PROCEEDINGS IADAT-aci2006

International Conference on Automation, Control and Instrumentation

IADAT

Technological Advances

applied to

Theoretical and Practical Teaching

July 5-7, 2006
Valencia, SPAIN

Edited by
IADAT

Published by

International Association for the Development

of Advances in Technology

IADAT

ISBN: 84-933971-8-0

Depósito Legal: BI-1080-04

The papers included in this publication have represented the programme of the IADAT-aci2006 International Conference on Automation, Control and Instrumentation, held from 5th July to 7th July, 2006 at the Valencia Conference Centre in Valencia, Spain.

Edited by:

IADAT. International Association for the Development of Advances in Technology

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P.O. Box 988. 48080 Bilbao. Spain

ISBN: 84-933971-8-0

Deposito Legal: BI-1080-04

Printed in Spain

IADAT-aci2006

Proceedings of the IADAT International Conference on Automation, Control and Instrumentation

Innovation, Technology and Research

Valencia (SPAIN), July 5th- 7th, 2006

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A FUZZY SYSTEM TO CONTROL MULTI-ROBOT FORMATIONS USING COMPUTER VISION

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Abstract

The necessity of carrying out complex tasks in variable environments has promoted the development of new robotics approaches, such as collaborative robotics. This way, multi-robot systems have become a very attractive field of research. This paper presents a behaviour-based method for multi-robot formations, using computer vision. A team of robots must follow a leader one, keeping a relative distance and orientation, and avoiding the possible collision with the obstacles. A very robust computer vision technique has been used for the localization of the leader robot using the images of the camera that each robot carries on its top. The final control has been built through the combination of several single behaviours using fuzzy logic. These algorithms have been tested over a team of WiFiBot robots with excellent results.

Keywords
Multi-robot systems, computer vision, formations, behaviours, control schemas, fuzzy logic.

1. INTRODUCTION. BEHAVIOUR-BASED ROBOTICS.

One of the major trends in current research on robotics is the development of techniques for autonomous navigation. This way, the objective is to build a system that is able to move with a purpose and without human intervention in a determined environment. Sometimes, for the accomplishment of a global objective, the collaboration of a team of robots is necessary. In some occasions a single robot cannot carry out the task on its own, and thanks to the collaboration, the task can be done quicker and in a more reliable way. One of the problems that rise in the field of collaborative robotics is the maintenance of formations, what implies a team of robots to move around keeping a relative position between them, and avoiding the collision with possible obstacles at the same time.

Several methods have been developed to carry out formations maintenance. One of them is the behaviour-based control [1][2]. Inspiring in biology, in this control, the combination of several basic behaviours constitutes the global behaviour. To carry out the control of formations, a reference must be taken in the formation. Each robot must keep a relative position respect this reference, so, a behaviour must be designed to bring the robot to the correct position. The major advantage of this method is its simplicity, due to the fact that it splits the problem in different simple behaviours, and the method can be improved easily, just adding new behaviours, e.g., behaviours for obstacle avoidance.

A behaviour is a system that transforms the inputs from the sensors in an action pattern that will be used to carry out certain task. In object-oriented programming, a behaviour can be seen as a class with two methods, *perceptive_schema()*, which implements the algorithm for the perception and stores the results, and the method *motor_schema()*, that uses the perception to calculate an array which specifies the output direction and speed. Then, in a behaviour-based system, there are several behaviours that, when active, depending on the sensory input will return different action patterns that can be, for example, a linear and steering speed or a direction angle (depending on the robot kinematics) in the case of robots navigation. This way, through the combination of these different responses, the global control action will be built.

However, several difficulties outcome when working with robots in real world. First, the knowledge about the environment is usually incomplete, uncertain and approximate, and it should be taken into account when calculating the control action. Second, the information that is acquired through the sensors is usually unreliable, due to the limited range and the effect of environmental features, like lighting and occlusion. Also, the effect of the control actions is neither completely reliable. To overcome all these difficulties, fuzzy logic can be used. Its heuristic nature will made it a specially useful tool for dealing with problems caused by uncertainty.

Fuzzy logic can be applied to several issues in the field of behaviour robotics. The first and most common application of fuzzy logic techniques is to implement individual behaviour units. Fuzzy logic controllers incorporate heuristic control knowledge in the form of if-then rules, useful when a model of the system can not be easily obtained. As an example, [3] developed a fuzzy controller for obstacle avoidance, using a simple algorithm to obtain information about occupied and free areas in front of the robot from a video camera. [4] integrates vision-based wall following and obstacle avoidance, using predictive fuzzy control for obstacle avoidance. Another application of fuzzy logic is for behaviour coordination, this means, how to combine the results from different behaviours into one command to be sent to the robot's effectors. The most popular approaches of this type are based on a vector addition schema. Each command is represented by a vector, and commands from different behaviours are combined by vector combination. [5].

