Design, Fabrication and Modelling of Four-Wheeled Mobile Robot Platform with Two Differential and Two Caster Wheels

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Abstract- This paper presents a design and modeling of wheeled mobile robot (MWR) when navigating autonomously in environment such as road and factory. It needs a good and robust design and control for wheeled mobile robot to move from one to another points with smooth moving and small tracking errors. This paper is focused on mechanical design and modeling of wheeled mobile robot. Autodesk inventor software is used to draw the design of the WMR because this software is simple to make any design and a wheeled mobile robot structure is designed with a center of gravity to be located below the axle wheels level. The wheeled mobile robot is driven using two differential drive and two castor wheels to balance robot while it is moving in the environment. Two kinds of coordinate systems are used to describe the movement of the robot in the environment; namely are Local and global coordinate system; where local is related to the heading angle and the deferential wheel shaft, however the global describes the motion in x, y and z directions. The kinematic model is derived for the four wheeled mobile robot using angular velocities equations for the left and right wheels with estimation the heading angle of the robot.

Keywords- Four-wheeled mobile robot, autonomous navigation, design and modeling WMR.

I. INTRODUCTION

Nowadays, mobile robots are a common use in many applications that represent a hazardous, complex, high accurate or hard tasks in worldwide fields, like aerospace, under-water, military, medicine, inspection, mining etc. Usually the robot is supposed to navigate autonomously in its environments; which needs high robust control to determine its path within terrain and avoiding obstacles. In some conditions such as road environments, it is indeed required to control robustly the robot in the planned path [1] otherwise it will crash cars or people. The wheeled mobile robot locomotion is accomplished using the wheels with two, three and four wheel mobile robot. Two wheel robot such as Segway robot, is required Gyro Sensor to keep it balancing in order to stay in stable continuously [2]. There are two types of three-wheeled robot; the first one comes out with two differential drive wheels to move the robot plus caster wheel for balancing, others type is a synchronous 3 wheels robot [3,4], in which both wheels are rotating by certain velocity at same time or 3 mecanum Wheels [5], which have a small cylinder rollers inside and allow the mobile robot to move in all directions. Lastly, Four Wheeled Mobile Robot or Ackerman driving are used for driving mobile robot with two rear wheels [6] that can move continuously, and two front wheel that are used as ordinary wheels. A wheeled mobile robot's navigation system in real-time contain many tasks such as control of motion, planning of the path, and self-localization [7-10]. The control of motion is the important task to make sure that the robot is operating well in its path without environment collision [10,11]. The path planning is the process of finding a path for the moving of robot from the start destination to the end destination while avoiding obstacles and disturbances [12-15]. The self-localization is the robot's skill to specify its position within the environment. In this research, the wheeled mobile robots is supposed to explore in restricted environment such as factories and road to perform a certain path with zero tracking errors. The robot control system involves the utilization of laser simulator based on active force control to improve the WMR control system. The AFC has generally two loops; first loop is used for kinematic parameters control and another loop for dynamics control of mobile robot. The active force control have been used to reject the unwanted disturbance of frictional force in pipe [16], tracking the wheeled mobile robot in pre-planning path in difficult environment [17]. It was used to solve the problem of removing the effect of disturbance in the system and any disturbance in the dynamic system [18], and avoid the disturbance and noise [19]. The Proportional-integral-derivative (PID), Active Force Control and sliding mode controller (SMC) [16] have been resulted with signal error oscillate from 1 second to 10 second and after 10 second the signal become stable at zero level. Resolved Acceleration Control (RAC) with Active force control (AFC) [17] have shown that there are no difference between reference path and actual path when there is no disturbance for RAC-AFC. With constant and variable disturbances, the tracking error has no significant difference between reference path and actual path which is small error in power 10^-2. A feedworward active force control (AFC) with Robust controller [18] and active force control (AFC) with computed torque control [19] shows that the tracking errors is oscillated between -0.01 to 0.02 rad in comparison with computed torque control system which oscillates from -0.04 to 0.03 rad. AFC is perform more better than much lower than compute torque.

In this paper we are trying to develop a WMR prototype with four wheels, two differential and two caster wheels, to enable robot to move robustly in the environment. The following sections explain the design and kinematic modelling for this robot.

II. WHEELED MOBILE ROBOT DESIGN

Autodesk inventor software model of the wheeled mobile robot is shown in Fig. 1 below. The WMR platform body is driven by two castor wheels located in front and back of the platform with two differential wheels at the side of platform which are controlled by a dc motor to make a mobile robot move and turn to right and left position. The design can be considered as simple mechanical design since it uses only two brushless DC motors to move the wheels of mobile robot.

