Analyzing Omnidirectional Robots Navigation

Farhan Daemi[1],

[1] *Imam Khomeini International University, Tehran, Iran*

Abstract

This paper represents the Analysis of Omnidirectional movement for robots with special wheels that allow them to move in any direction without rotation and lowest possible friction. Navigation of an omnidirectional robot using a lidar sensor is also discussed in this paper.

Keywords: Robots, Navigation, Omnidirectional Movement

1. Introduction

Nowadays the interaction of humans in industry is being replaced by robots. Robots will do humans jobs faster and in a better quality. In general robots can be divided into two categories, resident robots and moving robots. Resident robots are robots that do their tasks in a single position and don't need to move themselves like robotic arms. Moving robots can move into other positions in order to do their tasks, such as storekeeper robots or human companion robots. The number of moving axis will affect their performance and efficiency in some cases. Omnidirectional moving systems will help these robots to move in any direction in a 2 dimensional space. To use this system we need to be able to add force to the ground in two directions using motors and wheels.

2. Robots movement

As we mentioned in section 1, Robots can be divided into two categories, resident and moving robots. A very simple mechanism for a robot to move is using four wheels which are controlled by direct current motors. With this mechanism we can make the robot move in two directions, forward and backward. By controlling the speed of each motor we can make more directions. For example if we turn the left two motors in maximum speed and right-side two motors in lower speed the robot will go forward and deviate to the right side. By controlling the speed of right motors we can control the amount of deviation. Another mechanism which is now being used by automobiles today, is steering system. This mechanism uses four wheels which two of them can be turned around its vertical axis. In order to move in a direction, this mechanism will help the robots to move in limited directions. This limitation is because of two reasons. First of all the front wheels have limited turning freedom. And also the back wheels still can only move in two directions. One of the advantages of this mechanism is that we only need to use one direct current motor for moving and one motor for controlling the steering system which can be either a Servo or a Step motor. As you can see in figure 1, a robot can move in a curved shape using steering mechanism. Other mechanisms can be used to move a robot in limited directions but most of them use rotation for making directions to move or there is a friction that wastes an amount of energy.

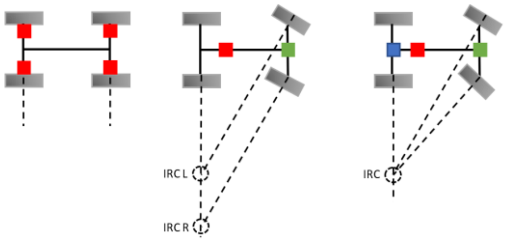

Figure 1. Steering mechanism

3. Omnidirectional movement

Omnidirectional mechanism is a mechanism that allows the robot to move in any direction without rotating itself and with minimum amount of friction and energy loss. This mechanism uses special wheels which can be rotated around the motor shaft that the wheel is attached to, and can move in the direction of the motor shaft using smaller free wheels that are attached around the main wheel.

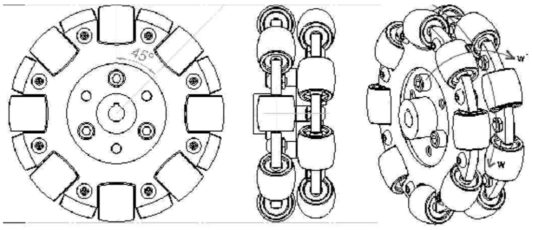

Figure 2. Omnidirectional Wheel

To make the robot move in two axes, at least we need three omnidirectional wheels which can be controlled with direct current motors. It's better to make the robot in cylinder shape, so that we can attach the motors to the base of the cylinder on the circle's diameters as shown in figure 3. $\boldsymbol{\varphi}$ is the robot angle in the coordinating system which is shown by x and y. θ_2 and θ_3 are angles of each motor (We consider $\theta_1 = 0$ for the first motor). If we consider the speed of each wheel as $\boldsymbol{v}_1$, $\boldsymbol{v}_2$ and $\boldsymbol{v}_3$, we can calculate the directional speed of the robot.[1]

$$\begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix} = \begin{pmatrix} -\sin(\varphi+\theta_1) & \cos(\varphi+\theta_1) & R \\ -sin(\varphi+\theta_2) & cos(\varphi+\theta_2) & R \\ -sin(\varphi+\theta_3) & cos(\varphi+\theta_3) & R \end{pmatrix} \begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\varphi} \end{pmatrix}$$

