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Concept and Behavior Learning by Soft-Computing Techniques applied to the Mobile Robot Navigation problem TIC2003-04900

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Abstract

The development of intelligent and autonomous robots needs the incorporation of knowledge to its software architecture. This knowledge can be incorporated in the system by its designer or it is can be acquired or tuned by the own system. This second option has the advantage that make easier the design of the system and the obtained system present a better adaptation to the work environment. In the case of the mobile robot navigation problem, we have developed a navigation architecture based on fuzzy behaviors, where the mobile robot can achieve a safe navigation inside of an indoor environment. With this architecture, the robot can detect some important elements of the environment and build a topological map to represent the structure of an office-like floor. However, in the design of the system, we have used a considerable expert information for implementing the rules that describe the control behaviors and for defining the perceptual objects that the robot can find out during its navigation. This fact implies that the robot has not the ability for modifying the knowledge presents in the control behaviors, object definitions and for identifying new objects. The main aim of this project is to research in algorithms based on soft-computing techniques to allow the robot be able to acquire new knowledge or tune the current knowledge to obtained an improved robot navigation architecture.

Keywords:Learning algorithms, Soft-Computing, Mobile Robots.

1 Objectives of the project

1.1 Initial hypothesis and main objective

The knowledge needed for the right performance of many systems, is hard to obtain in some cases as for example in the mobile robot navigation problem. The team that supports this project has worked, on one hand, on issues related to machine learning through the use of fuzzy rules. On the other hand, a software architecture for mobile robot navigation has been also developed. Thanks to this architecture a Nomad 200 mobile robot is able to navigate in a safe way within an office-like indoor environment. Taking into account these two previous

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efforts in both areas (machine learning and robotics), the main objective of the project is to enhance the navigation architecture adding the skill of knowledge acquisition and learning. More specifically, the idea is the building of a knowledge acquisition module to be incorporated to the existent architecture in order to the robot be able to:

- learn new perceptual objects or tune its knowledge on certain perceptual object as the doors of the indoor environments.
- learn new control behaviors or tune its knowledge on the behaviors already implemented in the architecture.

The way for carrying out the knowledge acquisition process is intent to be autonomous in some cases and be supervised in other ones. That is, the human-robot interaction will be necessary in certain cases.

The initial hypothesis is supported by the experience of several members of the team on both machine learning and robotic areas. In regard to machine learning, the team has participated in different projects financed by the Spanish National Research and Development Plan: CICYT TIC 92-0665, CICYT TIC95-0453 and CICYT TIC96-0778, being a member of the team the main researcher in the two last projects. In these projects we have developed several machine learning techniques. For this project, we would like to distinguish the interesting properties of an inductive learning algorithm based on the iterative genetic model that allows us to describe the behavior of a system through a fuzzy rules set.

The team has also worked in the European project GENESYS: Fuzzy controllers and smart tuning techniques for energy Efficiency and overall performance of HVAC systems in buildings, European Commission, JOULE Program Code JOE3CT980090. In this project several tuning techniques were developed to tune fuzzy controllers applied to air conditioning equipments.

In regard to the robotics area, we have participated in the project EUROBOT-IBERIA: Network on Physical Agents TAP99-1354-E, Planet: European Network on Planning that has a section dedicated to robotics and in the Andalusian Network on Robotics. In this area we have developed a behavior-based architecture for mobile robot navigation.

1.2 Specific objectives

In order to achieve the main objective shown above, there exist several more specific objectives. They are described following:

1. Development and implementation of sensor data fusion techniques, with the treatment of uncertainty.

   The robot has several sensory systems as for example infrared and ultrasound systems. In this project, a camera will be added to the robot to obtain visual information of the environment. The analysis of the visual information supplied by the camera will be the most important aspect in this phase. Furthermore, fuzzy logic will be used to deal with the uncertainty and vagueness as well as to facilitate the data fusion process.

2. Development and implementation of tuning and learning techniques of perceptual objects.

   The idea is that the robot be able to detect perceptual objects from its sensorial system. As a perceptual model based on ultrasonic and infrared data have been already developed by the team, therefore, the attention will be focused on visual data. Fuzzy logic and genetic algorithms will be applied to set the perceptual features of certain objects like the doors.

3. Development and implementation of learning techniques of fuzzy rules applied to the control behaviors.

   The system will be able to adapt the implicit knowledge existent in the rules that describe the control behaviors of the robot. Thus, it will be possible to achieve a more robust and accurate behavior of the system.

4. Integration of the new developed techniques within the navigation architecture.

   The knowledge acquisition module will be inserted within a deliberative-reactive architecture to achieve a safe and robust navigation of the robot. It is hoped that the robot will enhance its perception capacities, map building process and skills to reaction under changes in the environment.

