A MULTI-AGENT COLLABORATIVE CONTROL ARCHITECTURE WITH FUZZY ADJUSTMENT FOR A MOBILE ROBOT

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Abstract: One of the current challenges of control research is to make systems capable of showing intelligent responses to changing circumstances. To address this task, more complex systems are being developed. However, it is technologically difficult and potentially dangerous to build complex systems that are controlled in a completely centralized way. One approach to building decentralization systems is using multi-agent technology for building control architectures. But it seems risky to recursively extend using multi-agent systems to develop part of the system, such as a single behaviour.One alternative approach is to use collaborative control to deploy specific (low level) behaviours, so that several controllers are combined in a single agent of the multi-agent architecture in order to achieve the wanted behaviour. This paper presents a collaborative controller applied to the goto behaviour. The experiments were carried out using a Pioneer mobile robot.

1 INTRODUCTION

One of the current challenges of control is to make systems capable of showing highly flexible and intelligent responses to changing circumstances. Artificial Intelligence provides learning and adaptation methods, as well as decision making techniques to achieve these control properties. However, it is technologically difficult and potentially dangerous to build complex systems that are controlled in a completely centralized way (Murray et al., 2003).

In this line, (Rosenblatt, 1997) built an architecture composed of distributed, independent, asynchronous decision-making behaviours that were coordinated by a central arbiter. The overall behaviour of the system is rational, coherent and goal-oriented while preserving real-time responsiveness to its immediate physical environment. In (Bryson, 2001) several architectures are analyzed. The advantages of this architecture are the following: they facilitate their development and lead to the evolutionary creation of robust systems of incrementally greater capabilities. In these architectures, each behaviour is implemented by a module with communication abilities.

Recent advances in Multi-Agent Systems (MAS) have inspired researchers to go one abstract level further in implementing the architectures, in which modules are replaced by agents.

Nevertheless, behaviours considered in these architectures are not simple. For example, a **goto** behaviour, in a free-obstacle path, should take into account if the target point is close or far away from the current robot position.

In order to tackle the design of each behaviours, two approaches can be followed. On one hand, each behaviour can be implemented as a MAS again, assuming the risk that the robot could not be reactive enough to avoid obstacles when it moves too fast or the obstacles are mobile. And on the other hand, it is possible to take advantage of collaborative control to make up a single behaviour, combining several controllers in a single agent.

Integrating both research lines (the multi-agent approach and collaborative control) we get as a result a MAS architecture with collaborative controllers. Collaborative control is applied to design and develop a single behaviour, while the overall robot architecture is based on a MAS where each agent represents each behaviour. In this paper we give a detailed explanation of how the collaborative control approach based on Fuzzy Logic (Klir and Folger, 1992) is implemented in a single agent. Details on the MAS approach can be found in (Innocenti et al., 2006).

This paper is organized as follows. In Section 2,

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the related work is presented. Then, in Section 3 the MAS architecture is described while the collaborative control proposal is given in Section 4. In Section 5 the results are shown. Finally, some conclusions and future work are drawn in Section 6.

2 RELATED WORK

As stated above, our approach concerns MAS and collaborative control. Collaborative control has a general meaning, so, each time an algorithm to control a complex task is defined, the idea of collaboration in control is introduced. Thus, any development of complex systems with MAS can be considered as a collaborative approach.

On one hand, there are several architectures built as multi-agent systems to control a single robot, as for example (Neves and Oliveira, 1997), (Busquets et al., 2003), (Giorgini et al., 2002) or (Ros et al., 2005). Most of them present a centralized behaviour coordination and each behaviour has only one controller to set the desired outputs.

On the other hand, there are some works related to collaborative control in robots ((Goldberg and Chen, 2001), (Figueras et al., 2002), (Gerkey et al., 2002)). In the latter, collaborative control is obtained by relying on the physical dynamics of the robot's actuator. Due to their nature, motors temporally average their inputs, so Gerkey and colleagues propose that a population of non-communicating controllers drive the robot by interleaving commands to them. The resultant robot motion is then achieved as a superposition of the different control signals.

In accordance with (Saffiotti, 1997), our hypothesis is that, instead of superposing measures, higher decision making procedures can be used to coordinate the different controllers. Particularly, we propose using Fuzzy Logic to model the control actions provided by heterogeneous controllers and to decide, according to the robot motion dynamics, which combination of control actions have to be executed at a given time.

