Fabrication and Simulation of Mecanum Wheel for Automation

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Abstract - Today, Industrial, Automotive and technical application of mecanum wheel drive is continuously gaining importance. This type of drive using mecanum wheel will be the future of industrial application, transportation and many more commercial purposes. So in this respect our paper discusses about a new type of automated drive using mecanum wheel that will bring upon a revolution in the emerging market of AGV's, parking system and some practical industrial application. This paper introduces an omni-directional drive composed of mecanum wheel. The term 'omni-directional' is used to describe the ability of a system to move instantaneously in any direction from any configuration. We have fabricated mecanum wheels using rollers. These rollers are made up of rubber polymer named Delrin and aluminum is used for hub. An automated prototype of mecanum drive is developed using mecanum wheels for material handling. We are following a particular path demonstrating the motions followed by mecanum wheel along with an obstacle detection program for avoiding collision in the path.

Keywords: Mecanum wheel, Delrin, omni-directional, rubber polymer

I. INTRODUCTION

The main requirements of an automated vehicle are its ability to move through the given operational space, avoiding obstacles, finding its way to the next location and carrying heavy loads and products, in order to perform its task. Our project mainly aims at improving the material handling techniques which will result in improvised space utilization and safety while handling.
Basically the Mecanum drive allows the wheels to drive on a straight path from a given location on the floor to another without having to steer first. These omni-directional mobile platforms are needed for robotic systems and vehicles that operate in environments congested with obstacles such as those found in offices, factory workshops and warehouses, eldercare facilities, hospitals, parking and traffic. The mobility of common wheeled vehicles using conventional or skid steering is limited in such environments due to the non-holonomic constraints of their wheels and tyres, While they can generally reach any position and orientation in the environment, it may require complex manoeuvres.
Vehicles and robots with omni-directional mobility i.e. the ability to move instantaneously in any direction from any configuration would be desirable for industrial application such as material handling.

II. METHODOLOGY FOR MECHANICAL DESIGN

A) DESIGN OF WHEEL

One of the more common omni-directional wheel designs is that of the Mechanum wheel, invented in 1973 by Bengt Ilon, an engineer with the Swedish company Mecanum AB (Ilon, 1975). The wheel itself consists of a hub *1* carrying a number of free moving rollers *2* angled at 45° about the hub's circumference (Fig. 1). Because the solution shown in Fig. 1 is more difficult to manufacture, a simpler wheel hub has been chosen (Fig. 2).
The angle between rollers axis and central wheel axis could have any value but in the case of conventional Swedish wheel it is 45˚. The angled peripheral rollers translate a portion of the force in the rotational direction of the wheel to a force normal to the wheel direction. Depending on each individual wheel direction and speed, the resulting combination of all these forces produce a total force vector in any desired direction thus allowing the platform to move freely in the direction of the resulting force vector, without changing of the wheels themselves.

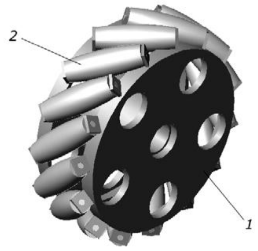

Fig.1 Mecanum wheel (Type-1)

The rollers are shaped such that the silhouette of the omni-directional wheel is circular. We can get the shape of a roller if we cat a cylinder, having as diameter the external diameter of the wheel, by a plane angled at γ (the angle between roller and hub axes), in our case γ = 45 degree.
This shape should represent the equation:-

$$\frac{1}{2}x^2 + y^2 - R^2 = 0 \qquad (1)$$

where R is the external radius of the wheel. If the roller length, Lr, is much smaller than the wheel external radius, R, then the roller shape could be approximated with a circle arc having $2R$ as radius.

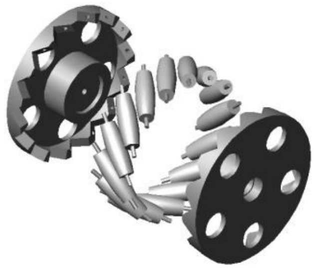

Fig.2 Mecanum wheel (Type-2)

In order to get a circular profile for the wheel, a minimum number of rollers should be computed. According to Fig. 4, if the roller length is chosen, L_r, we get the number of rollers, n

$$n = \frac{2\pi}{\varphi} \qquad (2)$$

Where;

$$\varphi = 2\arcsin\left(\frac{L_r}{2R\sin\gamma}\right) \qquad (3)$$

If we assume that number of rollers n is known, we can get the roller length:

$$L_r = 2R\frac{\sin\frac{\varphi}{2}}{\sin\gamma} = 2R\frac{\sin\frac{\pi}{n}}{\sin\gamma} \qquad (4)$$

