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An Automated Fuzzy Logic Based Low Cost Floor Cleaning Mobile Robot

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Abstract: In recent years, there has been increasing interest in developing new designs of low cost floor cleaning mobile robots. One of the challenges has been to reduce the number of sensors as it contributes considerably to the cost of the robot. In this study, the design and development of an automated floor cleaning robot which can navigate and clean a floor at the same time is discussed. It involves hardware construction and software implementation. The 2 wheels are centre mounted are used to move the robot in all direction. Electric brush is mounted in front of the cleaning robot to perform the sweep cleaning process and a mini-water pump is installed within the water tank mounted at the back of the cleaning robot to perform the mopping function. A PIC18F46K22 microcontroller and a L293D motor driver are incorporated into the cleaning robot for processing sensors signals and controlling DC motors. The 3 ultrasonic sensors are mounted on the cleaning robot for obstacle avoidance during its navigation. A RF module is installed on the main board to enable wireless control of the robot. Fuzzy logic techniques have been implemented in the control process. A prototype robot was fabricated and tested in a real environment. It has been found that the robot is able to collect hair, dust, small materials and mop the room floor avoiding obstacles during the cleaning process. The proposed method results in a self-navigating obstacle avoiding cleaning robot which is capable of dry and wet cleaning at a lower cost.

Key words: Mobile robot, fuzzy logic, floor cleaner, automatic mode, sensors

INTRODUCTION

Robotic cleaners have received major attention in robotics research due to their usefulness in helping human beings in floor cleaning applications at homes, restaurants, hotels, hospitals, offices, universities etc., Mostly, robotic cleaners are differentiated based on their cleaning capability like dry vacuum cleaning floor mopping etc., Obstacle avoiding systems used are based on infrared sensors or laser mapping techniques. Every mechanism of robotic cleaners has its own advantages and disadvantages. For instance, obstacle avoidance system based on infrared sensors is comparatively time consuming and less energy efficient due to random cleaning but less costly while obstacle avoidance system employing laser mapping techniques is comparatively faster, less time consuming and energy efficient but costly. Many economically under developed countries are importing floor cleaner robots from abroad at a very high cost. Use of the proposed method enables local manufacture at low cost in such countries. The Medium and Long Term Science and Technology Planning of China (2006-2020) clearly stated that the service robot will be the priority development of strategic hi-tech in the future. The Japanese robot industry association forecasts that the demand of service robot of Japan's market will amount to $10 bln and the world's market can be as high as $150 bln or more. By the end of 2016, the cleaning robot market will reach at $2 bln it is indicated that the cleaning robot will be one of the main growth points (Zhangjun, 2012). As a new technology in recent years, the cleaning robot gets extensive research grants both at home and abroad. The cleaning robot technology has made a breakthrough in nearly a decade and it has entered the stage of application.

The American professional robot company, iRobot (I'ROBOT Company, 2015) launched its own first intelligent automatic vacuum cleaner in September 2002. The famous home appliance manufacturer, Electrolux of England also launched its own intelligent automatic

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vacuum cleaner named Trilobite (Ren *et al*., 2009) also Neato Robotics Company USA, recently developed a vacuum cleaner robot named 15-14 (Neato, 2015).

Machinery and Electronics Research Institute of Zhejiang University and Suzhou TEK Company cooperatively researched and developed an intelligent automatic vacuum cleaner. An autonomous vacuuming robot was successfully launched by fluid transmission and control laboratory of Zhejiang University (Ren *et al*., 2009). An autonomous vacuuming robot also successfully launched on June 8, 2007 in Harbin Institute of Technology (Zhiguo *et al*., 2012). Ecovacs Company of Suzhou develops a vacuum cleaner robot named Deepoo760. KV8 company developed KV8 510B. Each of these robots has its own advantages and has good sales. Moreover, there are many other researchers working in this field and they achieved fruitful research results (Dyson Company, 2015; Jones, 2006; Peng and Huang, 2013). Mopping robot has always been the research emphasis in cleaning robot industry (Kongsin and Kirita, 2012; Han, 2013). The mopping robot named Scooba 390 was developed by the iRobot company.