In addition, the output of the collaborative controller is the output of a single behaviour, instead of being directly connected to the robot actuators. The output of the single behaviour (agent) is coordinated in a multi-agent architecture to decide the next robot action.

3 MAS ARCHITECTURE

In our MAS architecture, agents can be grouped into perception, behavioural, actuator and deliberative agents. Perception agents obtain information about the environment and about the internal conditions of the robot; behavioural agents carry out specific actions, such as avoiding obstacles; deliberative agents implement high-level tasks such as planning; and actuator agents are in charge of controlling the linear and angular speed of the robot interacting directly with motors.

The **goto** agent is a behavioural agent which is responsible for driving the robot to the target position at different speeds. Other behavioural agents, are the **avoid** agent, responsible for avoiding obstacles and the **goThrough** agent, that is in charge of driving the robot through narrow places like doors. All the agents coordinate their behaviours by means of a distributed protocol in order to assure that no conflicting actions are sent to the robot motors (see (Innocenti et al., 2006) for a detailed explanation).

4 COLLABORATIVE CONTROL

In this section we present our collaborative control method based on combining multiple controllers using Fuzzy Logic to implement the behaviour of the goto agent.

Instead of developing only one quite elaborated controller, we design several controllers to cope with different control aspects separately and join their actions in order to obtain the complex behaviour of the **goto** agent.

Our starting point is the aggregation function proposed in (Gerkey et al., 2002), that we extend by adding weights corresponding to the relevance of each controller according to the current context. Therefore, the desired speed calculation is defined as:

$$\Omega = \frac{\sum_{i=1}^{n} \eta_t \cdot w_t}{\sum_{t=1}^{n} w_t} \qquad (1)$$

where η_i is the requested wheel speed over time, Ω the final wheel speed, n the number of controllers and w_t the weights that satisfy $\sum_{t=1}^{n} w_t = 1$. By using weights, it is possible, to give more or less importance to the controllers.

In order to determine the weights, we propose to introduce knowledge about the environment, such as whether the robot is near the destination point or not. Depending on this information, we can combine two position controllers: one that is *fast* and the other that is *accurate*. When the robot is **far** away from the destination point, we can stress the fast controller; when the robot gets **closer** to its destination, we can give more importance to the commands provided by the accurate one.

Fuzzy terms such as **far** or **close** can be modelled by fuzzy sets, in terms of the distance left (d) to the destination point. d is defined as $d = (d_{max} - d_{rec})/d_{max}$ where d_{max} is the distance between the initial and final coordinates, and d_{rec}, the distance from the initial to the current coordinates. Thus, the fuzzy set **close** is defined as:

$$\mu_c(d) = \left\{ \begin{array}{ll} 1 & d \leq min \\ \frac{(-d+max)}{(max-min)} & min < d < max \\ 0 & d \geq max \end{array} \right\} \quad (2)$$

where min and max parameters have been tuned empirically.

According to this definition and depending on the robot's movement, the distance to the destination point can be nonlinear along time, making the fuzzy set also nonlinear.

On the other hand, the fuzzy set **far** is defined as:

$$\mu_f(d) = 1 - \mu_c(d); \quad (3)$$

Based on the above fuzzy set definition, we can resolve the fuzzy concurrent control adjustment as:

$$\begin{array}{l} w_{fast} = \mu_f(d) \\ w_{slow} = \mu_c(d) \end{array} \quad (4)$$

where w_{fast} corresponds to the weight of the faster controller and w_{slow} to the accurate one.

Note that the way we use the fuzzy values determines, according to equation 1, the relevance of the commands of the different controllers. According to equation 4, both controllers collaborate in an intermediate situation, that is, in the sloping part of the fuzzy sets. Therefore, there is no abrupt change in the control, but progressively one controller has less influence in the final decision while the other one takes control (fuzzy adjustment).

5 RESULTS

We have implemented the MAS architecture in C++ adhoc MAS platform due to communication constraints. The experiment shown in this paper focus on the implementation of goto agent as a collaborative controller, so we assure that they were performed in obstacle-free paths meaning that the goto agent does not need to coordinate its desired actions with the rest of the behavioural agents in the MAS architecture. All the experiments were carried out with our own model (Innocenti et al., 2004) of the commercial robot Pioneer 2DX of ActivMedia Robotics.

