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Hybrid Control Mode Based On Multi-Sensor Information by Fuzzy Approach for Navigation Task of Autonomous Mobile Robot

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***Abstract*—**This paper addresses the issue of the autonomous mobile robot (AMR) navigation task based on the hybrid control modes. The novel hybrid control mode, based on multi-sensors information by using the fuzzy approach, has been presented in this research. The system operates in real time, is robust, enables the robot to operate with imprecise knowledge, and takes into account the physical limitations of the environment in which the robot moves, obtaining satisfactory responses for a large number of different situations. An experiment is simulated and carried out with a pioneer mobile robot. From the experimental results, the effectiveness and usefulness of the proposed AMR obstacle avoidance and navigation scheme are confirmed. The experimental results show the feasibility, and the control system has improved the navigation accuracy. The implementation of the controller is robust, has a low execution time, and allows an easy design and tuning of the fuzzy knowledge base.

***Keywords*—**Autonomous mobile robot, obstacle avoidance, MEMS, hybrid control mode, navigation control.

I. Introduction

AUTONOMOUS MOBILE ROBOTS (AMRs) are machines capable of performing tasks without the intervention of human operators. Hence, they should contain built-in machine intelligence and an onboard control system [1]. Since autonomous robots are complex systems that require the interaction or cooperation of numerous heterogeneous software components, most AMRs are designed to perform high-level tasks on their own or with very limited external control [2]. The trend among many AMRs (such as planetary exploration vehicles and microrobots) is to restrict the onboard control system to a small size, light weight, and low power consumption, which suggests the need for embedded controllers capable of real-time operation [1].

In recent years, the use of the multi-sensors has grown, and positioning capabilities have increased. In order to use multi-sensors effectively, some methods are needed to help integrate the information provided by these sensors into the operation of a mobile robot [3]-[7].

Generally speaking, the kinematic equations of a mobile robot with nonholonomic constraints are nonlinear and time-varying differential equations. Thus, engineers find it difficult to design a controller by traditional method if the dynamics equation of the mobile robot is unknown or partially unknown. It is well recognized that fuzzy theory results from the desire for the linguistic description of complex systems and it can be utilized to formulate and translate the human experience to properly control approaches. This kind of human intelligence is easily represented by the fuzzy logic control structure. Fuzzy logic-based techniques have been applied successfully to build the control system of intelligent AMR: from low-level controllers for sensors and actuators and intermediate modules that carry out simple individual behaviors to high-level modules that integrate and coordinate primitive behaviors [1]. The advantages of fuzzy logic-based techniques include the fact that they enable the building of robust and smooth controllers starting from heuristic knowledge and qualitative models; consider imprecise, vague, and unreliable information; and integrate symbolic reasoning and numeric processing in the same framework [1].

Obstacle avoidance control can be classified into motion control and dynamics control according to whether its controllers consider the dynamic properties of the robot [8]. Recently, many authors have proposed various fuzzy control techniques for avoidance control [5], [8]-[15]. Moreover, the autonomous fuzzy parking control has been successfully implemented by [1]-[4].

Mobile robot navigation is a crucial aspect of mobile robot research; it is a hot subject in the robot research area, too [13]. In general, the navigation task of AMR is composed of path planning, path-following trajectory generation, and tracking control [3]. Given a target position in the real scene, the process requires that the mobile robot be able to move to the position in smart real-time mode. That is to say, the smart system must estimate a couple of paths which contain the possible roads. The mobile robot can move from its initial to the target position based on those paths. Thus, to solve such kinds of problems, the mobile robot must provide sensors. There also must be some tasks from which the mobile robot might learn and use the information collected by the sensors [6]. Therefore, [16] proposes the method to solve Simultaneous Localization and Map Building (SLAM) using digital magnetic compass and ultrasonic sensors. Incidentally, the Micro Electro Mechanical Systems (MEMS) sensor demonstrates the characteristics of smaller size, lighter weight, and lower price than the traditional rate sensors and other navigation units. Hence, [17], [18] address a navigation approach for mobile robots using MEMS to improve positional accuracy. Furthermore, the paper

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proposed an efficient localization scheme for an indoors mobile robot using Radio-Frequency Identification (RFID) design is verified in [19], [20]. However, the reader antenna detects several tags within its detecting range, and the mobile robot moves while the reader gathers the tags; the position-estimation error is inherent for such a method. For this reason, the specific localization task is difficult with the RFID-based system. However, as the review of the above articles, the hybrid control mode based on multi-sensor information for navigation task of AMR is still under investigation.

