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Sensor-Based Autonomous Robot Navigation with Distance Control

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Intelligent systems to increase the road safety have been widely applied in the automotive sector; similarly, they have critical importance in the robotics to navigate the robot safely. This paper deals with an automatic distance control system, which helps to avoid collision between vehicles. We present an algorithm to maintain a distance between the robot and the object. It keeps the autonomous mobile robot at a safe distance from the object. It is implemented in a wheeled mobile robot to track the moving object. The surrounding information is obtained through the range sensors that are mounted at the front side of the robot. The central sensor gives instructions for the forward and backward motion, and the other sensors help for the left and right motion. To avoid collision, safety distance, which makes the movement easy in the out of range, stop, forward, and backward modes, is predefined in the mobile robot. Each time the range data is compared with the predefined distance measurements, and the respected function is activated. The robot is characterized due to low cost and simple control architecture. Different experiments were carried out in the indoor and outdoor environments with different objects. Simulation and experimental results have shown that the robot tracks the object correctly by maintaining a constant distance from the followed object.

Keywords: Object Tracking, Autonomous Mobile Robot, Distance Control, Range Sensor, Microcontroller.

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1. INTRODUCTION

Navigation strategies are very critical for the mobile robots to move in the unknown environment. Mostly, these are required to guide a mobile robot to a desired location. Therefore, different sensors are utilized to attain the required information about the surroundings. Autonomous mobile robots perform sensing and control operations independently without any human support. The position and relative orientation of the surroundings are crucial for the autonomous robot to navigate correctly. The robot navigation has been investigated and executed in a number of ways, where localization has been an essential element in the whole process.

There has been a problem in justifying the chased object using the sensors. The sensors are used to detect the objects in the surrounding and to locate the position of the objects. From the attained information, movement of the robot is controlled. The amount and type of the sensors are selected according to the complexity and verity of the environment.

The research on the wheeled mobile robots (WMRs) has been studied in detail. The vehicle hardware in the loop method was investigated, where the robot was tested by developing an artificial real traffic road environment.[1] To move faster, the robots should turn over wheels that require low power and simple control operations. A sensor-based accident avoidance system for the vehicles was studied.[2] The information was obtained through the range sensors, and control functions were carried out through the microcontroller.

Different algorithms and methods have been illustrated to avoid collision from the static and dynamic objects.[3,4] Fuzzy logic system (FLS) can be used to improve the performance of the system; however, it requires a high speed controller.[5–7] The main advantage of the FLS is that it helps to represent and implement the human's heuristic knowledge. From simple IF-Then rules, decision can be formulated. Different techniques were reviewed for the sensor fusion in the mobile robot navigation, and different problems were discussed for the navigation.[8] It has been tried to implement the robot by integrating different types of sensors.[9] A sensor-based localization and navigation of

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a mobile robot was provided using ultrasonic sensors.[10] Furthermore, efficient sensor based methods for mobile robot navigation have been studied in detail.[11–14] A collision warning and avoidance system was demonstrated and implemented in which different warning alerts and collision avoidance functions were activated.[12] The warning alerts were made only for the specific distance ranges. The collision warning system (CWS) helped to alert the driver before accident. Likewise, the proposed method helps to avoid collision between vehicles or robots.

In recent years, numerous vision-based applications have been demonstrated. Vision-based methods have been applied in automobiles to avoid accidents and for collision prediction and warning. They have increased the safety by generating a safe braking action and by automatic overtaking system.[15,16] These methods are advantageous because they can identify the object easily. However, they need high computations, and are expensive. Therefore, sensor-based navigation is preferred to make the system cost-effective and to decrease the computational load. Moreover, a collision warning system and a collision avoidance system were demonstrated to decrease traffic accidents and tested with real cars by calculating the time to collision (TTC), which is a well-known parameter in collision warning and collision avoidance systems, and the time gap (TG).[17] The TTC, which is the time would take the vehicles to collide at their current speed, can be calculated by Ref. [18]

$$TTC = \frac{D}{V_t - V_l} \tag{1}$$

where D is the distance between the vehicles, V_t is the speed of the trailing vehicle, and V_l is the speed of the leading vehicle. The time gap (TG), which is the time it would take the trailing vehicle to cover the current distance to the leading vehicle, can be determined by Ref. [17]

$$TG = \frac{D}{V_t} \tag{2}$$

In autonomous mobile robotics, multi-robot system is efficiently becoming mature, because it can often handle difficult tasks.[19] This work also gives an idea to extend it for the multi-robot system. For example, a team of autonomous robots can move from one position to another by tracking an object in a faster and reliable way. A vision-based state estimation method was presented for the autonomous robots, where robots in a team determined their joint position and tracked the autonomous moving objects.[20]

To operate independently and effectively, a robot must be able to autonomously explore its own space. The main purpose of this study is to develop a low-cost mobile robot to track the object smoothly. If a hurdle came in the way, the robot was stopped to avoid collision by keeping a safe distance from the hurdle. The presented method can be used to control the distance between the autonomous mobile robots. As the autonomous mobile robots need collision avoidance system to navigate safely, the proposed method is highly acceptable for ground autonomous robots.

