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Integrating qualitative and quantitative reasoning spatio-temporal models and their application to robotics TIC2003-07182

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Abstract

Autonomous navigation of real robots includes four problems: mapping, locating, planning and motion control. The mapping problem is been currently solved by representing the environment of the robot by hybrid information: imprecise quantitative measures provided by sensors and the corresponding qualitative representation, mainly by cognitive maps. The rest of the problems in autonomous navigations is been currently solved using quantitative techniques, usually probabilistic, in order to overcome with the imprecision.

The idea of an autonomous robot navigating by using qualitative or common sense reasoning comes from the last 80th (i.e. the approaches developed by Kuipers et al.), although they have never been applied to real robots because they assume unreal perfect sensor information. In the 90th decade, all around Europe, a lot of theoretical qualitative models of different aspects of space and time were developed. Although the idea of applying them to robot navigation was very attractive, and some results were obtained in representing qualitatively the environment, no qualitative reasoning process has been used for solving any of the navigation problems on real robots.

In this project we want to use qualitative representation enhanced with quantitative imprecise data in a hybrid representation, and qualitative or common sense reasoning to solve the four problems of autonomous real robot navigation. Moreover, we will continue developing theoretical qualitative models of those aspects of space, time and movement that we need in order to solve particular problems. We also are going to deal with sensor integration: sonar, laser and vision based on biological models.

1 Objectives of the project

The integration of qualitative and quantitative spatio-temporal models for real robot navigation is a challenging research subject in Europe and United States. At the end of 80th in Kuipers et al.'s approaches, qualitative models were applied to simulated robot navigation, where the robot perception where perfect and unreal. Afterwards, a lot of theoretic qualitative spatio-temporal models have been developed. However, up to now, real robot navigation has been solved using quantitative techniques, usually probabilistic. The integration of theoretical spatio-temporal qualitative models and quantitative techniques for real robot navigation is a challenging problem.

From 1994, our research group (Cognition for Robotics Research, C4R2, www.c4r2.uji.es) has been working in the definition of a theoretical qualitative model which allows us the integration of several spatio-temporal aspects into the same model [Escrig & Toledo 98a]. Up to now we have integrated 2D orientation [Escrig & Toledo 96a], 3D orientation [Pacheco et al. 01a, 01b, 01c, 02a, 02b, 02c, 02d], cardinal directions [Escrig & Toledo 98c, 00b], topology [Museros & Escrig 00, 01a, b], named distances [Escrig & Toledo 96b, 97a, 97b, 98c, 00b], compared distances [Escrig & Toledo 01a, 01b], velocity [Escrig & Toledo 02a, 02b, 02c], topology and time [Museros & Escrig 02a, 02b, 02c, 02d], movement [Escrig et al. 02], for point and extended objects [Escrig & Toledo 96b]. This integration has been accomplished thanks to consider each aspect to be integrated as an instance of the constraint satisfaction problem [Escrig & Toledo 98d], solved using approaching techniques such as path consistency, by means of constraint logic programming extended with constraint handling rules as tool. This model of integration has been applied to simulated agent navigation by the structured environment of the streets of a city [Escrig & Toledo 98b, 00a, 00c]. Preliminary results in the use of qualitative spatial reasoning for real robot navigation has also been obtained.

The general objectives of the project can be divided into two parts. In the theoretical part of the project we will go on working in the integration of spatio-temporal aspects in the same model, if they were necessary for our practical applications. We are also going to work on sensor integration: infrared, sonar, laser and vision. A qualitative interpretation of sensor information will allow us a treatment of the robot environment and the robot obstacles, similar to human common sense. The advantage of the use of common sense is an enhancement of the level of the robot intelligence, which will allow us an efficient, quick and robust sensor use. We want to go into qualitative vision systems based on biological models.

In the practical part of the project, we will define robot navigation algorithms in which we will integrate the qualitative/quantitative spatio/temporal models which have been theoretically developed. We will work in three applications: the navigation in the structured environments of public buildings with two kind of robots (Khepera and Pioneer); the automatic construction of mosaic design by using qualitative shape recognition of ceramic pieces; and the navigation in an environment similar to brain structure with a legged robot.