The robots reported above are useful for either vacuum cleaning or mopping and are also very costly. In this study, researchers propose the design and development of a floor cleaning mobile robot at low cost. This can work in two modes “automatic and manual”. Unlike any other floor cleaner robots, this is not a vacuum robot and it can perform both sweeping and mopping operation. The main objective of this work is to enable manufacture of single self-navigating obstacle avoiding robot for both sweeping and mopping at low cost using local resources.

MATERIALS AND METHODS

Design and construction of floor cleaner mobile robot: In the design of the cleaner robot prototype is shown in Fig. 1. The microcontrollers provides a high speed processing with internal clock source up to 64 MHz and has a higher performance among the PIC 18F series microcontrollers. In term of memory, PIC18F46K22 has up to 1024 bytes data Electrically Erasable Programmable Read-Only Memory (EEPROM) and 64 Kbytes linear program memory addressing while PIC18F25K22 has 256 bytes data Electrically Erasable Programmable Read-Only Memory (EEPROM) and 32 Kbytes linear program memory addressing. It can operate in 16 Mln Instructions Per Second (MIPS). Besides, it has a lower cost compare to other higher performance microcontroller and thus, it is selected as the main chips for this system. Furthermore,

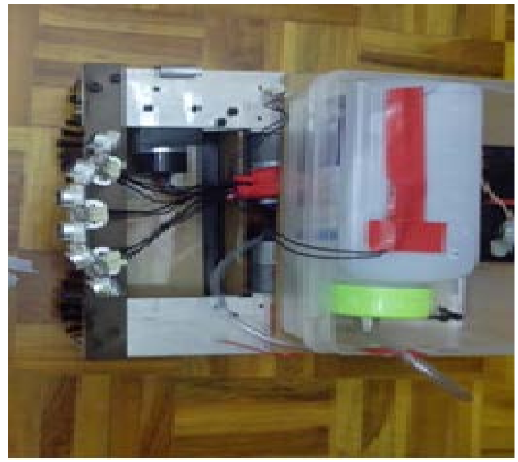

Fig. 1: A prototype floor cleaner

there is an enhanced CCP Module where in PWM mode, this module provides modulated outputs for controlling half-bridge and full-bridge drivers such as motor driver.

Motor driver L293D has been chosen as the motor controller. The device can be used for starting and stopping a pair of motors at one time selecting the direction of robot movement such as forward, backward, left and right, selecting and regulating the speed of motors regulating or limiting the torque and protecting against overloads and faults. There are internal diodes in the driver that protect against the back EMF and thus it will be more reliable than relays. Besides that the motor driver has included a built in H-bridge which is more reliable than relays. Besides that the motor driver has included a built in H-bridge which is much cheaper and easier to be implemented if compare to use of relays and MOSFET where the H-bridge hast to be designed and constructed by own. Hence, motor driver L293D is recommend in the design as the use of relays and MOSFET might complicate the circuit implementation later.

Sensitivity of ultrasonic sensor: As for the obstacles detection, 3 ultrasonic range sensors, HR-SC04 has been deployed at the left, center and right of the front robot as shown in Fig. 2. It has few advantages over other alternatives such as can have accurate distance measurement and better performance as compared to other IR alternatives and more economical than the laser rangefinder. The configuration of the ultrasonic sensor is shown as in Fig. 2. A 2×16 LCD and 2 switches are to be added in the configuration as to allow easy testing, debugging and troubleshooting purpose. With these

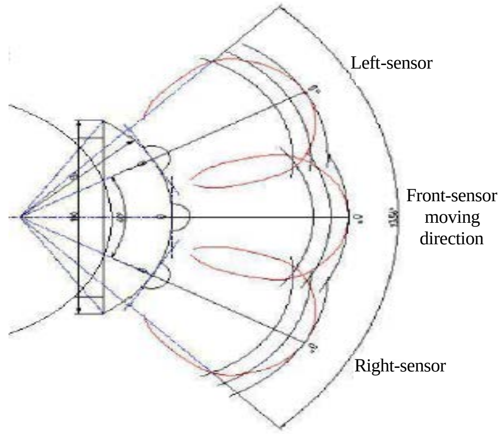

Fig. 2: Configuration of ultrasonic sensors

features, the user will gain better understanding while carrying a real-time programming as the LCD can be programmed of displaying important parameters or values of sensors from time-to-time. However, due to the energy consumption of the LCD was very high and its value only for debugging phase, it was removed from the circuit board after the product was finished.