The paper is organized as follows. Introduction and related work are described in Section 1. In Section 2, we will discuss architecture of the autonomous mobile robot and different modes to control the robot navigation. Then, a brief description of the hardware design is presented in Section 3. Section 4 describes the distance control algorithm. Section 5 includes real time experiments and results. Finally, the paper is summarized in Section 6.

2. MOBILE ROBOT NAVIGATION

To track an object, WMRs are efficient for industrial applications. For example, they can carry equipment easily from one place to another by following an object. Therefore, we decided to implement the proposed approach on the wheeled mobile robot. Four wheels were used for the robot vehicle to move precisely in the indoor as well as in the outdoor environment. Two wheels at the front side can be rotated below 45 degrees on both sides, and other wheels can be rotated 360 degrees on both sides.

The system is divided into three sections: sensors, control unit, and motors, as illustrated in Figure 1. Coordination between the main modules is necessary for the robot to function properly. To make the system low cost, three sensors were used to get the surrounding information. The infrared (IR) range sensor can detect an object at a minimum distance of 10 cm and a maximum distance of 80 cm. The ultrasonic sensors helped the robot to get information from the left and right directions. They sent instructions to the motor module directly. The IR range sensor gave guidelines to the control unit, and then speed of the motor was controlled from the distance information. Speed of the

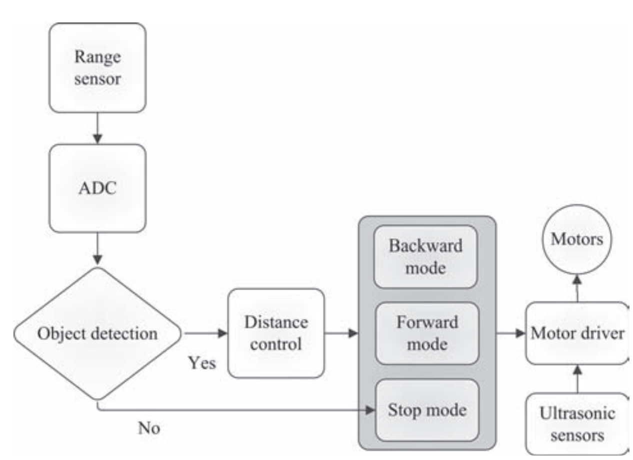

Fig. 1. Object tracking system illustrating the security unit to control the distance between the robot and the object.