1.3 Tasks and planning

The planning of the project is divided in six phases to carry out during three years. Firstly it would be done a general analysis where all the general and particular (to be achieved in each phase) requisites of the system will be specified. The next four phases correspond to the four specific objectives to achieve and the last one will be of experimenting and testing of the whole system. In the last phase it should be possible to verify the improvement incorporated to the system thanks to the new knowledge acquisition module. Also, new aims could be defined to achieve in a future work. The six phases will be the following:

- Phase 1 - General analysis of the problem.
- Phase 2 - Development of sensor data fusion techniques.
- Phase 3 - Development of tuning and learning techniques of perceptual objects.
- Phase 4 - Development of tuning and learning techniques of fuzzy control behaviors.
- Phase 5 - Integration into the navigation architecture.
- Phase 6 - Global system testing.

Likewise, each phase corresponds to certain tasks that will be accomplished through the following planning.

1.4 Phase 1.

To carry out in the months 1 - 4 in the first year.

- T1.1. Analysis of the general requisites as well as for each one of the phases.
- T1.2. Definition of the interface between each one of the phases.

1.5 Phase 2.

To carry out in the months 5 - 12 in the first year and 1 - 2 in the second year.

- T2.1. Acquisition of the vision equipment and the pan-tilt and its installation in the Nomad200 robot.

- T2.2. Development and implementation of the techniques for extraction of characteristics, segmentation and shape recognition applied to visual data.
- T2.3. Analysis of the problem of data fusion and combination of visual information with distance information.
- T2.4. Development and implementation of methods based in Soft-Computing for data fusion.
- T2.5. Integration of the information supplied by the vision system with the current perception model.
- T2.6. Test of the techniques developed at this phase.

1.6 Phase 3.

To carry out in the months 1 - 10 in the second year.

- T3.1. Analysis of the learning problematic applied to the classification of perceptual information about the objects.
- T3.2. Adaptation of the existing techniques that were already used in previous projects or the development of new learning methods.
- T3.3. Implementation of the chosen techniques for the learning or tuning.
- T3.4. Tests to the impact of the learning or tuning in the capacity of the system.

1.7 Phase 4.

To carry out in the months 9 - 12 in the second year and 1 - 4 in the third year.

- T4.1. Analysis of the learning and tuning methods applied to the design of fuzzy behaviors in mobile robots.
- T4.2. Adaptation of existing techniques that were used in previous projects, or the development of new methods.
- T4.3. Implementation of techniques for the learning or tuning. This will be done in simulation.
- T4.4. Validation of the obtained results by tests in the real world with the new rule databases.

1.8 Phase 5.

To carry out in the months 1 - 10 in the third year.

- T5.1. Incorporation of the knowledge acquisition module in the architecture.
- T5.2. Adaptation of the execution and monitorization module.
- T5.3. Adaptation of the map building process.
- T5.4. Adaptation of the localization method.
- T5.5. Adaptation of the planning level.
- T5.6. Tests the new modifications in the architecture.

1.9 Phase 6.

To carry out in the months 10 - 12 in the third year.

- T6.1. Building of the topological map of the environment.
- T6.2. Development of complex navigation tasks where requisites defined in the analysis phase are needed.
- T6.3. Tests using those navigation tasks.
- T6.4. Evaluation of the test results and accomplishment of all objectives.
- T6.5. Definition of future work.

2 Level of success achieved in the development of the project

2.1 Phases 1 and 2

In the phase 1, the general analysis of the problem was carried out defining the requirements of the other phases and the interface among them. In the phase 2, the vision system was installed in the Nomad 200 robot and the visual information was dealt with as a new sensorial system.

Thanks to the incorporation of the visual information to the system, we have achieved in this second phase, a multi-agent system structured in three layers that uses a concurrent activation of both visual behaviors and fuzzy behaviors for the Nomad 200 navigation. The higher layer receives order from an external operator and generates a high level of abstraction plan consisting in the sequence of rooms and corridors to transverse and doors to cross to go to a desired place. This plan is decomposed in the middle layer in a sequence of skills that the robot is able to accomplish. These skills arises from the interaction of visual and fuzzy behaviors implemented in the lower layer of the architecture. Fuzzy behaviors takes as input the information provided by the range sensor and uses fuzzy rules to manipulate the imprecision and vagueness of the sensor data allowing a safe navigation to accomplish each part of the plan. Visual behaviors gathers the visual information from a single camera placed at the top of our robot and allows the system to know the location of the doors of the environment and indicate the straight direction to cross it. The camera is placed over a pan-tilt unit (PTU) that allows to move the camera independently from the movements of the robot giving to vision an active role in our system. We assume that all doors are opened because our robot cannot open them. To ease the door detection, artificial landmarks with numerical information in it have been placed beside the doors. Once the robot detects the landmark it must keep watching at the landmark indicating the straight direction to the door.

