a suitable method that allows us to align this kind of maps. In order to do this, we have performe an evaluation of a set of aligning methods: RANSAC (Random Sample Consensus), SVD (Singular Value Decomposition), ICP (Iterative Closest Point) and ImpICP(Improved ICP). The ImpICP method is a modification of ICP implemented *ad hoc*. The rest of methods have been already applied to map alignment or point registration. A more detailed explanation of the functioning of these methos can be seen in [1]. Basically, these methods establish correspondences between the landmaks of two local maps, based on the descriptor similarity. Then, given this set of correspondences, an estimate of the alignment is computed. Obtaining the alignment means obtaining three parameters: traslation in x and y, and rotation (t_x, t_y, θ).

In these experiments, the local maps have been built by means of the FastSLAM algorithm. This algorithm is performed in several iterations. Since the aim of this study is to observe the behaviour of the aligning methods at different stages of the SLAM process, we obtain the most probable map at each selected iteration. The most probable map is the map of the most problable particle at that specific moment. Then, given two maps, the alignment is carried out by each aligning method. Finally, the solution is evaluated as an error measure computing the Euclidean distance between that solution and a *ground truth*. This *ground truth* is a measure of the real relative initial position of the robots.

Figures 2 and 3 show the results obtained after comparing the aligning methods previously mentioned. They present the error in the estimate of the aligning parameters *vs*. the $k - Iteration$ of the FastSLAM algorithm. Figure 2 shows the traslation error (in meters), i.e., in the estimate of tx and ty. Then,

figure 3 presents the rotation error expressed in radians (estimate of θ).

As the iteration of FastSLAM is higher, i. e., when the number of landmarks in the maps grows, two situations may arise. On the one hand, it is probable that the overlapping part between the local maps is bigger, i.e., there will be more correspondences between the maps we want to align. In this situation, the estimate of the aligning parameters will be better. This fact is visible in the results obtained. Particularly, it can be seen in Figure 2 how the error of the solutions obtained by ICP and ImpICP decreases from $k - Iteration = 200$ till $k - Iteration = 600$. On the other hand, having more landmarks does not mean necesarily having more correspondences. For this reason, when the size of the maps grows, it can happen that the non-overlapping parts are bigger. This fact adds complexity to the search of correspondences (preliminary step of the aligning methods to compute the alignment). In this cases, the aligning methods are requested to be specially robust to false correspondences. In Figures 2 and 3 it can be observed that the error obtained is bigger around $k-Iteration = 1000$. Nevertheless, it is worth noting that RANSAC is invariant to the situations described. Moreover, it obtains a quite accurate estimate of the alignment, since the error values are very close to zero. RANSAC is therefore an aligning method robust to the percentage of common landmarks and is able to obtain low error results. Regarding the rest of methods, SVD obtain acceptable solutions although not so accurate as RANSAC. ICP and ImpICP do not obtain good results, since obtain errors close to 4 meters in the estimate of the traslation and close to -0.2 radians in rotation (ICP). Furthermore, they present results with high variance, what denotes some randomness in the estimate of the alingment.

Figure 4 shows an example of two maps (represented by asterisks and stars) as the typical used to be aligned is these experiments. These are 3D visual maps that initially have different reference systems. In the figure, it can be noticed that a set of common landmarks (correspondences) have been identified between the maps. These correspondences are used to compute the aligment between the maps.

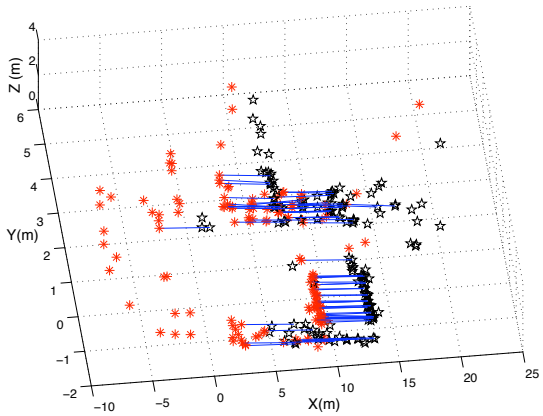


Figure 4: Correspondences established between two maps to be aligned.

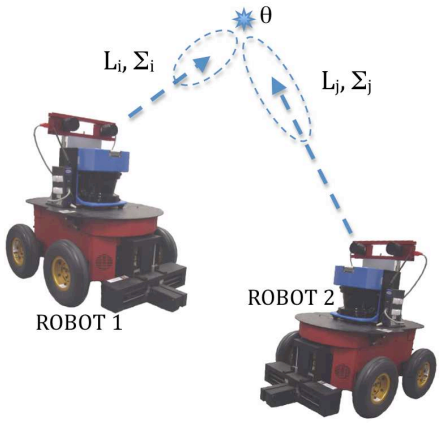


Figure 5: The same landmark θ has been observed by two different robots and integrated in their respective maps as L_i and L_j.

5 Map merging

Once the aligment is performed, the local maps have the same reference system. However, in order to obtain a unique global map, these local maps have to be merged. Figure 5 presents the situation in which the same point of the scene (θ) has been observed by two robots ($ROBOT1$ and $ROBOT2$) from different positions. This point is incorporated by each robot as a landmark in its respective local map. Particularly, the landmark is added as L_i and L_j respectively, as shown in Figure 5. Logically, the same landmark in different local maps will have different uncertainty (Σ_i and Σ_j). This uncertainty is represented in Figure 5 as an ellipse and depends on several factors, such as the distance between the robot and the landmark when it is observed, the uncertainty on the pose of the robot and the fact that this landmark can be reobserved during the SLAM process. Those factors affect the magnitude of the uncertainty in the estimate of the landmarks represented by the size of the ellipse.