The concrete objectives of this project are the following:

1. The demonstration of the equivalence among the qualitative spatio-temporal models based on intervals. Our goal is to obtain a general model, for which all spatio-temporal qualitative named models are instances.

2. An integration of the quantitative imprecise information provided by sensors into a qualitative, more abstract level. As the result of this, the robot will extract the main features of the environment in a quicker and more robust way.
3. We will deal with vision in a more cognitive way, by doing qualitatively shape representation, segmentation and matching processes.
4. We will develop navigation algorithms where the theoretical qualitative models of space and time are going to be incorporated. We are going to use four kind of robots: the Khepera, the Pioneer, the Aibo ERS7 and the Lauron IV.
5. We also want to develop our programs to be independent of the robotic platform. Therefore we are going to use the architecture based on multiagent systems and ontology defined in our group [Manzano & García 02].

In order to afford our objectives, we have defined the following tasks:

TASK 1. Demonstration of the equivalence among qualitative models based on intervals.

SUBTASK 1.1. Study of the state of the art of qualitative models based on intervals.

SUBTASK 1.2. Definition of a general spatio-temporal qualitative model based on intervals.

TASK 2. Qualitative/quantitative sensor integration of distance sensors: sonar, infrared and laser.

SUBTASK 2.1. Sonar, infrared and laser sensors provide distances among the robot and the obstacles. For the case of sonar and infrared, these distances contain a lot of imprecision. In this subtask we will represent distances qualitatively. For ring sensor robots, we will qualitatively integrate distances and orientation. The qualitative treatment of measurements manage the imprecision of data.

SUBTASK 2.2. The previous CICYT project was coordinated with the vision research group of our University. From this collaboration, the vision group provided a 3D reconstruction of any environment by a laser range finder. In this project we want to represent the results of this work in qualitative terms, i.e. describing walls and obstacles. We are interesting in obtaining landmark points of these features, i.e. corners of walls or obstacles.

TASK 3. Qualitative/quantitative sensor integration of sensors: vision.

SUBTASK 3.1. Study of the art on qualitative shape representation and cognitive vision.

SUBTASK 3.2. We will take from the state of the art the most satisfactory approach for our necessities or we will develop our own approach if there is no satisfactory one. We will extract the main features of the image by qualitative representation. We will provide a qualitative recognition of shapes.

SUBTASK 3.3. We will provide an automatic matching process. We will study the possibility of doing a qualitative segmentation of the image.

TASK 4. Development of robot navigation algorithms by using representation and reasoning qualitative spatio-temporal models.

SUBTASK 4.1. Study of the art on mobile real robot control architectures.

SUBTASK 4.2. Adaptation of the control architecture chosen in the previous subtask for the development of a navigation algorithm for the Khepera robot. Gradual incorporation of the representation and reasoning qualitative models of different aspects of space and time into this architecture and the sensor integration algorithm. We will build a structured environment adapted to the size and sensor reach by the Khepera robot. The robot will automatically learn the environment structure in a cognitive map. The robot will navigate towards an objective. The complete algorithm will be tested in a mobile robot simulator software, called Webot developed by Cyberbotics Ltd. (www.cyberbotics.com).

SUBTASK 4.3. We will build an obstacle detection module and another module for recovering from errors when the robot gets lost, for the Khepera robot, which will be added to the algorithms developed in the previous task.

SUBTASK 4.4. The algorithms developed in the previous tasks will be tested in the Khepera real robot.

SUBTASK 4.5. We will adapt the algorithms developed in the previous task for the Pioneer robot (www.activmedia.com). We will test initially the algorithms with the Webots simulator of the Pioneer robot.

