Simulation of Robot Navigation for Hospital's Confined Space Areas Using Fuzzy Control

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***Abstract*—The atmospheric hazards that may be present in confined space pose a serious threat to human while carrying special task in the respective location. Among the areas that are considered as confined space are utility tunnel, boiler, storage tank, sewage lines, utility holes and underground electrical fault. This study is concerned with hospital's enclosed space areas which include mechanical room and medicine storage area. Currently, there is no specific technique to replace worker for a task such as navigation and collecting air sample in the confined space for monitoring the hazards. A mobile robot integrated with CCD camera can be used to manoeuvre through the environment and at the same time monitor the situation in confined space. This paper discusses simulation of robot navigation for hospital's confined space areas. Fuzzy control was implemented to allow the robot to perform semi-autonomous obstacle avoidance in the simulated environment. The result shows that the robot was able to manoeuvre around without any collision.**

***Index Terms*—CCD Camera; Fuzzy Rule; Microcontroller; Wireless Transmit and Receive; Pulse Width Modulation**.

I. INTRODUCTION

A confined space is an area where structure or materials that may present danger to the workers while performing jobs such as repair, service or maintenance. A poorly ventilated zone in the confined space will decrease the oxygen and increase the concentration of hazardous volatile compounds. The small area condition is preventing workers to operate at a safe distance from the potential hazards induced by faulty mechanical or electrical system. The chemical hazards can also be present due to the leakage of flammable liquid in a poorly ventilated area. The situations also pose potential dangers to the rescue personnel who attempted to save workers during an accident. So, workers that are being assigned to work inside the confined space should be equipped with proper equipment and training on safety. Their safety should always be monitored while performing the job. Also, the area safety aspect such as minimum radius for entry and exit, ventilation system and workspace, as shown in Figure 1, must be adequately studied before performing their job [1].

This paper discusses the development of a mobile robot for confined space application. The system and technical specifications are built based on the specific application to replace human for performing dangerous tasks, particularly mobile operation [2].

Malaysia already has so many examples of confined spaces various classification. Currently, there is no a specific technique to substitute worker for a task such as collecting air sample in the confined space for hazards monitoring. In this paper, more focus is made on the hospital's restricted space areas.

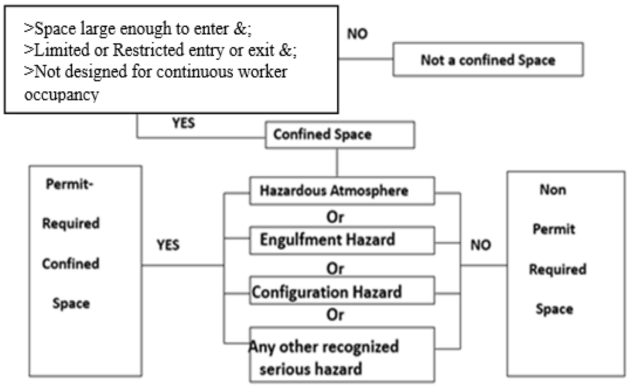

Figure 1: The confined space criteria.

II. MOBILE ROBOT FOR CONFINED SPACE

A. System Architecture

The mobile robot for confined system architecture is shown in Figure 2. The structure of robot body is made from mild steel, and it's used four DC motor which used the differential technique for the movement. The robot is controlled using embedded PIC microcontroller, and the software was written in C language. A wireless Charge Coupled Device (CCD) camera attaches to the robot and is positioned at the robot front-end for the front view visual information with an ultrasonic sensor for obstacle detection. Information visual can be display on light crystal display (LCD). A radio frequency (RF) remote control device was used to control the robot movement. The robot used single 12V DC lead-acid battery as drive power supply and 12V DC lithium battery.

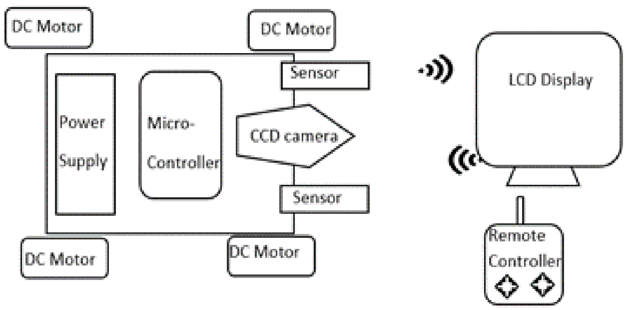

Figure 2: Mobile robot architecture.