Hence, this paper addresses the issue of the AMR navigation approach based on the fuzzy obstacle avoidance rule and the MEMS sensor fuzzy orientation compensation rule. The novel hybrid control mode based on multi-sensor information by using fuzzy approach will be presented in this research first. An experiment is simulated and carried out with a pioneer mobile robot. In this new navigation scheme, the reduction of the error and drift can be proved. The experiment results demonstrate the effectiveness and performance of the proposed navigation scheme. This paper is organized as follows. The system structure of the implemented robot, which consists of mechanism module, control card module, stepping motor module, sensor module, and wireless communication module, will be demonstrated in Section II. Section III addresses the hybrid control mode design. The real-time path tracking control of the mobile robot is presented in Section IV, and conclusions are given in Section V.

II. System Structure

The proposed mobile robot of this research is a full autonomous wheeled robot. Consider a kinematic model of the AMR as shown in Fig. 1, where the real wheels are fixed parallel to the car body. The front wheels can turn to the left or the right, but the left and right front wheels must be parallel. The center of mass of the mobile robot is (x, y). The angle θ is the orientation of the steering wheels with respect to the frame of the AMR. V_L and V_R indicate the speed of the left and right wheels, respectively.

AMR demonstrates a design viewpoint that recognizes various functions so that it can be used not only in path tracking but also in obstacle avoidance. Thus, the hardware implementation of the mobile robot consists of the mobile robot mechanism, control card module, stepping motor module, sensor module, and wireless communication module. The overall hardware architecture of the mobile robot is shown in Fig. 2.

The mobile robot mechanism is a four-wheeled vehicle with front-wheel drive and front steering wheels. The mobile robot mechanism carries the Arduino board, communication module, sensor module, circuit board, batteries, etc.

A. Mobile Robot Mechanism

The mobile robot mechanism is a four-wheeled vehicle with front-wheel drive and front steering wheels (Fig. 2). The mobile robot mechanism carries the Arduino board, communication module, sensor module, circuit board, batteries, etc.

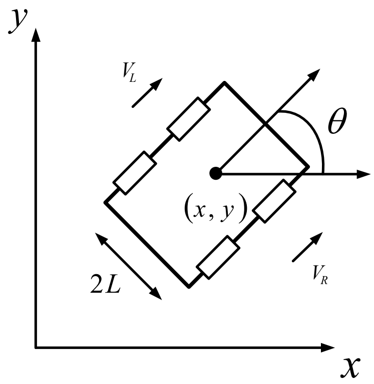


Fig. 1 Kinematic model of a mobile robot

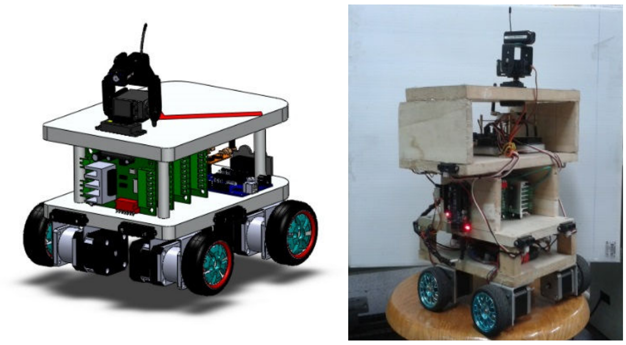


Fig. 2 Hardware implementation of the AMR

B. Control Card Module

The Arduino Mega 2560 is to be used as the control board of this study. It has 54 digital input/output pins, 16 analog inputs, 4 Universal Asynchronous Receiver Transmitters (UART), a 16 MHz crystal oscillator, and a USB connection. It contains everything needed to support the microcontroller; the user simply connects it to a computer with a USB cable or powers it with an AC/DC adapter or battery to get started. The software consists of a standard programming language compiler and a boot loader that executes functions on the microcontroller. The Arduino board in this implementation presents several advantages, such as low price, small size, and flexibility.

C. Stepper Motor Driving Module

The stepping motor in the mobile robot mechanism is used to drive the steering angle of the mobile robot. A driver module (Model: THB6064H), manufactured by Toshiba, provides 8 steps and 16 output current settings to meet the variable speed requirements. The THB6064H is assembled in a PCB board to drive the stepping motor.

D. Sensor Module

To facilitate obstacle avoidance, the robot is equipped with a set of sensors. The robot uses proximity infrared (IR) sensors (Model: GP2Y0A21YK, Sharp Co.) to gather area information and then set up direction function to detect the obstacles. By measuring the reflected light, the robot detects whether there is obstacle along the route. According to the sense signal received, the robot can count the relative distance between itself and the obstacle. Four IR proximity sensors are mounted in the proposed AMR; this type of proximity infrared sensor has an analog output that varies from 3.1V at 10cm to 0.4V at 80cm.

Moreover, another MEMS sensor module (Model: GY-80) is also mounted on the AMR for sensing purposes. The MEMS sensor module contains the accelerator, compass, and gyroscope. In this research, an accelerator is integrated into the compass for the azimuth calibration in order to compensate for the output signal and to sense the earth findings.