To start measurement, a digital input of high pulse (5 V) for at least 10 us must be sent to the Trig pin as an initiator to the sensor board. HC-SR04 will transmit eight cycle pulses at 40 kHz through the transmitter and wait for the return of signal as shown in Fig. 3. A digital high pulse (5 V) will be sent through the Echo pin and delay for a pulse width proportional to the distance detected. In order to get an accurate value, the timing mechanism of main board should be set as small as possible. In this system, the echo signal will be collected in terms of microseconds. The constant value of the Eq. 2 is computed so a simpler calculation can be done in the program. The parameters time taken, t is in term of microseconds and distance in centimeter:

$$t = \frac{2d}{v}$$

Speed of propagation, v = 343 m sec^{-1} for sound wave. After conversion of unit, v = 0.0343 us c m^{-1}.

$$t = \frac{2d}{0.0343}$$

$$t \approx 58d \quad (1)$$

Radio frequency module is a wireless communication device to transfer data through radio wave. RF-TX-315

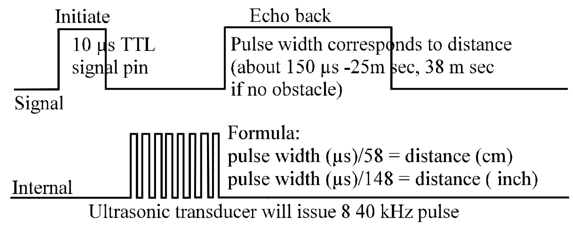

Fig. 3: Timing diagram of HC-SR04

and RF-RX-315 is low cost RF transmitter and receiver module that used in this system. They are much cheaper than a duplex RF transceiver that can be found in the market. They are small in dimension and able to transmit and receive radio frequency signal at specific frequency which is 315 MHz. The RF transmitter has a very wide operating supply voltage from 3-12 V, it is seriously affecting the transmission efficiency. They can transmit up to 100 m when 12 V is applied and correct antenna length (24 cm) is used. In this system, the signal received by RF receiver module is then sent to the microcontroller through the RX pin. RF transmitter module and serial communication board is attached to the controller board while the RF receiver module is connected to the cleaner robot for wireless control. In the consideration of the power consumption and load involved a 12 V lead acid battery for supplying 5 V to microcontroller, sensors, driving wheel motor, mini water pump and electric brush motor. Although it is heavier than the lithium-ion polymer battery but it is much cheaper and last for longer time of being a rechargeable power module.

When the electronic connection and mechanical structure of robot are completed, process of designing, writing, testing, debugging and troubleshooting the source code is to be carried out. The micro PRO compiler and PICkit2 with UIC programmer are being utilized upon achieving the objective of this project. In the design the source code of obstacle avoidance navigation system based on fuzzy logic are to be designed. Meanwhile, the program code for wireless communication module to select the manual and automatic mode is to be implemented. Analysis and testing of the pin connection has to be done before the debugging process. Debugging or troubleshooting is a very crucial task in the last process. It is to ensure that the robot can function properly in the end.

Software design and implementation of robotic floor cleaner: The general program flow of the main program starts with the initialization after the power on the 12 V

