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Design and Fabrication of a Prototype Mobile Platform with Holonomic and OmniDirectional Motion

Final year project (FYP 18-7)

by

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Declaration

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List of Abbreviations

DC Direct Current

UN United Nations

SDG Sustainable Development Goals

DAC Digital to Analog Converter

PWM Pulse Width Modulation

SLAM Simultaneous Localization and Mapping

LIDAR Light Detection and Ranging

Abstract

The majority of today's mobile platforms are non-holonomic. They only have one or two degrees of freedom that are independent. As a result, its maneuverability is limited, and it frequently requires a large amount of room to manage functions such as turning and parking. By increasing a vehicle's degrees of freedom, maneuverability, it can take various complex trajectories that are difficult or impossible for non-holonomic vehicles to take.

This project, therefore, proposes a prototype mobile platform with both holonomic and omnidirectional motion whilst using castor wheels. Since castor wheels are difficult to control we intend to introduce Direct Current (DC) Motors that will enable the control of the castor wheels. This allows the platform to move in complex trajectories without stopping to reset the wheels. Ground clearance has been enhanced on the created platform, which is important for outside difficult terrain activities.

Despite these advantages, controlling the mobile platform to gain the desired motion is a hard task that necessitates the use of an inventive algorithm. To achieve three degrees of freedom motion with four independent wheels with eight degrees of freedom, there is a duplicate control problem that necessitates a complicated control system. We will attempt to resolve these challenges by using an forward kinematics model of the platform and a multiple input multiple output software design using advanced micro controllers.

1 Introduction

1.1 Background

Mobile robots are continuously increasing in non-industrial applications such as military, disaster management, and home applications. Mobile robots can be classified according to the type of motion. The type of motion can be as holonomic or non-holonomic. The holonomic mobile vehicles have the advantage that they have a controllable degrees of freedom equal to the total degrees of freedom of the mobile robot. Omnidirectional on the other hand is that a robot can change the direction of motion without having to perform intermediate rotation steps and they are able to move in all directions from a given starting point while simultaneously rotating [1]. Current mobile vehicles obtain mobility using wheels. This project proposal will seek to apply the concept of omnidirectional and holonomic motion to a set of wheels to develop a mobile platform that can have applications in industrial settings. The wheels in consideration are castor wheels applied in the home, industrial plants, warehouses, and other huge objects that require mobility.

1.2 Problem statement

Mobile robots and platforms have found general applications in homes and other non-industrial applications. These vehicles are largely unmanned and operated remotely. This technology can be adopted for industrial use in the application of casters. Casters are used to move heavy and large objects on the warehouse or factory floor. This process is manual and the operator has to push around the caster physically. The next step involves removing manual control and controlling the caster wheels.

Despite this being the obvious next step, caster wheels in the industry currently require manual control. Casters require an initial push force to begin rolling. Other applications of caster wheels such as shopping trolleys and hospital beds also require manual control. The current implementation of caster wheels defies the trends in technological innovation being observed in the world. Maintaining manual control on casters is less efficient compared to an automated version. Furthermore, laborers get tired easily when pushing the heavy casters around especially due to difficulty in maintaining the correct swiveling. The need, therefore, arises to develop a controllable version of castor wheels so that the process can be automated.

1.3 Objectives

1.3.1 Main objective

To design and fabricate a prototype mobile platform capable of omnidirectional and holonomic motion

1.3.2 Specific objectives

1. To design and build a mechanical chassis and a platform that can hold all the electrical components and have an application fitted onto it.

2. To design and construct a power transmission unit

3. To design a DC motor control circuit for individual caster wheels

4. To develop algorithms to control the motors and achieve simultaneous holonomic motion from the caster wheels and remotely control the mobile platform

1.4 Justification of the study

The apparent availability of cheap and accessible technologies that are bridging the gap between nonholonomic and holonomic motion control leads us to conduct this study. Holonomic motion is very efficient, with navigation to and from tight spaces being a reality. Furthermore, developing a cheap holonomic mobile platform in the field of mobile robots, especially in Sub-Saharan Africa aligns with one of the United Nations (UN) Sustainable Development Goals (SDG) goals, building infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation [2]. This is where the world is headed, and it is only appropriate for us to try and head in the same direction.