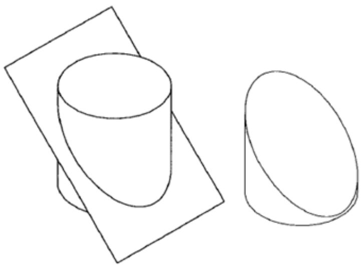

Fig.3: Roller shape: (a) cylinder sectioned by a plane; (b) Resulted shape

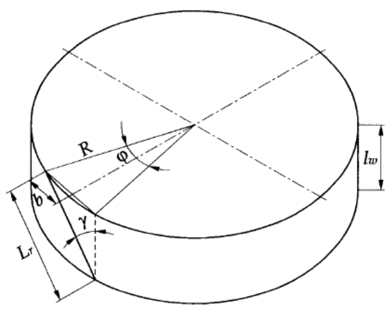

Fig.4 Wheel parameters

The wheel width of the roller will be:

$$l_w = L_r\cos\gamma = 2R\frac{\sin\frac{\pi}{n}}{\tan\gamma} \qquad (5)$$

In our case, γ=45 degree, it means:

$$L_r = 2\sqrt{2}R\sin\frac{\pi}{n} \qquad (6)$$

$$l_w = 2R\sin\frac{\pi}{n} \qquad (7)$$

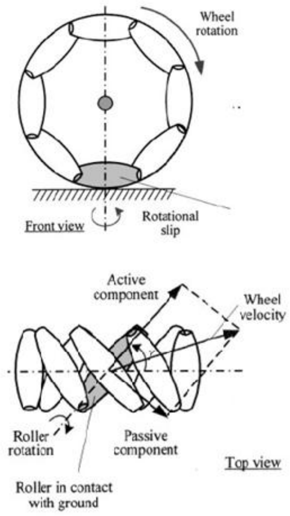

Fig.5 Front View & Top View of wheel

The rollers are neither actuated nor sensed. The key advantage of this design is that, although the only wheel rotation is powered along the main axis, the wheel can kinematically move with very little friction along many possible trajectories, not just forward and backward. A Swedish omnidirectional wheel has 3 DOFs composed of wheel rotation, roller rotation, and rotational slip about the vertical axis passing through the point of contact. In the omnidirectional wheel, the wheel velocity can be divided into the components in the active direction and in the passive direction. The active component is directed along the axis of the roller in contact with the ground, while the passive one is perpendicular to the roller axis.

B) DESIGN OF CHASIS:
SIZE OF CHASIS : 12” x 9” Inch
GROUND CLEARANCE : 3” Inch
MATERIAL USED : 1. Aluminum 2. Plywood

C) KINEMATICS:-

When Mecanum wheels are actuated, the angled peripheral rollers translate a portion of the force in the rotational direction of the wheel to a force normal to the wheel direction. Depending on each individual wheel direction and velocity, the resulting combination of all these forces produce a total force vector in any desired direction thus allowing the platform to move freely in the direction of the resulting force vector, without changing of the wheels themselves.

If we consider a *Xs Os Ys* frame attached to the robot chassis (see Fig. 6), we can write the body speed equations as follow:

$$\begin{bmatrix} u_x \\ v_y \\ w_z \end{bmatrix} = \frac{R}{4}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & -1 & 1 \\ -\frac{1}{l_1+l_2} & \frac{1}{l_1+l_2} & -\frac{1}{l_1+l_2} & \frac{1}{l_1+l_2} \end{bmatrix} * \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} \qquad (8)$$

Where: R is the wheel radius; ωi is the angular velocity of the wheel i (i = 1..4); $l1$, $l2$ are the distances between wheel axis and body center. If the speed of the robot is imposed, we have to compute the angular speed of each wheel (inverse velocity solution).

$$\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_3\\ \omega_4\end{bmatrix} = \frac{1}{R}\begin{bmatrix}1 & 1 & -(l_1+l_2)\\ 1 & -1 & l_1+l_2\\ 1 & -1 & -(l_1+l_2)\\ 1 & 1 & l_1+l_2\end{bmatrix} * \begin{bmatrix}u_x\\ v_y\\ w_z\end{bmatrix} \qquad (9)$$

