

# 충돌회피환경에서의 퍼지 규칙 기반 멀티 모바일 로봇 시스템

## Multi-Mobile Robot System with Fuzzy Rule based Structure in Collision avoidance

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**Abstract:** This paper describes a multi-mobile robot system with fuzzy rule based structure in collision avoidance. Collision avoidance is an important function to perform a given task collaboratively and cooperatively in multi-mobile robot environments. So the important but challenging problem is handled in this paper. Considered obstacles for collision avoidance between multi mobile robots are static, dynamic, or both of them at the same time. Using the fuzzy rule based structure, distance and angle from a robot to obstacles are described as fuzzy linguistic values and steering angle for the robot are updated from the collision environments. As a result, the multi-mobile robot can modify a global path from a robot itself to its own target. In addition, avoiding collision with static or dynamic obstacles for the robot system can be achieved. Simulation based experimental results are given to show usefulness of this method.

**Keywords:** multi-mobile robot system, fuzzy rule based structure, collision avoidance, dynamic obstacle

### I. INTRODUCTION

The motion planning problem is to determine a path of a mobile robot from its initial position to a goal position through a workspace populated with obstacles [1]. The obstacles may be static, dynamic, or both of them at the same time. The desired path is an optimal one with no collisions between the robot and the obstacles. In addition, the environment is getting complex and there need to perform a given task collaboratively and cooperatively using a team of robots. With increasing popularity and interest in multi-robot systems, there are many research topics with huge potential to make the systems possible in real-life applications [2]. Many related issues such as intra-and intercommunications among the multi-robot systems, relative position sensing, real time multi-robot system controls, fusion of distributed sensors/actuators, efficient man-machine interfaces for supervision and interaction, and design approaches supporting the economical production [2] have been studied, and many technical issues have to be resolved. During the last decades, many researchers have contributed to development of planning methods and algorithms for the purpose of navigation of mobile robots. Arkin [3] supplied a survey of techniques used for navigational planning along with a comprehensive study of the issue. Jan *et al.* [1] proposed optimal path planning algorithms based on a higher geometry maze routing algorithm for navigating mobile rectangular robot among obstacles and weighted regions. Robust path planning for a mobile agent in a general environment by finding minimum cost source to destination path is proposed by Hu *et al.* [4] A path-panning algorithm for the classical mover's problem in three dimensions using a potential field representation of obstacles is presented by Hwang *et al.* [5] Dynamic obstacle avoidance of a mobile robot navigating in an unknown environment has been investigated by Wu *et al.* [6] They applied vector-distance function method which permits the detection of

obstacles and generates a path that can avoid collisions. So getting the optimal path, we focus on the multi-mobile robot and its path planning with collision avoidance, which is a fundamental issue that has yet to be resolved with a high degree of reliability.

### II. AUTONOMOUS MULTI-MOBILE ROBOT SYSTEM

In this section, we describe how multi-mobile robot can move to its desired destination without collisions. To show the effective exploration and collision free navigation the autonomous multi-mobile robot simulation is presented.

#### 1. Multi-mobile robot system environment

Multi-mobile robot (MmR) system is designated to cooperatively perform a given task under various environments. Reasoning system of the Multi-mobile robot system should be able to obtain information about the environments. This means some kind of sensory data processing system be mounted on the mobile robots. These sensing systems are input to the MmR that will provide basic functionalities and abilities about outside world. To identify the environment around the MmR, a number of different sensors can be used but sonar sensor is a very popular in robot research. The popularity comes from low cost, low power consumption, low computational effort, and high reliability. In our development, the sonar sensor will be used and the shape of the mobile robot is assumed to be circular. There are a total number of 6 sonar sensors equipped on the mobile robot. Concept of sensor's locations and their range are shown in Fig. 1. The sensors are oriented at a 36-degree apart.

Generally, the object range  $r_0$  is computed from echo travel time  $t_0$  using

$$r_0 = \frac{ct_0}{2} \quad (1)$$

Where  $c$  is the sound speed and factor 2 means the round trip travel distance to a range measurement. The information obtained from the sensors is processed to identify static or dynamic obstacles.