The compass uses magnetic field (the North Pole) to examine direction. The compass measures the change of angle when an object changes direction. The compass consists of a couple of vertical coils and follows the electromagnetic induction to find the direction, which measures the vector from the voltage in the two coils. In addition, the MEMS sensor module offers the characteristics of smaller size, lighter weight, and lower price than the traditional rate sensors and other navigation units. Through the MEMS E-compass and accelerometer, we can determine the steering angle and the position information. Furthermore, in order to obtain a more complete view of the environment, the wireless camera is adopted to capture the scene.

Consequently, as mentioned above, some sensors such as the infrared sensors, accelerator, E-compass, gyroscope, and wireless camera can also be used to gather information regarding the surroundings. The information data from the sensors is taken through the Arduino Mega 2560 control board to determine and analyze its validity and application. Combining all of the data from the sensor, the robot can calculate the optimum route and moving speed.

E. Wireless Communication Module

The wireless communication module of this research uses APC220 and Xbee. The APC220 radio module provides a simple and economic solution for wireless data communications. The employment of an embedded high speed microprocessor and high performance IC creates a transparent Transistor-Transistor Logic (UART/TTL) interface and eliminates any need for packetizing and data encoding. The *XBee* product family is a series of modular products that make deploying wireless technology easy and cost-effective. The Xbee shield enables an Arduino board to communicate wirelessly using Zigbee. Hence, the system can send the sensing data via the Arduino Mega2560 control board to the control computer (NoteBook) through wireless communication module. Then, the operator codes the control algorithm in LabVIEW for control programming. The chart of the communication module is indicated in Fig. 3.

Moreover, the component of the AMR is composed of two floors. The lower floor is the power supply area, which provides power to the system. The upper floor is the core control area.

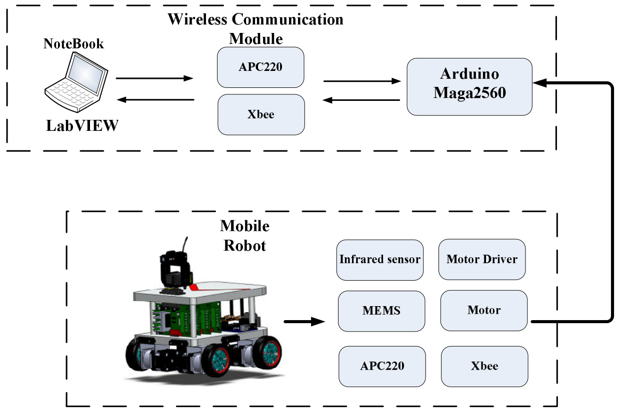


Fig. 3 Communication Module

III. Hybrid Control Mode Architecture

The strategy of path planning involves estimating the shortest path that the robot might move from one position to a target in a global map. Such problems are solved by using the approximate angle and distance between the obstacle and the robot. Therefore, considering path tracking control with obstacle avoidance, this study proposes a hybrid control mode for AMR. Fig. 4 shows the procedure of the navigation by using the proposed hybrid control mode algorithm. In this way, AMR can autonomously reach the goal with obstacle avoidance. By fusing the information from the sensors, the control structure shown in this research not only includes obstacle avoidance mode but also a lot of rules to recognize the situation in which it finds itself and which action should be applied. Firstly, the mobile robot is given the initial location and the target location by the user. Then, it starts to navigate toward the target based on a calculated heading angle between the start and the target. The shortest way between the two points is a straight line; hence, the desired AMR path planning can be constructed based on this concept. Three principal control modes are considered in this control architecture. The priority sequence mode is constructed by recognizing sensory information that determines which actions should be utilized in the behavior work. The first priority of the proposed hybrid control mode is the obstacle avoidance mode. The mobile robot avoids the obstacles automatically using the infrared sensors. As long as no obstacles are detected, the robot will gracefully head toward its target location. If an obstacle is detected, however, the obstacle avoidance behavior becomes active and steers the robot away from the obstacle. The second priority mode is the orientation identification mode, and it can modify azimuth automatically according to the desired target orientation. Finally, the third priority mode is the move-forward mode. Whenever there are no obstacles between the robot and the target position and no azimuth is needed to identify the setting, then the robot moves forward to the target; this is called the move-forward mode.