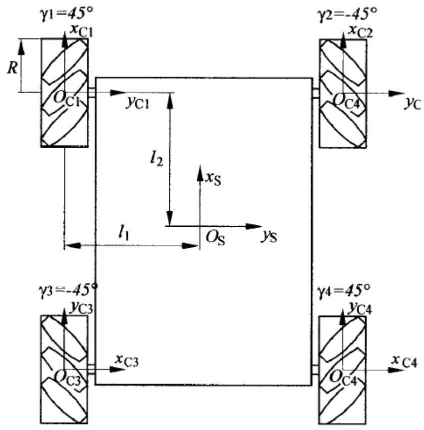

Fig.6 Kinematics of the robot

D) CALCULATION:

Let's assume: R = 5 cm

Lr = 2.5 cm

Bore diameter = 1.8 cm

From equation no. 3

$\varphi = 2\arcsin\left(\frac{L_r}{2R\sin\gamma}\right)$

$\varphi = 2\arcsin\left(\frac{2.5}{2*5*\sin 45}\right)$

$\varphi = 2\arcsin(0.35)$

$\varphi = 0.72$

Now, n = (2*π/φ)

n = (2*π/0.72)

n = 9

Number of rollers will be fixed at distance of 40 degree i.e. 9 rollers will be fixed at 40 degree.

Now let us calculate the width of roller from equation no.5

$l_w = L_r\cos\gamma = 2R\frac{\sin\frac{\pi}{n}}{\tan\gamma}$

$lw = 2R\ (\sin\frac{\pi}{n} / \tan 45°)$

$lw = 2 \times 5\ (\sin(\pi/9)/\tan 45°)$

$\boldsymbol{lw = 5.4\ cm}$

III. COMPONENTS FOR AUTOMATION OF MECANUM WHEEL

A) Main Board

This board is the main board which controls all the functionalities, actions and motions of a robot. This board have the following features. Compatible with most of the 8051 and 8052 series of 40 pin microcontrollers. Available with P89v51rd2 micro controller On board motor driver for driving 4 DC motors or 2 stepper motors LCD interface PC interface through UART 8channel ADC converter 11.0592 MHz crystal Exposed one 8 channel I/O port for general-purpose application five tact switches for external input, reset and interrupt Four test LEDs for status and debugging purpose Buzzer for generating audible response Exposed ISP pins for Programming can be done through serial port for P89v51rd2 micro controller On board regulated power supply.

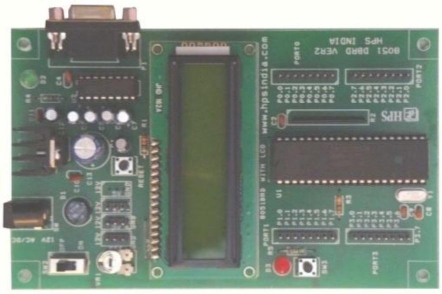

Fig.7 Micro controller

B) 16x2 LCD

This device can be use to display any message, status or also can be use for debugging purpose.

Fig.8 LCD

C) Chassis for building robot

Chassis of a robot is basically decides the physical structure of a robot. It holds all hardwires circuit boards and power supply of a robot. This chassis used here is a black colored mild steel chassis it can hold two DC motors, a ball caster, the main circuit board and sensors.

D) Centre shaft DC geared motor 60rpm DC geared motors are used to drive the wheels. The speed of the DC geared motor used here is 60 R.P.M. and its torque is up to 2Kg/cm2 at 12V DC.

TYPE	PERMANENT MAGNET DC
VOLTAGE-RATED	12VDC
RPM	60 RPM
DIAMETER-SHAFT	0.187 inch (4.75 mm)
LENGTH- SHAFT & BEARING	0.570 inch (14.48mm)
MOUNTING HOLE SPACING	1.88 inch (47.63mm)
FEATURES	GEAR BOX

E) Battery

A 12 Volt 1.2 Ampere-Hour sealed lead acid battery is used to power the main board, sensors and motors.

F) Connector with Wire

It's a part of Power Supply Section and used to connect supply to main board.

G) Analog optical Sensor

This sensor can be used as a line sensor, proximity sensor or as an obstacle sensor. It gives output in the form of analog voltage. To read this sensor it needs an ADC. This sensor basically consist of a high glow red LED as a transmitter and a photo diode as receiver.

