Solar-Powered Path Finding Carrier (SPC) Robot

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Abstract — **The SPC is an autonomous path-finding carrier robot that is completely solar powered. It features technology such as Lidar and Bluetooth. The goal of the SPC is to assist the user with carrying up to 25 pounds of cargo, while either following behind the user or autonomously navigating to GPS coordinates. The SPC is equipped with a GPS module that is used to navigate the robot to specific coordinates given by the user. In addition, the Lidar sensor is used to avoid obstacle collision. The motivation behind this project was the desire to improve our daily lives while assisting an individual to carry extra an load with a following robot. As this project is very large and required many different challenging aspects, numerous fields of engineering teamed up together, including: Electrical, Computer Science and Optical Engineering.**

Index Terms — **GPS positioning, Autonomous, Lidar, Communication, Solar-powered vehicles.**

I. INTRODUCTION

In today's hyperactive and busy world, carrying items is something we are constantly and actively doing. The issue that then plagues us is the number of things we are readily able to carry with our hands. When we get our groceries either from the car into the house or vice versa, having the option of a one-time trip is always satisfying. However, like many things there will always be obstacles that we just can't overcome on our own, which makes a one-time trip nearly impossible due to an item being too big/heavy to carry.

Perhaps, you may know someone or be in the specific situation yourself, where you're having issues carrying items from point A to point B. This could be due to age or health related issues and unfortunately, we cannot always have someone to be there to help/assist at that point in time. These concerns are what led our team to consider making our "Solar-Powered Path-Finding Carrier Robot" project.

Our project is to design and build a path-finding carrier robot that is completely solar powered. This robot will assist the user with carrying up to 25 pounds of cargo, while either following behind the user or autonomously navigating to GPS coordinates. Our carrier robot will be equipped with Bluetooth so that it can follow the user effectively. In addition, a GPS module and compass will be used to navigate the robot to specific coordinates given by the user. The motivation behind this project was the desire to improve our daily lives while assisting an individual to carry an extra load with the carrier robot. Our robot can be used by the everyday consumer to carry their groceries to their house or textbooks around campus, as well as assisting disabled individuals with everyday tasks.

For our robot to safely move around autonomously and avoid obstacle collision we will be using a LIDAR sensor. This sensor will be designed and built tailored for our carrier robot needs. This sensor will be using the time-of-flight principle to map out the distances of surrounding objects. The TOF principle is a method of measuring the distance between a target and the sensor, based on the time taken for the emitted signal to return to the sensor after being reflected off the target. This will create a 2D map of the robot's surrounding area with every potential obstacle in its way. Our LIDAR sensor will have a range of 20-25. This will give the robot the ability to detect an obstacle in its way and find an alternative path. The LIDAR sensor will be placed on the top-front side of the robot to give it a 360-degree scan of its environment.

Finally, the robot will contain PV solar panels which will allow for the recharge of the batteries. Solar panels are useful because they convert the particles of sunlight into energy or electricity. This will help with not having to charge the robot directly to an outlet, over time occurring at a higher and higher cost. In addition, this will make the robot truly autonomous as it will be able to charge on its own, versus having someone plug it in or change its batteries.

II. SYSTEM CONCEPT

A. System Overview Concept

The robot is comprised of multiple parts that were put together to make the robot functional. In the following section (System Components) we will discuss further

understanding of these parts and how they function. In the flow chart below on figure 1, we can see how all those parts connected together to be able to make a complete system. This system comprises of most of our parts on our SPC robot.
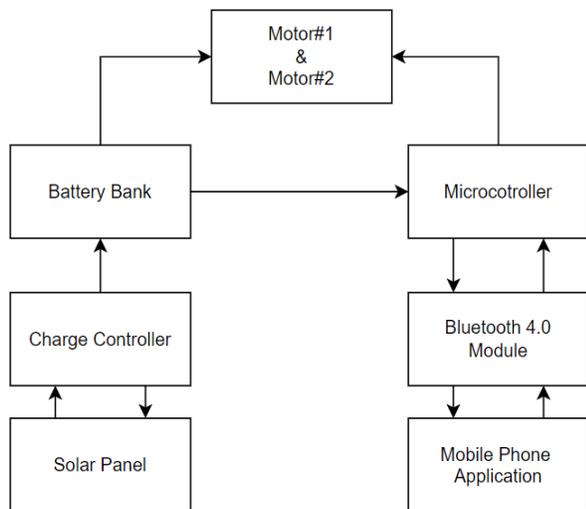

