NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 2, ISSUE 6, JUNE-2015

DESIGN OF A DIFFERENTIAL DRIVE MOBILE ROBOT PLATFORM FOR USE IN CONSTRAINED ENVIRONMENTS

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ABSTRACT

Mobile robotics is a growing trend in recent years as mobile robots are being used in service as well as industrial sectors. This paper introduces a novel design of a mobile robot platform for use in constrained workplaces. The constrained environments are nothing but congested places, for example hospitals, ware houses, offices, shop floors where various equipments and machineries are to be arranged in small areas. For robots mobility in such places, various methods are being used such as differential drive system, Omni-directional mobility etc. This paper presents the design of mobile robotic platform with application of the differential drive system for enhancing mobility of the robotic platform. The 3-D Model of mobile robot is prepared in CAD software CATIA V5R19. The shape of the robot is selected as rectangular, with two driving wheels and two caster wheels. The driving wheels are located at the front side of the robot, which helps the robot to drive on to the slope. Two caster wheels are attached at the back side of the robot for stability purpose. In this robotic platform, the two driving wheels are driven by using independent motors, for forward, backward as well as rotational motion. This designed and developed robotic platform has the capability to implement algorithms for path planning, path control, dynamic steering, obstacle avoidance, position control, image recognition etc.

KEY WORDS: Differential Drive System, DC Motor, Modeling, Wheeled Mobile Robots.

INTRODUCTION

Due to the advances in the technology, the mobile robotics is very rapidly developing. As a result of which this field has attracted the attention of many researches, industries, universities and many government organizations for the scope of developments. Currently, the use of robotic system in various applications is become very familiar and interesting. The uses of robots in various applications make the things easier for humans. Help of robots to the humans, according to their requirement, indicates that in near future, the use of mobile robots will surely increase. The mobile robotic platforms available in market for research purposes are very few in numbers. On such platforms, the different researches can apply their ideas. However, for many researchers, purchasing a new robot for different applications is not a realistic alternative. The robots may be used for service or industrial purposes but due to lack of available space, working environments are becoming constrained now days. Hence, this study will present a design of a mobile robotic platform which will be multitasking and available for many researchers to implement their ideas such as path planning, path control, dynamic steering, obstacle avoidance, position control, image recognition etc. Hence also, one of the motives behind the work presented in this paper is to design a mobile robot platform which could be use in constrained environments such as hospitals, factories, and offices etc where many types of equipment are placed in small area.

Nowadays challenging problem in robotics is to design of a mobile robot which can successfully move around its environment with obstacle avoidance. The wheels of the mobile robot must have good traction and continuous contact with the ground for good positioning. For improved maneuverability in constrained environments the robot must also be able to rotate around a center of mass. This also minimizes the energy required for turning. All of these factors need to be considered during designing of a mobile robot.

The flow of this paper is as follows: Section 2 of this paper presents literature review, which reveals the study of existing work in the robotics field and also gives the existing architectural designs of the mobile robot platforms. It also gives background about the Omni-directional movement using Omni-wheels and Mecanum wheels, which are having some advantages as well as disadvantages over traditional wheels. Literature review reveals that differential drive method can be used for locomotion in congested places. Section 3 highlights the detailed design of the mobile robot platform. Also this chapter reveals the various types of wheels and wheel configurations used for locomotion in constrained environments. The Section 4 will provides the kinematic analysis of the differential drive mobile robots. In Section 5 the experimental results are presented and Section 6 gives conclusions and future scope of this work.

LITERATURE REVIEW

This section presents the detailed literature review of the existing mobile robot platforms, wheel configuration, method for mobility etc. The mobility of a mobile robot in constrained environments such as hospitals, ware houses, offices can be achieved by two means; one is by using Omni-directional mobility and by using Differential drive system [1],[5]. Omni-directional mobility can be again achieved by two ways i.e. by using Omni-wheels (Three wheeled structure) [2],[3] or by using Mecanum wheels (Four wheeled structure) [4]. Wen-June Wang and Jun-Wei Chang (2012) presented a robotic platform by using three Omni- wheels arranged at an angle of 120^0. F. Cuellar (2006) presented the design and analysis of the three wheeled mobile robot by using Omni- wheels. Kinematic model of the robotic platform was also presented in his work. M. O. Tatar *et al* (2014) presented the design and development of four Mecanum wheeled mobile robot with kinematic model. P. Petrov (2010) proposed a dynamic model of the differentially steered mobile robot. F. A. Salem (2013) presented the dynamic and kinematic analysis of the differentially steered mobile robot. He also introduced the mathematical models of the Permanent Magnet DC (PMDC) Motor, and the tachometer. The simulation of the overall system was performed in MATLAB/Simulink and presented.