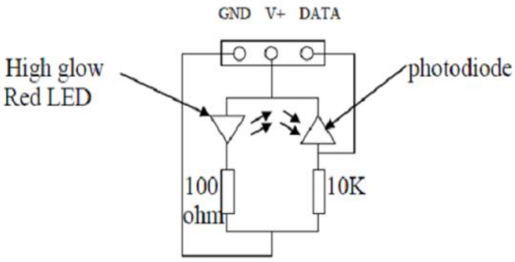

Fig.9- Analog optical Sensor

Photodiode (Receiver) is used in potential divider in a reverse bias mode. So when Light transmitted from the transmitter is reflects back from a light colored surface, say white, the resistance of the photodiode would decrease and this in turn exceeds the voltage at output terminal (voltage across resistor).

When light reflects from a darker colored surface, say black, the resistance of the photo diode would increase and this in turn decrease the voltage at output terminal (voltage across resistor).

H) Obstacle detector

When an autonomous robot is designed to detect hurdles (e.g. wall or any object) in its path, an obstacle sensor is used. It consists of three major components. The first is an Infra-Red (IR) transmitter (an IR LED); second is an Infra-Red receiver module and third is a timer (IC 555).Fig below shows the circuit diagram for an obstacle detector.

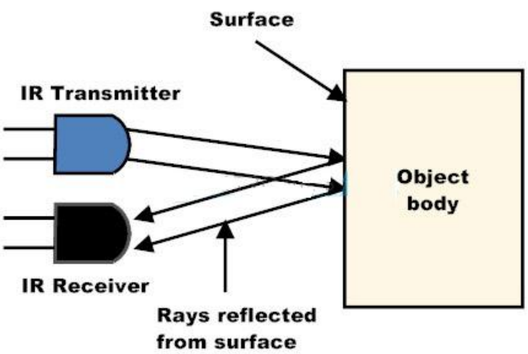

Fig.10 a)- Basic Principle of Obstacle detector sensor

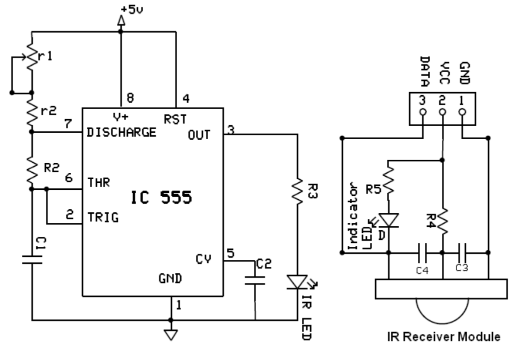

Fig.10 b)- Circuit of Obstacle sensor

The major distinction between ordinary LED and IR LED is that IR LED emits Infrared rays, which we cannot see by our naked eyes. IR receiver module requires the incoming signal to be modulated at a particular frequency and would ignore all other signals. It is also immune to ambient IR light. They are available for different carrier frequencies from 30 kHz to 56 kHz. IC 555 is a Timer IC using which we are modulating a transmitting signal, i.e. we are generating sequence of square wave pulses. It is configd in as table mode to generate the square wave signal at particular frequency.

A constant stream of square wave pulses is generated using IC555 centered at particular frequency. This is used to drive an IR LED. Whenever this modulated signal is detected by receiver it changes its output. The data pin of TSOP is generally high. When TSOP receives the reflected pulses it makes the data pin low.

I) Software Used:

- KEIL MICROVISION (KEIL µV)
- FLASH MAGIC

The KEIL µVISION is used for compiling C language. The KEIL µVision Integrated Development Environment (µVision IDE) supports three major microcontroller architectures and sustains the development of a wide range of applications. 8-bit (classic and extended 8051) devices include an efficient interrupt system designed for real-time performance and are found in more than 65% of all 8-bit applications. Over 1000 variants are available, with peripherals that include analog I/O, timer/counters, PWM, serial interfaces like UART, I²C, LIN, SPI, USB, CAN, and on-chip RF transmitter supporting low-power wireless applications. Some architecture extensions provide up to 16MB memory with an enriched 16/32-bit instruction set. The µVision IDE supports the latest trends, like custom chip designs based on IP cores, which integrate application-specific peripherals on a single chip.

FLASH MAGIC TOOL is used for dumping the language programming compiled in the KEIL µVISION. This tool comes into action after the C program is correctly compiled in KEIL.