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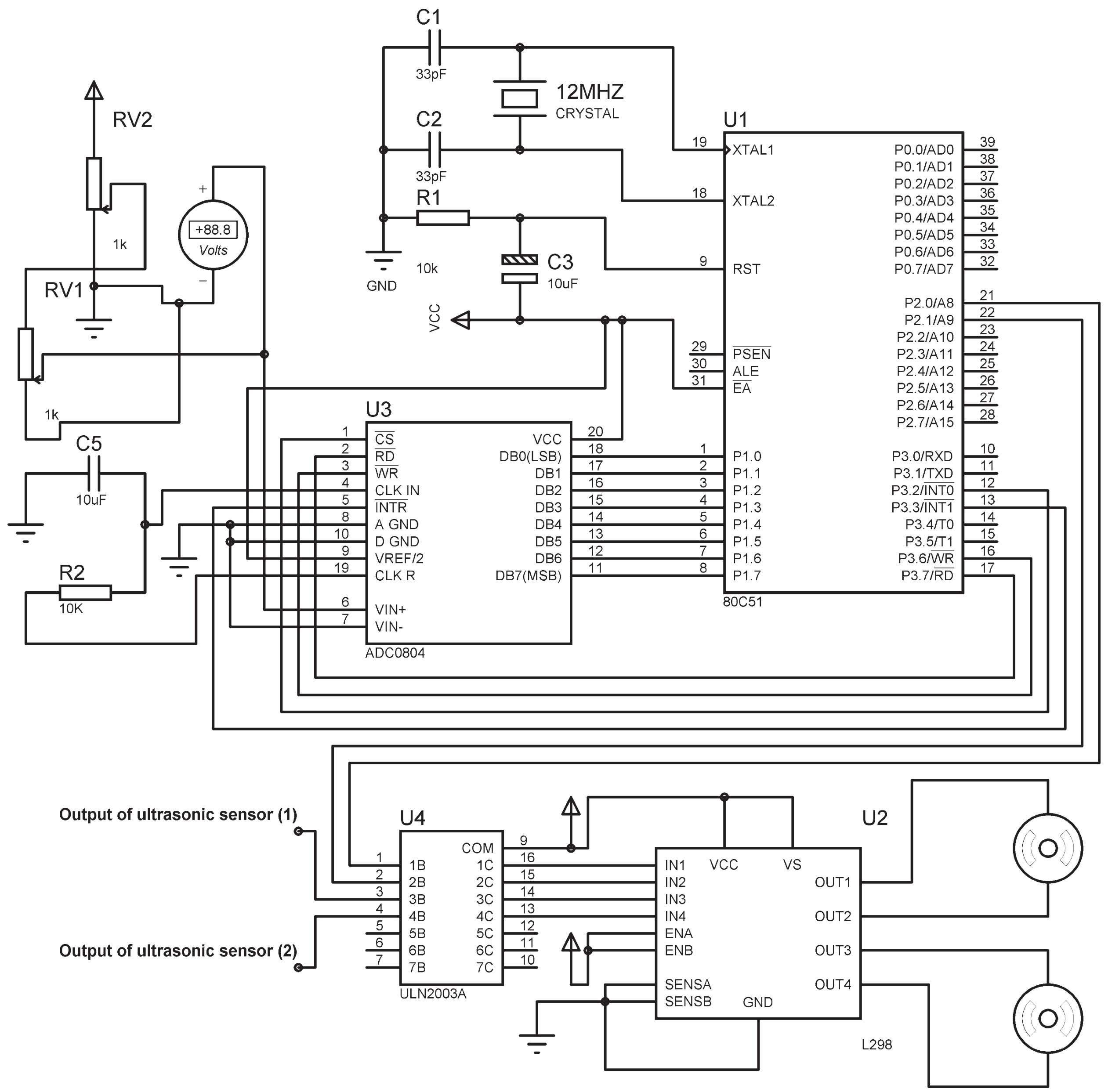

Fig. 2. Schematic of the hardware circuit, which is used to test the range sensors.

robot was changed in each mode, because it was depended on the position of the chased object.

The system had three modes: out of range, stop, and forward/backward, which are described below.

1) ***Out of Range:*** When the object was not detected, the robot activated the out of range mode. If the object remained out of range, the stop function was activated. The control unit waited for the object, and it started to follow the object after the object detection. In this mode, the robot continuously sent signals through the IR range sensor and the ultrasonic sensors to get information about the surroundings.

2) ***Stop:*** In this mode, the control unit maintained the distance between the robot and the object. It was accomplished by calculating the distance between the robot and the object. When the object was at a distance of 30 cm, this mode was activated. When the detected object was motionless, the robot maintained the constant distance from the object.

3) ***Forward/backward:*** From the predefined distance measurements, the speed of the robot was controlled. If the current value from the IR range sensor was higher or lower than 30 cm, the corresponding forward and backward functions were activated. The speed of the robot was incremented and decremented by the instructions from the control unit, where the speed depended upon the distance between the robot and the object. When the object was at far distance, the speed of the robot was high. Likewise,

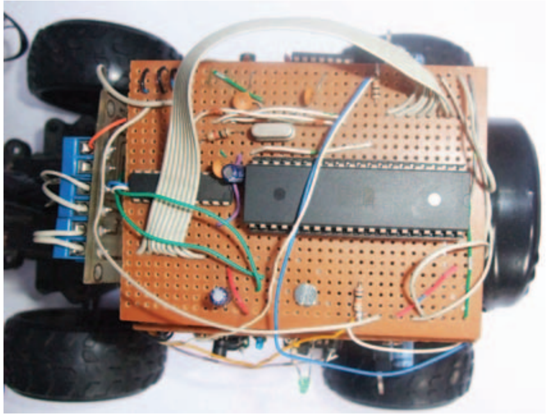

Fig. 3. Hardware design of the microcontroller board.