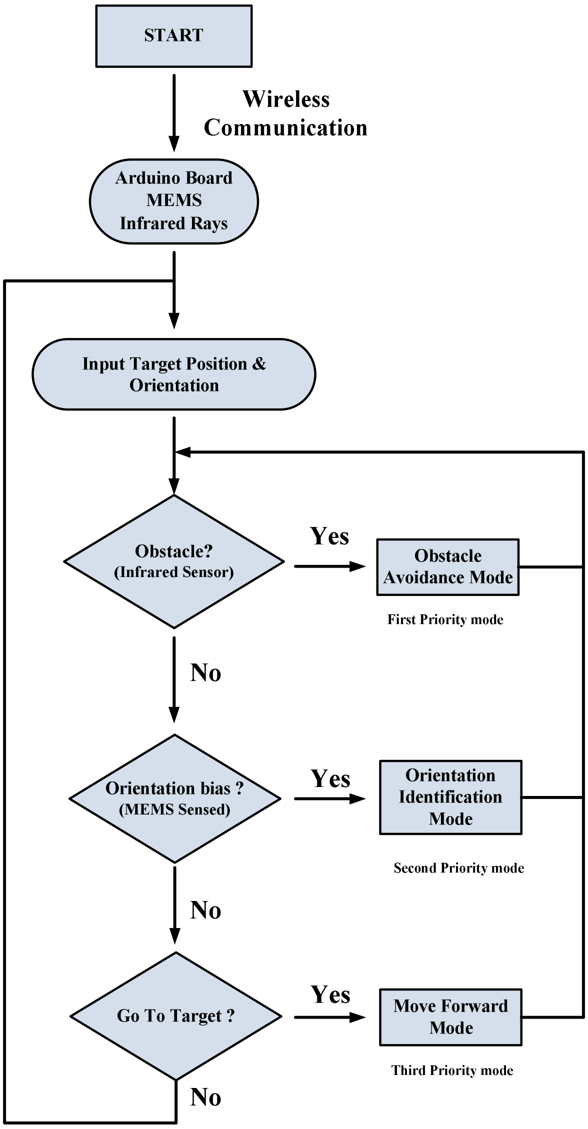


Fig. 4 Hybrid control mode for autonomous mobile robot

A. Obstacle Avoidance Mode

The problem in this situation is that the obstacle avoidance behavior gathers no information about the target location; thus it can steer the mobile robot in any direction to avoid the obstacle. This may work well; however, there are times when it may be desirable for the robot to steer in a direction which takes it closer to its desired path. The obstacle avoidance function faces three issues: where the obstacles are, when the robot needs to avoid obstacles, and which direction the robot can go to avoid the obstacles [6]. Hence, the theme of this subsection is the design of a real-time target tracking control scheme for AMR through the use of infrared sensors. In this study, the mobile robot uses four infrared sensors to avoid obstacles. The IR sensors are mounted on the front and both sides of the AMR, as indicated in Fig. 5. The sensors include the front, left side, and right side of the robot, namely IR_1, IR_2, IR_3, and IR_4. The mobile robot is guided by online sensor information attained while navigation is performed. This approach adopts the method of driving a mobile robot through direct mapping between sensors and motors without building predefined environmental maps. Thus, the control structure of obstacle avoidance mode is based on a task to avoid obstacles; the input of the control system involves sensor data, and the output involves the motor commands. The mobile robot wheels are controlled independently.

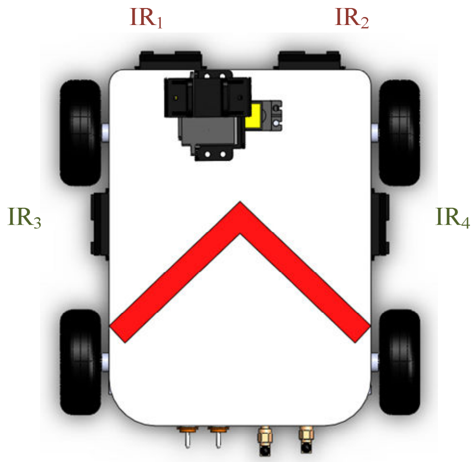


Fig. 5 IR sensors location on the AMR

B. Orientation Identification Mode

In this paper, we suggest an improved MEMS compass north-finding method to detect the robot's azimuth in a short time. Then we set up this system into the AMR to detect the steering angle. The sensitive axis and the robot steering use the same angle. In order to compensate for the output signal and sense the earth's sensitivity, an accelerator is also integrated into the gyroscope for the attitude calibration in this research.

The mobile robot estimates the orientation angle from the current and previous location information. The robot recalculates the orientation of the target location and determines the steering angle of mobile robot to reach the target again [19]. Exploiting the approach described above, the desired orientation of the goal $\theta_{desired}$ is derived from the initial and target location by

$$\theta_{desired} = \arctan\left(\frac{y_{target} - y_{initial}}{x_{target} - x_{initial}}\right), \tag{1}$$

where (x_{target}, y_{target}) represents the coordinate of the target location and $(x_{initial}, y_{initial})$ indicates the coordinate of the start location. If we assumed that the robot moves straight, so that the incident angle θ_1 equals the pose of the robot:

$$\theta_1 = \arctan\left(\frac{y_{current} - y_{previous}}{x_{current} - x_{previous}}\right), \tag{2}$$

where $(x_{previous}, y_{previous})$ and $(x_{current}, y_{current})$ denote the coordinates of the location scanned previous and current, respectively.