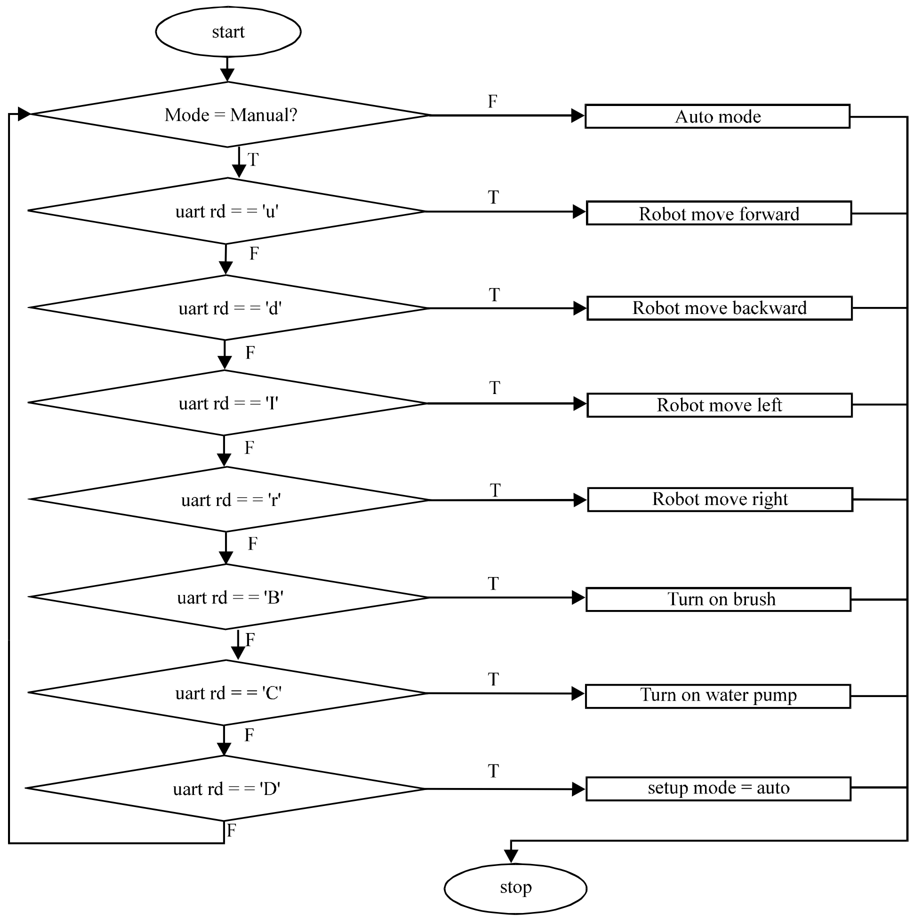

Fig. 4: Flow chart of the manual mode

switches. Then, the microcontroller will wait for the user to select the mode of operation. In manual mode, the user can control the cleaner robot to move in all direction, control the mini water pump to perform mopping cleaning process or control the electric brush motor for control the mini water pump to perform mopping cleaning mopping cleaning process. If the user press button "D" on the controller board, the cleaner robot will perform the mopping and sweeping cleaning process automatically. The user can return to manual control of the robot by pressing button "A" on the controller board.

Initialization: Firstly, the MCU oscillating frequency is selected at 4 MHz. All pins of the MCU are defined as "0" for the output and "1" for the input respectively for the sensors and DC motor control. UART module has been initialized at 2400 bps and some delay time for the module to stabilize. Then, the build in PWM module in the MicroC PRO compiler initialized at 1k Hz. The LCD module will only be initialized during the debugging phase. Lastly, the ultrasonic sensor will be warmed up a bit to for the module to stabilize.

Manual mode: In this mode, the cleaner robot will wait for the signal to be sent from the controller board. If a signal has been captured by the receiver module the cleaner robot will act according to the command. The flowchart of manual mode is shown as following Fig. 4.

Automatic mode: In the automatic mode, the cleaner robot will get its environment reading by three ultrasonic sensor sensing. The flowchart of automatic mode is shown in Fig. 5. After it get the information around, it will start to turn on the water tank pump every 3 sec. Table 1 shows the fuzzy logic rules for the obstacles avoidance system.

The control structure is based on a task for obstacles avoidance and the input of the control system is the environment sensors data from the ultrasonic sensor and the output are the motor command. The control structure is shown in Fig. 6.