2 Literature Review

2.1 Introduction

The majority of mobile platforms or unmanned vehicles in use today are non-holonomic. They only have one or two degrees of freedom that are independent. As a result, its maneuverability is limited, and it frequently requires a large amount of space to control functions such as turning and parking. This can be seen when a car wants to turn 180.° By increasing a vehicle's degrees of freedom we are improving its maneuverability. It can follow many complex trajectories that conventional nonholonomic vehicles find difficult or impossible. Holonomic refers to the relationship between controllable and total degrees of freedom of a robot. A holonomic platform is any mobile platform with three independent degrees of freedom in a plane. If the controllable degree of freedom is equal to the total degrees of freedom, then the robot is said to be holonomic. Independent degrees of freedom indicate that it can change its orientation or position without affecting other motions, as opposed to car-type vehicles, which must turn or change their orientation when moving. A robot built on castor wheels or Omni-wheels is a good example of a holonomic drive as it can freely move in any direction and the controllable degrees of freedom is equal to total degrees of freedom.

2.1.1 Mobile platforms

Over the last three decades, researchers have been working on omnidirectional wheeled mobile robots. There are also legged mobile robots which achieve both holonomic and omnidirectional motion. Legged mobile platforms have the advantage of highly adapted to uneven terrain, low soil interaction and the ability to perform tasks in congested and narrow environments. Nevertheless, their slow mobility, low payload weigh to mechanism weight ratio, complex design and control makes them difficult to find [3].

2.1.2 Castor Wheel

A castor or caster wheel is a relatively free-rolling ,not powered, small undriven wheel. They are designed to be attached to the bottom of a larger object, to enable easy movement across a floor or other hard surface. Castor wheels are manufactured in either a single wheel, double wheel, or compound wheel configuration.

Most castors are used simply to make a heavy or cumbersome piece of furniture or machinery - the vehicle - easier to move. Affixing small, unobtrusive wheels to the bottom of any large or bulky item is a great way to make it more mobile in certain scenarios. In most cases, they are attached to the underside of the vehicle via a fixed top plate, from which the wheel assembly hangs.

When choosing the type of casters to use in an application, weight considerations need to be considered depending on the load the casters will be required to move. To achieve this, we need to consider the weight of the item being supported as shown by equation 2.1.

$$total\ load\ capacity = individual\ weight\ rating * number\ of\ wheels \tag{2.1}$$

The total load-bearing capacity of your castors should always be at least 30% higher than the total weight of the item when fully loaded, to give a sufficient safety margin. Another consideration to take into account is the type of surface the castors will be moving on. These surfaces are either flat and smooth that can accommodate small wheels or rougher surfaces that require wheels with larger diameters. There are several types of castors each suited to a different application. The most common casters are as shown by figure 2.1, figure 2.2 and figure 2.3

Ferrous wheels, Figure 2.3 provide the highest load capacity, impact resistance, temperature range, and rollability of any caster wheel available due to their solid structure, making them excellent for harsh situations such as warehouses and manufacturing factories where a floor protection is not a priority. Polyurethane tread wheels, Figure 2.1 provide good

Figure 2.1: Polyurethane Castor Wheels [4].

Figure 2.2: Synthetic Tread Wheels [4].

Figure 2.3: Ferrous Caster Wheels [4].

floor protection and have a 3,000-pound capacity and strong impact resistance [4]. Synthetic wheels Figure 2.2, have a harder tread with lower rolling resistance and higher impact strength and reliability. While most synthetic wheels are ideal for high-impact and harsh situations, they are louder than softer materials and are less forgiving when colliding with debris.