B. Mechanical Part of the Mobile Robot

The environment in confined space is typically limited and small, so it is more suitable for wheel robot [3]. The wheel robot structure design is quite easy and popular because of its mobility, fast and energy efficient [4]. The robot structure ground clearance and tire pattern will determine the efficiency of power transfer from wheel to ground.

The robot application also will decide numbers of wheels for weight distribution. Narrow wheels will be used because of its high speed and low power consumption, while wide wheels will be selected for better grip [5].

Four-wheel configurations, shown in Figure 3, are selected for the structure design because of the easy control, good mobility and well balance that is suitable for the confined space harsh environment. The configuration is stable because the wheel is attached to each corner of either rectangular or square shaped robot's structure. The wheels are placed on the right, left, front and back side of the robot's structure that will increase the development efficiency [4].

A 12-volt DC power window motor independently drives each wheel. The motor rotates at 85 RPM velocity and less than 5A for no-load rating. The motor open-looped control uses differential drive configuration from two motor drivers. The motor will rotate with load at 60 RPM and less than 15A. The motor is controlled by using pulse width modulation (PWM) from the onboard microcontroller.

Therefore, PWM input is used to control the speed of the DC motor. That because PWM is a common alternative use a constant supply voltage which is continuously being switched on and off by a controller. By varying the PWM ratio of the input signal, the speed of the motor will change according to the average output voltage. The movement is easier to control even in manual or auto mode. The speed will depend on the PWM because, in auto mode, the speed will vary because of the distance of obstacle was unknown and the sensor will measure the distance between the robot and the obstacle.

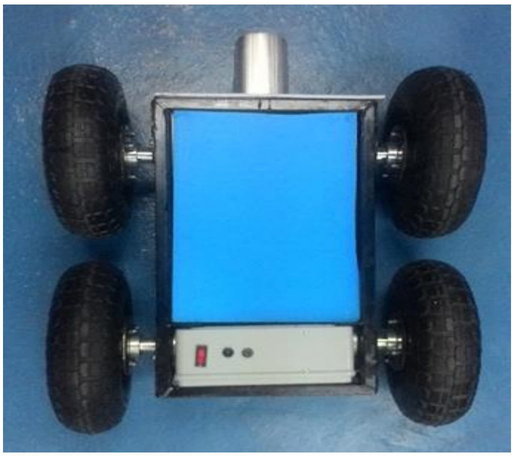

Figure 3: Four-wheel mobile robot.

C. System of the Mobile Robot

Microcontroller controls the robot. The microcontroller circuit and board are shown in Figure 4. The microcontroller embedded software is developed to control the movement of the robot and at the same time to assist the robot during movement determine using the fuzzy build in the microcontroller.

The microcontroller can be determined which mode is running at the time. The mobile robot operation will depend on the condition of the environment at the confined area spaces. If the situation was easy to move, it could change to an autonomous mode that means the mobile robot will depend on the sensor reading with fuzzy control during movement.

The sensors can cover a 45° angle with up to a 300 cm detection range. Due to the specification angle, the sensor will be placed at the right and left only as the 45° coverage will cover the centre of the mobile robot. During operation, the microcontroller will calculate the time-of-flight of the ultrasonic sound of the sensor to determine the distance between the robot and obstacles. The information will be used by the microcontroller to perform fuzzy algorithm during robot's movement to enables the system for obstacles avoidance. The fuzzy was built in the microcontroller to control the speed of the DC motor and avoided the mobile robot from crushing the wall.

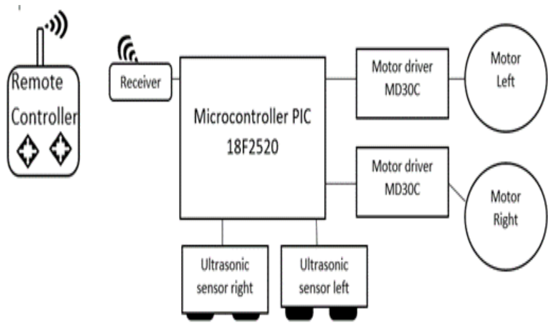

Figure 4: Interface microcontroller blog diagram

D. Visual System

The robot also is attached with a wireless Charge Coupled Device (CCD) camera, which is positioned at the robot front-end for the front view visual information and a direct link to the LCD monitor. The connection from the CCD camera to the LCD monitor through wireless transmitter and receiver is shown in Figure 5.