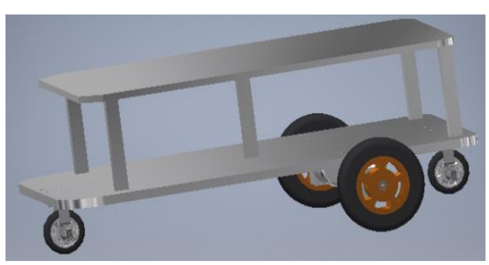
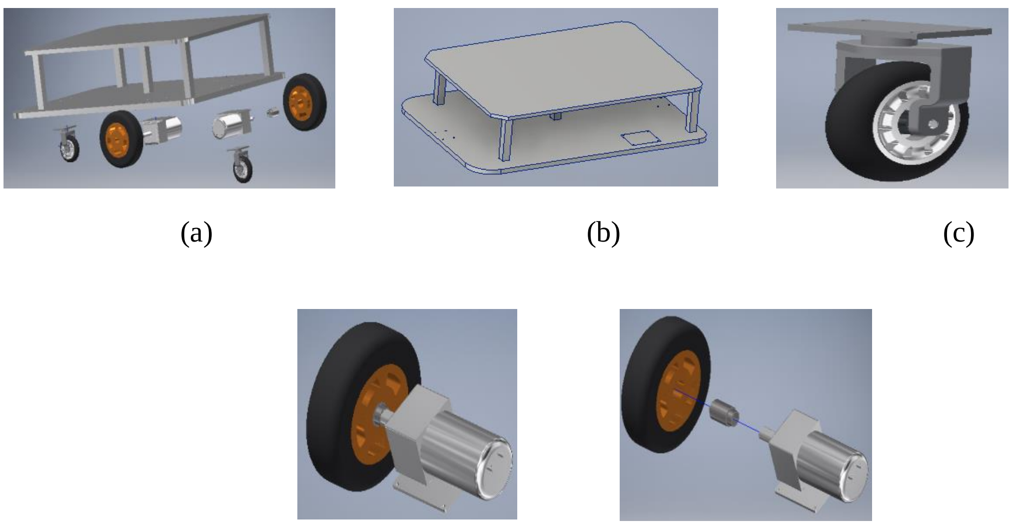


Fig.1: The design of four wheeled mobile robot with front and back castor wheel.

III. MECHANICAL DESIGN

The first objective of this wheeled mobile robot design is to build and create a new WMR platform capable to perform well at any environment and complex space such as road. The design of this wheeled mobile robot includes three main characteristics. The first is a wheeled mobile robot that can move from one point to another point and can move in restricted spaces. The second is that the platform of WMR is still stable even it move in slope condition and not smooth terrain. The third is the design of wheeled mobile robot has two differential wheels that attached at left and right side of the WMR's platform to move the mobile robot and two castor wheels at front and back platform as a supporter of wheeled mobile robot to make a its more stable and smooth moving as shown in Fig. 1. The main of wheeled mobile robot mechanism components are divided into three subsystems. The part by part diagram of the wheeled mobile robot is shown in Fig 2. Fig. 2(a),2(b), 2(c) and 2(d) are tweak component, chassis, castor wheel and differential wheel. The two differential and castor wheels are attached to the body platform. The differential wheel subsystem Fig 2 (e) is show of wheel, bush, bearing, drive gear and DC-motor.



(a) (b) (c)

(d) (e)

Fig. 2 : Mechanical Subsystems of Wheeled Mobile Robot

IV. WHEEL MOBILE ROBOT FABRICATION

The full fabrication of wheel mobile robot is shown in figure 2 below. The WMR's frame is build by using aluminium profile (3cm x 3cm) and aluminium sheet.

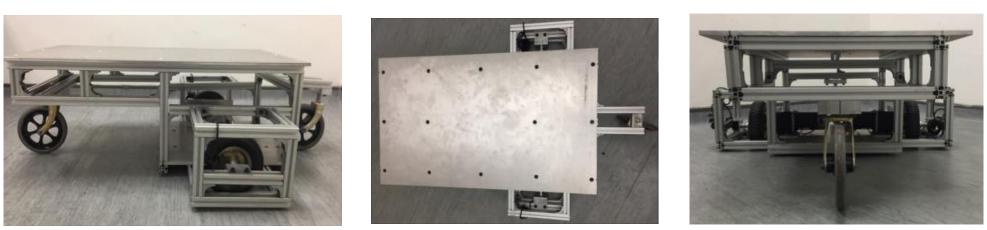


Fig.2: The full fabrication of four wheeled mobile robot.

A motor and wheels is connected by using shaft. A diameter of shaft is 30mm and modified by using CNC machine to make a hole and threat. This step is quite complicated because it requires the exact size of the hole with a motor shaft to make a tyre move smoothly. Screw 6mm is used to tie a shaft of tyre with motor shaft.

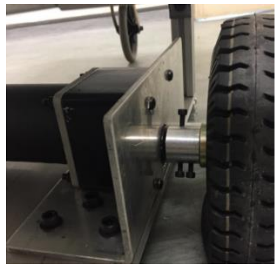


Fig.3: The position of motor and wheels

Encoder is used to measured a rotation of wheels. An encoder is connected by using spring coupling with tyres. The diameter of coupling is 20mm and length is 30mm.