2.2 Existing Technologies

2.2.1 Wheel design

For wheeled mobile robots, we have [5]: conventional wheels, omnidirectional wheels, and ball wheels. The conventional wheels are the ones we see on cars and trolleys every day. An omnidirectional wheel is a disk-shaped wheel with numerous conventional wheels mounted on its periphery. A ball wheel [6], [7] is shaped like a ball but its implementation is difficult because including an axle in the design sacrifices usable workspace. It is also difficult to provide power transmission to the wheel. For large and heavy outdoor robots, four-wheel or car-like driving mechanisms have traditionally been used. Because the non-holonomic constraints on their wheel mechanisms prevent sideways movements, these vehicles are quite restricted in their motion [8] [9] [10], especially when operating in tight environments. Improved motion capabilities have been investigated in a number of research centers and demonstrated on laboratory robots. These motion capability enhancements are typically derived from the use of two independent driving wheels supplemented by casters. This allows the platform to rotate around any point but does not allow for sideways motion. Another motion can be achieved using two steerable and independently driving wheels [11], or three steerable and coordinated driving wheels [11]. These two implementations allow for both platform rotation and sideways motion through coordinated steering of the wheels. However, in these latter systems, the controls for translational and rotational motions are not fully decoupled or independent, as very strict compatibility conditions exist between the steering and driving velocities of the wheels [12]. To achieve the full three degrees of freedom of planar rigid body motion, these platforms must be controlled as strongly constrained systems. Furthermore, steering necessitates the rotation of the wheels around a vertical axis, which, in the case of heavy payloads or vehicles with wide tires, may result in significant wheel sliding and friction. The traditional wheel is probably the simplest and most durable of the designs. However, not all conventional wheels can provide omnidirectional motion [5] [12] [13]. It is widely accepted that caster design provides full mobility [14]. Mecanum wheels also achieve holonomic and omnidirectional motion by having a series of rollers attached to their circumference [15]. These rollers have an axis of rotation at $45t°$o the plane of the wheel. The angled peripheral rollers translate a portion of the force in the rotational direction of the wheel [15]. Each mecanum wheel in a drive system has independent actuation and the resulting combination of forces to move these wheels produces a total force vector that allows the platform to move freely in any direction. Different variations of mecanum wheels depend on the number of rollers attached to individual wheels, as shown in figure 2.4.

In the development of mecanum and other omnidirectional wheels [16] [17], undesirable vibrations are frequently present in the motion due to a large number of small rollers on the wheel's periphery.

2.2.2 Omnidirectional and holonomic motion

A lot of design work on omnidirectional vehicles has been conducted over the years. The earliest omnidirectional mobile vehicle to be proposed was based on introducing a methodology for the kinematic modelling of an omnidirectional wheeled mobile robot equipped with four omnidirectional wheels which were based on passive rollers arranged in an overlapping way [1]. These wheels were positioned in pairs on the same axle but with opposite orientations. Another proposal by Wada and Mori [18] presented a new type of holonomic mobile robot which was equipped with steerable and coordinated driving wheels using conventional tires to provide an omnidirectional capability by actuating the wheels axis and a steering axis independently. In another paper by Javier Moreno, Eduard Clotet, and others design [1] validate a three-wheel holonomic motion system for an assistant personal robot. The paper analyzes the kinematics of the motion system and

Figure 2.4: Different variations of mecanum wheels [15].

validates the estimation of the trajectory by comparing the displacement estimated with the internal odometry of the motors and the displacement estimated with a Simultaneous Localization and Mapping (SLAM) procedure based on Light Detection and Ranging (LIDAR) information .

