'92 KACC 1992. 10. 19~21

Cooperative Mobile Robots using Fuzzy Algorithm

Seunghwan JI , Hyuntae KIM , Minkee PARK , Mignon PARK

Dept. of Electronic Engineering
Yonsei University

Abstract

In recent years, lots of researches on autonomous mobile robot have been accomplished. However they focused on environment recognition and its processing to make a decision on the motion. And cooperative multy-robot, which must be able to avoid crash and to make mutual communication, has not been studied much.

This paper deals whth cooperative motion of two robots, "Meari 1" and "Meari 2 " made in our laboratory, based on communication between the two. Because there is an interference on communication occurring in cooperative motion of multi-robot, many restrictive conditions are required. Therefore, we have designed these robot system so that communication between them is available and mutual interference is precluded, and we used fuzzy interference to overcome unstability of sensor data.

1. Introduction

The function of a desired autonomous mobile robot which we're in pursuit of is to move in real-time, adapting itself to environment variations, without using artificial landmark. There has been much research carried out up until the present. But most research on intelligent mobile robots which have been on a single robot's recognizing the surrounding environment and moving alon a given path. Because the ideal and final purpose of the mobile robot is to carry out given tasks instead of human being, we often encounter situations where it is necessary for many robot to carry out tasks in cooperation.

In the field of manipulator, there have been much research on the cooperative motion of a multi-arm system. But the study of cooperative multi-robot motion has not been accomplished much yet. Therefore this paper suggests a hardware structure suitable for cooperative motion among mobile robots, and the cooperation algorithm obtained through experiments.

To make mobile robots move cooperatively, the solutions to three problems are needed.

a) recognition of the surrounding environment and task sharing among robot sensors.

b) recognition of the movement and the position of neighbor mobile robots for cooperation.

c) method to apply the optimal algorithm in order to overcome unstability of sensor data.

These problems are solved in this paper as follows.

In case of (a), we must realize that when the environment area which each mobile robot has to recognize in cooperational movement is much smaller than that during single movement, the cooperational movement can have the same significance as cooperation among human beings.

From this viewpoint, this paper suggests optimized task-sharing among robot sensors in order to reduce the burden of recognizing the environment.

In case of (b), hardware-recognition is doneusing ultrasonic sensors and infrared sensor, and software-recognition is done mutual communication among robots to recognize the motional conditions of the counterpart mobile. We use both of them simultaneously and make them collaborate in real-time.

In case of (c), to overcome the unstability of sensor data and to determine velocity and direction, a fuzzy reasoning algorithm using Fuzzy logic in processing sensor information and communication information is used.

Finally, we confirm the validity of the cooperational method and the algorithm suggested through experiments, which carry out the task of collision-avoidance through cooperation between the two mobile robots ,Meari 1 and meari 2 made in our laboratory, consisting of one CPU30 board and three other boards.

2. Brief outline of mobile robot

2.1 Hardware configuration

The experiment system is shown in Fig.2-1. A Sun Sparc 2 workstation is the main host computer for the development tool and a real time O/S VxWorks is used for the development environment. As shown in Fig.2-1, each mobile robot has a VME bus system and developed programs are downloaded for each action of mobile robot from the host computer through the Ethernet. Each mobile robot has one CPU30 board which contains one 68030 for main CPU, 68882 coprocessor for mathematical operation, one Ethernet cannel and three RS232C channels. And it has also one motor control board and two sensor boards. Using Vxworks, a real time O/S, CPU30 processes four program routines for above each board multiply.