Figure 1: Complete Electrical and Communication System

B. Software Concept

To better understand the software system, below is the breakdown:

Mobile App Block Status:
- ♦ Input: User gives commands to the SPC robot
- ♦ Output: Connects to the GPS block through Bluetooth and prompts the data with instructions on what to do

GPS/tracker Block:
- ♦ Input: Receives data from the Mobile App Block which then gives information on the GPS location. It also has information coming from the Motor Control block updating the direction of the SPC robot
- ♦ Output: It provides the current location to the Mobile App and Motion sensor block

Motion sensors Block:
- ♦ Input: Receives the obstacle in front of the SPC from the transmitter and then passes along the information to the receiver on any potential obstacle in the surrounding of the SPC robot.
- ♦ Output: This gives out warnings to the Motor Controls block about any obstacle or threat in its surroundings and then suggests a different route or comes to a complete stop.

Motors Controls Block:

- ♦ Input: Receives information from the Motion Sensors block which warns the motor controls to navigate the movement of the robot to ensure accurate control if there are obstacles in the way.
- ♦ Output: This controls the speed at which the motors operate and the direction the user prompts the robot towards. It also gives updated information to the GPS block to ensure accuracy in the direction and speed of the SPC robot.

C. Optical Concept

Our lidar sensor is made up of 4 main components with several additional parts to assist them. The first main component is the transmitter. We are using a pulsed laser diode to emit short pulses of light into the surrounding environment that will reflect off the objects around it and return to the sensor. A pulsed laser driver including; a MOSFET and driver, current sensing resistor and a comparator is used to run the pulsed laser diode.[1]

The second is the receiver, the receiver's job is to transmit the pulses of light that come back from the object into electrical data so that the time-of-flight measurement can be done. We will be using an avalanche photodiode as our receiver. With the help of a transimpedance amplifier the current output from the photodiode can be amplified to a usable voltage [2]. From there, a high-speed comparator captures the data and sends it to a time-to-digital converter (TDC) for calculation of the ToF measurement as shown in Figure. The comparator works by tying one of the inputs to a reference voltage and comparing the reflected pulse to this voltage. If the reflected light pulse from the object is above the reference threshold, the distance to that object will be sent to the TDC and measured. The TDC measures the start and stop time from when the pulse left the laser diode to when it was picked up by the receiver and converts this time interval into a digital (binary) output. Using the equation:

$$D = \frac{c \times t}{2}$$

where d is the distance, c is the speed of light, and t is the time interval from start to stop, the distance from the sensor to the object can be calculated.
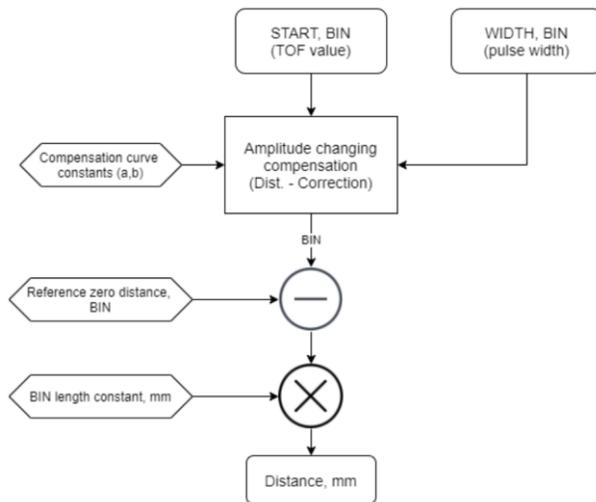
Figure 2: TOF block diagram

The third main component of the LIDAR sensor is the Lens and filters. A laser lens and M12 mount and holder are used to focus the collimated light from the laser diode onto the mirror. A photodiode lens with a CS mount and CS lens holder are placed on top of the photodiode to capture the signal of the incoming pulse from the object. Also, the photodiode has a built-in bandpass filter from 870nm- 940nm, with the peak at 905nm. This means that any light picked up by the receiver that has a lower wavelength than 870nm or a higher wavelength than 940nm will not pass through the filter. This is extremely helpful for blocking out the noise of background light from the environment when the senor is operating outdoors.

