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LOW COST COLLISION AVOIDANCE SYSTEM ON HOLONOMIC AND NON- HOLONOMIC MOBILE ROBOTS

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Abstract

Technological advancement in industries necessitates development in autonomous mobile robots with obstacle avoidance for applications in industries, hospitals and educational environment. Holonomic motion allows the mobile robots to move instantaneously in any direction with no constraints while non-holonomic motion restricts the motion in limited directions. This study presents the comparison of obstacle avoidance performance using low cost sensors on holonomic and non-holonomic mobile robots. The robot prototypes are developed and implemented with stable control system for better mobility. Experimental results show that the omnidirectional mobile robots avoid collisions with limited space and less time while non-holonomic mobile platforms exhibits reduced computational complexity and efficient implementation. The developed mobile robots can be used for diverse task specification applications.

Keywords

Obstacle Avoidance, Multi-Ultrasonic Sensor Fusion, Navigation, Mobile Robots

1. Introduction

Advancement in technology demands constant development of robotic applications in industries, service and educational sectors. Most of the developed mobile robots in the market perform autonomous navigation with holonomic or non-holonomic motion. In addition, the mobile robots detect obstacles and avoid it during motion. Thus, efficiency of obstacle avoidance system and the nature of motion of the mobile robots are major consideration in development of mobile robots for various applications.

Asimo (IEEE Spectrum: Technology, Engineering, and Science News, 2018) is a humanoid robot developed by Honda with bipedal walking technology for motion. Even though, there are researches (Azeta et al., 2018, Choudhury et al., 2018, Ito et al., 2018, Xiang et al., 2015) focusing on the development of the mobility replicating human motion, humanoid robots with omni wheels provide efficient mobility. Pepper robot (Pandey & Gelin, 2018) is a humanoid designed and developed with omni wheels for motion. In addition, there are recent researches that focus on holonomic and non-holonomic motion. Autonomous mobile robots are developed with omni wheels (Ignatiev et al., 2016) to achieve high maneuverability over standard wheels while a motion tracking control design for non-holonomic wheeled mobile robots is proposed (Fu et al., 2018) to autonomously move with high speed.

Researches focusing on obstacle avoidance for autonomous nature of mobile robots perform stabilized motion with appropriate control system. Most of the obstacles are static which allows a mobile robot to detect obstacles with good accuracy. Researches focus on low cost vision sensors (Feng & Feng, 2017, Zhang et al., 2018) and multi ultrasonic sensors (Chen et al., 2018, Kuo et al., 2018, Moussa et al., 2018). In a recent research study, low cost sensors including sonars, laser range finder and vision cameras are integrated (Pu et al, 2018) to generate efficient sensor network. However, the performance of vision sensors is limited in terms of illumination, lighting conditions and colours of the obstacles comparing to ultrasonic sensors in unknown environment.

Researches (Ramasamy et al., 2016, Zhou et al., 2018) focus on combination of different low cost sensors on various environments for precise obstacle detection system. The researches related to navigation and obstacle detection focus on different aspects of requirement including accuracy, precision, computation complexity and space limitations for different applications and thus require an effective guideline for selection. However, advanced researches (Babayemi, 2017, Haryoko & Jaya, 2018, Imagawa et al., 2017, Phyoe et al., 2015) use technology as a reliable solution for diverse applications.

2. Development of the Hardware Platform

The research study uses mobile robot with omni wheels for holonomic motion and mobile robot with standard wheels for non-holonomic motion. However, both robots use the same power input, control system and low cost sensor system implementation.

2.1 Development of the Mobile Robot with Holonomic Motion

The robot is holonomic when controllable degree of freedom of a mobile robot is similar to the total degree of freedom of a mobile robot. This can be achieved by the use of omni wheels, castor wheels or Mecanum wheels which allows motion in any direction without any constraints. A mobile robot with four omni wheel is designed as in Figure 1.

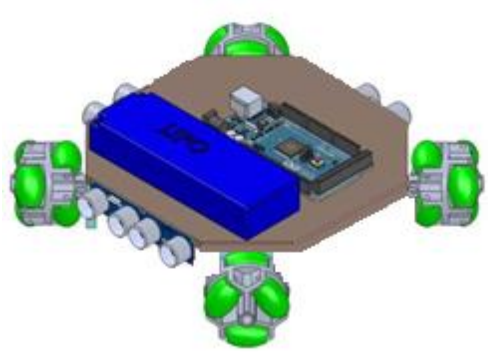

Figure 1: *3D CAD Design of the Mobile Robot with Omni Wheels*

The robot uses four 12V DC motors with 64 counts per revolution quadrature encoder. The motors are controlled using two L298N Dual H Bridge motor drivers. The robot uses a 12V Li-ion rechargeable battery with 6800mAh and a Bluetooth module for data transmission. The mobile robot uses Arduino controller and ultrasonic sensors for obstacle detection. The developed mobile robot as shown in Figure 2 is light, simple in construction and has the ability to navigate with ease.