2.3 Gap Analysis

Huge leaps have been made in the development of mobile vehicles or robots with holonomic and omnidirectional motion. Mecanum wheels have taken center stage, and the use of rollers attached to a conventional wheel has found great applications in small-scale robots and mobile platforms. However, these wheels cannot be applied to certain applications that involve heavy payloads or rough terrains. Such applications are moving objects in warehouses or factory floors. Castors are predominantly used in these areas, but it involves manual control. This process can be automated by modifying the castors by adding motors for directional control and adding the concept of remote control. This, however, has not been adopted which necessitates this research.

3 Methodology

To achieve the specific objectives, three modules: mechanical, electrical, and control will have to be developed in a synergistic manner.

3.1 Mechanical Module

3.1.1 Castor Wheels

Several considerations need to be taken into account when selecting the type of castors to use, the most important being the load capacity of the wheel. This will be determined by the diameter of the wheel. The castor should also be easy to modify to achieve motion from a motor.

3.1.2 Mechanical chassis and platform

The chassis will form the underside of the mobile platform and will be used to attach the caster wheels and their drive systems. It will also hold platform onto which the electrical and electronic components, including the motors and control unit will be supported. The platform will cover up the electronics and allow for an application to be added to the system. The two modules will be made from the same material, preferably metal. Some of the design considerations for this material are:

- It should be lightweight and able to handle heavy loads, i.e., it should have excellent tensile strength.
- It should have high machinability which would make fabrication easy.
- It should have corrosion resistance.
- It should be readily available.

These design considerations narrow down the list of appropriate materials to aluminium, steel, and stainless steel. The metal that satisfies these considerations will be selected for the design work.

3.1.3 Power Transmission Unit

To transmit power from the motor to the wheels, a power transmission unit will be required. The mechanical power transmission elements under consideration are shafts and couplings, gears and gear trains, brakes and clutches, and chains. Some of the things to consider when assembling a power transmission unit are:

- Torque transmitted
- Parallel or non-parallel shafts
- Shaft size
- Speed of rotation

The mechanical shaft is the most important part of the power transmission unit. Sub-components such as couplings, gears, and chains are mounted onto a shaft to transmit power or rotation from a motor. The connection should ensure the connection transmits the load, power and rotation without slipping and within the accuracy requirement of the design. Load, power, and rotation speeds will be determined from the motor characteristics.

3.2 Electrical and Electronics Module

3.2.1 Motors

The motor is the main actuation unit in the system. Each wheel will have its own independent actuation unit made up of motors and power transmission components. In particular, DC motors will be used, and several parameters of the motor will be considered before settling on a final design. Some of these parameters are horsepower, rotation speed, and maximum torque. These characteristics will depend on the mechanical structure of the mobile platform. The size, weight, and maximum load characteristics will ultimately determine the motor speed, torque, and power requirements. The choice of motor will also depend on :

- Maximal speed. The duration of how long it takes to have the sustained maximum speed needs to be calculated. If we are using a gearbox, the available gear ratios will help us calculate the maximal speed of the motor

- Maximal torque. The maximum torque enables the vehicle to start in a given slope. It is possible to calculate the highest torque required by the electric motor considering the differential and gearbox, if using a gearbox. Maximal weight is also to be taken into consideration.

- Maximal power. The maximum power is found simply at maximum speed, this is the case where the vehicle as a large frontal area or goes at very high speed. This translates to having a motor powerful enough to go through all the different conditions the vehicle can be submitted to. The maximum power enables the vehicle to reach and maintain a constant speed under stringent slope and speed conditions. To calculate the maximum power, you need to have a simulator that takes in account the drag and friction coefficients of the vehicle in addition to the forces needed for the climb.

- Battery Capacity. The battery capacity is typically calculated using a simulator to go through a reference cycle typical of the usage of the vehicle. The simulator can output the consumption of the vehicle in Wh/m.

- Battery Voltage. The battery voltage is dependent on the size of the vehicle. As the battery voltage increases, the current output is lowered. So in the cases where the vehicle continuous power is high like in bigger vehicles, you want to keep the size of the conductors at a manageable level by increasing the battery voltage.

