ISSN 2395-1621

Design of a Differential Drive Mobile Robot Platform for use in Constrained Environments

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ABSTRACT

a **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.**

Keywords: Differential Drive System, DC Motor, Modeling, Wheeled Mobile Robots, Analysis.

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. 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. This study presents 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. The robots may be used for service or industrial purposes but due to lack of available space, working environments are becoming constrained now days. 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 presents the literature review, which reveals the study of existing work in the robotics field and also gives the existing architectural designs of the mobile robotic platforms. It also gives the background of Omni-directional movement of mobile robots using Omni-wheels and Mecanum wheels, which are having some advantages as well as disadvantages over traditional wheels. Literature review reveals that the differential drive method can be used for locomotion in congested places. Section 3 highlights the detailed design of the mobile robotic platform. Also this chapter reveals the various types of wheels and wheel configurations used for locomotion in constrained environments. The Section 4 provides the stress analysis of the base plate. In Section 5, the experimental results are presented and Section 6 gives conclusions and future scope of this work.

1.

II.LITERATURE REVIEW

a This section presents the detailed literature review of the existing mobile robotic platform, 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 the 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 however 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 platform. 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.

III. DESIGN OF ROBOTIC PLATFORM

a 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 the 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 robotic platform design starts with identifying working environment and components or parts of the robot.

Before designing any system need of the system is prime thing. In this work the need of customer is to design the robotic platform for constrained environments, as working places such as hospitals, ware houses, offices, factories etc. are becoming congested nowadays.

Considering the need and literature review it was decided to build a mobile robot by using differential steering system. The steps for building a mobile robotic platform are CAD model designing, selection of the appropriate components and then actual manufacturing of the robotic platform.

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 1.

Caster wheel

Driving wheel

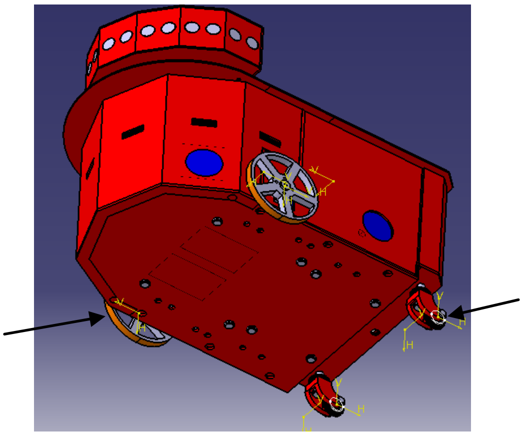


Figure 1: Wheel configuration of the Robot.

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

B. Criteria for selection of components.

The first step in building a mobile robotic platform is to find the purpose or need of work. In terms of robots it is what your robot should do. Based on the need appropriate components are selected for building the robotic platform. The first step in building the mobile robot is to choose the type of robotic platform, there are various types of robots are existing such as wheeled robot, legged robot, submarines, stationary robot. In this work the wheeled robot using two driving wheels and two caster wheels equipped with springs is selected.

After platform selection next step is to choose actuator which will make the robot to move. Various types of actuators are available such as DC motors, Geared DC motors, AC motors, Servo motors etc. DC geared motors is nothing but combination of DC motor and gear box which helps to reduce the motor speed and increase the torque. For example if a DC motor is rotating at 100 RPM and produces a torque of 0.001N-m, and if it is equipped with a gear 19.5:1, the speed of DC motor would reduce by factor of 19.5 i.e. speed will be 5.12 RPM (100/19.5). It will also increase the torque of motor by factor of 19.5 i.e. torque would be 0.195 N-m (0.001*19.5). DC geared motor can rotate in clockwise or counterclockwise direction. DC geared motor can also be available with encoder to measure the number of rotations of motor. Here DC geared motor Pittman GM8224D201-R2 With encoder is selected for the actuation of the robotic platform. The DC geared motor selected in this work has efficiency of 73%.

The calculation for torque can be as follows:

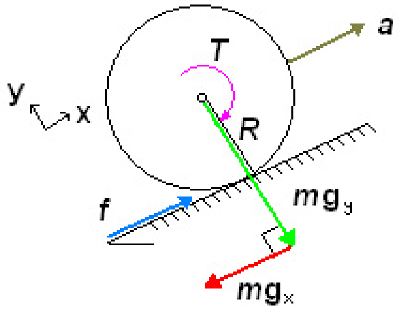


Figure 2: Schematic of robot wheel

Consider robot is moving on an inclined plane of angle θ, radius of wheel is R, f is the frictional force, T is the torque and a is the acceleration of robot.