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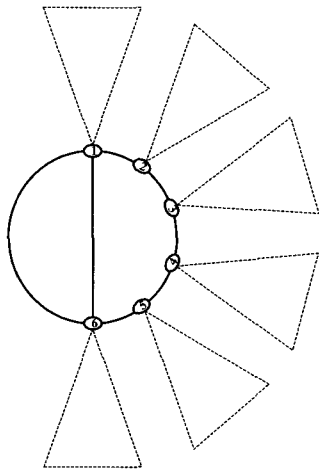


그림 1. 센서의 위치와 범위에 대한 정의.  
Fig. 1. Concept of sensor's locations and their range.

2. Fuzzy rule based structure

Rule-based method like fuzzy logic system has been an active and popular approach to robot control in the real -world environment and multi-robot domain. In this paper, the fuzzy rule based system is employed for collision avoidance with unknown obstacles (either stationary or moving and other moving robots). The overall concept of local collision avoidance is described in Fig. 2. By observing the current values of proximity sensors, local collision avoidance technique can calculate collision avoidance margin and steering angle of corresponding mobile robot between obstacles and other moving robots.

Sensor reading is represented as two different fuzzy variables; *distance* and *angle* from robot and obstacle, respectively. The variable, *distance*, has three different values that will be used as input value to the fuzzy rule based system: *far*, *near*, and *very near*. These values are defined as fuzzy membership function (MF) and described in Fig. 3. Though Gaussian MF is applied here but another MF type can be applicable for the fuzzy linguistic values. The other variables, *angle* has five different values which are *left big*, *left small*, *zero*, *right big*, *right small* and it is also used as input values to the fuzzy system. Corresponding membership function for the angle is shown in Fig. 4. From the inputs of the fuzzy system, angle and distance, the steering angle of a robot can be determined using the input information. The output, *steering angle*, has also five different linguistic values, *left big*, *left small*, *zero*, *right big*, *right small*, and depicted as Fig. 5. Parameters of each MF in Figs. 3-5 which are number of MFs and range of each variable are shown in corresponding figure.

Each linguistic terms used in the fuzzy membership function and their values are shown in Table 1. Using the two inputs, *distance*, *angle* and output, *steering angle* we considered 15 fuzzy rules as below. Considering Rule 3, 8, and 13, two types of

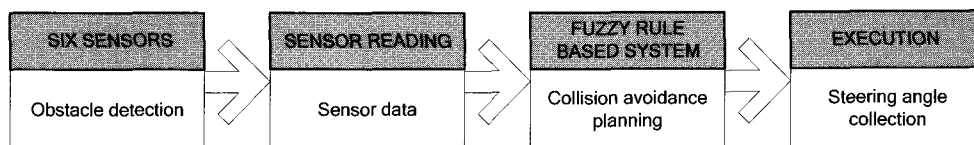


그림 2. 퍼지 규칙기반 시스템을 이용한 충돌회피에 대한 개념.  
Fig. 2. Concept of collision avoidance using fuzzy rule based system.

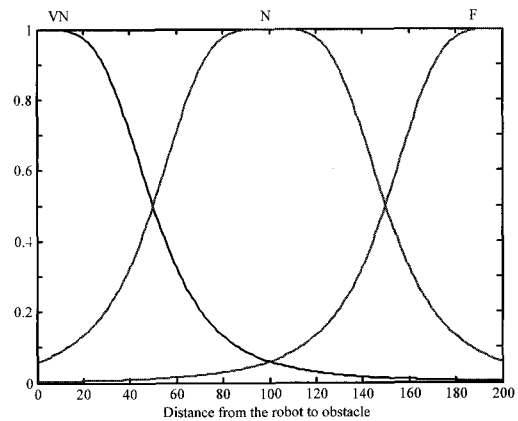


그림 3. 로봇과 장애물 사이의 거리에 대한 퍼지변수 값.  
Fig. 3. Fuzzy linguistic values for *distance* from robot to obstacle.

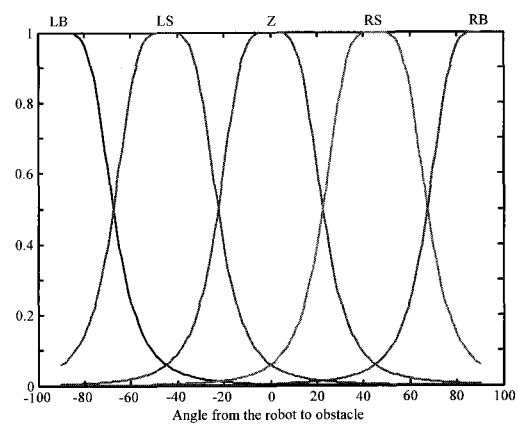


그림 4. 로봇과 장애물 사이의 각도에 대한 퍼지변수 값.  
Fig. 4. Fuzzy linguistic values for *angle* from robot to obstacle.