This work presents a behaviour-based method for multi-robot formations using computer vision, where the co-ordination of the behaviours is carried out using fuzzy logic. A team of robots must move around the environment, following a leader and keeping a relative position (distance and orientation) between them and avoiding the collision with possible obstacles. The position of the leader is tracked using computer-vision methods, using the images captured by the camera they carry on their top. The developed algorithms have been tested over a team of *WiFiBot* mobile robots, with good results.

2. IMPLEMENTATION ON THE WIFIBOT.

2.1 Location system

The robot used to develop all the algorithms is the *WiFiBot,* a low-cost 4-wheel, non-holonomic robot characterized by its flexibility, which allows its use in different environments and situations. To extend its possibilities, we have included in both models a PC-104+ board (P4M 1.4 GHz, 512 Mb RAM, 2 Gb Flash Disk), with *Linux Debian* operative system. The position and orientation of the leader robot $[x_l, y_l, \theta_l]$, is obtained using computer vision. This leader is identified using a mark on its back, consisting on four black points or 2.5 cm diameter whose centres form a 4 cm side quadrate over white background. Knowing the shape and size of the graphics, the follower is able to calculate the distance and orientation to the leader using a very robust method [6], based on Thales Theorem and Projective Geometry. Fig. 1 shows the data that must be calculated. Fig. 2 shows the formation of the image in the image plane.

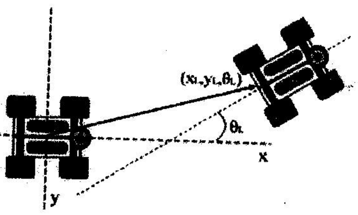


Fig 1. Coordinates System for localization of the leader robot

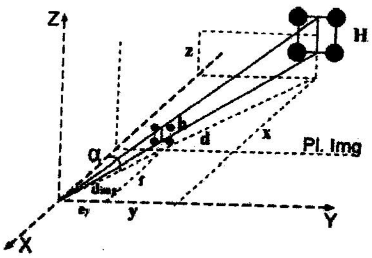


Fig. 2. formation of the image of the label in the image plane.

2.2 Basic behaviours

An architecture has been developed over the WiFiBot that allows the navigation while a team of robots maintain some pre-defined geometric shape. To do it, four basic behaviours have been implemented: *Go To Destination, Avoid Obstacles, Maintain Formation* and *Look For Reference*. These behaviours generate the control action that must be applied to the robot. This action consists on a linear speed and turning speed. These basic behaviours are combined using fuzzy logic to create two high-level behaviours: *Navigate*, that locates the destination and directs the robot towards it avoiding possible obstacles, and *Form*, which allows maintaining a constant position and orientation relative to another robot that is moving.

- ***Go To Destination***: This behaviour makes the robot move until it reaches a determined destination. It is composed of a perceptive schema and a motor schema as shown on fig. 3. The first one locates the destination position for the robot (using the captured image). The motor schema calculates the speed arrow that allows the robot directs to the destination.

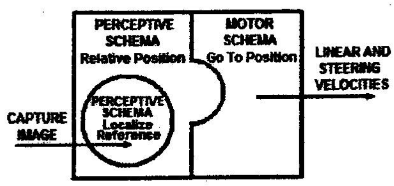


Fig. 3. Behaviour *Go To Destination.*

• ***Avoid Obstacles.*** It generates a repulsive effort when an obstacle is ahead the robot. It is also composed by two schemas, the perceptive one *Obstacle Position* and the motor one *Avoid.*

• ***Look For Reference.*** The robot moves around describing circles looking for the reference. Taking into account that the system does not provide communication between the robots and neither a common global reference system for all the robots, it is necessary to carry out first a research of the leader.

• ***Maintain Formation.*** It allows the following of a mobile object keeping a relative position and orientation respect to it. It is composed by the same perceptive schema than the behaviour *Go To Destination* and a motor schema *Follow Reference* that is in charge of the activation of the behaviour when the reference is detected.