Moreover, the angle θ_2 describes the angle between the current and the target location:

$$\theta_2 = \arctan\left(\frac{y_{target} - y_{current}}{x_{target} - x_{current}}\right). \quad (3)$$

From (2) and (3), the steering angle θ_s toward the target can be defined as in (4). Accordingly, the steering angle θ_s is also updated by (4):

$$\theta_s = \theta_1 - \theta_2 \quad (4)$$

The inputs to the fuzzy reasoning are the mobile robot steering angle (between robot orientation and the robot target orientation).

C. Move Forward Mode

As long as no obstacles are detected, the robot will gracefully head toward its target location. If an obstacle is detected, however, the obstacle avoidance behavior becomes active and steers the robot away from the obstacle. The first priority control mode is the obstacle avoidance mode. The second priority mode is the orientation identification mode, and it can modify the azimuth automatically for the desired target orientation. While there are no obstacles between the robot and target position, and no azimuth is needed to identify them, then the robot moves forward to the target, thus demonstrating the move-forward mode. Hence, the third-priority mode is called the move-forward mode.

IV. Controller Implementation

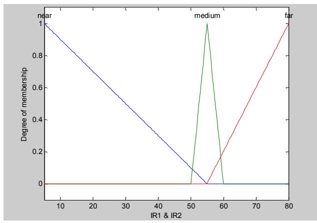
A. Fuzzy Sets for Obstacle Avoidance Mode Implementation

One of the primary fields of research in robotics is the development of methods for the guidance of autonomous robots. There are many complex problems in this field, mainly due to the nature of real environments, which are difficult to model. Knowledge about an environment is often incomplete, uncertain, and approximated; the information often supplied by the robot sensors is limited and not totally reliable; and the environment in which the robot is located usually has a dynamism which cannot be predicted. For all of these reasons, fuzzy logic is a useful tool in the autonomous robots, as has been demonstrated in numerous studies carried out for guidance in real environments, obstacle avoidance, route planning, etc. [8]. Fuzzy logic, unlike classical logic, is tolerant to imprecision, uncertainty, and partial truth. This makes it easier to implement fuzzy logical controller to nonlinear models than other conventional control techniques.

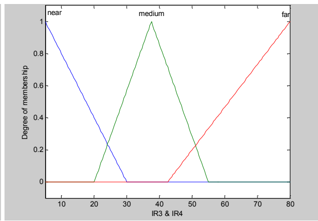
In order to avoid obstacles without encountering any obstacles, the AMR should take sensory information about obstacles into account. The proposed FLC in obstacle avoidance mode uses the sensory information from four proximity sensors as the inputs and controls of the four motors. The FLC translates the sensor measurements directly to actuator actions. If there is an obstacle, the controller will determine the optimum route and order the mobile robot to move, and then it will scan the area again. The front two IR sensors (IR_1, IR_2) perform the front obstacle detection. Both IR sensors (IR_3, IR_4) detect obstacles on either side. Hence, the fuzzy membership functions for obstacle avoidance can be classified as two pairs (IR_1, IR_2) and (IR_3, IR_4). In this research, we propose two fuzzy controllers, which are called type I and type II fuzzy controller, for obstacle avoidance for comparison purposes. When the robot starts moving, it will scan to determine if there is an obstacle or not. If there is one in front, it will calculate whether going to the right side or the left side presents a shorter route. Then the controller will send data to the stepping motor to process real-time action for obstacle avoidance

Three membership functions (MF) are considered for type I fuzzy controller: *near*, *medium*, and *far*. Normalized triangular membership functions are selected for rule bases. Each of these functions is shown in Fig. 6. In consideration of the sensor transmission reaction time is about 0.3 second, if we define the "*near*" is too narrow for the front infrared sensors (IR_1, IR_2), it will be easily to lead the mobile robot to hit the obstacles and then begin to execute the obstacle avoidance behavior. Hence, the definition "*near*" is set to the biggest area among the three fuzzy sets for (IR_1, IR_2) membership function based on operator's experience (Fig. 7 (a)). Moreover, the other side infrared sensors (IR_3, IR_4) may be taken into account in the narrow passageway can pass through the obstacles to the target goal, the membership function graphics settings on a more even (Fig. 6 (b)).