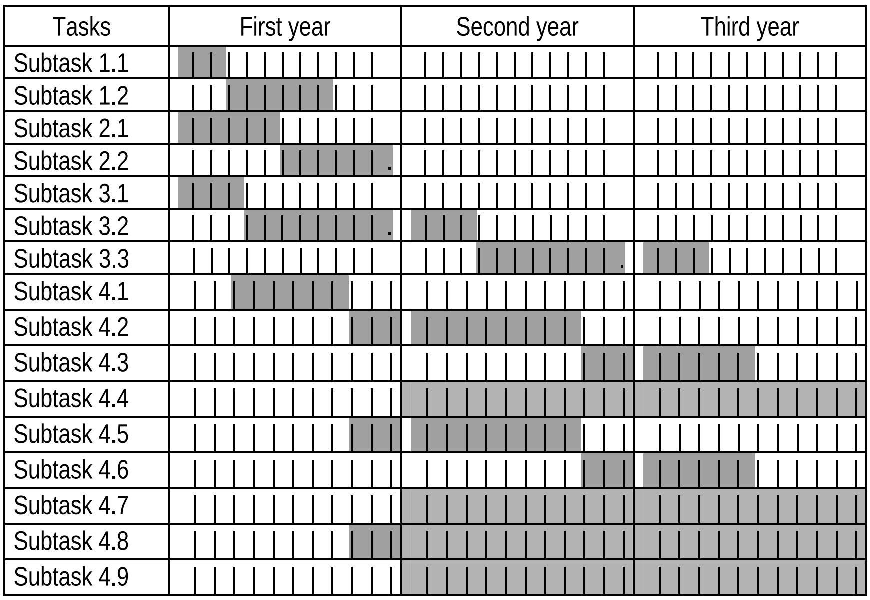
SUBTASK 4.6. We will build an obstacle detection module and another module for recovering from errors when the robot gets lost, for the Pioneer robot, which will be added to the algorithms developed in the previous task.

SUBTASK 4.7. The algorithms developed in the previous tasks will be tested in the Pioneer real robot.

SUBTASK 4.8. We will adapt the algorithms developed in the previous tasks for the legged robots: AIBO ERS7 and LAURON IV.

SUBTASK 4.9. Definition of general modules which includes all the functionalities previously solved which can be used by different robotic platforms.

We have planned to execute the previous defined tasks following the next timetable:



We are currently starting the second half of the seconf year of the project.

2 Level of success of the project

We are currently working on task 1 although we have not published any results yet.

Subtask 2.1 has been mostly finished [Falomir & Escrig 04a,b]. It has to be tested in different real robot platforms, which is our current work. The theoretical results are very promising.
Subtask 2.2 has been momentary oriented towards the qualitative interpretation of 2D laser sensor, because for the applications that we have in mind (autonomous real robot navigation) we do not need a precise 3D reconstruction of the environment. We have already obtained a qualitative description of landmarks of the environment (namely corners of walls and obstacles) at different levels of granularity which can automatically be adapted depending on the environment and the application, as well as the definition of qualitative places (where the main features of the environment are invariant) [Peris & Escrig 05].

Subtask 3.1 has been partially accomplished, we need to a do a deeper study of the art on cognitive vision. Subtask 3.2 has been partially accomplished. We have completely accomplished the qualitative representation, recognition and matching of shapes of objects in two different applications: the 2D shape recognition of ceramic piece in order to build a mosaic given a vector design [Museros & Escrig 04a, 04b, 04c, 04d]; and the 3D shape recognition of robot obstacles [Museros & Escrig 04e]. The matching process to be developed in subtask 3.3 has been accomplished. The part which needs complementary work is the qualitative image segmentation. Quantitative preliminary results have been obtained in [Museros & Escrig 05]. We still have not provided any results on the integration of distance sensors (sonar, infrared and laser) with vision. However, we will afford this in brief.