- Gearbox or direct-drive. The high torque/low speed of the motor allows it to directly interface with standard axle differentials without the need for an intermediate gearbox. While improving system reliability and reducing overall maintenance costs.

- Cost

3.3 Control Module

3.3.1 Processing Unit

Responsible for executing the application logic, sending instructions to the motor driver, and reading inputs from the proximity sensors in the system. The choice of a micro controller or microprocessor will be determined by the following factors.

- Analog Pins: This is the interface between the motor driver and the control module. The analog pins should be able to send the different modes to the motors attached to the motor driver. The availability of approximately 16 will guide the choice of micro controller needed

- Digital to Analog Converter (DAC) Resolution Since we need a fine grain control of speed on the motors we will therefore need a micro controller or microprocessor with a higher DAC resolution.

- Wireless capability: Since we need the mobile platform to be remotely actuated we need a micro controller that can be able to connect to a wireless standard preferably WiFi or Bluetooth low energy. The availability of this two wireless standards will guide the choice of micro controller needed.

- Energy consumption Since we are running on battery power we should be able to use the source of energy wisely. We should be able to choose a micro controller that is not power hungry. The maximum, idle and rated power of the micro controller will guide the choice of micro controller needed.

3.3.2 Motor Control

Responsible for executing the application logic, sending instructions to the motors through a motor driver. The choice of a motor controller will be determined by the following factors. The procedure of how we will be controlling the motor is shown by figure 3.1. We will get the user input through remote control as shown by figure 3.2. This will translate it to the specific trajectory the robot will undertake. The trajectory will be passed through a fuzzy logic controller which understands our system. This will output the actuator values. We will cross reference the values with an ideal kinematic model and then actuate the motors. This will happen through a power transmission link. We will continually collect sensor data to check how our system is behaving and try to optimize it.

- Voltage rating of the motor driver A motor driver with a voltage of either 9v or 12v is ideal as it is difficult to find battery sources with more than 12V currently
- Type of control We will be controlling the speed and direction of rotation of the DC motors. This will guide us in looking of speed controllers for motors
- Type of motor being used
- Continuous current supply by the analog pins
- Control method wither Pulse Width Modulation (PWM) or analog voltage