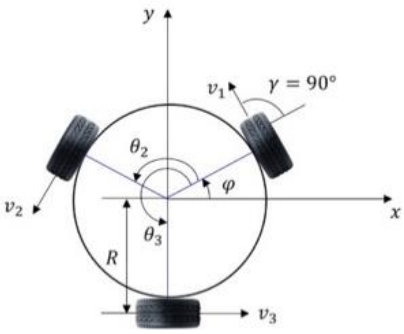

Figure 3. Three wheels omnidirectional mechanism

We can also use more than three wheels for better performance when we need more power. Using 4 motors is more common in robots using this mechanism. First of all with four motors we'll get more power and the robot will be able to carry more weight. Also four motors and four omnidirectional wheels are easier to control and more accurate. A little disadvantage of this mechanism is that we have to make our robot in cylinder shape. Even if we use other shapes, we have to place all the motors crossing one point in the center of the robot. That's where Mecanum wheels are useful. Mecanum wheels are designed with the same structure as omnidirectional wheels but with a little difference. Mecanum wheels have some small free wheels around the main wheel but these free wheels are placed at a 45 deg angle with the main wheel plane. When the main wheel is rotating, the force will be applied to the ground at a 45 deg angle. So with mecanum wheels we don't have to place motors crossing one point. A mecanum wheel structure and its small free wheels are shown in figure 4.

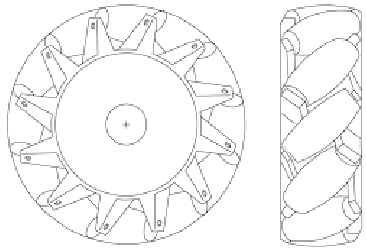

Figure 4. Three wheels omnidirectional mechanism

Some simple and basic movements using mecanum wheels are shown in Figure 5. As you can see it is very similar to four omnidirectional wheels. Also the equation for calculating each motor speed with directional speed is similar to omnidirectional wheels. Mecanum wheels will let the robot move in any direction with or without rotating itself and also this system has the minimum friction and energy loss. Also the power to carry weight is better than other mechanisms. To use these kinds of wheels we must notice if we look at the robot from the top view, in each four main wheels all small free wheel directions must be crossing the center point of the robot. If we do not pay attention to this matter we won't be able to have the right movements for the robot.[2] Mecanum wheels are now being used by small robots to giant machines in industry. They are seen mostly in storage systems. In the following section the robot's navigation algorithm is described using a 4 mecanum wheel system.

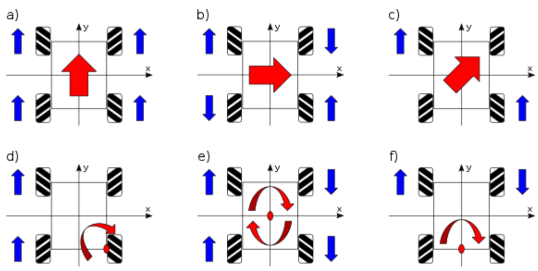

Figure 5. Three wheels omnidirectional mechanism

4. Navigation

Basically, a robot's navigation algorithm is finding a path from an origin to a destination position in order to stay off the obstacles and not bounce or touch them. In order to do this job we need our robot to be able to see around itself using sensors. There are lots of sensors that can give robots the ability to see objects in both two and three dimensions. In fact, a robot that moves on the floor using wheels, is actually moving in a three dimensional space but to simplify our calculations we can consider that the robot is moving in a two dimensional space. So we can use sensors that can give the robot a two dimensional vision. A sensor that can measure the distance from objects in front of it can help us out in this case. But most distance sensors use radiation and reflection of ultrasonic sound or infrared light and that limits the measurement into one direction. Also using many sensors around the robot to cover the whole 360 degrees is not affordable and it might be very hard to communicate with this amount of sensors. A very helpful device that can be used in this situation is lidar sensors. A lidar sensor uses only one distance sensor which rotates and scans 360 degrees completely. Using a lidar sensor we can give the robot the ability to scan the area around itself and make a map out of the data. Making a clear and complete map is not possible because the lidar sensor can not see what is behind an object and that is because it uses light radiation and reflection to calculate the distance. The map can be completed when the robot moves and scans in more positions. An output of a two dimensional lidar sensor is shown in figure 6. The black points are showing the obstacles or unwalkable places.