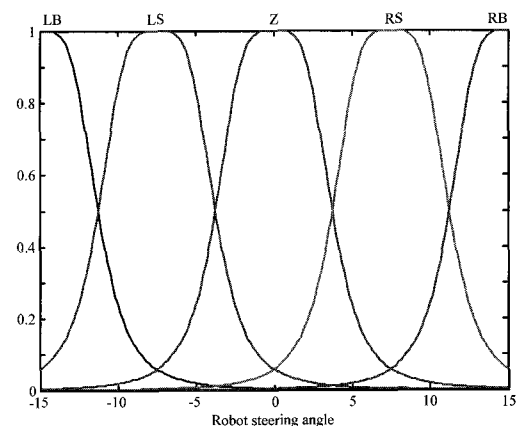


그림 5. 로봇과 장애물 사이의 조향각에 대한 퍼지변수 값.  
Fig. 5. Fuzzy linguistic values for *steering angle* from robot to obstacle.

표 1. 퍼지 변수와 의미에 대한 용어정리

Table 1. Terms of fuzzy linguistic values and meaning.

Linguistic Variables	
Term	Value
LB	Left Big
LS	Left Small
Z	Zero
RB	Right Big
RS	Right Small
F	Far
N	Near
VN	Very Near

steering angles are available for the fuzzy rules.

- Rule 1. If *distance* is *F* and *angle* is *LB*, then *steering angle* is *Z*
- Rule 2. If *distance* is *F* and *angle* is *LS*, then *steering angle* is *Z*
- Rule 3. If *distance* is *F* and *angle* is *Z*, then *steering angle* is *RS* or *LS*
- Rule 4. If *distance* is *F* and *angle* is *RS*, then *steering angle* is *Z*
- Rule 5. If *distance* is *F* and *angle* is *RB*, then *steering angle* is *Z*
- Rule 6. If *distance* is *N* and *angle* is *LB*, then *steering angle* is *Z*
- Rule 7. If *distance* is *N* and *angle* is *LS*, then *steering angle* is *RS*
- Rule 8. If *distance* is *N* and *angle* is *Z*, then *steering angle* is *RB* or *LB*
- Rule 9. If *distance* is *N* and *angle* is *RS*, then *steering angle* is *LS*
- Rule 10. If *distance* is *N* and *angle* is *RB*, then *steering angle* is *Z*
- Rule 11. If *distance* is *VN* and *angle* is *LB*, then *steering angle* is *RS*
- Rule 12. If *distance* is *VN* and *angle* is *LS*, then *steering angle* is *RB*
- Rule 13. If *distance* is *VN* and *angle* is *Z*, then *steering angle* is *RB* or *LB*
- Rule 14. If *distance* is *VN* and *angle* is *RS*, then *steering angle* is *LB*
- Rule 15. If *distance* is *VN* and *angle* is *RB*, then *steering angle* is *LS*

III. SIMULATION BASED EXPERIMENT RESULTS

In order to validate the effectiveness and usefulness of the autonomous multi-mobile robot navigation with collision-free motion planner, we developed a simulation environment and conducted some experiments of multi-mobile robot navigation. We assume all robots are autonomous and homogenous robotic systems which are equipped with sonar sensors for identifying the environment around the robots. Since the target of the paper is collision avoidance navigation, we did not consider complex dynamics of mobile robots. Our simulation environment was developed using visual C++ programming language. Several parameters of multi-mobile robot system can be set in this paper. Number of robots: 0-4, position of a static obstacle, starting point of each robot, position of each robot's target can be specified. Each range of X-Y axes and orientation of each robot are (160-580) and (0-360), respectively.

Fig. 6 shows an example of a multi-mobile robot system in

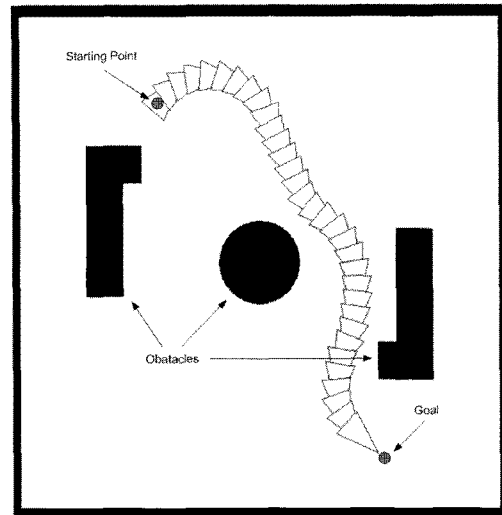


그림 6. 두 가지 형태의 정적 장애물에서 단일 로봇의 궤적.  
Fig. 6. Trajectory of single robot in two different types of static obstacles.