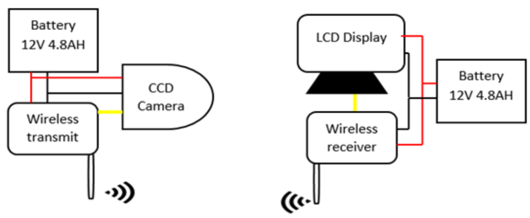

Figure 5: Interface of CCD camera with wireless transmitter and receiver

E. Mobile Robot System

The robot control main program flow chart is shown in Figure 6. The program will convert the received data from a time in a microsecond (μs) to distance in centimetre (cm). The flow of program continues to check the converted distance with the defined distance data. The comparison process flowchart will give the decision to the robot to change the direction to left, right or stop according to the comparison result by the fuzzy rule in the fuzzy simulation. The mobile robot will continue to move following the signal from remote control if the data are still in the safe range.

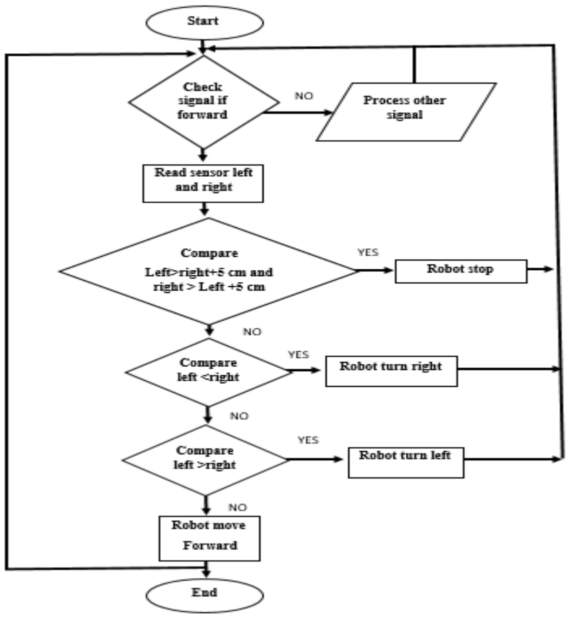

Figure 6: Main flow chart

III. SIMULATION OF FUZZY CONTROL

Simulation of fuzzy control for the mobile robot has been done to establish the fuzzy rule and ensure that the decision made is correct. For this simulation, the Mamdani type is selected because of the data is more accessible to display compared to Sugeno and more suitable for mathematical analysis. Reproducibility test and repeatability test need to be done to guarantee the strategy utilised is flexible and possible.

A. Setup Simulation Parameter Membership of Fuzzy

The range for the sensor reading in this simulation has been set with three conditions; very near, near and far. The scope of the obstacle for three conditions is shown in Figure 7.

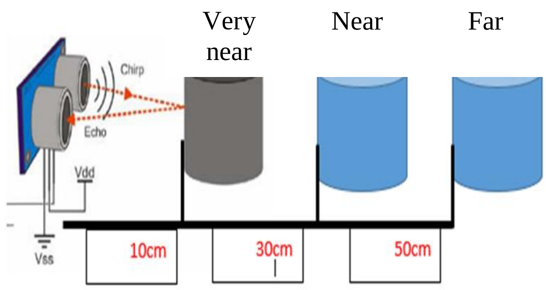

Figure 7: Obstacle set up the distance

B. Fuzzy Control Design

The fuzzy controller's input and output are shown in Figure 8.

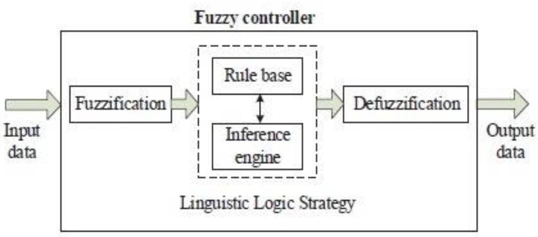

Figure 8: Fuzzy control system

The configuration of the system for the left sensor and right sensor is shown in Figure 9 and Figure 10. From the table, the range of distance detection have been set from 0 to 50 cm