From the literature review a circular frame with driving wheel axle moving along diameter, and having two supporting casters on front and back side was also considered for designing which has some advantages as well as some disadvantages. Advantage is that it will allow the robot to rotate around its true center. Disadvantage is that it would have difficulty when moving from a flat surface onto a slope. Based on the literature review and workplace survey it was decided to build a rectangular frame for the robotic platform. This allows easier positioning and accessibility of parts within the robot. The mobility of a robot can be achieved by using a differential-drive system in which the two motors are driven and controlled independently for forward, backward, and rotational movement. Also these driving two motors or wheels are located at the front of the robot which helps the robot to move easily onto a slope. Two caster wheels are attached at the back of the robot for the support.

DESIGN OF A MOBILE ROBOT

Any mechanical design is a creative activity in which the designer satisfies the customers need. For a given customers requirement, the designer analyses and thinks on various aspects and may design product something differently, which shows that design process is unique activity and does not involve any predefined approach or methodology. The design of a mobile robot is influenced by many factors, such as: weight of the robot, wheel configuration, type of wheels, material of the wheels, and environment in which robot is to be moved. The mobile robot design starts with identifying the working environment and components or parts of the robot.

Before designing any system need of the part is prime thing. To determine the need of the customer or user a workplace survey must be done. In case of robot platform design to use in constrained environment a workplace survey of congested places is to be carried out. The constrained environment to be considered for this work is hospital ward, where beds and various equipments are arranged in a small area. Survey of various hospitals is done to know the actual placement and measurements of the equipments, a layout of this working environment is prepared and shown in Figure 1.

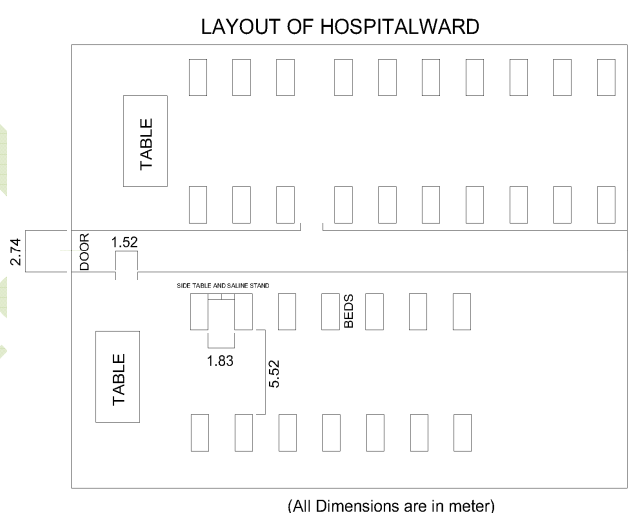

Figure 1: Layout of Hospital Ward

Based on the literature review and workplace survey it was decided to build a mobile robot by using differential steering system. The block diagram of the various hardware parts used in robot is shown in Figure 2.