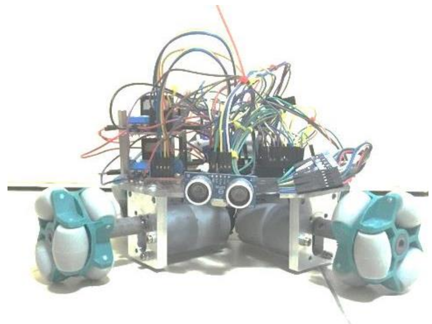

Figure 2: *Developed Mobile Robot with Omni Wheels*

2.2 Development of the Mobile Robot with Non-Holonomic Motion

When controllable degree of freedom of a mobile robot is less than the total degree of freedom of a mobile robot, the robot has non-holonomic motion. Use of standard wheels allows motion in position axis and orientation. However, motion perpendicular to the direction of motion is restricted. Thus, the robot has constraints of motion during navigation. The designed mobile robot is shown in Figure 3.

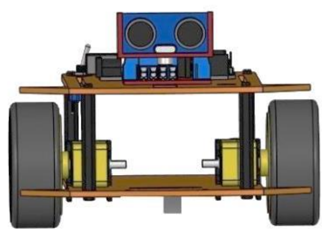

Figure 3: *3D CAD Design of the Mobile Robot with Standard Wheels*

The robot uses two DC motors attached to two standard wheels. In addition, a castor wheel is attached for balance and has independent movement. Optical encoders are attached to the system for robust controlling of the motors and the motors are controlled using L298N Dual H Bridge motor driver. The robot uses a 12V Li-ion rechargeable battery with 6800mAh and a Bluetooth module for data transmission. The mobile robot uses Arduino controller and ultrasonic sensors for obstacle detection. The developed mobile robot as in Figure 4 is light, simple in construction and moves steadily in indoor environments.

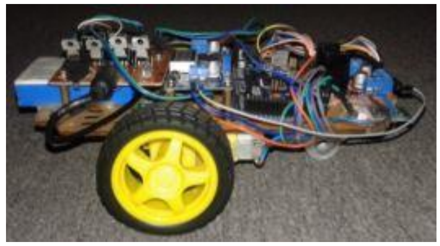

Figure 4: *Developed Mobile Robot with Standard Wheels and a Castor*

3. Development of the Control System Platform

Intelligent control system is required for mobile robots for efficient operations to avoid uncertainties and non-linear performance. Proportional-Integral-Derivative (PID) control strategy is currently implemented in various industrial applications and innovative technological approaches due to fast computation and simple implementation. The developed mobile robots can be stabilized with a simple PI controller since the vibration is negligible in the system. However PID controller is adapted for precise control system.

Signal generated from proportional, integral and derivative actions of error signal e(t) is combined with the control signal u(t) as in the architecture given in Equation (1).

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \quad (1)$$

The encoders from both the mobile robots provide required data to find the difference between the current value and the selected set point which corresponds to the proportional component (K_p) whereas the integral component (K_i) measures the time taken for corrective action using the timer inbuilt in Arduino. The derivative component (K_d) responds to the rate of change of error. This control algorithm is easy to implement with minimum resources and provides robust tuning.

Autonomous mobility of a mobile robot requires collision avoidance system during navigation to avoid obstacles without any external controls. Low cost sensors such as ultrasonic sensors, infrared sensors and Sharp infrared sensors and precise sensors including camera and laser sensors are used in robotics applications for obstacle avoidance. The developed mobile robots use ultrasonic sensors due to availability, accuracy requirement and cost consideration. In addition, the results from these sensors are not affected by lighting conditions and dust comparing to infrared sensors. The sensors emit acoustic wave with a frequency higher than human audible range, which produces an echo if there is an obstacle as shown in Figure 5.