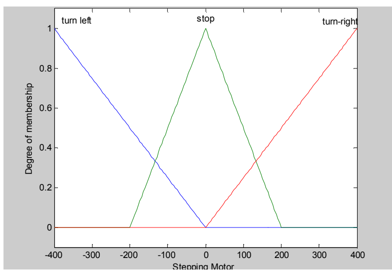
In addition, the control problem for the AMR is how to independently control the left and right turns. Hence, there are three fuzzy sets: *turn_right*, *turn_left*, and *stop* for stepping motors to control the left and right wheel, respectively (Fig. 6 (c)). Thus, the fuzzy obstacle avoidance control mode has 4 inputs and 2 outputs. This means that there are 81 possible fuzzy rules.



(a) (IR_1, IR_2) pair MF



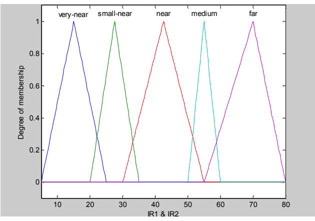
(b) (IR_3, IR_4) pair MF



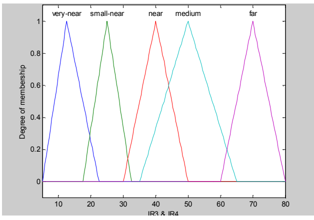
(c) Stepping motor command MF

Fig. 6 Type I fuzzy controller for obstacle avoidance mode

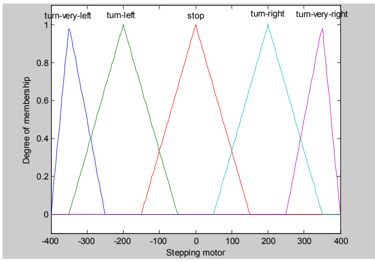
Even if the type I fuzzy sets is simple, however, there is an oscillation problem while facing obstacle avoidance. Hence, the proposed fuzzy control type II is based on the performance of the type I fuzzy sets. Five membership functions are considered here: *very_near*, *small_near*, *near*, *medium*, and *far*. The main difference between type I and type II is that the latter divides "*near*" into *very near*, *small near*, and *near*. The graphical representation of these membership functions for the IR sensors is given in Figs. 7 (a) and (b), respectively. Similarly, there are five fuzzy sets − *turn_very_right*, *turn_right*, *turn_left*, *turn_very_left*, and *stop* − for stepping motors to control the left and right wheels (Fig. 7 (c)). Hence, the knowledge base contains 625 rules.



(a) (IR_1, IR_2) pair MF



(b) (IR_3, IR_4) pair MF

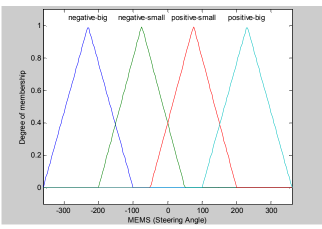


(c) Stepping motor command MFn

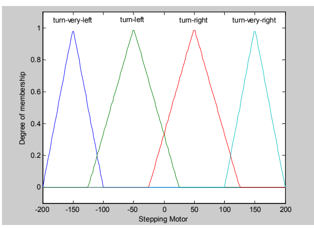
Fig. 7 Type II fuzzy controller obstacle avoidance mode

B. Fuzzy Orientation Identification Mode Implementation

The type I fuzzy set for orientation identification mode has been presented in Fig. 8. The steering angle θ_s fuzzy membership function using the triangular graph is indicated in Fig. 8 (a), and membership function for stepping motor in Fig. 8 (b). Here, four membership functions, *negative_big*, *negative_small*, *positive_small, and positive_big*, have been considered in this design for orientation identification purposes. Moreover, there are four fuzzy sets, *turn_very_right*, *turn_right*, *turn_left*, and *turn_very_left*, for stepping motors to control the left and right wheels.



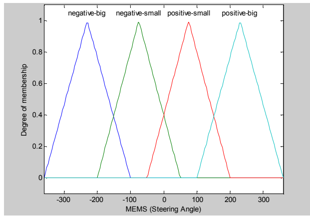
(a) MEMS sensor MF



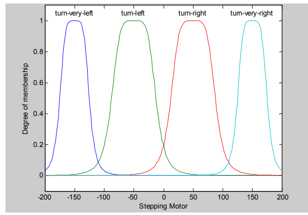
(b) Stepping motor MF

Fig. 8 Type I fuzzy controller for orientation identification mode

Moreover, the proposed fuzzy control type II is based on the bell function for the MEMS sensor and the stepping motor comm. The graphical representation of these membership functions for the MEMS sensors and stepping motor are given in Figs. 9 (a) and (b), respectively. Similarly, there have five fuzzy sets *turn_very_right*, *turn_right*, *turn_left*, *turn_very_left*, and *stop* for stepping motors to control the left and right wheel, respectively (Fig. 9 (b)).