The tasks described in Sections 1.4 and 1.5 have been completed since the robot is able to manage ultrasound and visual information using both distance and visual data. The information has been dealt with through Soft-computing techniques in order to manage the uncertainty and vagueness present in the sensor data. Some experiments have been carried out to validate the system. This test and others have been filmed and can be downloaded at *http://decsai.ugr.es/ eaguirre/research/Videos.htm.*

2.2 Phase 3 and 4

In phase 3 we have tried to characterize some basic objects to facilitate the robot navigation. In previous works some objects like walls, corridors, corners and doors have been defined using a ultrasound-based model. However this perceptual model is affected negatively by the drawbacks of the ultrasound sensors. In this project we have focused our effort in the use of visual information to detect the doors of the environment since the doors are a very important kind of perceptual object in office-like indoor environments. Using the information provided by the camera placed on our Nomad 200 mobile robot we are going to establish a new belief degree on the existence of doors in indoor environments. This belief degree, obtained using vision, can be easily integrated with other values that the robot can obtain applying the fuzzy perceptual model previously developed.

In this phase we develop a new method for visual door-detection based on the extraction of the segments of the image and the definition of several fuzzy concepts. The segments of the images are analyzed in order to detect which of them belong to the frame of a door. The fuzzy concepts *Simple Frame* (SF) and *Double Frame* (DF) are defined to differentiate those situations in which the frame edges of a door can be seen. Features of the segments like size, direction or the distance between them are measured and analyzed using fuzzy logic in order establish a membership degree on the defined fuzzy concepts. In a first step, the edges of the image are extracted using Canny, then the Hough Transform is calculated to extract the main segments of the image. Using fuzzy logic, the relationship between the segments is measured to detect the presence of the concepts SF and DF. The method is able to detect typical doors of indoor environments under variable illumination conditions in grey-level images. The method can detect the doors under strong perspective deformations caused by the two degrees of freedom (DOF) allowed for the camera of our robot. Furthermore, according to our experiments it is suitable for real-time applications in a mobile robot Nomad 200 equipped with a vision system and a laptop.

The use of fuzzy logic has allowed, on one hand, to limit the search space of the set of possible segments and to define in a natural way fuzzy concepts. On the other hand, it allows to analyze the segments with different directions and size obtaining a high degree of flexibility in the manipulation of the information contained in the images. This flexibility is necessary to take into account the different perspective deformations caused by the two DOF of our camera.

The experiments carried out show that the proposed method can detect effectively the door of our environment with a high degree of success (92%). We consider that the method is valid for a great variety of doors commonly present in indoor environments.

However this system has several parameters that have been established in an experimental way and using expert knowledge. In order to obtain a more robust and general system some automatic mechanism is needed. In our project we have used evolutionary algorithms to solve this problem. That is, we use genetic algorithms for tuning the membership functions of the visual fuzzy system previously developed by us for door-detection in indoor environments. In fact, the system is formed by different set of fuzzy rules each one with several parameters to take into account. Furthermore, the objectives to obtain are two: On one hand, it is desirable a high detection rate in the images with doors. On the other hand, a low false positive rate is necessary in images where no doors are present. Thus we have to solve a multiobjective problem.

The use of evolutionary algorithms to solve multiobjective problems has experimented a great advance with the introduction of the *Pareto-based fitness* concept. The idea consist of ranking the individuals of the population according to the proximity to the Pareto-optimum. This approach has been referred in the literature by the term *EMO* (Evolutionary Multiobjective). The main advantage of EMO algorithms is the ability of simultaneously searching several non-dominated solutions. EMO algorithms finds in a single run different non-dominated solutions to a problem while several runs of a normal algorithm would be required to obtain similar results.

In this project, we make use of the EMO SPEA2 for tuning the membership functions of the visual fuzzy system previously developed. The visual fuzzy system uses a hierarchy of fuzzy classifiers that finds, among the segments of an image, those that belong to the frame edges of a doorframe. It can be used on autonomous mobile robots for navigating, map-building and positioning purposes. The variables used, the number of membership functions for each variable and the rule base of the fuzzy systems have been determined based on expert knowledge. Nevertheless, instead of selecting manually the range of each membership function, they have been uniformly distributed covering the domain of each variable. The tuning process will adapt the membership functions of the visual fuzzy system to the conditions of our environment, i.e., to the usual conditions of height and size of the doors of the environment and to the distances and orientations under which they are seen by the robot. The tuning of the 59 parameters of the fuzzy visual system is performed using SPEA2. The use of SPEA2 has allowed the concurrent optimization of the two objectives: increase of the true positive detection and reduction of the false positive detections. As the experimental results show, the technique allows us to adapt the initial visual fuzzy system increasing its success percentage on the images of our database from 56.15% to 95.48%.