Summing all forces along X-axis,

$$\sum x = M*a = M.g.\sin\theta + f \quad (1)$$ USB

$$M*a = M.g.\sin\theta + (T/R). \quad (2)$$

Solving for T obtains,

$$T = (a + g.\sin\theta)*M*R \quad (3)$$

The above obtained torque is total torque required for acceleration of robot on inclined surface. Hence torque required for each actuator can be obtained by dividing total torque with number of actuators (n).

$$T = \frac{(a + g.\sin\theta)*M}{n} \quad (4)$$

The torque value with considering the efficiency (e), can be

$$T = \frac{(a + g.\sin\theta)*M}{n}(100/e) \quad (5)$$

In this work, the working environment is considered to be flat so that θ = 0^0. Hence torque value would be

$$T = \frac{M*a}{n}(100/e) \quad (6)$$

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

TABLE I

SPECIFICATIONS OF ROBOTIC PLATFORM

Characteristics	Quantity
Weight	14 Kg
Height	305 mm
Width	305 mm
Length	455 mm
Wheel diameter	100 mm

The power (P) required and maximum current (I) required using supply voltage (V), can be obtained by using following equations:

$$P = T*\omega \tag{7}$$

$$I = \frac{T}{} \tag{8}$$

The capacity of battery (c) pack can be obtained by using,

$$c = I*t \tag{9}$$

where, t is the time.

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.

C. Electronic System

The architecture of electronic system is illustrated in Figure 3.

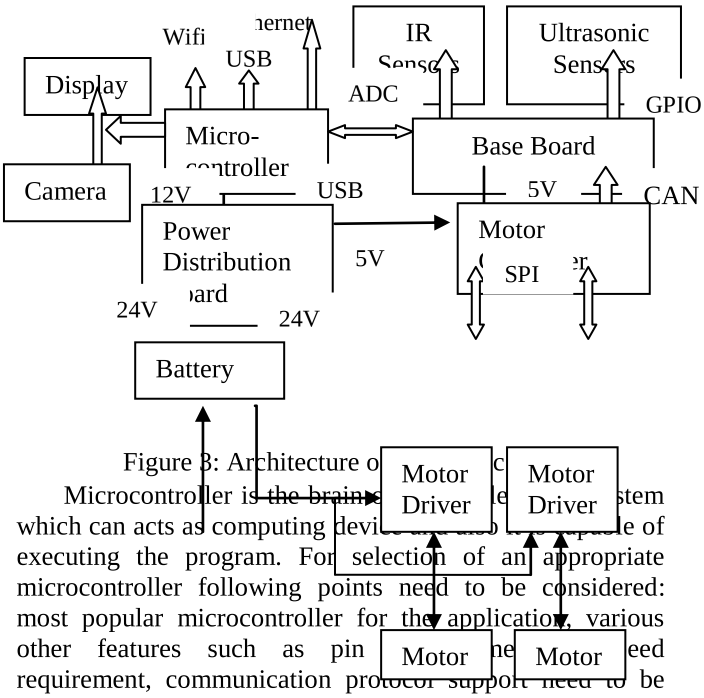


Figure 3: Architecture o[illegible]

Microcontroller is [illegible] system which can acts as computing device [illegible] capable of executing the program. For selection of an appropriate microcontroller following points need to be considered: most popular microcontroller for the application, various other features such as pin [illegible] speed requirement, communication protocol support need to be considered while selecting a microcontroller. Based on the requirement suitable microcontroller selected for this work is Atom PC, 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 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.

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.

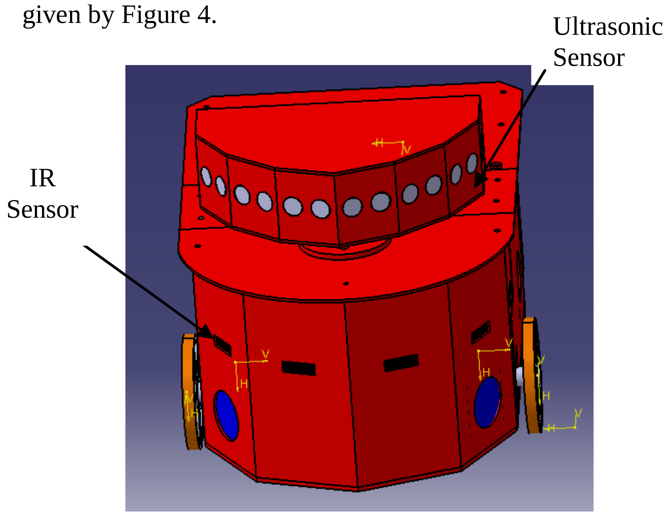


Figure 4: Front view of the Robot.

IV.STRESS ANALYSIS & RESULTS

a After designing any mechanical system its durability and reliability need to be checked. In this paper the analysis of mechanical behavior for the modeled parts under the static load conditions in order to study the robot functionality and selection of the suitable material for mobile robot is presented.

Stress concentration is defined as localization of high stresses due to the irregularities present in the component and abrupt changes of the cross-section. In the present analysis, ANSYS has been employed to find out the localized stresses in the plate. Initially the meshing of 3D model designed in CATIA V5R19 is done and boundary conditions are applied for the analysis.

The shape of base plate is shown in Figure 5.