Subtask 4.1 has partially been accomplished. In subtask 4.2 we have applied the topology extended with time model developed in [Museros & Escrig 02a, 02b, 02c, 02d] to describe the movement of the Khepera robot [Museros & Escrig 04e] which has been tested both with the Webots simulator and the real robot (at it was pointed out in subtask 4.4). We are interested in translating these results to the rest of the robots, because the sensor reach of the Khepera robot is too short for practical applications. We are going to abandon this platform in the future. Subtask 4.3. and 4.6 have not been solved yet. For the Pioneer and the AIBO robots we have developed other navigation algorithms [Escrig & Peris 05a, 05b], [Peris & Escrig 05]. In fact, we have applied qualitative spatio-temporal models for solving the almost-SLAM problem defined at the ROBOCUP competition. We are currently implementing the algorithms. Although conceptually is solved, we need to test the complete set of programs in the real platforms in order to obtain the statistical results of their behaviour. We think they will be completely finished at the end of the year for both platforms, AIBO and Pioneer. We also are working with the LAURON IV robot. For this task we need to implement a robust module to recover the robot from errors in locating, we need to test final integrated programs in real robots and to transfer programs from different robotic platforms to test the programs in all the platforms (subtask 4.7). For affording the subtask 4.9 we have defined a standard for working in our group: each program developed by any member of the group will have to be documented in a particular way and stored in an ontology, in order to be reusable for all people and robotic platforms. We also have developed a cross-compiler for reusing directly the code programmed for the Pioneer simulated in Webots and the real robot. We also have built in Webots a simulator of the LAURON IV robot [Pacheco & Benito 05].

3 Results

Funded by this project there are 5 people doing research for their PhD. Lledó Museros is going to defend her thesis at the end of this year. Juan Carlos Peris and Julio Pacheco need at least two years more to finish their PhD. The other two people have done only preliminary work. The group is very active. During this year and a half of the live of this project we have published 12 papers: [Museros & Escrig 05], [Escrig & Peris 05a, 05b], [Peris & Escrig 05], [Falomir & Escrig, 04a, 04b], [Museros & Escrig 04a, 04b, 04c, 04d, 04e], [Pacheco & Benito 05]. We also have edited a journal [Yager et al. 2005]. And we also have published a book [Escrig 05].

We have done a very big effort during this year and a half in the application of the theoretical qualitative models developed by our group to real robot navigation. We have obtained less publications than in the previous CICYT project because it has been tremendously difficult to obtain the first practical results with real robots. In summary we have obtained 6 main results: (1) We have built an application which automatically interprets a vector design of a mosaic and builds it from a set of ceramic piece pieces which are qualitatively recognized in 2D; (2) We already have a robot (Khepera) which qualitatively recognize obstacles in 3D; (3) The Khepera robot already navigates by using a qualitative motion model which integrates topology and time; (4) We already have a robot (Pioneer) which qualitatively recognize landmarks from the quantitative environment information provided by a laser sensor; (5) We have qualitatively integrated the information provided by any kind of distance sensor; and (6) We also have conceptually solved the almost-SLAM problem defined for the AIBO robots at the ROBOCUP competition. We have almost finished its implementation. We are also transferring the results for solving the problem of the automatic sweeping of any surface.

We have started relationships with factories in order to transfer our technology. Among other things, we want to apply the results of our work to build autonomous vacuum cleaner robots.

Last year we participated very actively in the elaboration of a proposal for a Network of Excellence (called Choros) in the VI European Framework Programme (EFP) which unfortunately finally does not succeed. The groups involved in Choros were: U. of Leeds, U. of Zurich, U. of Hamburg, U of Bamberg, U. of Muenster, Spanish Scientific Research Council, U. of Paris at Orsay, U. of Bremen, Örebro U., T.U. of Vienna, U. of Tuebingen, U. of Seville, U. of Geneva, U. Jaume I of Castellón, New Bulgarian U., and U. of Freifurg. The collaboration with the previous mentioned groups comes from the participation in the "Spacenet" Network of Excellence of the IV EFM for 4 years (1994-1998). We have particularly good relationships with the Christian Freksa's group in Bremen. Christian is a co-supervisor of Museros's PhD thesis.

Our group is also a member of the MONET European network of excellence (funded by the 5th EFP) on Qualitative Reasoning.

We are also very active members of the ARCA Spanish network on Qualitative Reasoning and Applications (funded by a CICYT project).

We also collaborate with the U. Valencia (Dr. Salvador Moreno) and the U. Valladolid in Segovia (Dr. José Vicente Alvarez) in a very active way.

Another indicator of the relevance of our work and the effort done to communicate the result of our research work has been the concession of two prices: the price on "Science and Technology" of the city of Castellón to M. Teresa Escrig in 2004 [Escrig 05], and the "Castellón Onda Cero Radio" price to the Cognition for Robotics Research group for their research trajectory.

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