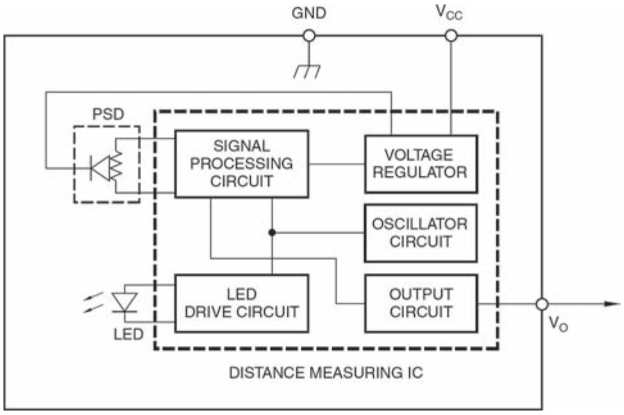

Fig. 4. Block diagram for distance measuring from the IR range sensor.

when the object was at near distance, the speed of the robot was slow. In this mode, the robot moved forward and backward to attain the desired constant distance.

The modes described above are only for the forward and backward motion. Generally, the robot should move leftward and rightward to track the object perfectly. Therefore, we used two ultrasonic sensors for the left and right motion. When the left ultrasonic sensor detected the object, the robot turned left. Similarly, when the right ultrasonic detected the object, the robot turned right. When both ultrasonic sensors detected the object, the robot motion was straight.

3. HARDWARE DESIGN

Circuit diagram, which shows the integration of the ultrasonic sensors, IR range sensor, motor driver, direct current (DC) motors, microcontroller, and analog to digital converter (ADC), is illustrated in Figure 2. While implementing the hardware design, sequential stages were carried out. Proteus™ was used to simulate the hardware design. We developed a controller board using a microcontroller (AT89C51) and an analog to digital converter (ADC0804), as shown in Figure 3. We used on-chip oscillator for the microcontroller and the ADC with the help of crystal oscillator and capacitors.

In the simulation, we used an analog voltage source, which worked same as that of the IR range sensor, and two variable resistances were used to vary the input voltage. Block diagram to measure the distance from the IR range sensor (Sharp™ GP2D12) is shown in Figure 4.[21] The ultrasonic sensor's circuit was designed using a tone decoder (LM567) and hex inverting Schmitt trigger (HEF40106BP), as shown in Figure 5. In the ultrasonic sensor, a sound wave pulse was sent and received after short intervals by using a tone decoder. To change the detection range of the ultrasonic sensor, voltage level from a variable resistance can be changed in real time. When an object came in the range of the ultrasonic sensor, it returned low signal otherwise high. Digital outputs from the microcontroller and the ultrasonic sensors were used to drive the motors, which were interfaced with a motor driver (L298). To make the robot cost-effective, we decided to go for the standard DC motors.

Power is a critical part of the design, because we have to make clear that we are not overloading or providing too little power to any component. To make each main component independent, we used three sets of power supplies: 5 V for the sensors, 9 V for the motor module, and 5 V for the controller board. All components used in the robot were interconnected. If any mechanical part (e.g., motor) failed, the robot was not able to perform the required task. The microcontroller was reprogrammed step by step to make a perfect synchronization between the sensor and the control system.

The robot had two ultrasonic sensors and an IR range sensor. They were mounted on a rectangular sheet at the front side of the robot, as shown in Figure 6. The position of the IR range sensor was at the center, and the ultrasonic sensors were placed on the sides. To detect horizontal movement, the transmitters were places above the receivers. To prevent interference, ultrasonic sensors were located at a distance of 15 cm from each other.

4. DISTANCE CONTROL ALGORITHM

In Table I, we summarize the distance control algorithm, where *A*, *B*, and *C* are the predefined arrays of the hexadecimal numbers. To acquire an array of the hexadecimal numbers, input analog voltages from the variable resistors were changed with a step size of 0.01 V (Fig. 2), and the output digital data was noted at the ADC. As the transmitted signals from the IR range sensor were in the analog form, the ADC was used to convert the analog signals into digital. Each incoming hexadecimal number was compared with the predefined arrays of hexadecimal numbers. If it was found from any array, the respected function was performed for the forward and backward motion. The delay was determined by the current value from the IR range

