World Automation Congress

Eighth International Symposium on Robotics with Applications

Maui, Hawaii
June 11-16, 2000

A Nonholonomic Mobile Robot Navigation In Uncertain Environments Based On Behavior Control

Wei Li, Jay Farrell, F. M. Wahl and Krzysztof R. Kozlowski

A NONHOLONOMIC MOBILE ROBOT NAVIGATION IN UNCERTAIN ENVIRONMENTS BASED ON BEHAVIOR CONTROL

WEI LI
Department of Computer Science and Technology Tsinghua University, Beijing 100084, China

JAY FARRELL
Department of Electrical Engineering, University of California, Riverside, CA 92521 USA

F. M. WAHL
Institute for Robotics and Process Control, Technical University of Braunschweig Hamburger Str. 267, D-38114 Braunschweig, Germany

KRZYSZTOF R. KOZLOWSKI
Poznan University of Technology, Department of Control, Robotics, and Computer Science ul. Piotrowo 3a, 60-965 Poznan, Poland

ABSTRACT

This paper presents a method for navigating a nonholonomic autonomous mobile robot in a workshop based on a global vision system. In order to deal with uncertainty in the environment, a fuzzy logic strategy is used to represent mobile robot navigation behavior. The method is implemented on a nonholonomic mobile robot in IRP in Germany, and some experimental operations are performed to demonstrate its effectiveness and robustness.

KEYWORDS: Robotics, Sensor-Based Motion Planning, Robot Navigation, Behavior-Based Control.

INTRODUCTION

In robot applications in the real world, a mobile robot should be able to deal with uncertainty in its environment. This paper presents a method for navigating a nonholonomic autonomous mobile robot, as shown in Fig. 1, in a workshop based on a global vision system.

Fig. 1: A vision based nonholonomic robot

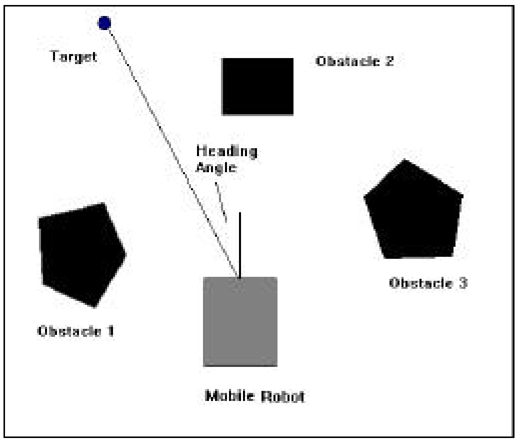


Fig. 2: Behavior based control strategy

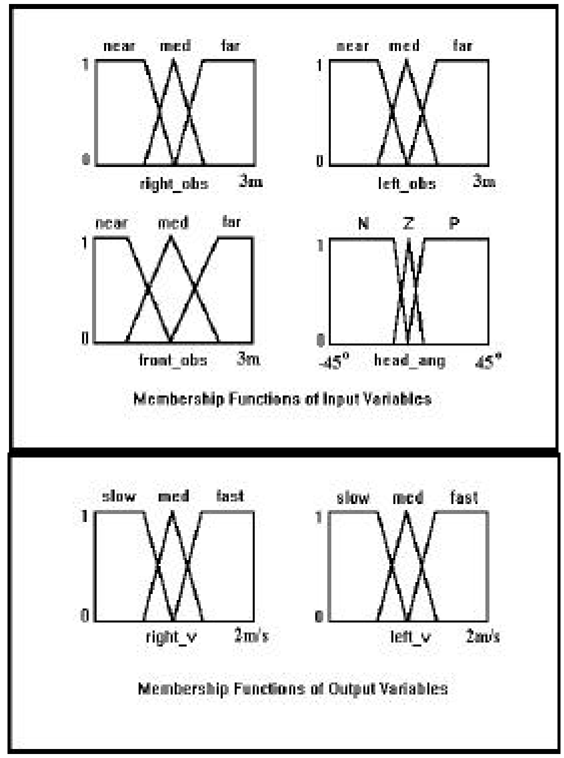


Fig. 3: Membership functions of variables

Behavior based control [1, 2] shows potential for robot navigation in unknown environments since it does not require building an exact world model or a complex reasoning process. However, before behavior based control is used to navigate a mobile robot in the real world, significant effort is required to solve problems with it, such as, the quantitative formulation of behavior, the efficient coordination of conflicts and competition among multiple types of behavior. In order to overcome these deficiencies, fuzzy logic based behavior control schemes have been proposed [4, 5, 9, 10]. Robot navigation in these fuzzy logic strategies is based on sonar data. However, ultrasonic sensors can only provide local information about the robot environment. Experimental results show that information from sonar data is not reliable due to its uncertainty.