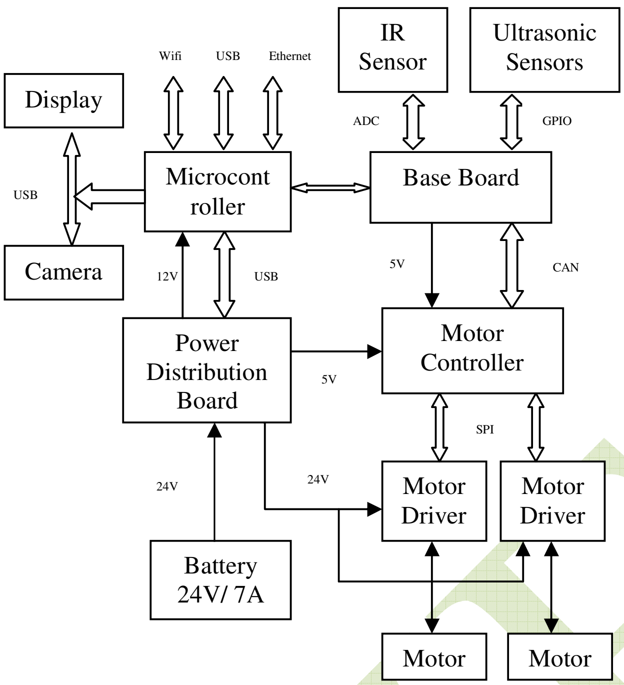

Figure 2: Block diagram of Hardware

A. CAD Model of Robot Platform

The design of a mobile robot is done in CAD software CATIA V5R19. The 3D model gives the details of fits and functionality of each and every component. The differential drive mobile robot consists of two wheels, two DC motors, transmission system with gear 3:1 gear reduction ratio, two caster wheels, a microcontroller, power distribution board, motor controller unit etc. The two driving wheels on the front side are equipped with separate DC motors and two rear caster wheels are used for the stability. The arrangement of wheels is shown in Figure 3.

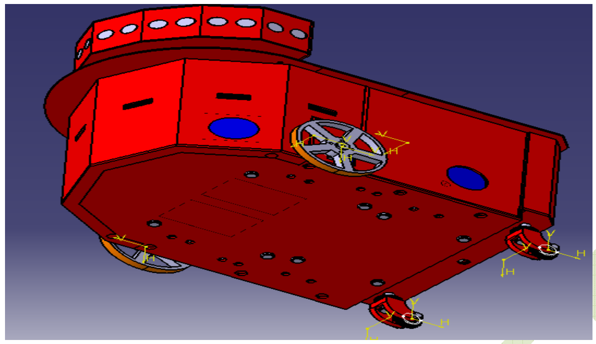

Figure 3: Wheel configuration of the Robot.

The caster wheels designed and used in this robot are having spring which acts as a suspension system.

The overall specifications of the robot are shown in Table 1.

Table 1: Specifications of Robot

Characteristics	Quantity
Weight	13 Kg
Height	305 mm
Width	305 mm
Length	455 mm
Wheel diameter	100 mm

The robot is also equipped with six Infrared Sensors and eight ultrasonic sensors for obstacle avoidance. Display unit, USB port is also provided in this platform for the various other applications such as mounting camera. The sensor mounting is shown in the front view of the robot and given by Figure 4.

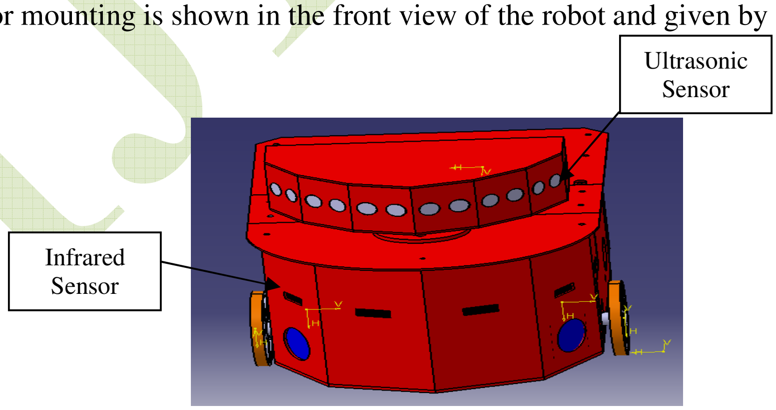

Figure 4: Front view of the Robot.

B. Electronic System

The architecture of electronic system is illustrated in Figure 2. The system consists of Atom PC as a microcontroller which can operate on Windows operating system. The robot is powered by using 24V/7A battery which is connected to power distribution board which acts a power management unit. The power distribution board supplies power to all the robot components and it has 3.3V, 5V and 12V output channels. The main control board for motion control used in this robot is Hydra.

Currently 8 ultrasonic sensor and 6 IR sensors are connected to the board. Hydra also sends command to the DC motor control board (Cheetah-CB). Cheetah-CB is the motor controller board which accepts command from the Hydra for both the motors and sets the speed for both the motors accordingly. It also takes feedback from encoders which is connected to the motor shaft and achieves the desired speed and accuracy. The DC motor used in this robot is a Pittman GM8224D201-R2. It has maximum speed of 170 RPM. The gear ratio of motor is 19.5:1 where as transmission ratio is 3:1 between motor and wheel shaft.