Fig.4: The position of encoder and wheels

I. GLOBAL COORDINATE SYSTEM OF WHEELED MOBILE ROBOT

The wheeled mobile robot in this paper consists of four wheels control system with two castor wheels that are controlled using active force control (AFC) as shown in Fig. 3. Local and global coordinate system is used to see the motion of wheeled mobile robot as shown in Fig. 3.

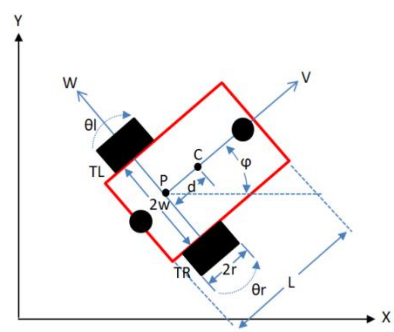


Fig 3: Local /global coordinate system with wheeled mobile robot

This is the notation for Local /global coordinate system with wheeled mobile robot:
C: The center of mass mobile robot
d: The distance between the center of mass and driving wheels axis in x-direction
P: The intersection of the axis of symmetry with the driving wheels axis
w: The distance between each driving wheel and the robot axis of symmetry in y-direction

II. KINEMATICS OF WHEELED MOBILE ROBOT

As in the design described above, the wheeled mobile robot is driven using two differential drive and two castor wheels. For the velocity of wheeled mobile robot, it can be derived as in Eq. 1 :

Velocity for right wheel = Vr = $\dot{\theta}_r$ .r

Velocity for left wheel = Vl = $\dot{\theta}_l$ .r

$$V = \frac{Vr + Vl}{2} = \frac{r\dot{\theta}_r + r\dot{\theta}_l}{2} = \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \end{bmatrix} \begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix} \qquad (1)$$

The difference between angular velocity of right and left wheels can be written in relation with heading rotation angle as in Eq. 2:

$$\dot{\varphi} = \frac{r\dot{\theta}_r + r\dot{\theta}_l}{2b} = \begin{bmatrix} \frac{r}{2b} & \frac{-r}{2b} \end{bmatrix} \begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix} \qquad (2)$$

Global coordinate system can be written as shown in Eq. 3

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} cos\varphi & dsin\varphi \\ sin\varphi & -dcos\varphi \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V \\ \dot{\varphi} \end{bmatrix} \qquad (3)$$

For $\dot{x}$:

$\dot{x}$ = Vcosφ + dsinφ $\dot{\varphi}$

$$= \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \end{bmatrix} \begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix} \cos\varphi + d\sin\varphi \begin{bmatrix} \frac{r}{2b} & \frac{-r}{2b} \end{bmatrix} \begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix}$$

$$\dot{x} = \frac{r}{2}\dot{\theta}_r \cos\varphi + \frac{r}{2}\dot{\theta}_l \cos\varphi + d\sin\varphi \frac{r}{2b}\dot{\theta}_r - d\sin\varphi \frac{r}{2b}\dot{\theta}_l \qquad (4)$$

For $\dot{y}$:

$$\dot{y} = V sin\varphi - d cos\varphi \ \dot{\varphi}$$

$$= sin\varphi \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \end{bmatrix} \begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix} - d cos\varphi \begin{bmatrix} \frac{r}{2b} & \frac{-r}{2b} \end{bmatrix} \begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix}$$

$$= \frac{r}{2} sin\varphi \ \dot{\theta}_r + \frac{r}{2} sin\varphi \ \dot{\theta}_l - d cos\varphi \frac{r}{2b} \dot{\theta}_r + d cos\varphi \frac{r}{2b} \dot{\theta}_l$$

$$= \left[\frac{r}{2} sin\varphi - \frac{dr}{2b} cos\varphi \right] \dot{\theta}_r + \left[\frac{r}{2} sin\varphi + \frac{dr}{2b} cos\varphi \right] \dot{\theta}_l \qquad (5)$$

The Kinematics equation of wheel mobile robot can be written:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} \frac{r}{2}\cos\varphi + \frac{dr}{2b}\sin\varphi & \frac{r}{2}\cos\varphi - \frac{dr}{2b}\sin\varphi \\ \frac{r}{2} sin\varphi - \frac{dr}{2b} cos\varphi & \frac{r}{2} sin\varphi + \frac{dr}{2b} cos\varphi \\ \frac{r}{2b} & \frac{-r}{2b} \end{bmatrix} \begin{bmatrix} \dot{\theta}_r \\ \dot{\theta}_l \end{bmatrix}$$

III. CONCLUSION

In this paper we presented a wheeled mobile robot design with two differential wheels and castor wheels as supporter. The objective is to make the wheeled mobile robot able to move in any environment and restricted space. The mechanical design of a new autonomous wheeled mobile robot platform has been described in details in this paper using Autodesk Inventor software. For the future we will work on simulation and implementation of control system to drive the robot in restricted environment.

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