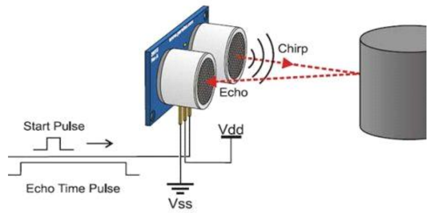

Figure 5: *Working Principle of Ultrasonic Sensor*

The mobile robot is programmed using Arduino to perform forward movement. If an obstacle is found in the forward direction, the mobile robot will choose a forward left or forward right direction depending on the available space for motion. The proposed mobility algorithm with obstacle avoidance is shown in Figure 6.

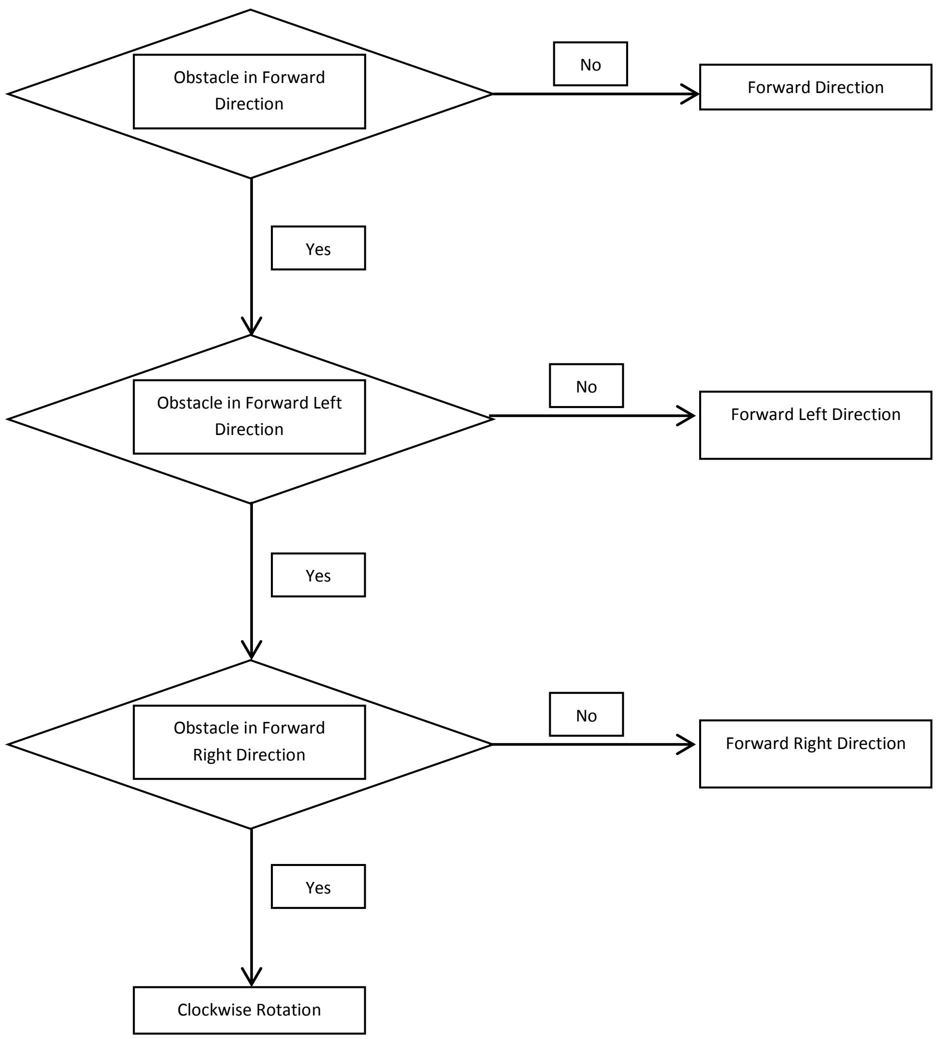

Figure 6: *Proposed Obstacle Avoidance Algorithm*

In addition, since the ultrasonic sensor uses air as the medium to transfer the acoustic wave, the following Equation (2) is used in the algorithm to find the distance between the obstacle and the robot.

$$Range = \frac{High\ Level\ Time \times Velocity\ of\ Sound\ in\ Air\ (340ms^{-1})}{2} \quad (2)$$

4. Results and Discussion

The encoders are aligned on the chassis considering the leading between the channels as shown in Figure 7. The aligned encoders are used to calculate the angular velocity for performance precision.