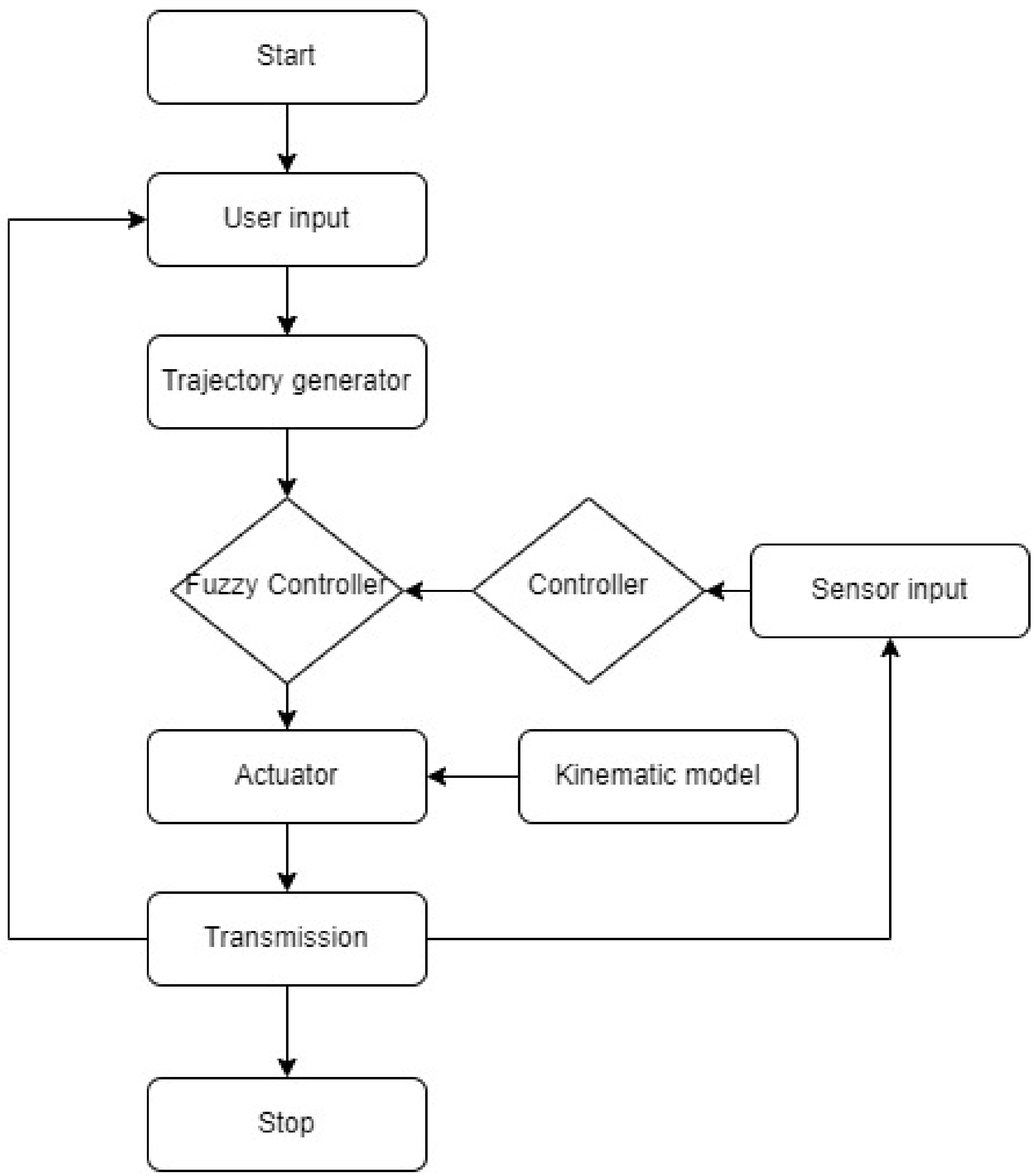

Figure 3.1: Flow chart for Motor Control

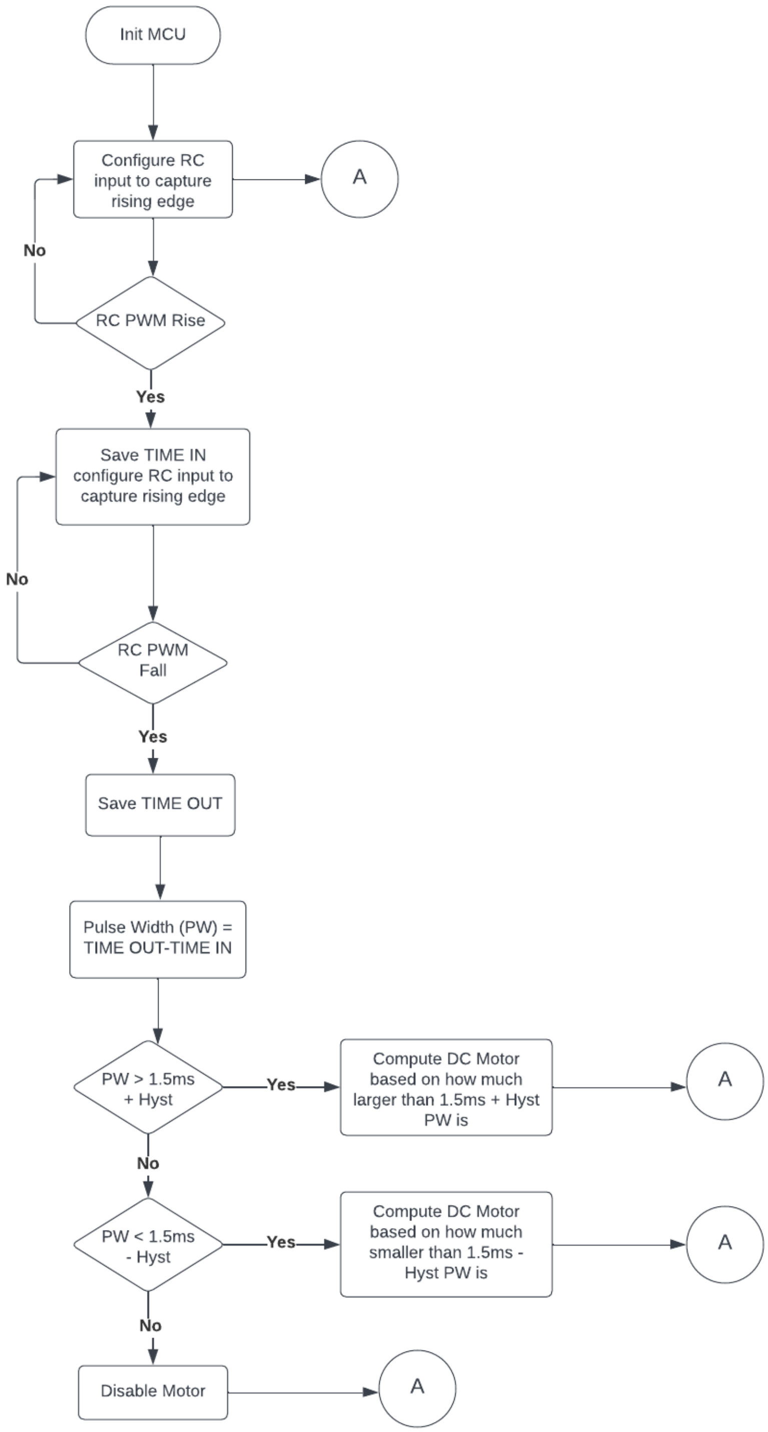

Figure 3.2: Flow chart for Remote Motor Control

4 Expected Outcomes

1. Fabricated mechanical chassis to have an application fitted onto it.

2. Synergistic Integration of DC motors for individual caster wheels

3. An algorithm to control the motors and achieve simultaneous holonomic and omni-directional motion from the caster wheels

4. To remotely connect to the mobile platform and drive it

5 Budget

No.	Item	Quantity	Supplier	Unit Cost	Total cost
1	DC motor	8	Pixel Electric	200	1600
2	Microcontroller	1	Pixel Electric	600	600
3	Wireless module	2	Pixel Electric	500	1000
4	JoyStick	2	Pixel Electric	250	500
5	Proximity Sensor	4	Pixel Electric	250	1000
6	Battery	1	Pixel Electric	500	500
7	Aluminium Sheet 50cm X 50cm	1	Hardware	1500	1500
8	Castor Wheels	4	Nerokas	200	800
9	Steel wires	5	Hardware	60	300
10	Gears	16	Hardware	200	3200
11	Chain	8	Hardware	200	1600
12	Miscelleneous	1		2000	2000
				TOTAL	14600

Table 5.1: Budget

6 Time Plan

	SEMESTER 1										
Week	1	2	3	4	5	6	7	8	9	10	11
Project Proposal											
Continuous Presentation											
Literature Review											
Mechanical Design											
Electrical Design											
Software Design											
Material Acquisition											
Assembly											
Testing											
Demonstration											

Table 6.1: Semester 1 Time-plan

	SEMESTER 2													
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Proposal														
Continuos Presentation														
Literature Review														
Mechanical Design														
Electrical Design														
Software Design														
Material Acquisition														
Assembly														
Testing														
Demonstration														

Table 6.2: Semester 2 Time-plan

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