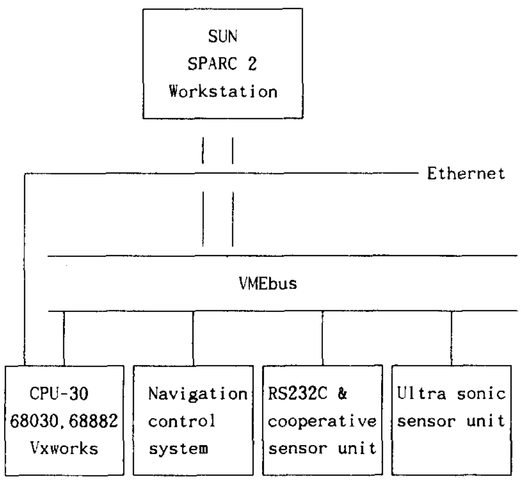

Fig.2-1. System configuration

2.1.1 Cooperative sensors

Cooperative sensors are necessary to recognize the other robot's position. Its configuration is shown in Fig.2-2. In oder to measure distance between two robots, two pair of ultrasonic sensors are attached to each robot's side on different height for eliminating interferences. Using two different distance information from these sensors, the angle between two robots can be derived. And to guage the degree of discrepancy between the two in forward direction, five pair of infrared LED and Photo TR are mounted on each side. Each robot radiates light from five infrared LED. Then each robot can acquire the discrepancy information from five photo TRs.

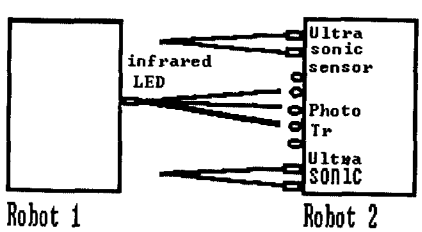

Fig.2-2. Cooperative sensors

2.1.2 Collision detect sensor

For mobile robot, environment recognition sensor is required. there are a lot of sensors like laser, ultrasonic sensor, vision etc for environment recognition. In this experiment, ultrasonic sensor is used because it is simple, easy to manipulate and adequate for past information process. Ultrasonic sensor, we use, have a range to 1 m , and its accuracy is 5 cm.

2.1.3 Communication equipment

There are a few of alternatives for inter-mobile robot communication. we use wireless RS232C for communication because it is got easily and simple. Two wireless module boxes are mounted on each robot and one of the two sensor board takes charge of the inter-robot communication. With this device, two robots exchange messages defined in 3.2.

3. Cooperative navigation of two mobile robots

3.1 cooperative navigation of two mobile robots

As shown in the Fig.3.1 when two robots are moving, it is assumed that there is no preinformation about the environment and all obstacles are convex. Two robots navigate a initially planned path maintaining same distance between them, making synchronization. In this operation Meari 1 is in charge of master and its operation is independent of Meari 2's operation as a slave. If an obstacle is abruptly emerged or an emergency happen, Meari 1 transfers messages to Meari 2 in order to control Echo 2's operation. Echo 2 recognizes Meari 1's movement through cooperative sensors and maintain synchronization with Meari 1 by fuzzy inference. If Meari 2 find out an obstacle or an emergency, it transmits messages to Meari 1 and waits next order from the received data and activates collision avoidance algorithm. After avoidance of the obstacle, two robots keep navigating initially planned path. In the meanwhile Echo 2 continues fuzzy inference to chase Meari 1's movement.

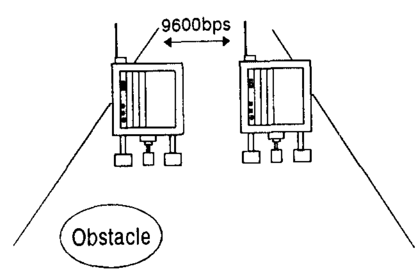

Fig.3-1. Navigation of Two Robots

3.2 Exchanged message in the middle of navigation

As in the preceding subsection there are various message exchanges between two robots in the middle of navigation. In this experiment a message format is defined Fig.3-2. As shown in the Fig.3-2, a message format consists of type and its content. There are three type of messages. Message type is necessary when this system is used in more complex situation. Type 1 is for an exceptional occasion like an obstacle occurrence or synchronization failure from cooperative sensors. This message can be transmitted from two robots equally. the content of type 1 message 'LEFT' , 'CENTER', , 'RIGHT' , and 'OUT' , 'LEFT' messages are transmitted when obstacles are founded at the left of the robot. 'CENTER' message is transmitted when obstacles are detected at the right of the robot. 'OUT' message is transmitted by only Meari 2, which means Meari 2 can't detect Echo 1. When Echo 2 receives this message, Meari 2 determines next action from previous mutual location. Type 2 message informs the end of exceptional occasion and only Meari 1, the master of navigation, can transmit this type of message. Type 2 contains 'END' message which implys arriving at target point or 'NORMAL' message which means to start robot's moving again along the initially planned path. Type 3 message is a response after receiving type 1 or type 2 message to inform the transmitter of receive complication.