(a) MEMS sensor MF



(b) Stepping motor MF

Fig. 9 Type II fuzzy controller for orientation identification mode

V. REAL TIME EXPERIMENTAL RESULTS AND DISCUSSIONS

The established AMR is shown in Fig. 2; its corresponding dimensions are 25 cm in length, 30 cm in width, 100 cm in height, and 2 kg in weight. For a target goal and obstacle avoidance test, the dimensions for the experimental space are 500 cm in length and 300 cm in width. In order to verify the performance of the proposed hybrid control modes, three different obstacles scenario environments have been constructed. It is noted that Case I is a symmetrical obstacle scenario, Case II is a narrow passageway scenario, and Case III is the extremely obstacle scenario case.

The behavior network possesses the fuzzy obstacle avoidance control mode, the fuzzy orientation identification control mode, the move forward control mode, and three hybrid control modes to deal with different situations in real applications.

Moreover, the comparison trajectory tracking error in a normalized root-mean-square (RMS) e_{RMS} is defined as

$$e_{RMS} = \sqrt{\sum_{k=1}^{N} e_k^2 \,/\, N}\,, \qquad (5)$$

where N is total number of samples, and e_k is the tracking error at each sampling time.

A. Case I Experimental Scenario Environment

Case I is the first test case in order to verify the validity and reliability of the proposed control scheme. The path tracking during the experimentation is shown in Fig. 10. It can be seen that the robot avoided obstacles as it approached the obstacle while it's in the security zone; the mobile robot planned a path similar to a straight line, turning to the target point.

To further verify the performance of the proposed controller, Table I compares the normalized root mean square (RMS) tracking deviation, which contains X-direction, Y-direction, and steering angle for different fuzzy control methodologies. It shows that the fuzzy controller based on type I and II can also track the desired trajectory successfully.

This experimental finding confirms that type II controller reduces the trajectory tracking deviation (RMS) in X-direction by approximately 9.97%, representing a 26.92% reduction in Y-direction, and a 2.78% diminution in steering angle tracking. The controlled response confirms that the type II fuzzy controller can effectively suppress the trajectory tracking drift of the AMR. Moreover, the task completion time can be further reduced by as much as 19.8% when the type II controller is applied. It is shown that the use of a proposed fuzzy type II reduces the tracking error slightly (Table I). It can be concluded that the proposed fuzzy controls type I and II can perform obstacle avoidance successfully as well as path tracking.

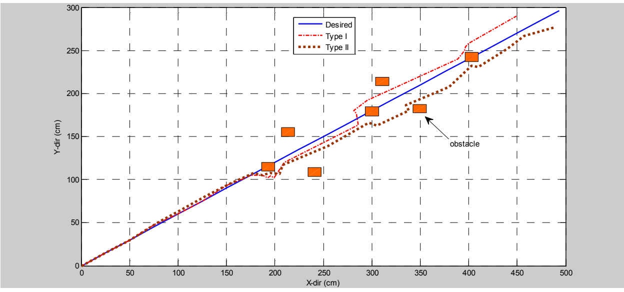


Fig. 10 The tracking performance for case I experimental scenario environment

TABLE I
COMPARES TRAJECTORY TRACKING ERROR FOR DIFFERENT CONTROL SCHEMES

Case I Scenario Experiment (RMS)				
Control Type	Tracking deviation in X-dir. (cm)	Tracking deviation in Y-dir. (cm)	Tracking steering angle Error θ_s (deg)	Task completion time (sec)
Type I	53.97	32.74	8.77	141
Type II	48.59	23.92	8.52	113
Error Reduction (Type I-Type II)	9.97%	26.92%	2.78%	19.8%

B. Case II Experimental Scenario Environment

Case II is the second test case in order to verify the validity and reliability of the proposed control scheme. Even if the type I fuzzy set is simple, however, there is an oscillation problem while facing obstacle avoidance in narrow passageway. Hence, the proposed fuzzy control type II is based on the improvement performance of the type I fuzzy sets. Fig. 11 demonstrated the path tracking during the experimentation under Case II scenario environment. It can be also seen that the robot avoided obstacles as it approached the obstacle. While it's in the security zone; the mobile robot planned a path similar to a straight line, turning to the target point.

In addition, during the AMR operation under Case II, the tracking deviation in X-direction can be reduced as compared to type I by as much as 0.96% when type II controller is applied, and the tracking deviation in Y-direction can be reduced by 0.9% when the proposed type II fuzzy controller is used. Similarly, the experiment also demonstrates that the type II controller reduces the tracking steering angle error under the Case II scenario by approximately 70%. Furthermore, the task completion time can be reduced from 187 seconds to 171 seconds by as much as 8.6% in total when the type II controller is applied (Table II). Thus, the proposed fuzzy control rule scheme (type II) diminishes the tracking error during as well as task completion time. Hence, even if a narrow passageway scenario, the proposed control algorithm can lead the mobile robot to pass the narrow pathway and moving to the target successfully.