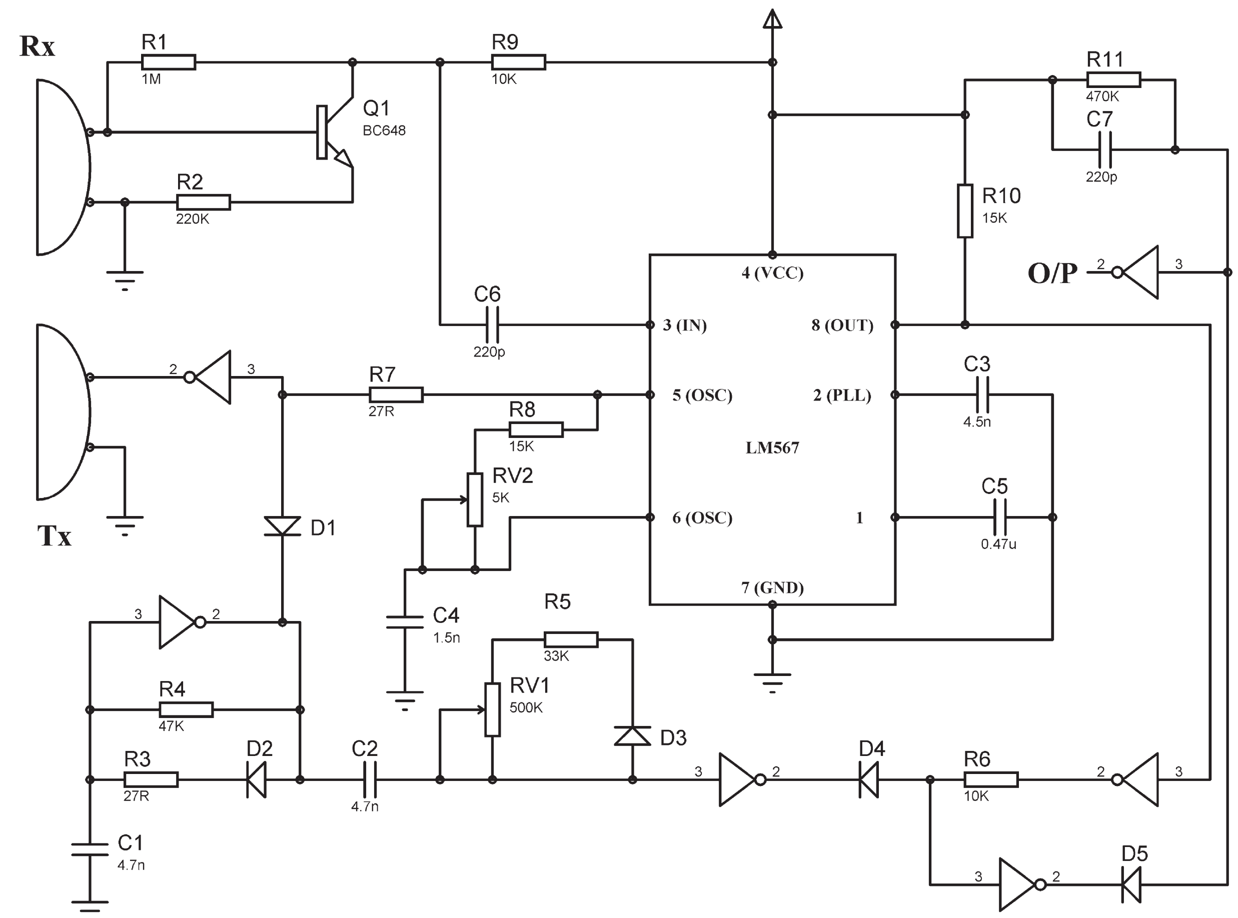

Fig. 5. Circuit diagram illustrating the ultrasonic transmitter and receiver.

sensor. It was used to control the speed of the DC motor. Here, it is noted that the distance control algorithm is only for the IR range sensor. However, the same algorithm can be used for the other sensors. For the current approach, we used only one IR range sensor to implement the algorithm, and two ultrasonic sensors were used for the left and right motion. One of the reasons to use only one IR sensor is that it is costly than that of the ultrasonic sensor.

Table I. Pseudo code for the distance control algorithm.

```
Input = D; // current value from the IR sensor through ADC
Delay = L; // to control the forward and backward motion
Output = M; // command for DC motor to the motor driver

A = [1…n]; B = [1…m]; C = [1…u];// predefined arrays of the
hexadecimal numbers to represent the distance
for ( j = 1…n) // object detection in short range
  if (D = A) do {M = 1, L = (1…A)}
  else do {M = 0} // stop function
for ( j = 1…m) // object detection in medium range
  if (D = B) do {M = −1, L = (1…B)}
  else do {M = 0} //stop function
for ( j = 1…u) // object detection in far range
  If (D = C) do {M = 0, L = (1…C)}
  else do {M = 0} // stop function
```

5. EXPERIMENTS AND RESULTS

All the modules in the robot were well managed and installed properly. We performed different experiments to verify each module independently. Performance of the IR range sensor was verified from the real experiments with different objects. The objects were placed at different positions one by one, and the output analog voltages were measured. A graph was plotted from the obtained data. The plots are distance versus output voltage, as shown in Figure 7. It can be seen that the distance and the output voltages are inversely proportional to each other. The reflection of the IR light depends on the surface of the