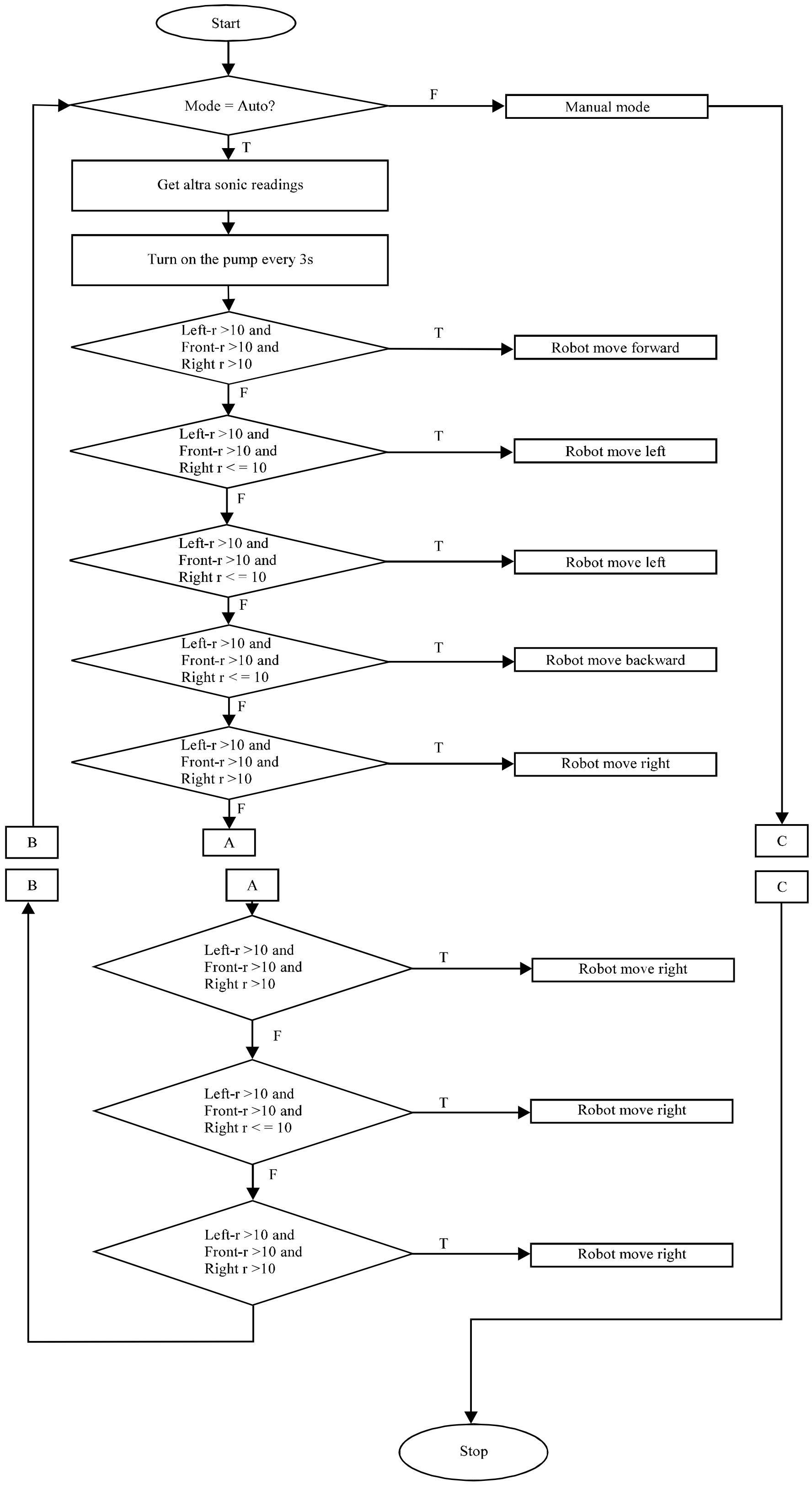

Fig. 5: Flow chart of automatic mode

Table 1: Fuzzy logic rules for the obstacles avoidance system

Left sensor	Front sensor	Right sensor	Robot direction
Far	Far	Far	Forward
Far	Far	Near	Left
Far	Near	Near	Left
Far	Near	Far	Right
Near	Near	Far	Right
Near	Near	Near	Backward
Near	Far	Near	Right
Near	Far	Far	Right