In order to improve navigation performance, a global vision system is used to acquire global information about the environment. The global system consists of a SUN workstation and two CCD cameras, which are mounted on the ceiling in the workshop. One of the CCD cameras is used to observe the left part of the workshop, and the other is used to observe the right part. Images taken by both the CCD cameras are transferred on-line to the SUN workstation. Using image process, the following two important tasks are completed. First, obstacles in the environment are recognized, and distances between the robot and obstacles to the left, front, and right locations are calculated. Second, a heading angle between the robot and each specified target is calculated. These information are the input signals to a robot control system. The outputs from the robot control system are the velocity commands of two wheels which are controlled by motors. Fuzzy-logic-based behavior control strategy is to determine the robot behavior based on global vision information. The method is implemented on the mobile robot in IRP in Germany, and some experimental operations are performed to demonstrate its effectiveness and robustness.

FUZZY LOGIC BASED BEHAVIOR CONTROL SCHEME

Fig. 2 depicts robot navigation in uncertain environments. One of the input signals is a heading angle, Θ, between the robot and a specified target. When the target is located to the left side of the mobile robot, the heading angle, Θ, is negative. The other input signals to the fuzzy control scheme are distances between the robot and obstacles to the left, front, and right locations, denoted by *left_obs*, *front_obs*, and *right_obs*, respectively. Here, *left_obs*, *front_obs*, and *right_obs* are defined by the minimal distances between the robot and obstacles. They can be calculated based on the geometry of the obstacles in the environment and the robot geometry. The outputs from the fuzzy control system are the results of behavior fusion to control the speed of two wheels of the mobile robot. The speed of the wheels is measured by an encoder and is controlled by a low-level controller. The linguistic variables *far*, *med* (*medium*) and *near* are chosen to fuzzify *left_obs*, *front_obs* and *right_obs*. The linguistic variables *P* (*positive*), *Z* (*zero*) and *N* (*negative*) are used to fuzzify the heading angle, Θ. The linguistic variables *fast*, *med*, and *slow* are defined for the velocities of the driving wheels *left_v* and *right_v*. Fig. 3 shows their corresponding membership functions.

In the proposed control system, three types of behavior are defined, *obstacle avoidance*, *target steering* and *edge following*. The study shows that *edge following* behavior is very important for a robot to escape from a U-shape region, in which a local minimum usually exists for potential based approaches. Based on the defined membership functions, these types of behavior can be described by fuzzy logic rules. For example, *obstacle avoidance* can be quantitatively represented by such a fuzzy rule:

If (*left_obs* is *far* and *front_obs* is *near* and *right_obs* is *near* and *head_ang* is *any*)
Then (*left_v* is *slow* and *right_v* is *fast*)

This rule means that the robot has to turn left without considering the target location because there are no obstacles on the left and the distances between the robot and the obstacles in front of the robot and on the right are too close. By using a rule base, *obstacle avoidance* behavior can be formulated according to different situations. Similarly, *edge following* and *target steering* can be also formulated by each fuzzy rule base, respectively.

BEHAVIOR FUSION BY FUZZY REASONING

A key issue of behavior based control is how to efficiently coordinate conflicts and competition among different types of behavior to achieve a good performance. A usual approach to coordinating multiple types of behavior is to fire a behavior according to a defined behavior emergency associated with artificial potential fields [2]. For example, if