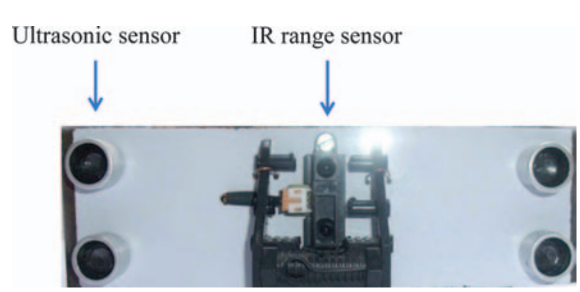

Fig. 6. Front view showing arrangement of the range sensors.

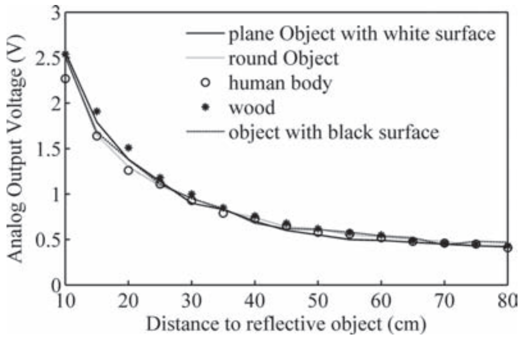

Fig. 7. Experimental outcomes of the IR range sensor with different objects. The plots are distance versus output voltage.

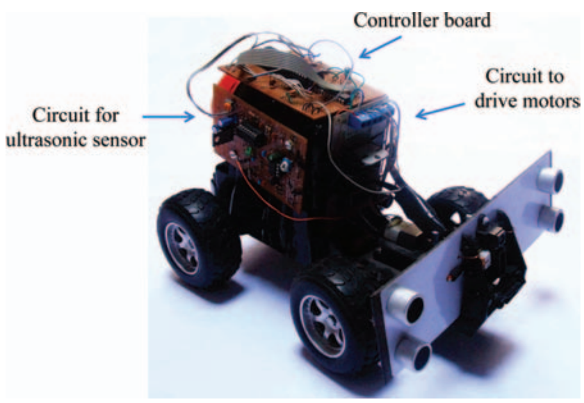

Fig. 8. Experimental prototype vehicle, control system, and sensors.

object. The divergence between the curves was obtained, due to the variation in the reflection. However, the variation was very little. Therefore, the graph shows similar curves. It can also be concluded that the sensor can detect any object with very little variation in the results.

The proposed object tracking system was implemented on the wheeled mobile robot to track the object smoothly. The hardware design of the mobile robot is shown in Figure 8, where the placement of different modules is indicated.

The distance control algorithm described above has been successfully implemented and verified in simulation using C-language and μVision™ software. To verify the distance control approach, the robot was tested in the indoor and outdoor environments. The experimental tests were carried out by moving different vehicles and objects in front of the robot. In an experiment, an object was placed in the front side of the robot. The robot successfully detected the object, and determined the distance from the object. After that, the robot activated the required mode and maintained the constant distance from the object, as shown in Fig. 9. Similarly, different objects were placed at different positions one by one, and the results were noted. In an experiment, an object was moved in the front side of the robot. In Figure 10(a), the object started to move in the forward direction, and the robot maintained the constant

Fig. 9. Experimental environment showing how the robot maintained the constant distance from the object.