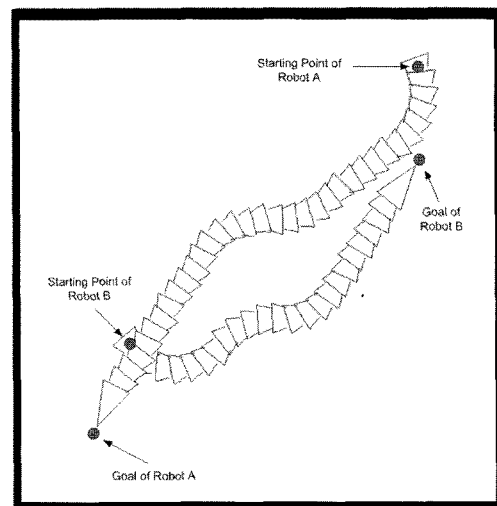


그림 7. 정적 장애물에서 두 로봇의 궤적.  
Fig. 7. Trajectories of two robots in static obstacle.

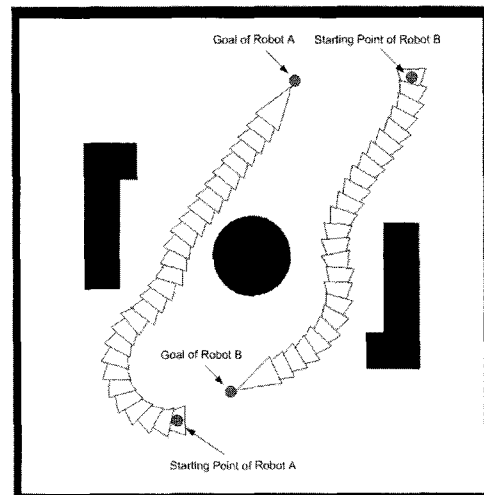


그림 8. 두 가지 형태의 서로 다른 장애물에서 로봇의 궤적.  
Fig. 8. Trajectories of two robots in two different types of obstacles.

which there are one mobile robot going toward to its goal and two different static obstacles. The robot starts from the top-left corner and the goal is set near the bottom-right corner. The robot encountered two types of static obstacles on its way to the goal. The motion of the obstacle avoidance begins when the robot reaches *circle* obstacle. The robot tried to keep away from the *circle* and slide outside to escape collision. After the robot found another *rectangular* obstacle, the robot tried again to keep safety distance from the obstacle and slide into its final destination. From the trajectory, the robot avoided static obstacles and reached its goal safely and successfully. Knowledge of this environment is unlikely in dynamic situations and not suitable in changing environment.

Figs. 7-8 show trajectories of two robots in static and dynamic obstacles, respectively. In this environment, final destination of each robot is separated from each other so to get the goal position the global path should be crossed. In this paper, each robot independently selects its destination and considers another robot as a dynamic obstacle. Fortunately Fig. 7 shows starting and goal position of each robot are totally different but in the middle, two robots are noticing they are approaching each other. There is an effect from the two robots and they turned their own direction toward little bit outside so they are not encountered each other and followed their safe path for the destination.

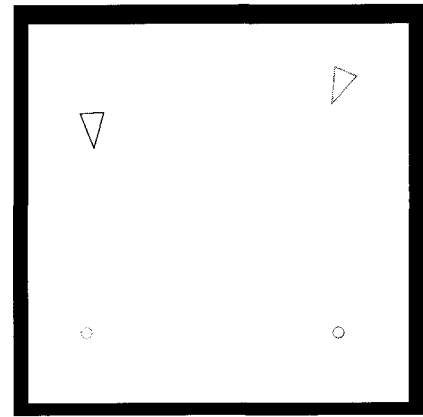
Fig. 8 depicts each robot is following the global path well, keeping away from the static obstacles and getting the final destination safely. In this case, there is no collision possibility for each robot.

