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Using fuzzy logic for autonomous robotics: an on-line workshop

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1 Overview

In October 1995, Takeshi Furuhashi and his collegues at the Bio-Electronics Laboratory of Nagoya University, Japan, organized the first of a series of *on-line* workshops, held entirely on the World Wide Web. The advertised advantages of the on-line format were to allow fruitful exchanges while avoiding physical travel, and to guarantee wide visibility of the discussion. The first two workshops in the series were devoted to evolutionary computation; they can be accessed on the web at `http://www.bioele.nuee.nagoya-u.ac.jp`. The third workshop, named "First On-Line Workshop on Soft Computing" (WSC1), had a broader scope, including all the techniques that go under the heading of "soft computing", like fuzzy logic, neuro computing, genetic computing, and so on. WSC1 took place from August 19 to 30 1996, and it is accessible on the web at `http://www.bioele.nuee.nagoya-u.ac.jp/wsc1/`. Because the declared goal of an on-line workshop is to prompt discussion, the rules for submission were looser than in most traditional workshops: papers were not subject to peer review, and it was possible to submit already published papers[1]. All the submitted papers were made visible on the web one week before the workshop, and people could send comments and questions by email during the two workshop weeks; all the questions, comments, and authors' replies are also visible at the WSC1 web site.

The first edition of the "Using Fuzzy Logic for Autonomous Robotics" event (FLAR, for short) was included as a special session of WSC1. Several reasons suggested the need for a session on this subject. First, there is a clear emerging market for truly autonomous robots; possible applications range from intelligent service robots in offices, hospitals and factory floors, to maintenance robots operating in hazardous environments, or rescue robots operating in disaster areas. Second, fuzzy logic has features that make it particularly geared to addressing the problems posed by autonomous robot operation, as witnessed by the large number of proposals presented in the literature. Finally, the papers on the use of fuzzy logic in autonomous robotics tend to be dispersed between the journals and conferences devoted to fuzzy logic, and those devoted to robotics and automation. The aim of FLAR was to bring together researchers who are applying fuzzy logic to autonomous robotics, and to provide a forum to critically assess the value of fuzzy logic techniques in this field.

The papers and the discussion are accessible on the web at the address `http://iridia.ulb.ac.be/FLAR/home.html`, or via the WSC1 site above. A quick look at the content of the FLAR pages reveals the peculiarities of the on-line format. First, most of the contributions are already published papers, meaning that the authors were more interested in the possibility of discussing their current achievements than in presenting new material. Second, although the session was small, including only ten contributed papers plus a general introductory paper by the organizer, it attracted a comparatively large audience: the FLAR pages have been accessed more than 500 times during the workshop, and about 400 times in the three months following the workshop.

[1]The original contributions to the workshop have been collected into a volume of proceedings, available from the WSC1 organizers by sending e-mail to wsc@bioele.nuee.nagoya-u.ac.jp.

Finally, most papers have been the object of a lively discussion, which is permanently recorded in the Web pages.

2 The contributions

Fuzzy logic has several features that make it particularly geared to address some of the main open problems in the field of autonomous robotics. The ten papers presented at FLAR give a wide, although very limited view of the uses of fuzzy logic in this field. The problems addressed can be classified in the following categories:

- How to *design* behaviour-producing modules that guarantee robust operation in spite of the limited knowledge available at design time.
- How to *combine* information coming from different sources, possibly affected by different types of uncertainty. This includes the sensor fusion problem—how to fuse information from different sensor modalities; and the coherence problem—how to register representations that belong to different levels of abstraction.
- How to *coordinate* the simultaneous activity of several, possibly competing behaviours. This includes the behaviour arbitration problem—how to decide which behaviours should be activated in each situation; and the command fusion problem—how to combine the commands produced by different concurrent behaviours.
- How to *integrate* processes at different levels of abstractions, like symbolic planning and numerical control. The problems of coherence and of behaviour arbitration also belong to this issue.

Perhaps the most obvious place for fuzzy logic in autonomous robotics is the use of fuzzy control techniques to *design* robust individual behaviour units. Fuzzy logic controllers incorporate heuristic control knowledge in the form of if-then rules, and are a convenient choice when a precise linear model of the system to be controlled cannot be easily obtained. They have also shown a good degree of robustness in face of large variability and uncertainty in the parameters. Fuzzy logic controllers have already been applied to several autonomous mobile robots, including the award-winning robots Flakey, Marge and Moria (see Saffiotti's introduction). At FLAR, four contributions (Tunstel; Yen and Pfluger; Ollero et al.; Bonarini) offered examples of the use of fuzzy rules to design robust motion control strategies. Bonarini's paper also illustrates the use of evolutionary techniques to automatically learn the fuzzy rules of each behaviour.

The second possible use of fuzzy logic is to *combine* uncertain information. Fuzzy logic can model several facets of uncertainty, including vagueness and imprecision, and offers many different combination mechanisms. These characteristics have been exploited by (Amat et al.; Gasos and Martin; Ollero et al.) to address the sensor fusion problem. The first two papers use fuzzy techniques to build an approximate map of the environment; the third one uses them for combining the input from several sensors into one fuzzy "virtual sensor" used for navigation. A fourth paper (Saffiotti and Wesley) deals with the coherence problem: how to compare perceived (fuzzy) features to an approximate map of the environment to update the robot's location.