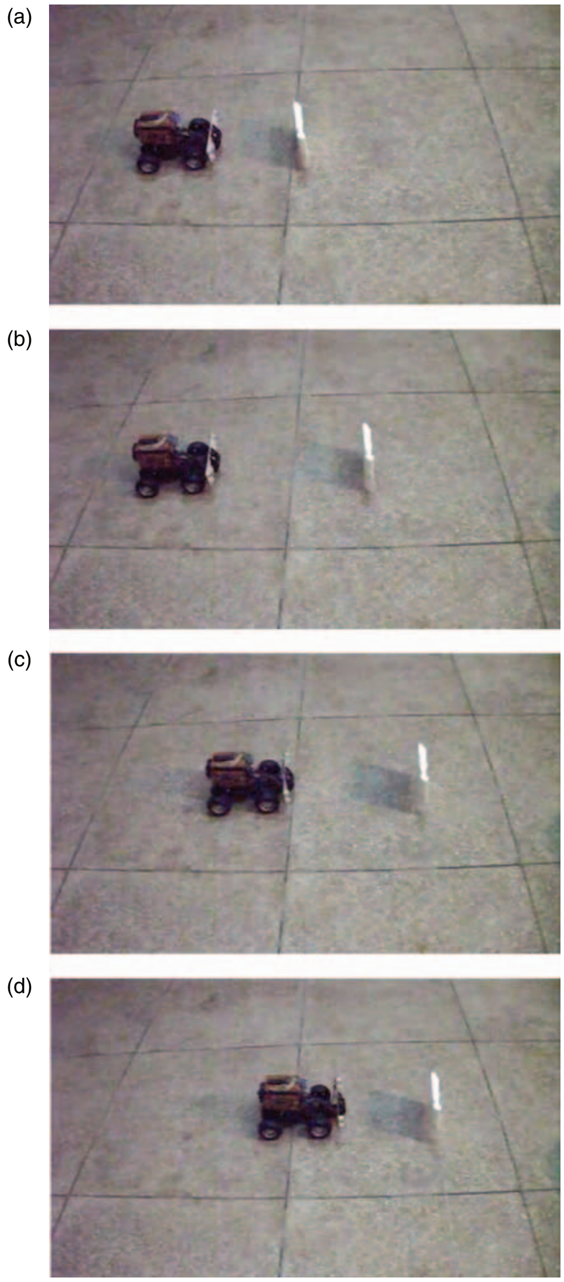

Fig. 10. Indoor tracking experiment: (a)–(d) the robot guarantees to keep a safe distance from the object.

Fig. 11. Object tracking experiment with convex and concave obstacles.

distance from the object. In Figures 10(b) and 10(c), the robot followed the object and tried to achieve the desired constant distance. In Figure 10(d), the object was stopped, and the robot maintained the constant distance from the object.

To verify the tracking system, an object was moved in the front side of the robot. When the object was detected only through the IR range sensor, the robot motion was forward and backward. When the object was detected through the IR range sensor and the ultrasonic sensors, the robot was able to track the object in forward, backward, left, and right directions. In another experiment, an object was moved in the forward direction, and the robot chased the object very accurately by maintaining a constant distance from the object, as shown in Figure 11. The results have shown that the robot maintained a distance of 30 cm behind the chased object. Furthermore, different objects were also moved one by one, and the robot maintained its goal without collision. The robot achieved the same speed as that of the followed object. Overall, the robot gave acceptable results in all situations. The results were very realistic, and we were able to move the robot during hours of tests.

Finally, we conclude that that there can be four complex situations in the object tracking. In the first situation, if the control unit detected an object with very high speed, which was beyond the limit, at the front side, it was disappeared after some interval. Therefore, it was considered out of range, and the stop function was performed. In the second situation, if the control unit detected an object with very high speed, which was beyond the limit, in the backward direction, there might be a collision. In the third situation, if the object took a turn more than 45 degrees in the left or right direction, which was beyond the turning angle for the robot, the object was considered out of range. In the fourth situation, when multi objects were detected, it was difficult for the robot to handle the situation. As the mobile robot can not recognize the chased object, it only tracks the detected object.

We tried to handle these situations in efficient ways. To handle the first and second situation, two modes in the proposed algorithm were defined. The speed of the robot was normal in the normal mode, and the high speed mode was activated immediately to attain the speed same as to the object's speed. However, if the speed of the object was beyond the limit, the object was considered out of range. A well-defined efficient motor control algorithm can be utilized to handle the third situation. The fourth situation can be overcome by installing a separate control unit to identify the tracked object. As a result, when multi objects will be detected, the robot will be commanded to follow the targeted object.

6. CONCLUSIONS

In this study, we have presented automatic distance control system for an autonomous mobile robot. The robot tracks the moving object with a specific speed, depending on the speed of the chased object. The control unit varies the speed of the robot according to the situation to avoid an accident. The efficiency of the robot has been improved by increasing smoothness in motion and by controlling the motion of the robot using distance control approach. To validate the planned approach, the system has been tested in the real environment with still and moving objects. Different objects were moved one by one, and the robot followed the object correctly. The robot successfully maintained a constant distance of 30 cm from the object in various situations.

Future work will focus on the high speed and long range sensors to improve performance of the robot. To achieve better results, a well-defined sensors architecture and improved version of the distance control system will be explored. To maintain smooth speed variation of the robot, the speed of the tracked object will be determined perfectly. Furthermore, we will explore a security system, which would be helpful in the automobile accident avoidance and overtaking. Currently, research is concentrating on multi-robot system. This work can be extended to multi-robot system, where a group of robots will follow the object with collision reduction. Each robot will move by maintain a constant distance from the other robot. The robots in the group will be moved in different shapes (e.g., cube, star, straight line, and so forth).