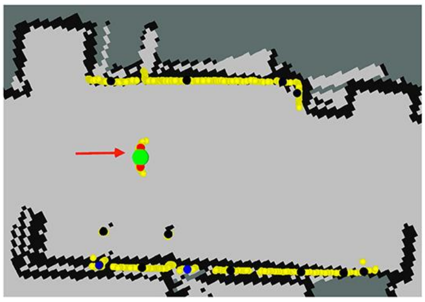

Figure 6. Lidar Sensor Output

5. Driving and Circuit

There are various types of DC motors that can be used in a robot which is using omnidirectional wheels. The important point for selecting the motor is being able to control both the rotating direction and speed of the motor. Using a simple direct current motor it is possible to control the rotating direction using an H-bridge transistor or IJBT. An H-bridge circuit using four Epitaxial silicon transistors is shown in figure 7. A DC motor driver component like L298 or L6203 which uses the same circuit as H-bridge with some additional filters can be used as well. In an H-bridge (figure 7) if we give Q1 and Q4 a logical one the motor will rotate in one direction and if we give logical one to Q2 and Q3 the motor will rotate in another direction.[3]

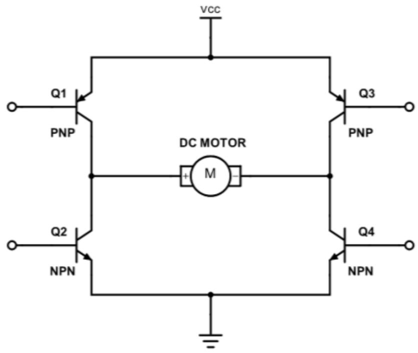

Figure 7. H-bridge using transistors

To control the motor's rotating velocity we can use a PWM signal, generated by a microcontroller. Using pulse width modulation (PWM) we generate a square pulse and give it two H-bridge inputs. This will turn the motor on and off and won't let the motor reach the maximum speed. By controlling the width of the square pulse signal we can control the motor speed. Most of the microcontrollers today have the ability to generate and control square pulse signals using PWM. In this case we will use an ARM microcontroller, STM32F103C8T6, which can give us 15 PWM channels, which means we can control 15 DC motors speed. As we mentioned, in H-bridge (figure 7) Q1 and Q4 will always take the same input so we can connect them to each other. Also same for Q3 and Q2, so we will have only 2 inputs for the H-bridge circuit. If we want to control the speed using PWM, only one PWM signal is enough for this purpose. The other input of the H-bridge can have two states for selecting the rotation direction. In general a simple block diagram is shown in figure 8. An encoder is a sensor device which gives our processor a square pulse signal when the motor is rotating. By measuring the pulse and time we can calculate the motor speed. Encoder is used as a feedback sensor to make sure that the motor is rotating at the right speed. It is also possible to use a PID controlling system for better performance and accuracy. Lidar sensor must be connected to a Computer to process its output. We are using “Robots Operating System (ROS)” to process lidar’s output and calculate speeds for each motor for moving toward a specific destination. Computer will generate a map out of Lidar’s output and find a path from the robots position in the map to the destination we select and send the motors speeds to the microcontroller.[4]

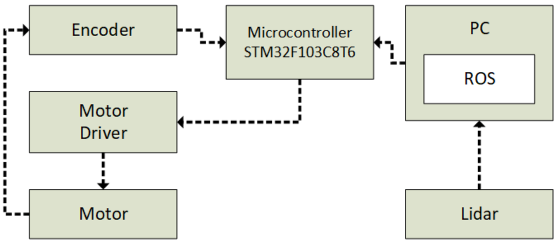

Figure 8. Block Diagram

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