Fuzzy logic is also useful for addressing the problem of behaviour *coordination*. Fuzzy meta-rules can be used to write general arbitration strategies, specifying in which situation each behaviour should be activated; and the combination mechanisms provided by fuzzy logic can be used to perform command fusion between the active behaviours (see Saffiotti's introduction). Although the potentials of fuzzy logic for behaviour coordination are scarcely noticed in general, this was not the case at FLAR, where six papers touched at this issue. Yen and Pfluger deal with command fusion; Kohout, Barfoot, and Barnes and Ghanea-Hercock address behaviour arbitration; and Bonarini, and Tunstel address both. In addition, Bonarini's and Barnes and Ghanea-Hercock's papers show the use of genetic algorithms to automatically learn fuzzy arbitration rules.

Finally, let us mention what we believe to be the most important feature of fuzzy logic, namely its intrinsic ability to integrate numeric ("fuzzy") and symbolic ("logic") aspects of reasoning. This double nature suggests that fuzzy logic can be used in layered robot architectures to address the problem of *integration* between high-level layers, which typically perform symbolic computations, and low-level layers, which typically perform numeric manipulations. Although no paper at FLAR directly addresses this issue, two papers indirectly touch at it: Saffiotti and Wesley integrate low-level perceptual information with high-level map information; and Barnes and Ghanea-Hercock suggest using a high-level planning process to generate scripts including fuzzy rules for behaviour arbitration. In both cases, fuzzy logic has been found to provide a convenient common representation of information to be shared between symbol-oriented and number-oriented processes.

3 The on-line discussion

One of the most attractive features of an on-line workshop is the opportunity to have extensive and relaxed interactions over the Internet. The discussion at FLAR followed the rules of WSC1 explained above. Each paper has been the object of two to six questions and answers, sometimes extending over several paragraphs. Many interactions focused on specific points of the presented papers; but the discussion also featured exchanges about more general issues related to the use of fuzzy logic in this domain. Two threads, prompted by the FLAR organizer, concerned methodological issues.

The first thread was about the experimental validation of the proposed approaches. Experimental validation is imperative in the domain of autonomous robotics, and almost all of the papers presented at FLAR included reports of experimental results. However, such reports are only meaningful insofar as the experimental set-up and the protocol used are carefully detailed. This is particularly true for experiments performed in simulation. While several of the papers at FLAR failed to be sufficiently explicit on this methodological issue, most of the authors took the opportunity given by the on-line discussion to greatly clarify the experimental setup used.

The second issue concerned the comparison between fuzzy and non-fuzzy techniques. Autonomous robotics is a melting pot of several disciplines, including artificial intelligence, cybernetics and control theory, many of which rely on a wide set of firmly established tools. If fuzzy logic techniques have to become accepted in this field, it is necessary that they be carefully evaluated against the existing tools. Most of the authors used the on-line discussion to debate the respective merits of fuzzy and non-fuzzy solutions, and to detail the reasons that led them to opt for the fuzzy ones.

A few emerging patterns of agreement can also be noticed which might provide some hints as to where the field is likely to move in the near future. First, although few authors have performed extensive comparisons between fuzzy and non-fuzzy techniques, all of the participants seem to agree that this sort of comparison should be done. Second, there is a tendency to move towards a formal analysis of fuzzy logic techniques, prompted by the desire to have formal guarantees of the good behaviour of a fuzzy system. Finally, more and more authors are realizing the power of fuzzy logic as an integration tool between high-level knowledge and processes, and low-level ones. Given the key role played by integration issues in autonomous robotics, it should be expected that this aspect will be essential to the future exploitation on fuzzy logic in this domain.

4 Concluding remarks

Fuzzy logic has features that are particularly attractive in light of the problems posed by autonomous robotics. The first FLAR event should be regarded as a limited but worthy attempt at establishing a discussion forum to critically assess the value of fuzzy logic techniques in this field. The on-line format of the workshop allowed the development of interesting interactions, and was generally appreciated by the participants. In retrospect, the limited time (two weeks) allowed for question-answering might have reduced the interactivity of the workshop. The organizers are now considering turning FLAR into a more permanent discussion forum based on the Web.

References[2]

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Bonarini, A. "Reinforcement learning of hierarchical fuzzy behaviors for autonomous agents".

Gasos, J and Martin, A. "Mobile robot localization using fuzzy maps".

Kohout, LJ. "Distributed architectures for CAM and other embedded robotic systems".

Ollero, A, Garcia-Cerezo, A, Martinez, JL and Mandow, A. "Fuzzy tracking methods for mobile robots".

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Tunstel, E. "Mobile robot autonomy via hierarchical fuzzy behavior control".

Yen, J and Pfluger, N. "A fuzzy logic based extension to Payton and Rosenblatt's command fusion method for mobile robot navigation".

[2]All the references are in: *Using Fuzzy Logic in Autonomous Robotics* (FLAR), special session at the First On-Line Workshop on Soft Computing (WSC1). Available on the World Wide Web at `http://iridia.ulb.ac.be/FLAR/` or at the WSC1 site given above.