3. CO-ORDINATION OF BEHAVIOURS USING FUZZY LOGIC.

As exposed in the previous section, a behaviour-based system is composed by several behaviours that, if they are activated, and depending on the input they have, they will calculate a control action. This control action will be composed by a linear and a steering speed in the case of robot navigation. Then, we have now to decide how to combine the schemas that each behaviour provides us to calculate the global control action for the robot. Different architectures have been proposed with this goal. Brooks [7] proposed a Subsumption Architecture where the different behaviours are hierarchically ordered in several levels. The most restrictive behaviour that is active at this moment is the one that imposes its control action. In [8], a votation method is proposed. There is a finite number of possible action patterns. Then, each behaviour selects one of these patterns and, at last, the most voted pattern is the one that is taken as the output. The different behaviours can also be combined in a linear way [9], calculating the average weighting of each behaviour according to how restrictive it is. At last, fuzzy logic techniques can be used [10].

In this work, fuzzy logic is used to build two high-level behaviours (one for the leader robot and another one for the follower ones). Each simple behaviour contributes to the high-level ones through a weight that depends on the situation the robot is. Then, the output of the system will be a weighted combination of the control action that each behaviour provides. To obtain these weights, fuzzy logic is used. Two high-level behaviours have been built, as shown on Fig. 4.

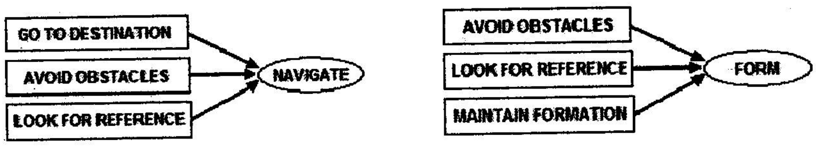


Fig. 4. High-level behaviours.

• **Navigate**. This behaviour is the result of the combination of the basic behaviours *Go To Destination, Avoid Obstacles* and *Look For Reference.* The controller will take the next inputs: Distance to the obstacle (x_1), orientation of the obstacle (x_2), distance to destination (x_3) and angle to destination (x_4). These inputs will be modelled using triangle sets, as shown of fig. 5. The distance inputs are divided in three sets; L (Little), M (Medium) and B (Big), and the angle variables are divided in L (Left), C (Center) and R (Right). The outputs will be the weights of the basic behaviours, *Go To Destination* (L_1), *Avoid Obstacles* (L_2) and *Look For Reference* (L_3). These outputs will be modelled using singleton sets.

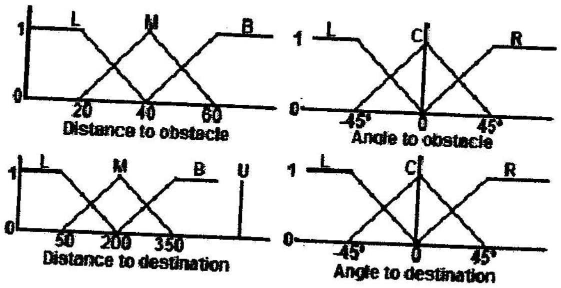


Fig. 5. Fuzzy conjuncts of the input variables to the fuzzy controller in the *Navigate* behaviour.

After exhaustive experiments, a set of IF-THEN rules has been built. Fig 6. shows an example of the tables that have been designed for these rules. In these tables, the first columns are the weights for the *Go to Destination* behaviour, the second for *Avoid Obstacles*, and the third for *Look for Reference*. When the distance to destination is *Unknown*, if there is an obstacle near, the most weighted behaviour is *Avoid Obstacles*. If it is far, the main behaviour is *Look for Reference* (due to the fact that the robot is lost). When the distance to destination is *Medium*, depending on the proximity of an obstacle, the main behaviour will be *Go to Destination* or *Avoid Obstacles*. If the obstacle is near, the system will try to avoid it. When the side the robot has to turn to avoid the obstacle is the same than the angle to destination, we will take profit to weight the *Go to destination* and *Avoid obstacles* behaviours. When the obstacle is far from the robot, the only behaviour that acts is *Go to destination*.

If x_3 is UNKNOWN

	If x_1 is L			If x_1 is M			If x_1 is B		
If x_2 is L	0	1	0	0	0,1	0,8	0	0	1
If x_2 is M	0	1	0	0	0,1	0,8	0	0	1
If x_2 is R	0	1	0	0	0,1	0,6	0	0	1

If x_3 is M

If x_1 is L

	If x_2 is L			If x_2 is M			If x_2 is R		
If x_4 is L	0,2	-0,5	0	0,1	-0.8	0	0,1	-0,8	0
If x_4 is M	0	0,8	0	0	0,8	0	0	-0,8	0
If x_4 is R	0,1	0,8	0	0,1	0,8	0	0,2	0,5	0

If x_1 is M

	If x_2 is L			If x_2 is M			If x_2 is R		
If x_4 is L	0,6	0,2	0	0,6	0,2	0	0,6	-0,2	0
If x_4 is M	0,5	0,4	0	0,5	0,4	0	0,5	-0,4	0
If x_4 is R	0,6	0,2	0	0,6	0,2	0	0,6	-0,2	0