References

1. J. Ploeg, H. E. Schouten, and H. Nijmeijer, Position control of a wheeled mobile robot including tire behavior. *IEEE Transactions on Intelligent Transportation Systems* 10, 523 **(2009)**.
2. I. Ullah, F. Ullah, and Q. Ullah, A sensor based robotic model for vehicle collision reduction, *Proceedings of the IEEE International Conference on Computer Networks and Information Technology*, July **(2011)**, Abbottabad, Pakistan.
3. C. Cai, C. Yang, Q. Zhu, and Y. Liang, Collision avoidance in multi-robot systems, *Proceedings of the International Conference on Mechatronics and Automation*, August **(2007)**, Harbin, China.
4. W. Chung, S. Kim, M. Choi, J. Choi, H. Kim, C. Moon, and J. Song, Safe navigation of a mobile robot considering visibility of environment. *IEEE Transactions on Industrial Electronics*, 56, 3941 **(2009)**.
5. I. Ullah, F. Ullah, and Q. Ullah, Real-time object following fuzzy controller for a mobile robot, *Proceedings of the IEEE International Conference on Computer Networks and Information Technology*, July **(2011)**, Abbottabad, Pakistan.

6. T. Das, and I. N. Kar, Design and implementation of an adaptive fuzzy logic-based controller for wheeled mobile robots. *IEEE Transactions on Control Systems Technology*, 14, 501 (**2006**).
7. G. Antonelli, S. Chiaverini, and G. Fusco, A fuzzy-logic-based approach for mobile robot path tracking. *IEEE Transactions on Fuzzy Systems*, 15, 211 (**2007**).
8. M. Kam, X. Zhu, and P. Kalata, Sensor fusion for mobile robot navigation, *Proceedings of the IEEE*, vol. 85 (**1997**) pp. 108–119.
9. S. G. Tzafestas, Integrated sensor-based intelligent robot system. *IEEE Control Systems Magazine*, 8, 61 (**1988**).
10. I. A. R. Ashokaraj, P. M. G. Silson, A. Tsourdos, and B. A. White, Robust sensor-based navigation for mobile robots. *IEEE Transactions on Instrumentation and Measurement*, 58, 551 (**2009**).
11. I. Ullah, F. Ullah, Q. Ullah, and S. Shin, Object following fuzzy controller for a mobile robot. *Journal of Computational Intelligence and Electronic Systems*, 1 (**2012**).
12. I. Ullah, F. Ullah, Q. Ullah, and S. Shin, Sensor-based robotic model for vehicle accident avoidance. *Journal of Computational Intelligence and Electronic Systems*, 1 (**2012**).
13. I. Ullah, Q. Ullah, F. Ullah, and S. Shin, Mobile robot navigation with distance control, *Proceedings of the IEEE International Conference on Robotics and Artificial Intelligence (ICRAI)*, October (**2012**), Rawalpindi, Pakistan.
14. I. Ullah, Q. Ullah, F. Ullah, and S. Shin, Integrated collision avoidance and tracking system for mobile robot, *Proceedings of the IEEE International Conference on Robotics and Artificial Intelligence (ICRAI)*, October (**2012**) Rawalpindi, Pakistan.
15. V. Milanés, D. F. Llorca, J. Villagrá, J. Pérez, I. Parra, C. González, and M. A. Sotelo, Vision-based active safety system for automatic stopping. *Expert Systems with Applications*, 39, 11234 (**2012**).
16. V. Milanés, D. F. Llorca, J. Villagrá, J. Pérez, C. Fernández, I. Parra, C. González, and M. A. Sotelo, Intelligent automatic overtaking system using vision for vehicle detection. *Expert Systems with Applications*, 39, 3362 (**2012**).
17. V. Milanés, J. Pérez, J. Godoy, and E. Onieva, A fuzzy aid rear-end collision warning/avoidance system. *Expert Systems with Applications*, 39, 9097 (**2012**).
18. S. Moon, I. Moon, and K. Yi, Design, tuning, and evaluation of a full-range adaptive cruise control system with collision avoidance. *Control Engineering Practice*, 17, 442 (**2009**).
19. T. Arai, E. Pagello, and L. E. Parker, Guest editorial advances in multirobot systems. *IEEE Transactions on Robotics and Automation*, 18, 655 (**2002**).
20. T. Schmitt, R. Hanek, S. Buck, and M. Beetz, Cooperative probabilistic state estimation for vision-based autonomous mobile robots, *Proceedings of 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems*, October-November (**2001**), 2001, Maui, U.S.
21. SHARP™, GP2D12 Datasheet. http://www.sharpsma.com/webfm_send/1203.

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