The ultrasonic sensor is used for detecting the obstacle and measuring the distance between two objects. This ultrasonic sensor operates on 5V supply and uses GPIO interface. Six sharp IR sensors-GP2Y0A21YK0F with measuring range 10 to 80 cm are also used for obstacle detection. This sensor uses ADC interface.

KINEMATIC ANALYSIS

Kinematics is the study of the mathematics of motion without considering the forces that affect the motion. It gives a relationship between the control parameters and, the behavior of a system in the space, in other way it represents the relationship between postures and the velocities of the non-holonomic wheeled mobile robot. The model of the robot is shown in Figure 5. In this model, the friction, inertia, and mechanical structure inaccuracies are neglected. Assume the angular orientation or direction of the wheel defined by an angle θ.

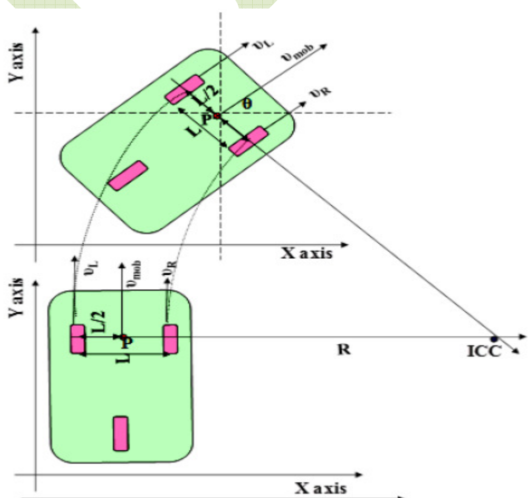

Figure 5: Differential Drive Motion.

The kinematic equations for the differential drive mobile robot in world frame are given as:

where,

$V_R(t)$ = linear velocity of right wheel,

$V_L(t)$ = linear velocity of left wheel,

$\omega_R(t)$ = Angular velocity of right wheel,

$\omega_L(t)$ = Angular velocity of left wheel,

r = Nominal radius of each wheel,

L = Distance between the two wheels,

R = Instantaneous curvature radius of the robot trajectory, relative to the mid-point axis,

ICC = Instantaneous Center of Curvature,

$(R - L/2)$ = Curvature radius of trajectory described by right wheel,

$(R + L/2)$ = Curvature radius of trajectory described by left wheel.

The Instantaneous Center of Curvature (ICC) is the point around which the robot must rotate, to avoid slippage and have only a pure rolling motion, ICC lies on the common axis of the two driving wheels. In case of differential drive, by changing the velocities V_L and V_R of the left and right wheels, the ICC of rotation will move and different trajectories will be followed, but at every time left and right wheels, moves around the ICC with the same angular speed rate ω_{mob}.

$$\omega_{mob} = V_{mob} / R \quad 1)$$

With respect to the ICC, the angular velocity of the robot is given as:

$$\omega_{mob} = \frac{V_R}{(R - \frac{L}{2})} \quad (2)$$

$$\omega_{mob} = \frac{V_L}{(R + \frac{L}{2})} \quad (3)$$

$$\omega_{mob} = \frac{V_R - V_L}{L} \quad (4)$$

The instantaneous curvature radius of the robot trajectory (R) relative to the mid-point axis is given by:

$$R = \frac{V_R + V_L}{V_R - V_L} * \frac{L}{2} \quad (5)$$

The above equations can also be represented in the following form:

$$\begin{bmatrix} Vx(\mathrm{t}) \\ Vy(\mathrm{t}) \\ \theta(\mathrm{t}) \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ sin\theta & 0 \\ 0 & 1 \end{bmatrix} * \begin{bmatrix} V(\mathrm{t}) \\ \omega(\mathrm{t}) \end{bmatrix} * \begin{bmatrix} V_L(\mathrm{t}) \\ V_R(\mathrm{t}) \end{bmatrix}$$

$$= \begin{bmatrix} \mathrm{V(t)cos\theta} \\ V(t)sin\theta \\ \omega(t) \end{bmatrix} * \begin{bmatrix} V_L(t) \\ V_R(t) \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{2}(V_R + V_L)\cos\theta \\ \frac{1}{2}(V_R + V_L)sin\theta \\ (V_R - V_L)/_L \end{bmatrix}$$

$$\begin{bmatrix} \frac{1}{2}\cos\theta & \frac{1}{2}\cos\theta \\ \frac{1}{2}sin\theta & \frac{1}{2}sin\theta \\ -1/_L & 1/_L \end{bmatrix} * \begin{bmatrix} V_R \\ V_L \end{bmatrix} \qquad (6)$$

From the above equations gives the relationship between postures and the velocities of the two wheeled differential drive robot.