The last main component is the rotating mirror. This mirror will reflect the pulses coming from the laser diode out into the environment and pulses coming from the environment into the photodiode. The mirror will be kept at a fixed 45-degree angle and placed in a holder so that it can be rotated. Using a stepper motor driver and motor attached to the back of the mirror, the mirror will rotate 360 degrees. By rotating 360 degrees, the sensor will be able to send and retrieve pulses from every surrounding object, creating a 2D scan of the robot's environment. By using a stepper motor, we are able to adjust the size and speed of the steps to our sensor's needs. By increasing the number of steps per revolution we are able to increase the resolution of the system by it will also increase the time it takes to complete one full scan.

III. SYSTEM COMPONENTS

A. Microcontroller

The micro-controller is the brain of our whole robot. It is constantly sending and receing signals and data between different components with their unique communication protocols. Because of this we made sure that the micro-controller we chose had I2C, SPI, and UART as different communication protocols. The microcontroller uses I/O pins so it can communicate with the other devices as well. It receives information via its inputs and gives out data or commands via the output. For this project we have the microcontroller control the motor controllers, sensors for collison detection, bluetooth, GPS, and a compass. When deciding which microconroller to choose we kept in mind that it must be able to operate all these different components, while also giving it their proper VCC, typically 3.3V-5V. We also took into consideration a microcontroller that has simplicity in terms of programming.

The MCU we decided to use is the ATmega328P. Arduino Uno is a microcontroller board based on the ATmega328P because this is the chip it has mounted on. This MCU is a very common and popular MCU used which gave us all the support we needed across the internet, while also checking off all our preferred specs that we wanted from an MCU. The ATmega328P will commonly be referred to as Arduino Uno on this paper.

It has 14 digital input/output pins, 6 of which we can use as PWM outputs. It also has 6 analog inputs, a 16MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. It has two 8-bit Timers with compare modes, and one 16-bit Timer with compare mode and capture mode. The timer on this board is also programmable like the previous board discussed. The timer also has a separate oscillator. The most special features to point out are the power-on reset, internal calibrated oscillator, external and internal interrupt sources, and the six sleep modes that are IDLE, ADC noise reduction, power-save, power-down, standby, and extended standby. This board has high endurance non-volatile memory segments. This board has 32K bytes of in-system self-programmable flash program memory, 1K bytes EEPROM, and 2K bytes internal SRAM. It also has the option to boot code section with independent lock bits. This means it has in-system programming and read-while-write operation. The memory also has programming lock for software security. Arduino software is its own IDE, which makes it easier to use and program for different levels of programmers. It is an open-source software that can be expanded onto C++ libraries. There are a vast variety of libraries that can already be implemented. It

also brings many different ports that are of benefit to us. Lastly, it provides all the communication protocols we would need to connect most parts.

B. Motors / Motor Driver

The Motor Driver Controller selected for this project was the BTS7960 Half bridge Motor Driver. These motor drivers are commonly used for systems with higher currents up to 43A. This Half bridge allows to control only one motor two directions, clockwise and counterclockwise. It contains one P-Channel MOSFET and one N-Channel MOSFET in addition to an Integrated Chip to control the logic input received from the microcontroller. The IC allows the user for easier connection with a microcontroller such as the ATmega328P chip used for this project. It also has an overtemperature protection circuit which shuts down both the output stages, which protects the system in higher temperatures.