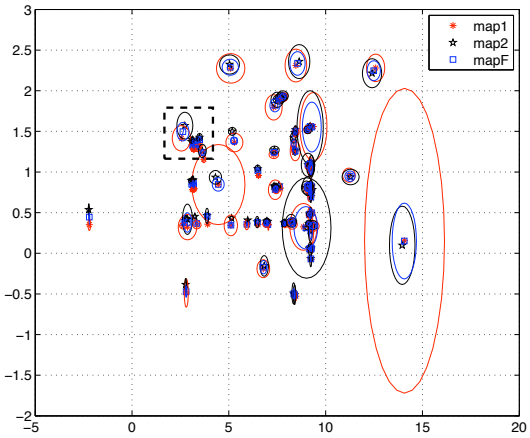
It is noticeable that when merging two local maps, the uncertainty of the landmarks have to be taken into account. For this purpose, our proposal in this pa-

per is a Multivariable Stationary Kalman filter. Given two maps (1 and 2), the fused map can be obtained by means of the following formulation:

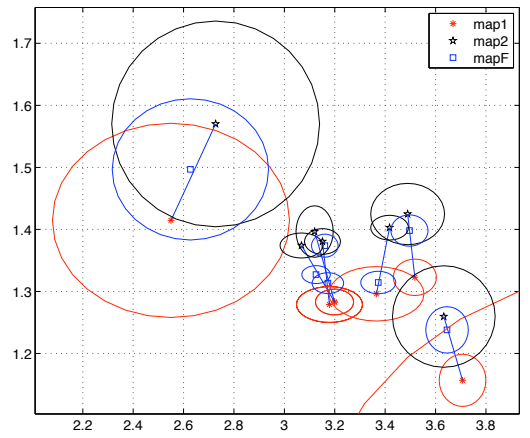
$$K_{\{m\}} = \Sigma_{i\{m\}} \cdot (\Sigma_{i\{m\}} + \Sigma_{j\{m\}})^{-1} \quad (1)$$

$$L_{F\{m\}} = L_{i\{m\}} + K_{\{m\}} \cdot (L_{i\{m\}} - L_{j\{m\}}) \quad (2)$$

$$\Sigma_{F\{m\}} = (I - K_{\{m\}}) \cdot \Sigma_{i\{m\}} \quad (3)$$



(a)



(b)

Figure 6: Results of map merging (2D view). (a) Presents correspondences of map_1 and map_2 aligned and fused into map_F. Error ellipses are also represented. (b) Zoom of the black rectangle drawn in (a). The fused landmarks (map_F) present a lower uncertainty (smaller ellipses).

where m is an index ($m \in \{1, M\}$, M: number of correspondences between the local maps) that denotes each pair of correspondences between the maps (in this case, i and j). L_i, L_j and L_F are the 3D coordinates of the landmaks in map_i, map_j and the fused map_F respectively. It is noticeable that map_i and map_j have been already aligned and therefore the landmarks are expressed in the same reference system. Then, Σ_i, Σ_j and Σ_F represent, by means of a 3×3 covariance matrix, the uncertainty of the landmarks belonging to map_i, map_j and map_F. It is remarkable that the aligment is not only applied to the coordinates of the landmarks, but also to the uncertainty ellipse. This is done by means of a rotation matrix (R) as shown below:

$$\Sigma_j = R^T \cdot \Sigma_{j0} \cdot R \quad (4)$$

$$R = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (5)$$

where Σ_{j0} is the covariance of map_j before the alignment.

In Figure 6 a real example of map merging is shown. Concretely, Figure 6(a) presents a set of landmarks identified as correspondences between two maps (1 and 2). In the figure, these maps have been already aligned so the correspondent landmarks almost overlap. Moreover, the resulting fused map (map_F) is also represented. Finally, the uncertainty in the estimate of the landmarks is represented by ellipses. For clarity reasons, a small area of this figure has been enlarged. Thus, the dashed rectangle is broaden to Figure 6(b). In this case, the correspondences can be seen connected by a line. Landmarks belonging to map_1 are represented by an asterisk and those of map_2 are represented by a star. Finally, the landmarks of the obtained map_F are represented by squares. As shown in Figure 6(b), the new landmaks, i.e., the landmarks of the fused map have lower uncertainty values since the uncertainty ellipses are smaller.

6 Conclusion

The approach proposed consists in maintaining independent particle filters in a multi-robot platform. In this case the relative positions of the robots is not need *a priori*. Furthermore, it is less computationally expensive than the case in which the map and trajectories is performed jointly.

After studying the map fusion problem, we conclude that RANSAC is the most suitable aligning method for this kind of maps, i.e., visual landmark-based maps. The experiments show also that the global map obtained presents less uncertainty than the

original local maps, thanks to the Multivariable Stationary Kalman filter. The results obtained regarding the map alignment and fusion problem are useful for any application using landmark-based maps.

Acknowledgements: The research has been supported by the SpanishMinistry of Science and Innovation under projects DPI2004-07433- C02-01 and CICYT DPI2007-61197 and by the Generalitat Valenciana (grant BFPI/2007/096).

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