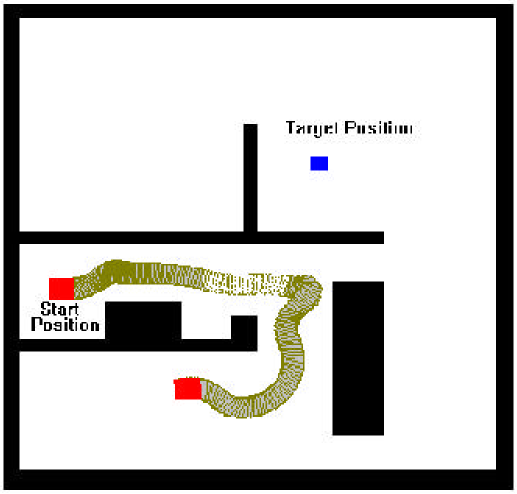


Fig. 4: Robot navigation by priority

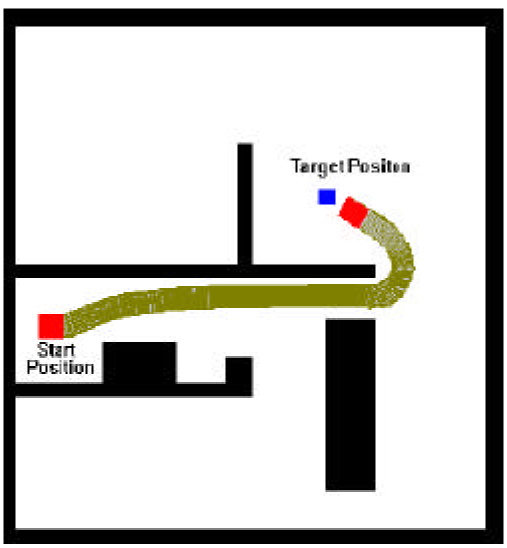


Fig. 5: Robot navigation by behavior fusion

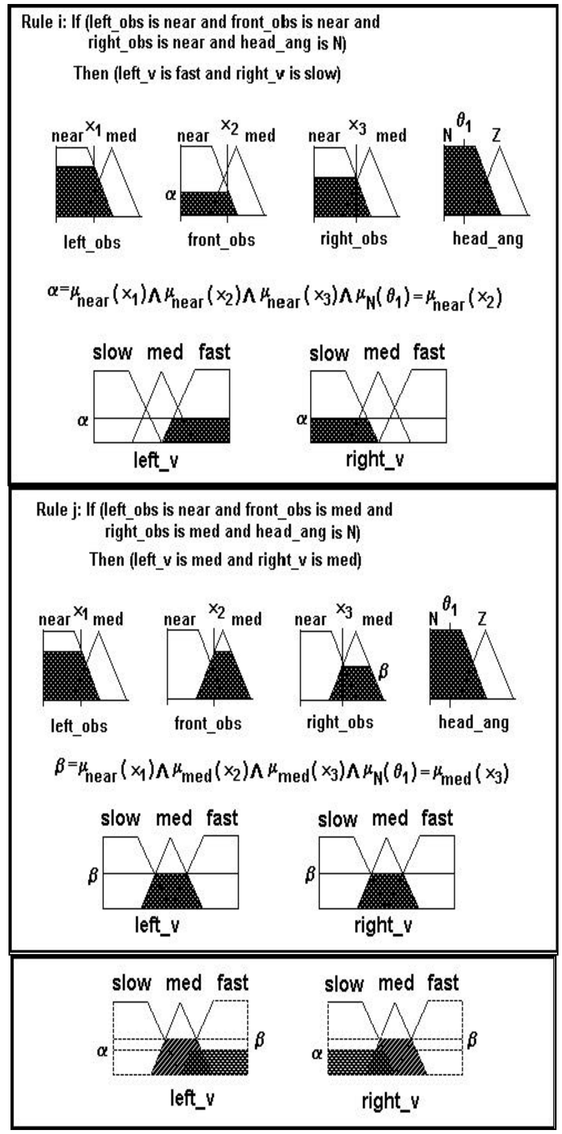


Fig. 6: Behavior fusion by fuzzy reasoning

obstacle avoidance is fired because the robot is too close to obstacles in the environment. The other behaviors, *edge following* and *target steering*, are inhibited and suppressed. The following are some deficiencies of inhibition and suppression based strategies noted in our experiments:

1. In some cases, the robot can not reach a given target. Fig. 4 shows that the robot is unable to get through the narrow channel to reach the given target. The reason is that the robot always activates *obstacle avoidance* behavior when it approaches this channel, so that it turns to the right to move into a large free space.
2. Much effort must be made during preprogramming to test and to adjust some thresholds for firing each behavior. These thresholds depend heavily on the environment and may not be suitable for other environments.

3. Robot motion with oscillations between different types of behavior may occur. When only one type of behavior can be activated at a given instant. In such situations two types of behavior with neighboring priority may be repetitively fired in turn.

Alternatively, when fuzzy sets and fuzzy rules are used to formulate each type of behavior, different strategies can be adopted to fuse these types of behavior. One of the common used approaches is to do behavior fusion by fuzzy reasoning. The following is an illustration of how this problem is dealt with by the Min-Max inference algorithm and the centroid defuzzification method. For instance, if the vision system of the mobile robot provides the following inputs, *left_obs*=x_1, *front_obs*=x_2, *right_obs*=x_3, $\Theta=\theta_1$, they are fuzzified by their membership functions, as shown in Fig. 6. Fuzzy rules associated with the inputs in the different rule bases are simultaneously fired. Because the fired rules from the different rule bases are used to describe different behaviors, they generate different velocity commands to the wheels in spite of the same inputs. Assume that *Rule i* (see below), formulating the *obstacle avoidance* behavior, and *Rule j* (see below), formulating the *following edges* behavior, are fired according to the fuzzified inputs (in fact, many more fuzzy rules may be activated):

Rule i: *If* (*left_obs* is *near* and *front_obs* is *near* and *right_obs* is *near*
and *head_ang* is *N*) *Then* (*left_v* is *fast* and *right_v* is *slow*).