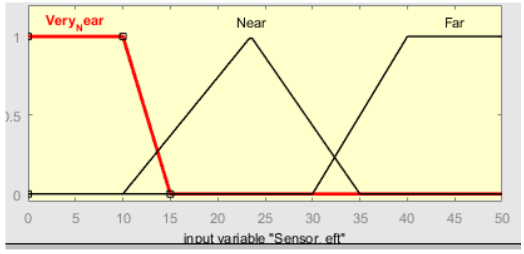

Figure 9: Input sensor left

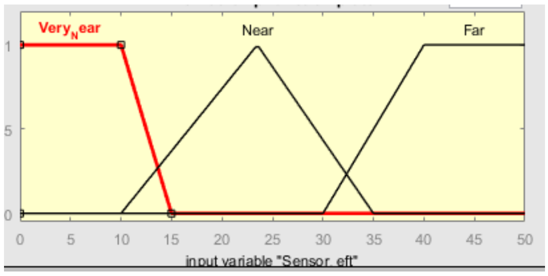

Figure 10: Input sensor right

Table 1 represents the fuzzy logic table rule. The fuzzy motor output measurement is in PWM to control the left and right motor.

Table 1
Fuzzy rule

Fuzzy Rule	Sensor Left	Sensor Right	Motor left	Motor right	Robot condition
1	Very near	Very Near	Tele op (prevent forward)	Tele op (prevent forward)	Tele-operation
2	Very near	Near	Forward	Slow reverse	Sharp turn right
3	Very near	Far	Forward	Slow reverse	sharp turn right
4	Near	Very near	Slow reverse	Forward	Sharp turn left
5	Near	Near	Slow forward	Slow forward	Move forward slowly
6	Near	Far	Forward	Slow forward	slight turn right
7	Far	Very near	Slow reverse	Forward	Sharp turn left
8	Far	Near	Slow forward	Forward	Slight turn left
9	Far	Far	Tele op	Tele op	Tele operation

The input has been set up for the fuzzy rule. The fuzzy rule was used to create output to fulfil the requirement of robot mobility for the required task in the mechanical room.

The outputs have been created based on the requirement from the fuzzy rule and are shown in Figure 11 and Figure 12.

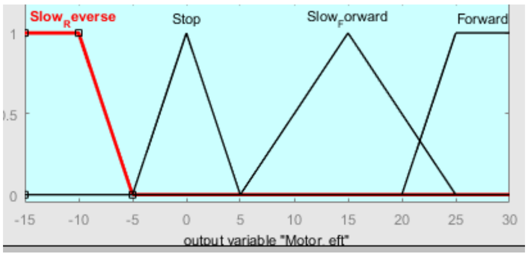

Figure 11: Output motor left

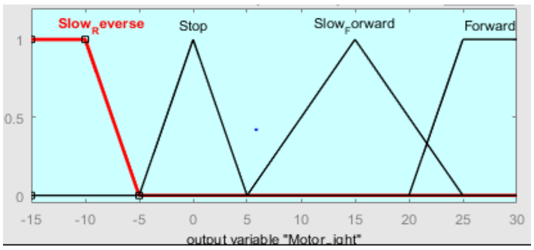

Figure 12: Output motor right

From a fixed starting point, the robot's navigation path will follow a set of predefined points in the environment. If the ultrasonic sensors detect an obstacle, the robot will avoid it by following the fuzzy logic embedded in the microcontroller that was simulated by using mobotsim.

The simulation area for the mobile robot was developed as in Figure 13. The environment follows the real setup in the hospital's confined space area. This area is actually a mechanical room which consists of an operating generator, generator panel and table with tools.

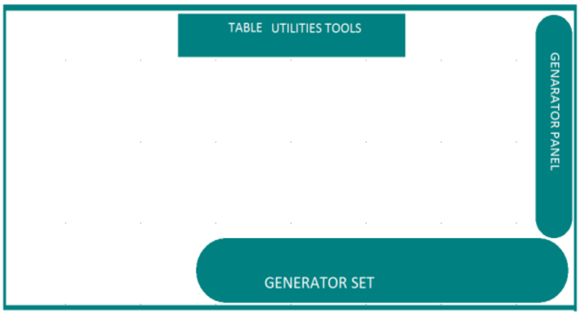

Figure 13: Simulation in the mechanical room

IV. RESULT AND DISCUSSION

The structure of confined space (mechanical room) has been set up in the mobotsim simulation to test the accuracy and performance of the fuzzy control on the mobile robot. The actual parameter was used throughout the simulation. Figure 13 shows the result of the simulation in the mechanical room.

Figure 14 shows the tracking of the mobile robot's movement in the mechanical room. The simulation result indicates that the mobile robot was able to move around to monitor the air quality in the mechanical room. The robot was also able to perform obstacle avoidance during the operation.