EXPERIMENTAL RESULTS

A real mobile robot with differential drive system for mobility is manufactured. The real manufactured robot is shown in Figure 6.

Figure 6: Manufactured Differential Drive Robot.

Three different cases were analyzed by using this real robot. The simplest case is the straight line motion in which both the DC motors are spin with the same speed or rate and in same direction, then from the equation (4) robot will have $\omega_{mob}=0$ and from the equation (5) R = Infinite i.e. robot will follow a straight line path.

In case two when both the DC motors are spin with the same speed but opposite in direction then robot will rotate in same place.

In third case if one motor spins faster than the other, then from equation (4) and (5) the robot will have certain ω_{mob} and R, and have tendency to turn in the direction opposite to the faster wheel.

CONCLUSIONS

The conceptual design was implemented, and a robotic platform with differential drive system was built. This robot platform can be used for in constrained environment as it has lower turning radius. When deciding on a type of wheel to use, wheels with a small width were selected so as to reduce the frictional forces when the robot rotates as frictional forces need to be considered to minimize the energy loss. Also, these wheels have rubber coating which also helps in minimizing the friction. More importantly, springs have been provided at the caster wheels for shock observance. The main approach is to make a balance among constraints such as weight, cost, and bulkiness. For this reason rectangular robot with differential steering system equipped with two free caster wheels which results in less number of actuators and ultimately low energy, less number of batteries, less weight and hence less expensive, has been selected

This mobile robot offers an open platform to various researchers to implement their ideas, and allows the expansion of mechanical as well as electronic system. This designed and developed robotic platform has the capability to implement algorithms for path planning, path control, dynamic steering, obstacle avoidance, position control, image recognition etc.

ACKNOWLEDGEMENT

It gives me immense pleasure in presenting a paper on dissertation "Design of a differential drive mobile robot for use in constrained environment". This work has certainly rendered me a tremendous learning as well as practical experience.

It is my proud privilege to work under the guidance of Dr. Jayesh L. Minase, Assistant Professor, and Department of Mechanical Engineering. I am thankful to him for his precious, timely guidance and continuous inspiration throughout my M.E. course. I am thankful to him for his critical judgments in preparing this paper.

Finally I dedicate my study efforts to my parents, friends and the Almighty.

REFERENCES

[1] P. Petrov, *"Modeling and Adaptive Path Control of a Differential Drive Mobile Robot", Proceedings of the 12th WSEAS International Conference on Automatic Control, Modelling & Simulation, pp. 403 – 408, 2010.*

[2] F. Cuellar, *"Analysis and Design of a Wheeled Homonymic Omni directional Robot", Proceedings of IEEE Robotic Symposium LARS, pp. 41 – 46, 2006.*

[3] Wen-June Wang, Jun-Wei Chang, *"Implementation of a mobile robot for people following", Proceedings of International Conference on System Science and Engineering, pp. 112 – 116, 2012.*

[4] M. O. Tatar, C. Popovici, D. Mandru, I. Ardelean, A. Plesa, *"Design and Development of an Autonomous Omni-directional Mobile Robot with Mecanum wheels", Proceedings of IEEE International Conference on Automation, Quality and Testing, Robotic, pp. 1 – 6, 2014.*

[5] F. A. Salem, *"Dynamic and Kinematic Models and Control for Differential Drive Mobile Robots", Proceedings of International Journal of Current Engineering and Technology, pp. 253 – 263, 2013.*

[6] M.H. Korayem, T. Bani Roatam, A. Nakhai, "*Design, Modeling and Error Measurement of Wheeled Mobile Robots", Proceedings of the International Journal of Advanced Manufacturing Technology, pp. 403 – 416, 2006.*

[7] M. Takahashi. T. Suzuki, H. Shitamoto, T. Moriguchi, K. Yoshida, "*Developing a Mobile Robot for Transport Applications in the Hospital Domain", Proceedings of the International Journal of Robotics and Autonomous Systems, pp. 889 – 899, 2010.*