If x_1 is B

	If x_2 is L			If x_2 is M			If x_2 is R		
If x_4 is L	0,8	0	0	0,8	0	0	0,8	0	0
If x_4 is M	0,8	0	0	0,8	0	0	0,8	0	0
If x_4 is R	0,8	0	0	0,8	0	0	0,8	0	0

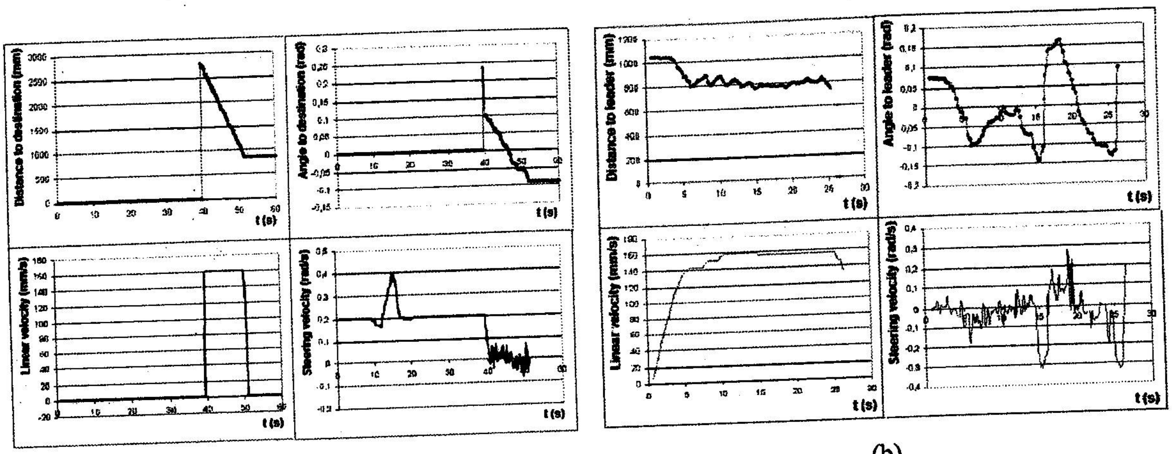
Fig. 6. Tables for the design of the *Navigate* behaviour.

- **Forming**. This behaviour is the result of the combination of the basic behaviours *Maintain Formation*, *Avoid Obstacles* and *Look For Reference*. The weights are obtained using fuzzy logic too using a similar reasoning method than for the Navigate behaviour. The controller will take the next inputs: Distance to the obstacle (x_1), orientation of the obstacle (x_2), distance to the leader (x_3) and angle to leader (x_4). The outputs will be the weights of the basic behaviours, *Maintain formation* (L_4), *Avoid Obstacles* (L_2) and *Look For Reference* (L_3).

4. EXPERIMENTAL RESULTS.

Several experiments have been carried out over a team of *WiFiBot* robots to test the performance of the high-level behaviours. Fig 7(a) shows the results obtained for the Navigation behaviour. Initially, the robot can not see the reference, and the purpose is to situate the robot at 0.8 m distance and 0 rad orientation to the reference. At first, the *Look For Reference* behaviour is the most important. It gives a constant steering speed to the robot. When the robot finds the reference (t = 40 s), the robot is directed to it stopping when it is situated in a threshold area around the target. In t = 10 s, the robot finds an obstacle, what makes it to turn to avoid it (*Avoid Obstacles* behaviour).

On fig. 7(b), the results for the *Form* behaviour are presented. The objective is that a robot follows the leader at 0.8 m distance and 0 rad orientation. As can be seen, the linear velocity increases to reach the same value as the leader.



(a) (b)

Fig. 7. Results for the (a) Navigate behaviour and (b) Form behaviour.

5. CONCLUSIONS.

A behaviour-based system for multi-robots formations has been presented. Through the combination of several basic behaviours using fuzzy logic, two high-level behaviours have been created to control the linear and angular speeds of the robots. The global control action is calculated as a weighted average taking into account the distance and orientation to the destination and the presence of a possible obstacle. As the experiments show, fuzzy logic offers a controller whose features are particulary attractive in the problems that outcome in autonomous robot navigation.

Acknowledgements

This work has been supported by Ministerio de Educación y Ciencia through project DPI2004-07433-C02-01 'Herramientas de Teleoperación Colaborativa. Aplicación al Control Cooperativo de Robots' and the Project PCT-G54016977-2005 'Robots Cooperativos para la vigilancia e inspección de edificios e instalaciones industriales'.

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