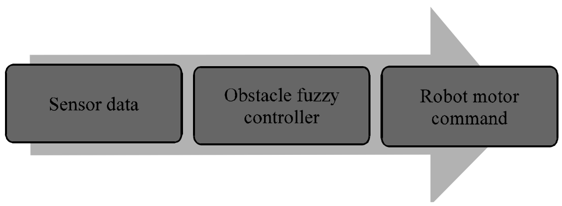

Fig. 6: The control structure in automatic mode

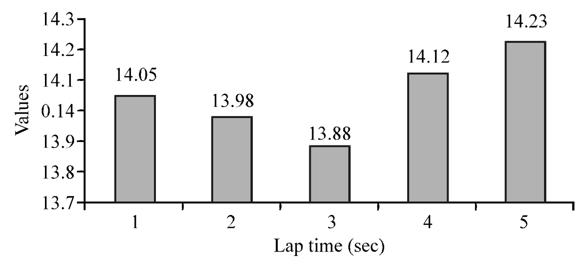

Fig. 7: Lap test

RESULTS AND DISCUSSION

Prototype testing: The prototype testing was carried out to gather the information on the performance of the sweeping mechanism, mopping mechanism and the capability of ultrasonic sensor on sensing different obstacles which are commonly found in the bedroom. In order to test the wireless control of the cleaner robot, a goal has been set 1m away from the robot. When the cleaner robot reached the destination, its performance and time taken is recoded. Firstly both the main board and controller board was switched on. The manual mode is selected to test the wireless control of the cleaner robot. The lap test results are shown in (Fig. 7).

Through this experiment as the range of the RF modules was very short and contains many noises in the signals, the cleaner robot were stop a few time when it heading toward the goal. Besides that the cleaner robot is not able to move in a straight line even through the user issue the "Forward" command.

Sweeping mechanism: Figure 8 shows a before and after picture of the room floor that has been cleaned with the cleaner robot. The cleaner robot was then tested with different small particle such as hair, dust, powder, animal fur and pencil. The prototype was able to collect small particle such as paper scrubs, hair, dust and animal fur into the dustbin except the pencil was too heavy to be scrub into the dustbin as shown in Fig. 9.

Fig. 8: Sweeping test

Mopping mechanism: The water is evenly distributed on the room floor but the width of the wet surface is less than the width of the robot. It is due to the dripping water system is unable to moisten the whole area of the sponge. However, the cleaning effect is satisfied. Figure 10 the cleaner robot can clean through a path which is covered with fine baby powder. However, it was found out that the brush and bottom surface of the robot came to be very dirty when utilising it as shown in Fig. 11. Therefore, these parts must be rinse in an easy manner.

Obstacles avoidance system testing: For the current ultrasonic sensor configuration, it can detect various