Type 1: Exception has occurred(Meari1,2 bothgenerate) such as an obstacle occurence or out-of bound of cooperative region

-> message content
- LEFT : obstacles are located left.
- CENTER : obstacles are located center.
- RIGHT : obstacles are located right.
- OUT : Can't detect Meari 1 (only Meari 2).

Type 2: Exception is terminated. (only Meari 1 can generate)

-> message content
- NORMAL : comeback to normal mode.
- END : arrival at target point.

Type 3: generate after receiving type 1 or 2 message.

message type	content of message
3 bit	5 bit

Fig.3-1. Message Format

3.3 Fuzzy inference for cooperative navigation

To track Meari 1, Meari 2 determine next velocity and steering angle by fuzzy inference.

3.3.1 Fuzzy variable

As in Fig.3-3. Echo 2's input variables are current

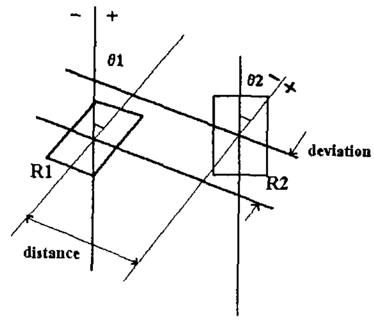

Fig.3-3. Input parameters

Echo 2's velocity, discrepancy, angle and distance from Echo 1. With these input variables the amount of velocity variation d and angle variation d are infered. In this process Echo 2's velocity and steering are decided as follows.

$$\nu_{next} = \nu_{current} + d\nu \quad \cdots\cdots\cdots\cdots (3\text{-}1)$$

$$\theta_{next} = \theta_{current} + d\theta \quad \cdots\cdots\cdots\cdots (3\text{-}2)$$

3.3.2 Fuzzy Navigation Rules

The rules for cooperative navigation are shown in Fig. 3-4 and its membership functions are shown in Fig. 3-5. These rules were obtained from consideration about mobile robots and revised by simulation. In this experiment, we built the rules to be so simple that realtime realization of the robot control is possible. Therefore, we conseder three membership functions of each fuzzy variable.

Relation for $d\nu$

dev \ ν	S	M	B
N	P	P	N
Z	P	Z	N
P	N	N	N

Relation for $d\theta$

dev \ θ	N	Z	P
S	P	P	Z
M	P	Z	N
B	Z	N	N

Fig.3-4 Rules for cooperative navigation

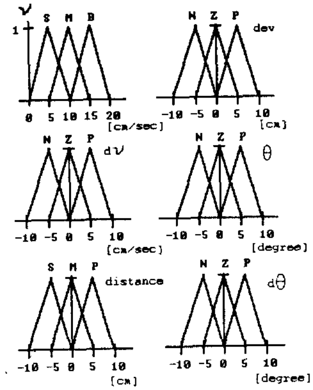

Fig.3-5. Membership function

4. Simulation and Experiment

The simulation was accomplished by using the rules built in last chapter. Fig. 4-1 and 4-2 is its result. At this time, the sampling time of the mobile robot was 1 ms, and its maximum velocity was limited to 30 cm/sec. To assure the synchronization between two robots, we considered collision avoidance as well as straight navigation. For simplicity, it is assumed that all obstacles are convex and static. The algorithm of collision avoidance was artificial potential field method, which is widely used.

In Fig. 4-1, meanwhile maintaining synchronization, two robots navigate the initially planned path. As shown by the result, two robots were synchronized and small deviation were overcome.

In Fig. 4-2, an obstacle is located on the initially planned path. By the result, in collision avoidance action of Meari 1, Echo 2, two robots are synchronized well, as well as in planned path.