C. Sensors

For our robot to safely move around autonomously, we will be using a LIDAR sensor. The primary optical component of this project is the LIDAR sensor, used for obstacle avoidance and autonomous navigation. This sensor will be designed and built tailored for our carrier robot.

This sensor will be using the time-of-flight principle to measure the distances of surrounding objects. The TOF principle is a method of measuring the distance between a target and the sensor, based on the time taken for the emitted signal to return to the sensor after being reflected off the target. In this case, the laser will emit very short pulses of light aimed at the mirror, because the mirror will be at a 45-degree angle, these pulses will then travel into the surrounding area. When one of these pulses hits an object, it will reflect back into the mirror and then into the photodiode. The photodiode is the receiver in this system, and it will collect all the reflected light pulses from the laser. With the help of an amplifier, comparator, and time-to-digital converter, the photodiode will be able to measure the exact time it took for that pulse to leave the laser and then return to the sensor. Using this time measurement and the velocity of light, the sensor will be able to measure the distance to that object. That is how one measurement is taken in one direction. By using a stepper motor attached to the back of the mirror so that it rotates 360 degrees, the sensor will be able to repeat

that process over and over again until it has a 2D map of its surrounding area with every potential obstacle in its way. Our LIDAR sensor will have a range of 20-25m. This will give the robot amble time to detect an obstacle in it's way and find an alternative path. The LIDAR sensor will be placed on the top-front side of the robot to give it the best view of its surroundings.

D. GPS

The word GPS is an acronym for Global Positioning System and is defined as a positioning system based on a network of satellites that continuously transmit coded information. This information is then interpreted by receivers to identify locations on earth by measuring distances from satellites.

In this project the autonomous robot takes the input from the GPS receiver and using those inputs it will be able to navigate through a set of points. These points are given to the GPS receiver via the phone app we will discuss in on the application section. To start the GPS receiver tries to get a fix on visible GPS satellites and computes the current latitude and longitude. It then looks at the direction it is pointing with the help of the compass and computes the direction of the next destination point specified. The robot will then move in the direction of the next specified point using the GPS component and compass help. The GPS will determine its location via geographical coordinates given to the bot. Once it reaches the next geographical coordinate the GPS will pass on the message to the robot and the robot will come to a halt.

The GPS component we decided to use alongside the Atmega328P Arduino microcontroller for our project is the NEO-M6, the 50-channel receiver. This GPS recognizes multiple constellations simultaneously and provides positioning accuracy in scenarios where urban canyon or weak signal are involved. It supports message integrity protection, geofencing, and spoofing detection. This helps the device to fighting against anyone that may attempt to hijack and give false geographical location to the GPS. The exact version of the NEO-M8 will be the NEO-M8N since it is their best performance version. It is also future proof which helps for customers who would like to keep their bot for a long period of time. The future proof is made easy with the internal flash that allows future firmware updates. Within the first 27 second it will try determining its position, this is considered the cold start, however if you tell the GPS the date, time, and position ahead of time this will drastically cut down start time to 3 seconds or less, this is considered an aided start. The accuracy of the location is about 2.5 meters and receives a signal for update between 30-60ns with signals

to receive and track being the L1C/A at 1575.42 MHz.. The NEO-M6 uses a power supply voltage of 3.6V to 5V. The NEO-M6 offers a power-optimized architecture with build-in autonomous power saving function to minimize power consumption at any given time.

E. Compass

The compass we used on this project is named HMC5883L. This is a 3-Axis Digital Compass with x,y,z axis. This compass is friendly to the ATmega328P Arduino family. It has multiple ways of self-testing via the example libraries on their IDE. Like all compass, before using you must give it a Declination Angle. This is the Error of the magnetic field in your location. This only might give the compass some help to find the true North. However, in our case this was not true. After giving it the declination angle, we then had to do multiple tests to give it a proper offset in order to have the compass find the angle to the correct true north.