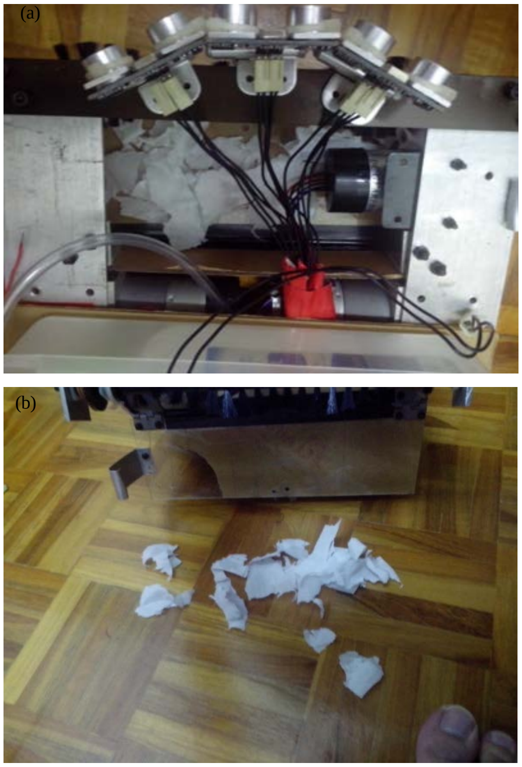

Fig. 9: Cleaning mode of the cleaner robot

Fig. 10: Cleaning on a powder surface

Fig. 11: Bottom surface with brush of the cleaner robot

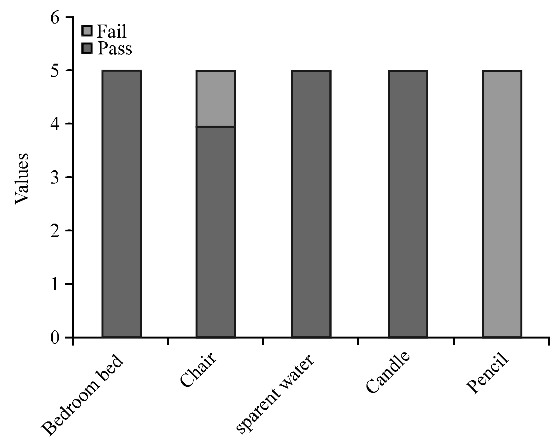

Fig. 12: Object sensing test

Table 2: Object sensing test

Test objects	1	2	3	4	5	t. pass	t. fail
Bedroom bed	p	p	p	p	p	5	0
Chair	p	p	p	F	p	4	1
Transparent water glass	p	p	p	p	P	5	0
Candle	p	p	p	p	p	5	0
Pencil	F	F	F	F	F	0	5

kinds of object which is commonly found in the bedroom such as bedroom bed, chair, water bottle, candle and pencil. About 5 times of testing for each object have been carried out for the justification of results. Its detection does not affect by sunlight or transparent material like others sensors. It is worth noted that the sensors only fail if object are too small as the limitation of the ultrasonic sensor could not detect object that are smaller than the wavelength. It also examined that an object must has surface area >0.04 cm^2. The object sensing test is shown in Fig. 12 and Table 2.

Table 3: Comparing data features (prices) with other existing floor cleaning mobile robots

Floor Cleaning Robots	Launce date	Manufacturer	Type of use	Technology	Price
Roomba (Jones, 2006)	2002	iRobot (USA)	Vacuum cleaner (Dry)	Auto-charging mechanism	USD500
Scooba (I'ROBOT, 2015)	2005	iRobot (USA)	Wet floor cleaner	IR with virtual wall accessories	USD500
Braava (I'ROBOT, 2015)	2006	iRobot, Kitech (Sony)	Hard surfaces clean	IR with virtual wall accessories for industrial cleaning	USD700
Neato XV-11 (Neato, 2015)	2010	Neato-Robots XV series California/China	Vacuum cleaning	Laser range finder technology, SLAM and auto-charging	USD399
EYE-360 (Dyson Company)	2015	Dyson (UK)	Vacuum cleaning	360° vision camera and a turbo brush and auto-charging mechanism	USD1000
Proposed a floor Cleaning mobile robot	2016	CRA Lab (MMU)	Dry and wet cleaner	RF module and a turbo brush	USD150

Comparison results with existing models: The Table 3 given below illustrates a comparison of various features of the proposed models with those of five recently reported models of floor cleaning mobile robot. It can be seen that the proposed robot model uses lower number of sensors compared to corresponding references (Jones, 2006; I'ROBOT Company, 2015; Neato, 2015; Dyson Company, 2015). Though the model of corresponding reference uses one mode with a function but the proposed model uses two modes with two functions (dry and wet). The proposed floor cleaning robot model provides all the navigational features and showing a lower cost.

CONCLUSION

In this study, the design and development of a single self-navigating obstacle avoiding robot for both sweeping and mopping at low cost using local resources is presented. This can work in two modes "automatic and manual". Unlike any other floor cleaner robots this is not a vacuum robot and it can perform both sweeping and mopping operations. It employs 3 ultrasonic sensors and only 2 wheels. Fuzzy logic techniques are used for obstacle avoidance and smooth navigation. A prototype has been fabricated and its performance has been tested in real environment. It has been found that the robot works successfully in performing both sweeping and mopping operations in manual and automatic modes.

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