To check the adaptability and flexibility of the proposed multi-mobile robot navigation method, we consider more complicated environment and discuss their results in Figs. 9-11. There are two mobile robots moving toward their different destination in Fig. 9. They started at the same time but the direction is totally different. Starting, ending points, and initial heading direction of each robot are shown in Fig. 9(a). Since corresponding goal to each robot is located on opposite direction, global path for each robot should be crossed at least once during navigation. They have been exposed to collision in the middle of path. In this case, the #2; green robot recognizes the #1; black robot as dynamic obstacle moving around as shown in Fig. 9(b). The distance in the fuzzy rule will be *near* or *very near* and angle between two robots will be almost *Zero*. So the #2 robot may employ the 8<sup>th</sup>, or 13<sup>th</sup> fuzzy rules to escape the collision and finally get the destination (Fig. 9(c)). In addition, the #1 robot gets some pieces of information about the distance which is *near* or *very near* in the center (Fig. 9(b)) but the angle recognized by #2 robot was *Left\_small*, finally, the 7<sup>th</sup> or 12<sup>th</sup> fuzzy rules may be activated to the #1 robot. After each robot performed the navigation with the collision-free motion using fuzzy rules, there wasn't dangerous collision between two moving robots.

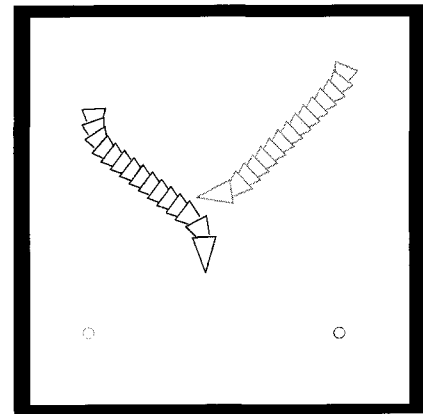
In Fig. 9, we have seen the results for collision avoidance of dynamic obstacles in which robots are exposed to collision with other moving robot.

We consider another complex scenario in Fig. 10. The robots need to avoid not only collision from the other moving robot but also static obstacle in the middle of the global path.

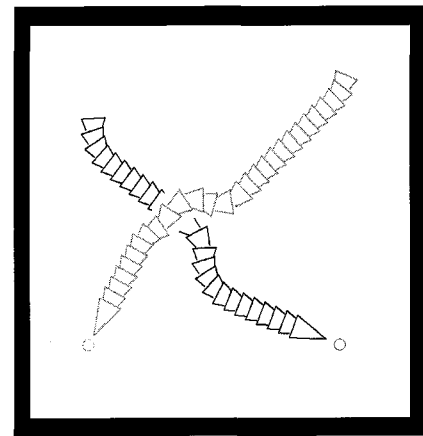
The initial poses of the robots are shown in Fig. 10(a). The #1 and #2 robots detected the obstacle ahead, respectively and



(a)



(b)

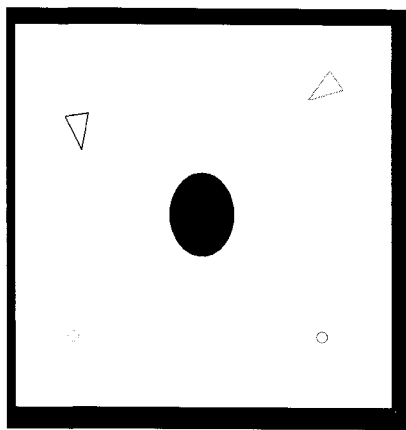


(c)

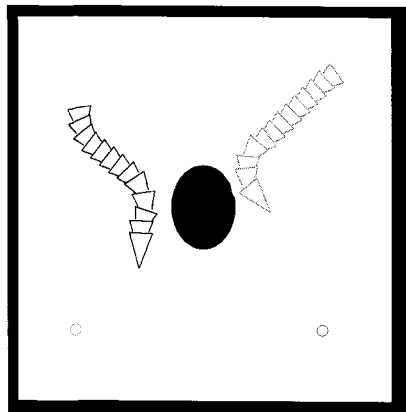
그림 9. 길 한가운데서 다른 로봇과의 충돌에 노출된 두 로봇의 궤적.

Fig. 9. Trajectory of two robots exposed to collision with other robots in the middle of path.