Rule j: *If* (*left_obs* is *near* and *front_obs* is *med* and *right_obs* is *med*
and *head_ang* is *N*) *Then* (*left_v* is *med* and *right_v* is *med*).

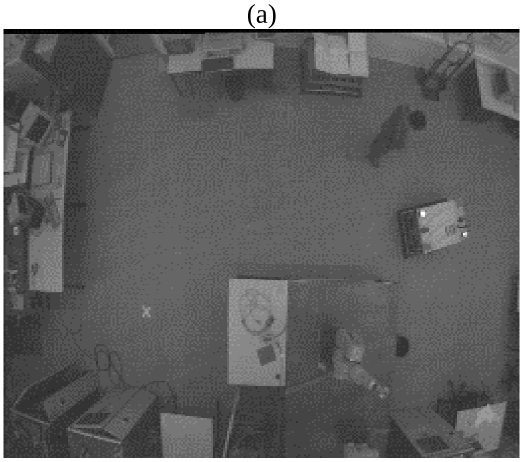
By fuzzy reasoning, both *Rule i* and *Rule j*, related to the *obstacle avoidance* and *following edges* behaviors respectively, are weighted to determine an appropriate control action of the robot's rear wheels, as shown in Fig. 6. By using behavior fusion based on fuzzy reasoning, robot navigation performance can be greatly improved. Fig. 5 shows that the robot can pass through a narrow corridor to reach the target, since by using behavior fusion the robot can efficiently weight multiple types of behavior.

EXPERIMENTS

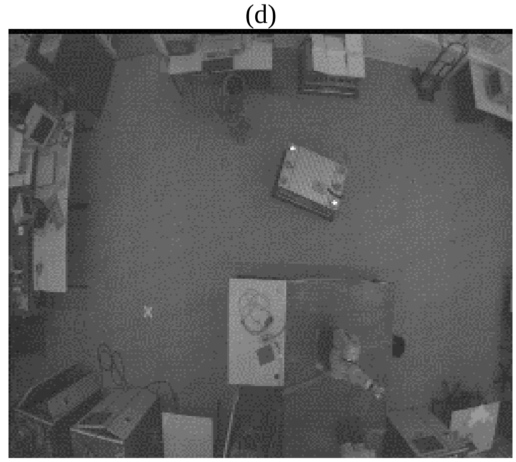
The proposed fuzzy logic based behavior control system is implemented on the vision based nonholonomic robot. In order to demonstrate its effectiveness, robot navigation experiments in an environment with unknown obstacles are carried out as shown in Fig. 7. The CCD cameras take pictures of the environment on-line, and the images are sent to the SUN workstation. In order to speed up image process, information about the environment are classified into static and dynamic information. Because some information about the environment is static, for example, the walls of the workshop or some fixed tables do not change during robot operation, these obstacles can be considered as static obstacles. Since the positions and geometry of the static obstacles in an image are unchanged after CCD camera calibration, we can construct a pattern before system operation to predefine their locations and geometry. Therefore, one of the major tasks of

(a)

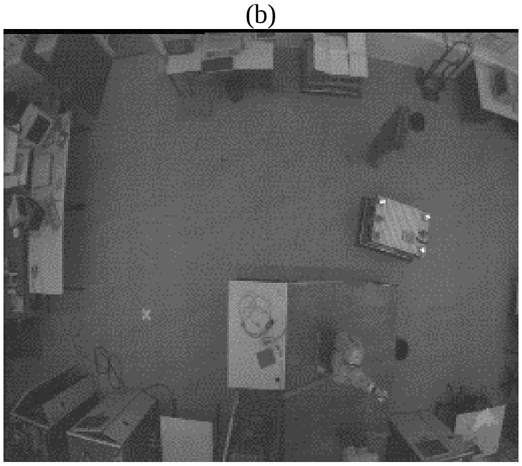
(d)