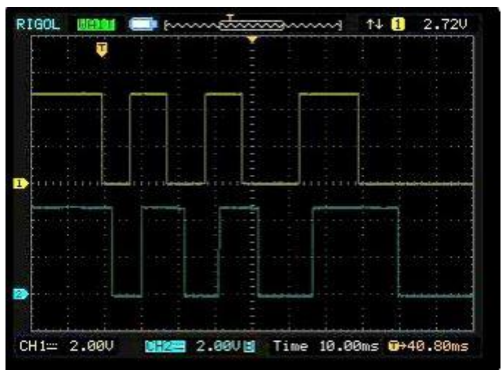

Figure 7: *Square Wave of the Encoder using Digital Oscilloscope*

PID controller is successfully implemented on both the mobile robots using manual tuning. The required system response is achieved as shown in Figure 8, and the values are adjusted to understand the relationship of speed of response, accuracy and stability variations in terms of proportional, integral and derivative gain as shown in Table 1.

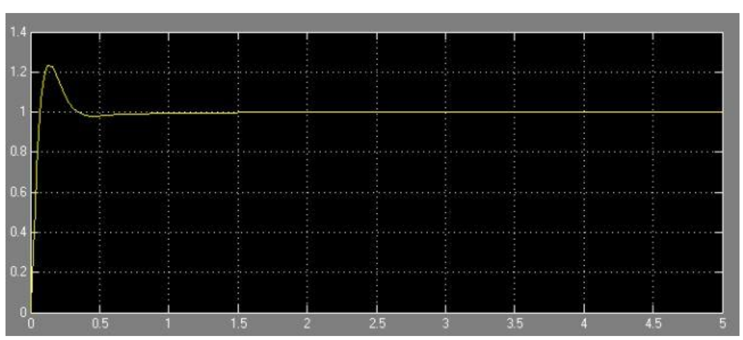

Figure 8: *Simulink Simulated required PID System Response*

Table 1: *Variation of factors based on Gain of PID*

Increase in Parameters	Speed of Response	Accuracy	Stability
K_p	Increases	Improves	Deteriorates
K_i	Decreases	Improves	Deteriorates
K_d	Increases	No Effect	Improves

The nature of mobility of the developed robots is different due to non-holonomic constraints. Thus, the proposed algorithm is modified to meet the requirements accordingly. Mobile robot with omni wheels is allowed to move in forward direction and when an obstacle is detected, respective diagonal motion is performed to avoid the obstacle. However, diagonal motion is restricted in non-holonomic mobile robot. Thus, the robot performs an additional motion to choose another orientation. This consumes time during collision avoidance. Even though, sensor implementation and sensor fusion technique applications can improve the system of non-holonomic mobile robot, the improvement is applied to the obstacle detection system and does not affect the navigation. Table 2 shows the experimental results of the developed mobile robots with respect to time taken for obstacle detection, time taken for collision avoidance, accuracy of the system, computation complexity, space taken and precision.

Table 2: *Experimental Results of Developed Mobile Robots*

Mobile Robot	Time Taken for Obstacle Detection	Time Taken for Collision Avoidance	Accuracy	Computational Complexity	Space Taken	Precision
Holonomic	Same	Low	Same	High	Low	Low
Non-Holonomic	Same	High	Same	Low	High	High

Even though, most of the recently developed industrial and service mobile robots are non-holonomic, it is clear that the efficiency of the holonomic mobile platform is high. The time taken for both holonomic and non-holonomic mobile robots are the same and thus, there is no influence of navigation method on obstacle detection. However, the time taken for obstacle avoidance is higher with non-holonomic mobile robots due to motion constraints. The platform development is expensive and the system is computationally complex in holonomic mobile robot. Nevertheless, holonomic mobile robot outperforms non-holonomic mobile robot for applications with high efficiency requirements in limited space.

5. Conclusion

The developed mobile robot with omni wheels exhibits holonomic motion with no constraints while the developed mobile robot with standard wheels and a castor wheel shows non-holonomic motion with constraints. Obstacle avoidance system implemented on the mobile robots conclude that for applications with consideration to space and time taken for collision avoidance, holonomic mobile robot outperforms non-holonomic mobile robot while for applications with consideration to precision and less computation complexity, mobile robot with standard wheels are ideal. This research study, even though only focuses on two types of wheels from each category, various other wheels including Mecanum wheels and expensive omniwheels can be used for comparison study. Further, the developed mobile robots can be used as the basic navigation platform for diverse future applications of robotics including communication, education and health-care.

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