Related to the tasks described in Section 1.6, we have focused our attention in the definition of the perceptual object "door" using fuzzy rules and tuning the system properly. A similar process will be done for other perceptual objects. Furthermore, we are working in the adaptation of other learning techniques.

The current state of the project is the beginning of the phase 4 although some tasks of phase 3 are still active.

3 Result rates

The results obtained in the development of the project have been shown in several national and international conferences as it is described below. Also, the project is being useful to allow the training of a post-graduate student that is carrying out his PhD. Thesis into the scope of the project. This student has obtained a grant of the Spanish Ministry of Education to carry out his post-graduate students.

3.1 International conferences

- Aguirre E., García-Silvente M., Gómez M., Muñoz-Salinas R., Ruiz C. A multi-agent system based on active vision and ultrasounds applied to fuzzy behavior based navigation. In Proc. of 10 Th International Symposium on Robotics and Applications (ISORA 2004) (En CD-ROM), Sevilla, 2004.

- Muñoz-Salinas R., Aguirre E., García-Silvente M. and González A. Door-detection using computer vision and fuzzy logic. In Proc. of 6th WSEAS International Conference on Mathematical Methods & Computational Techniques in Electrical Engineering (En CD-Rom ISBN: 9608457076), Atenas (Grecia), 2004.

- Muñoz-Salinas R., Aguirre E., García-Silvente M. and González A. Tuning a visual fuzzy system using SPEA2. In Proc. of First International Workshop on Genetic Fuzzy Systems (GFS'2005), pp. 37-43, Granada, 2005.

- Aguirre E., González A., Muñoz-Salinas R.. Mobile Robot Map-Based Localization using approximate locations and the Extended Kalman Filter. Information Processing and Management of Uncertainty in Knowledge-Based Systems (IPMU 2004) pp. 191 - 198. Perugia (Italia), 2004.

- Muñoz-Salinas R. Aguirre E., Garcia-Silvente M. and Gonzalez A., A Fuzzy System for Visual Detection of Interest in Human-Robot Interaction. Accepted in the 2nd International Conference on Machine Intelligence (ACIDCA-ICMI'2005), Tunisia.
- Muñoz-Salinas R. Aguirre E., Garcia-Silvente M. and Gonzalez A., People detection and tracking through stereo vision for robot-human interaction. Accepted in the Mexican International Conference on Artificial Intelligence (MICAI). Monterrey (México), 2005.

3.2 Spanish national conferences

- Aguirre E., Gómez M., Muñoz-Salinas R., Ruiz C. Un Sistema Multi-Agente que emplea Visión Activa y Ultrasonidos aplicado a Navegación con Comportamientos Difusos. Actas del IV Workshop de Agentes Físicos (WAF'2003), pp 63 – 74, Alicante, 2003.
- Aguirre E., García-Silvente M., González A., Muñoz-Salinas R. Detección de puertas mediante información multisensorial y su aplicación a la navegación de robots móviles. Actas del V Workshop en Agentes Físicos (WAF'2004), pp 33 – 42. Gerona, 2004.
- Aguirre E., García-Silvente M., González A., Muñoz-Salinas R. Detección de puertas mediante visión y lógica difusa. Actas del XII Congreso Español sobre Tecnologías y Lógica Fuzzy, pp. 389-394, Jaén, 2004.

3.3 Papers in International Journals

- Aguirre E., Argudo J. F., González A. y Pérez R., A Fuzzy Perceptual Model for Map Building and Navigation of Mobile Robots. Integrated Computer-Aided Engineering, vol. 11:3, pp. 239-258, 2004.
- Muñoz-Salinas R., Aguirre E., García-Silvente M. and González A., Door-detection using computer vision and fuzzy logic. WSEAS Transactions on Systems,Volumen: 10 n. 3 pp. 3047 – 3052, 2004.
- Muñoz-Salinas R., Aguirre E., García-Silvente M. and Gómez M., A Multi-agent system architecture for mobile robot navigation based on fuzzy and visual behavior. Robotica (Cambridge University Press). To appear in 2005.

3.4 Other activities of the member of the team

- A member of the team participated in the Organization Committee of the "First Workshop on Genetic Fuzzy Systems (GFS)" maintained from 17th to 19th March in Granada.
- Several members participate in the Program and Organization Committee of the "VI Workshop en Agentes Físicos" (WAF2005) within of the "I Congreso Español de Informática" (CEDI2005) that will be maintained in Granada.

Two research stays in foreign centers are planned:

- The member Muñoz-Salinas R., will go to the Advanced Mobile Robots & Intelligent Agents Laboratory. De Montfort University, Leicester (Reino Unido) from 30th June to 30th September 2005.
- The Dr. García-Silvente M., will go to the Instituto Tecnológico de Monterrey de México (ITESM) during a month in August 2005.