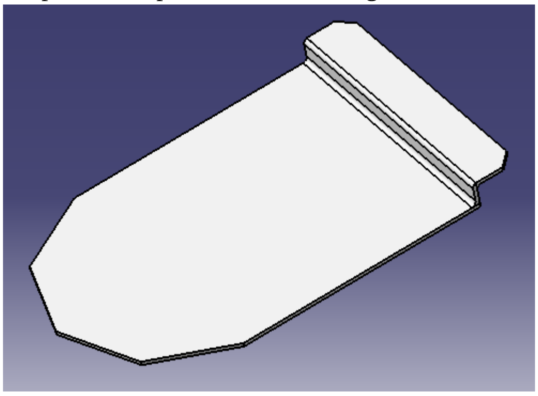


Figure 5: Shape of the base plate

The Young’s modulus (E) and Poisson’s Ratio (ν) of the steel plate are taken to be equal to 2.1x105N/mm2 and 0.3 respectively. The equivalent stress and total deformation of the plate are found by using ANSYS R.15. The results are as shown below.

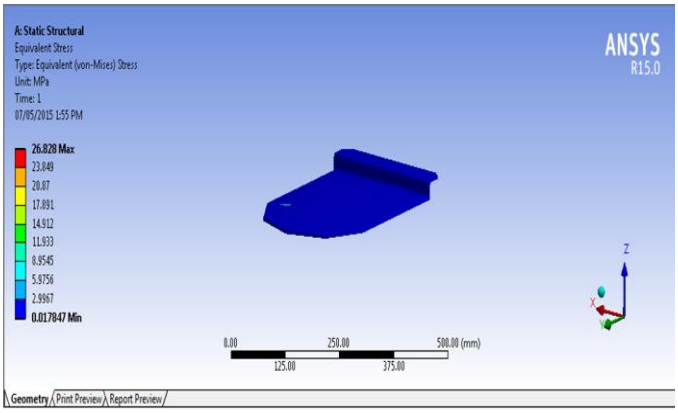


Figure 6: Equivalent Stress distribution

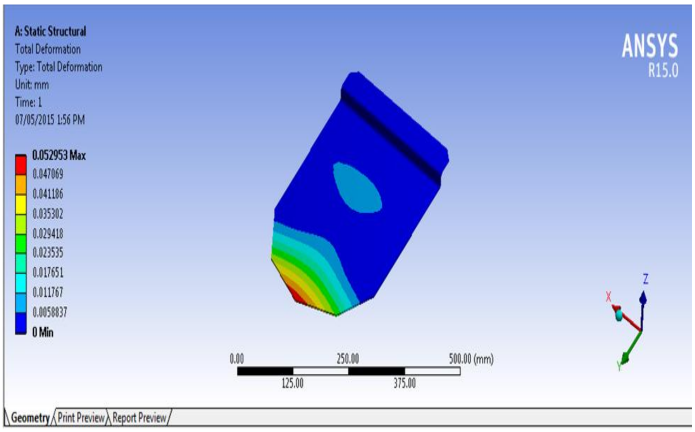


Figure 7: Total deformation.

From the above results it is concluded ANSYS provides a very suitable way to determine stress concentration in complex plates. This will eliminate the failure of the plate after manufacturing as it is pretested for the load in ANSYS.

A real mobile robot with diff ve system for mobility is manufactured. The ctured rol shown in Figure 8.

Figure 8: Manufactured Differential Drive Mobile 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 the robot will have $\omega_{mob}=0$ and the Instantaneous curvature radius of the robot trajectory, relative to the mid-point axis, R = Infinite i.e. robot will follow a straight line path.

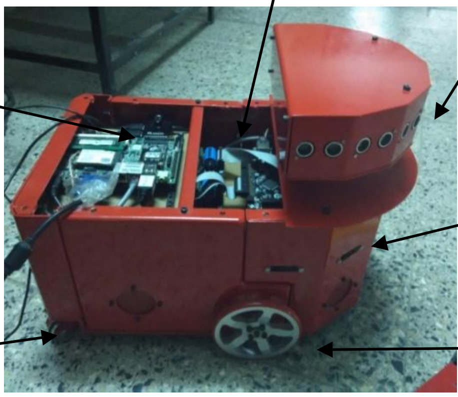
In case two when both the DC motors are spin with the same speed but opposite in direction then robot will rotate in same point.

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

Experiments for the straight line motion as well as rotational motion of mobile robot were performed and it was noted that the mobile robot can move in forward or backward direction and also it can have rotational motion

V.EXPERIMENTAL RESULTS

A real mobile robot with differential drive system for mobility is manufactured. The real manufactured robot is shown in Figure 8.



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VI.CONCLUSION

The conceptual design was implemented, and a robotic platform with differential drive system was built. This robot platform can be used for mobility in constrained environment. 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 provided at the caster wheels for shock observance. The main approach in this work is to make a balance among constraints such as weight, cost, and bulkiness. For this reason, a rectangular shape robot with differential steering system has been selected. It is also 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.

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.

ACKNOWLEDGMENT

It gives me immense pleasure to present a paper on “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, 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.

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