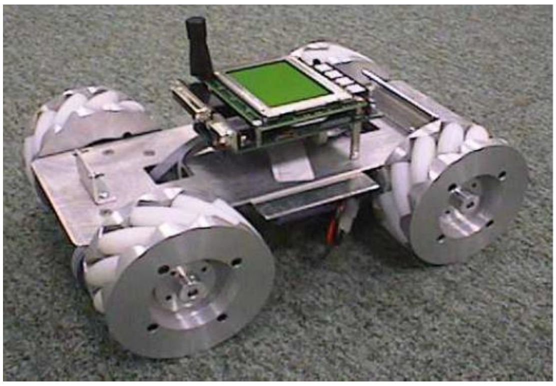

Fig.11- Construction of Mecanum wheel operated chassis for Automation

IV. MOTION PROVIDED BY MECANUM WHEEL

The vehicle is able to translate on any direction, forward/backward but also sideways left/right, cross and turning on the spot. This is especially helpful when having to maneuver in a tight environment such as a factory floor. The control procedure described in Fig. 16 is only valid for the actual solution of rollers orientation. The vehicle has been designed is such way that the front and rear wheels of right or left side could be exchanged between them. In such conditions (of changing the front and rear wheels) the control procedure will be totally different.

To avoid obstacle collisions when the vehicle is going in any motion i.e. forward/backward/right/left the vehicle will get stopped tself.

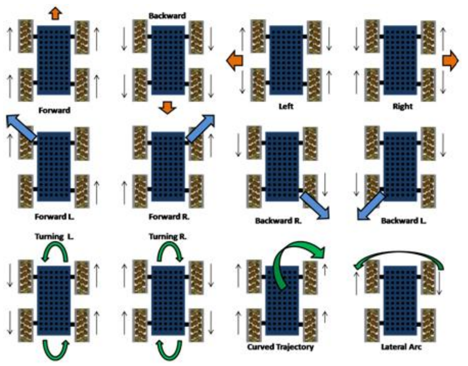

Fig.12- Representing the motion provided by mecanum wheel

V. ADVANTAGES OF MECANUM WHEEL

Robotic vehicles are often designed for planar motion; they operate on a warehouse floor, road, lake, table etc. In a two dimensional space, a body has three degrees of freedom. It is capable of translating in both directions and rotating about its center of gravity.

Most conventional vehicles however do not have the capability to control every degree of freedom independently. Conventional wheels are not capable of moving in a direction parallel to their axis. This so called nonholonomic constraint of the wheel prevents vehicles using skid-steering, like a car, from moving perpendicular to its drive direction. While it can generally reach every location and orientation in a 2D space, it can require complicated manoeuvres and complex path planning to do so.

Lateral parking of a differential drive mobile robot, when a vehicle has nonholonomic constraints, it cannot travel in every direction under any orientation. But in case of these wheels parallel parking becomes a simple job with the lateral movement of the vehicle. This capability is widely known as omnidirectional mobility. The term of omnidirectional is used to describe the ability of a system to move instantaneously in any direction from any configuration. Omnidirectional vehicles have great advantages over conventional (nonholonomic) platforms, with car-like Ackerman steering or differential drive system, for moving in tight areas. They can crab sideways, turn on the spot, and follow complex trajectories. These robots are capable of easily performing tasks in environments with static and dynamic obstacles and narrow aisles. Such environments are commonly found in factory workshop offices, warehouses, hospitals, etc. Flexible material handling and movement, with real-time control, has become an integral part of modern manufacturing.

Automated Guided Vehicles (AGV's) are used extensively in flexible manufacturing systems to move parts and to orient them as required. In contrast, non-holonomic robots can move in some directions (forward and backward) and describe some curved trajectories but cannot crab sideways. For example, for parallel parking, a differential drive robot should make a series of manoeuvres. A car-like robot cannot even turn in place.

VI. CONCLUSION

The Omni-directional technology will bring about a revolution not only in the automobile industry but also will change the scenario with regards to its numerous applications in robotics, medical fields that will enhance our day to day life. Our vision is to see all the vehicles using this Omni-directional technology that will reduce parking problems and even traffic congestion problems. We further see its importance in wheel chairs that will help the handicapped with easy manoeuvrability, thus reducing manual efforts. Also with the emerging industrial application like "Airtrax", we definitely can take it further to be completely benefited by this technology.

The mecanum wheels form the basis of the omnidirectional drive system. Manoeuvrability and mobility are essential to barrier free environments. It provides us with all directional mobility with high load bearing capability and numerous applications. The major problems when driving an omnidirectional vehicle are to detect and handle wheel slippage and to handle the failure of motors.

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