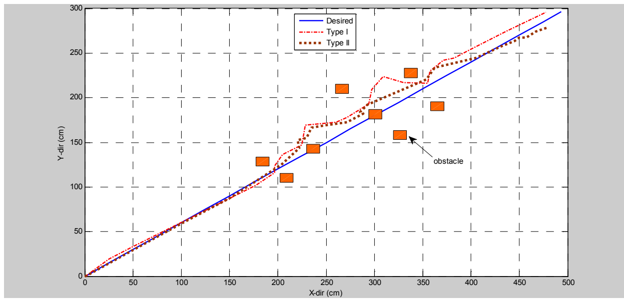


Fig. 11 The tracking performance for case II experimental scenario environment

TABLE II
COMPARES TRAJECTORY TRACKING ERROR FOR DIFFERENT CONTROL SCHEMES

Case II Scenario Experiment (RMS)				
Control Type	Tracking deviation in X-dir. (cm)	Tracking deviation in Y-dir. (cm)	Tracking steering angle Error θ_s (deg)	Task completion time (sec)
Type I	43.06	30.05	24.38	187
Type II	42.64	29.78	7.26	171
Error Reduction (Type I-Type II)	0.96%	0.9%	70%	8.6%

C. Case III Experimental Scenario Environment

Even if the mobile robot face the extremely obstacle scenario case (Case III), the control system also succeeds in avoiding collision and navigation task. The actual path tracking of the fuzzy navigation algorithm at Case III scenario environment is as shown in Fig. 12. There still have an oscillation problem while mobile robot facing obstacle avoidance by using type fuzzy I controller. It shows that the navigation strategy of fuzzy algorithm for avoidance obstacles is correct and effective by tuning fuzzy knowledge base. Through the employment of the proposed type II fuzzy control in the system, the tracking deviation is greatly reduced or even eliminated (Table III). We can see that the robot can avoid the obstacle safely and reach the target point successfully. Moreover, the path to the target is shorter than type I control while type II control scheme is introduced. At the same time, the tasking time is also gradually decreased. These experiments show that the mobile robot successfully tracks the desired trajectory. This experimental finding also confirms that rule II reduces the trajectory tracking error (RMS) in X-direction by 20%, representing a 22% diminution in Y-direction, and 67% attenuation in steering angle tracking. The controlled response confirms that the type II fuzzy controller can effectively suppress the trajectory tracking error of the AMR. Moreover, the task completion time can be further reduced by as much as 23% when the type II controller is applied. Through the comparison results, we can find that the design navigation scheme can be further improvement by tuning fuzzy knowledge base, especially in extremely obstacle scenario case. It also indicated that the proposed control algorithm has good effects because of its advanced characteristics of adaptability, stability and robustness.

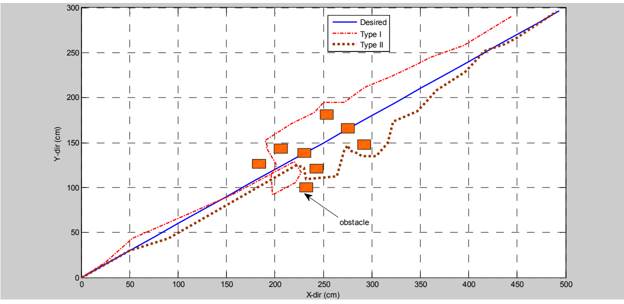


Fig. 12 The tracking performance for case III experimental scenario environment

TABLE III
COMPARES TRAJECTORY TRACKING ERROR FOR DIFFERENT CONTROL SCHEMES

Case III Scenario Experiment (RMS)				
Control Type	Tracking deviation in X-dir. (cm)	Tracking deviation in Y-dir. (cm)	Tracking steering angle Error θ_s (deg)	Task completi on time (sec)
Type I	76.65	31.03	55.53	312
Type II	61.20	25.26	17.88	239
Error Reduction (Type I-Type II)	20%	22%	67%	23%

VI. CONCLUSION

This study addresses the issue of the AMR navigation task based on the fuzzy obstacle avoidance rule and the MEMS sensor fuzzy orientation compensation rule. The novel hybrid control mode, based on multi-sensors information by using the fuzzy approach, has been first presented in this research. The mobile robot can send the sensing data via the Arduino Mega2560 control board to the control computer through wireless communication module. The control algorithm is coding in LabVIEW for navigation task. The proposed methodology was implemented and tested in three kinds of scenario environments. From the experimentation, the effectiveness of the proposed AMR obstacle avoidance and navigation scheme is confirmed. Through the comparison results, we can find that the navigation scheme can be further improvement by tuning fuzzy knowledge base, especially in extremely obstacle scenario case. The implementation of the controller is robust, has a low execution time, and allows an easy design and tuning of the knowledge base.

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