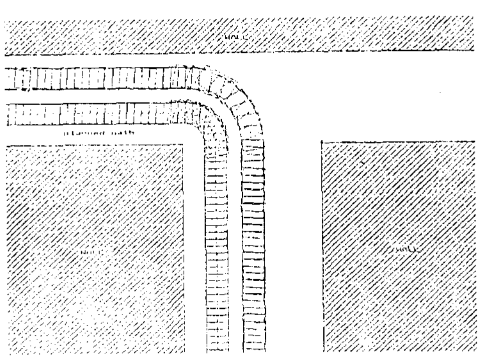

Fig.4-1. Obstacle free path

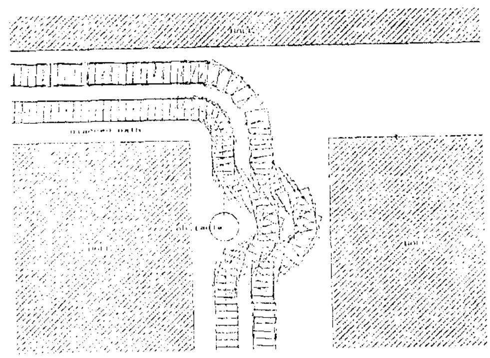

Fig.4-2. Path with obstacle

5. Conclusion

This paper is about cooperative operation of two robots, and we could have confidence in its possibility through simulation. Now we have been carrying out experiment with 'Meari 1' and 'Echo 2' to revise the system.

The problems we have to solve are:

o It is hard to obtain accurate information about robot side. With the sensors currently used, it is possible when differences are small, but it is very difficult when big.

o Besides "master-slave" cooperation like above, studies on more active cooperation is needed.

o Studies on navigation of more than two robots are also required as well as that of two robots.

We are now keeping on experimenting to solve the problems above.

6. References

[1] S. Premvuti, S. Yuta, "Consideration on the Cooperation of Multiple Autonomous Mobile Robots", 1990 IEEE International Workshop on Intelligent Robots and Systems(IROS '90), pp. 59-63

[2] H. Asama, K. Ozaki, H. Itakura, A. Matsumoto, Y. Ishida and I. Endo, "Collision Avoidance among Multiple Mobile Robots Based on Rules and Communication", 1991 IEEE IROS '91, pp. 1215-1220

[3] Fukuda T., Nakagawa S., Kawauchi Y. and Martin B., "Self Organizing Robots Based on Cell Structures-CEBOT", 1988 IEEE IROS '90, pp. 145-150

[4] Y. Ishida, H. Asama, I. Endo, K. Ozaki and A. Matsumoto, "Communication and Cooperation in the Autonomous and Decentralized Robot System", IFAC International Symposium Distributed Intelligence Systems (IFAC DIS '91), pp. 299-304

[5] R. G. Smith, "A Framework for Distributed Problem Solving", International Joint Conference Artificial Intelligence (IJCAI) 1979, pp. 836-841
[6] C. H. Lee, "A study on Navigation of Mobile Robot based on Fuzzy Theory", Dept. of Electronic Eng. Yonsei Univ. 1990, pp. 18-38
[7] T. Murofushi and M. Sugeno, "Fuzzy Control of a Model Car", Journal of the Robotic Society of Japan, Vol. 6, No, 6, pp. '536-541
[8] R. Chatila and R. Ferraz, "Open Architecture Design and Inter-task/Inter-module Communication for an Autonomous Mobile Robot", IEEE IROS '90, pp. 717-721
[9] J. L. Crowley, "Navigation for an intelligent mobile robot", IEEE Journal of Robotics and Automation 1985, Vol. RA-1, No.1
[10] Tsugawa et al., "An Intelligent Vehicles with Obstacle Detection and Navigation Functions", IECON '84
[11] Koren Y. and Borenstein J., "Potential Field Methods and Their Inherent Limitations for Mobile Robot Navigation", IEEE Conference on Robotics and Automation 1991, pp. 1398-1404
[12] T. Lozano-Perezn and M. A. Wesley, "An algorithm for planning Collision-free path among Polyhedral Obstacles", Communication of the ACM 1979, pp. 560-570
[13] C. W. Warren, "Global Path Planning Using Artificial Potential Fields", IEEE Conference on Robotics and Automation 1989, pp.316-321