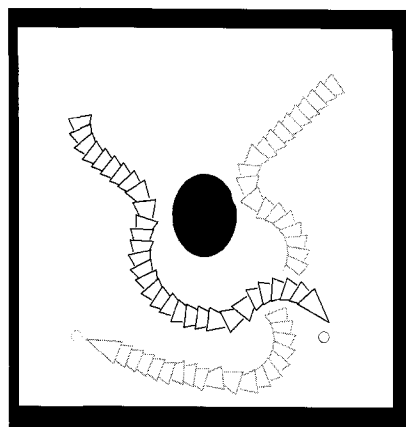
adjusted their steering angles to right and left direction to avoid a collision, respectively. (Fig. 10(b)). After the #1 robot detected the obstacle in the center, it turned direction to right. Meanwhile, the #2 robot starts to make a left turn to escape a collision from the obstacle. After right and left turn, respectively, each robot recognized again the other robot (moving obstacle) is approaching towards. So the #1 robot turned left again and the #2 robot is also turned left immediately on its side (Fig. 10(c)). Finally, they got their goal points safely. As seen from the figure, two robots avoided the obstacle located in the middle safely and detected



(a)



(b)



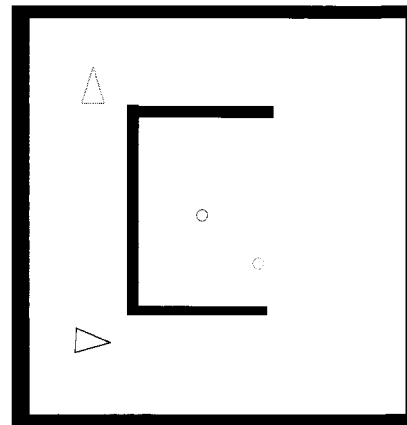
(c)

그림 10. 길 한가운데서 장애물과의 충돌에 노출된 두 로봇의 궤적.

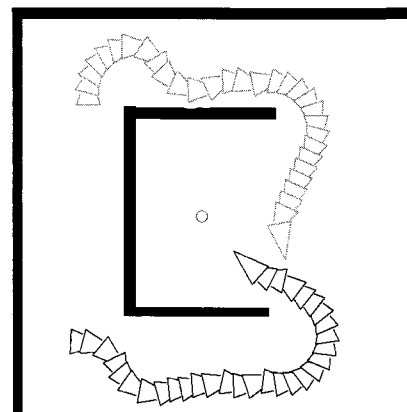
Fig. 10. Trajectory of two robots exposed to collision obstacle in the middle of path.

moving robot well so they reached their goals successfully without any collision with either static obstacle or other robot.

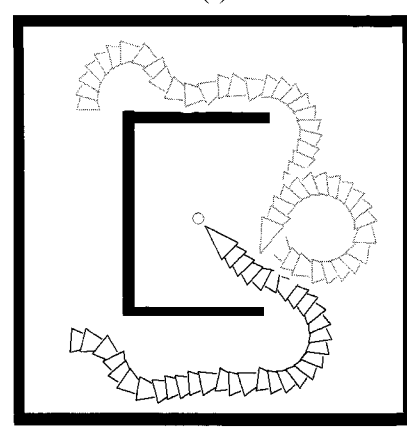
Again, we considered two robots that should follow a wall and be exposed to collision with each other in static obstacle simultaneously as shown in Fig. 11. Two robots are tried to follow the wall well and get the goal position safely without collision but they got a possibilities to crash near their destination. Even though they had some possibility to collide each other, they could turn their direction to avoid the collision. Finally they arrived their final goal without collision through the wall and other moving robot.



(a)



(b)



(c)

그림 11. 정적인 장애물과의 충돌에 노출된 채 벽을 따라 가는 로봇의 궤적.

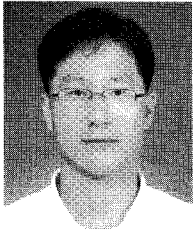
Fig. 11. Trajectories of wall followed robots exposed to collision with other robot in static obstacle.

#### IV. CONCLUSIONS

We have developed a collision avoidance methodology that gives efficient collision free path navigation to multi-mobile robot system. The proposed method is mainly based on the fuzzy rule based system. To validate the effectiveness and usefulness, several multi-mobile robot experiments are considered and static or moving obstacles blocked these multi-mobile robot are conducted. Every robot can always find a safe path and get final destination successfully.

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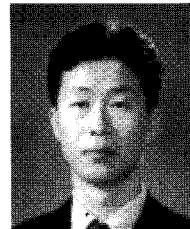
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