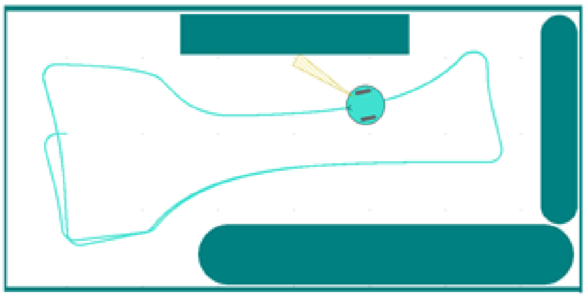

Figure 14: Tracking of the mobile robot in the mechanical room

From Figure 14 the values were evaluated by using simulation surface table in Matlab. Figure 15 shows the simulation surface table that was created. This result reflects the response of the sensors to the speed of the motor. This is because the sensors will represent the condition of the obstacles that have been detected. The change of the left and right sensor values will show the response of the motor speed condition as in simulation.

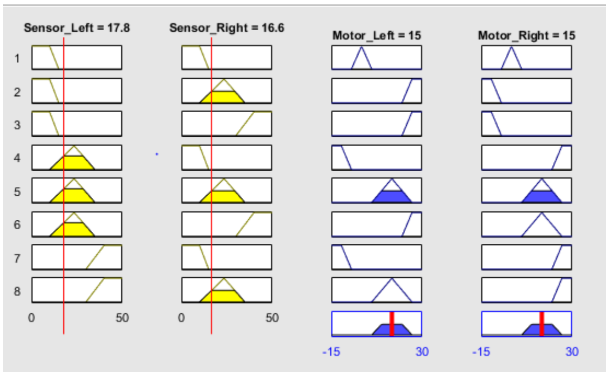

Figure 15: The simulation surface table in Matlab

Figure 16 shows the resulting response of the left motor concerning the left and right sensors of the mobile robot. The result has been plotted in 3D graph in relation to the fuzzy rule.

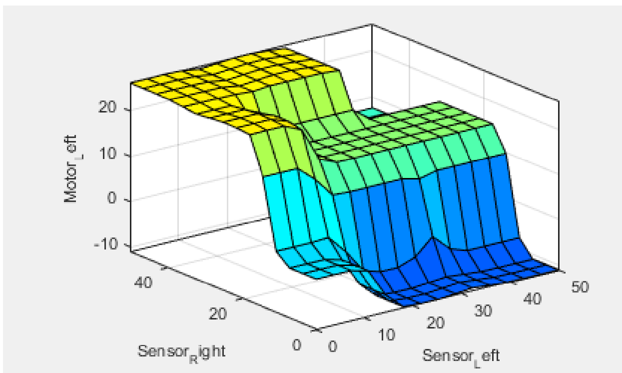

Figure 16: Result for motor left

Similarly, Figure 17 shows the response of right motor concerning left and right sensors. The evaluation of the right motor must follow the 3D graph because of the relation to the fuzzy rule.

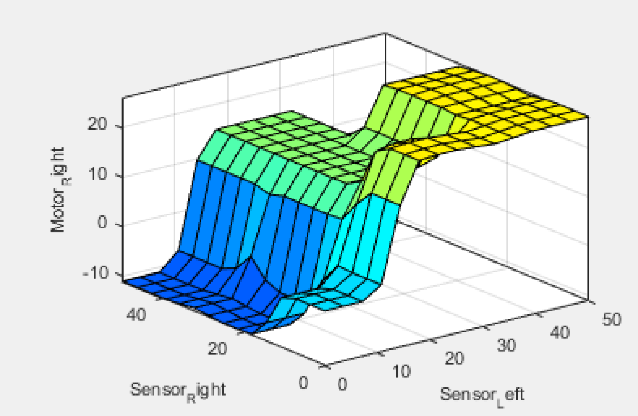

Figure 17: Result for motor right

Both Figure 16 and Figure 17 show the relation of both motors to the fuzzy rule. The response of the motor speed depends on the obstacle's range detected by the left and right sensor.

V. CONCLUSION

In this paper, the mobile robot for confined space (mechanical room) application was developed and simulated using fuzzy control. The robot design criteria were easy to control, stable with good mobility and suitable for the confined space's harsh atmosphere. The skid steering driving mechanism was selected since it is robust and straightforward with excellent traction for the rough surface environment. The fuzzy rule embedded in the microcontroller makes the mobile robot easy to control and performs an automatic immediate turn with wheeled skid steering mechanism. The mobile robot had been proved suitable to be used for confined space, particularly for mobile olfaction application. In the future, the robot's structure could be designed to have an adjustable structure for improved flexibility in confined space.

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