In order to design the goto agent, we choose to implement two different controllers and mix both control vectors by means of fuzzy weights. One position controller is very fast but does not arrive exactly to the set-point while the other is accurate and reaches the desired input. The output of the controllers are the desired linear and angular speeds. The best accurate controller achieved has a settling time of at least twice the time taken by the fast controller.

The control loop of the proposed concurrent control is shown in Fig. 1. The fuzzy concurrent control adjustment block is in charge of mixing the desired speeds of the controllers in order to change progressively from one controller to the other.

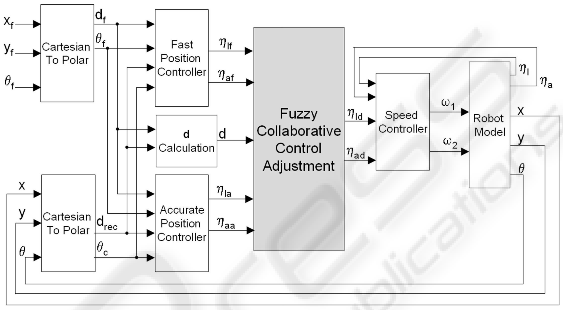

Figure 1: Block diagram of collaborative control loop.

Fig. 2 shows the response of the whole system using the collaborative control (1)) for the initial position and heading of $(x_0, y_0, \theta_0) = (0, 0, 0)$ and the desired set-point of $(x_f, y_f, \theta_f) = (-1, 5, 0)$.

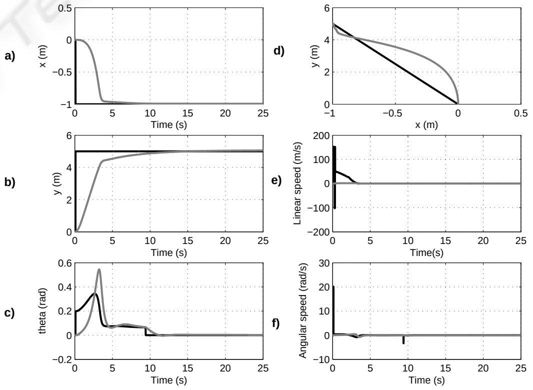

Figure 2: Response of the fuzzy concurrent control.

One interesting feature of this concurrent controller is that it works better than the controllers separately, especially for the unreachable states produced by the non-linear nature of the robot model. This behaviour can be seen in Fig. 3, where the graphics represents the response for the accurate controller, the fast one, and the collaborative approach respectively.

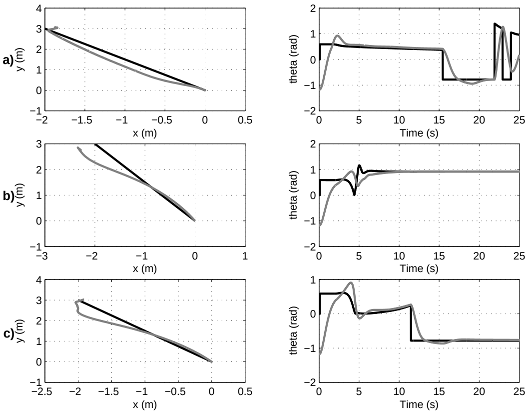

Figure 3: Comparison of the response of the controllers; a) the slow controller, b) the fast controller and c) the concurrent control.

6 CONCLUSIONS

In this paper we present a robot collaborative control architecture based on integrating recent advances in multi-agent systems and collaborative control. In particular, we focus on the design of a single agent, the goto agent, based on a fuzzy adjustment of two position controllers. This approach tries to introduce higher knowledge into the decision making process of the control system. We propose modelling the relevance of the controllers as a fuzzy set, considering the distance travelled by the robot.

To test our method, we have designed the goto agent of the MAS architecture with the proposed collaborative controller. We have performed several experiments to evaluate the responsiveness and efficiency of our architecture. With the fuzzy collaborative control, in which both controllers are combined, the response of the controlled system for several set-points is faster than the response of the accurate controller and more accurate than the response produced by the faster controller. Furthermore, it works for some of the unreachable set-points of the previous experiments (isolated controllers).

As further work, we are planning to extend our approach to n controllers. In addition, we are also exploring the extension of the collaborative control to other agents, such as the goThrough agent, which is responsible for driving the robot through narrow spaces, such as corridors or doors.

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