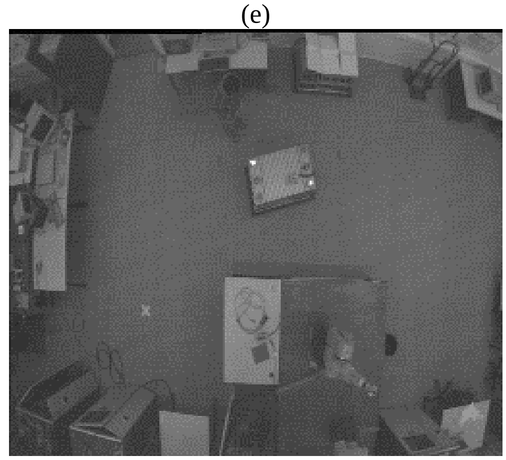
(b)



(e)



(c)



(f)

Fig. 7: Mobile robot motion with avoidance of unknown obstacles

image process is to recognize any unknown obstacle in the environment during robot operation.

Fig. 7 shows robot motion avoiding an unknown obstacle (a person). Fig. 7(a), the mobile robot moves in the middle of the workshop from right to left to avoid collision with static obstacles. When the vision system finds the person in right-front of the robot, the robot makes a little left turn to avoid collision with the person, as shown in Fig. 7(b).

While passing by the person, the robot also avoids collision with any static obstacles in the environment, as shown in Fig. 7(c)-(d). After the robot passes the person, the person moves to the right-front of the robot again. It can be seen that the robot avoids collision with this person based on updated images, as shown in Fig. 7(e)-(f).

CONCLUSIONS

In this paper, a global vision based behavior control strategy for robot navigation in uncertain environments is proposed. This strategy consists of image processing for understanding the environment and behavior based control for robot navigation. Using a global vision system, more information on environments can be obtained. The experimental results demonstrate that, using this system, navigation performance in complex and unknown environments can be greatly improved. In future work, we will discuss how to use fuzzy logic technology to recognize unknown obstacles and to locate the robot position efficiently and reliably.

REFERENCES

1 Arkin R. C. and Murphy R. R. “Autonomous Navigation in a Manufacturing Environment.” *IEEE Tran. on Robotics and Automation*. 6 (1990) 445-454.

2 Brooks R. A. “A Robust Layered Control System for a Mobile Robot.” *IEEE J. of Robotics and Automation*. RA-2 (1986) 14-23.

3 Khatib O. “Real-Time Obstacle Avoidance for Manipulators and Automobile Robots.” *Int. J. of Robotics Research*. 5 (1986) 90-98.

4 Li W. “Robot Obstacle Avoidance and Navigation Using Fuzzy Logic in Uncertain Environments.” *Technical report*, Department of Computer Science and Technology, Tsinghua University (1993).

5 Li W. “Fuzzy Logic Based 'Perception-Action' Behavior Control of a Mobile Robot in Uncertain Environments.” *Proc. of 1994 IEEE Conference on Fuzzy Systems*. Orlando, FL (June 26-29, 1994) 1626-1631.

6 Li W. “Fuzzy Logic Based Robot Navigation in Uncertain Environments by Multisensor Integration.” *Proc. of 1994 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems*, Las Vegas, Nevada, USA, (October 2-5, 1994)

7 Li W. “Neuro Fuzzy Systems for Intelligent Robot Navigation and Control under Uncertainty.” *Proc. of 1995 IEEE Conference on Fuzzy Systems*, Yokohama, Japan, (March 20-24, 1995)

8 Maeda M., Maeda Y. and Murakami S. “Fuzzy Drive Control of an Autonomous Mobile Robot”. *Fuzzy Sets and Systems*, 39 (1991) 195-204.

9 Pin F. G. and Watanabe Y. “Steps Toward Sensor-Based Vehicle Navigation in Outdoor Environments Using Fuzzy Behaviorist Approach.” *Journal of Intelligent and Fuzzy Systems*, 1 (1993) 95-107.

10 Saffiotti A., Ruspini E. H. and Konolige K. “Blending Reactivity and Goal-Directedness in a Fuzzy Controller.” *Proc. of 1993 IEEE Conference on Fuzzy Systems*, San Diego, CA (March 8-12, 1993) 134-139.

11 Sugeno M. and Nishida M. “Fuzzy Control of Model Car”. *Fuzzy Sets and Systems*, 16 (1985) 103-113.

12 Takeuchi T., Nagai Y. and Enomoto N. “Fuzzy Control of a Mobile Robot for Obstacle Avoidance.” *Information Science*, 45 (1988) 231-248.

13 Zadeh L. A. “Fuzzy Sets.” *Information and Control*, 8 (1965) 338-353.