F. Bluetooth

There are plenty of different electronics that have Bluetooth already integrated into the. This includes common electronics like laptops, tablets, cellular devices, many gaming devices, and many more that we know and use every day. Bluetooth has become one of the most useful tools for wireless connection between two or more devices that are near each other. For this reason, we have decided to use Bluetooth on our SPC robot. This is common technology that most users will now have access to. The implementation of Bluetooth is fairly simple to add to the SPC due to the MCU we have chosen to use. A common Bluetooth component used with Arduino is the HC-05 component. It is the module we used on our robot in order to communicate from the blynk app to the robot. The following are the configurations used to make the HC-05 function with our MCU:

- VCC – This pin supplies Voltage 5V
- GND – This pin is the ground pin
- TXD & RXD – This acts as the UART interface for communications.

Below in Figure 3 we can see the signal strength of the HC-05 found in its data sheet. This is also a key major as to why we chose this module besides its simplicity of use. According to the data sheet the range is most effective within 20 meters. Anything past the 20 meters will receive a significantly weaker signal and eventually lose connection. This error drastically jumps right after the 20-meter mark as well. Although there shows a small error bump on the 10 meters, this can possibly be done by

interferences from other electronics. However, our robot has a specification of about 3 meters max. Those 3 meters is so it follows behind the user. If the robot continuously stays within 3 meters of the person, then the errors should be very minimal according to the data sheet.
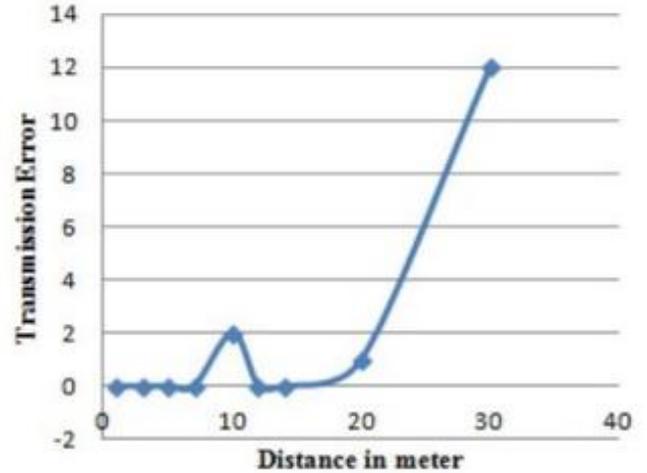
G. Mobile Applications

The mobile application used for this project is the blynk app which is available in the operating systems of both android and iOS. The mobile application we are using is a commonly used application when programming with microcontrollers. It also helps that it is user friendly. We will be controlling the SPC robot by using the blynk mobile app to connect to the Arduino uno. The app also comes with multiple features of which Bluetooth and GPS are part of and a button is set up in the blynk app to operate the SPC robot such as the ON/OFF button.

H. Power Supply

The Battery used for the project was a 12V 9ah rated lead-acid battery. It was selected due to its availability and popularity for 12V Kids Toy Cars. It is rechargeable and smaller when compared to other 12V/ 9Ah rated batteries.
Using the equation below it was possible to calculate the expected life cycle of the battery in between uses. Since both motors will be taking at least 4 Amps at the speed established it is possible to calculate that the total load of the system will be approximately 100W. It is possible to estimate that the possible continuous running time for the S.P.C (Solar Powered Path finding Carrier) is 1 hour and 8 minutes.

$$Battery\ (h) = \frac{V(V) \cdot Capacity(Ah)}{P(w)}$$

. (1)

The Charge Controller designed provides a simple yet effective charging solution. The LDO Charge Controller or Low Dropout Charge Controller allows for fast recharging times for the 12V/9Ah Lead-Acid Battery. The LDO Controller allows to maintain and higher voltage on the Panel side by regulating the battery voltage and allowing current to flow from the Panel into the Battery. In any case that the Panel's voltage decreases enough that the battery voltage is higher, then the charger will not allow the flow of current effectively turning off the charger. The Controller also possesses a reverse battery protection circuit in case the user connects the battery in reverse. Figure X. Illustrates the charging response of the battery connected to a 50W 12V Monocrystalline Solar Panel. It is possible to observe how the voltage of the battery increases over time as it is being charged using the LDO Charge Controller.
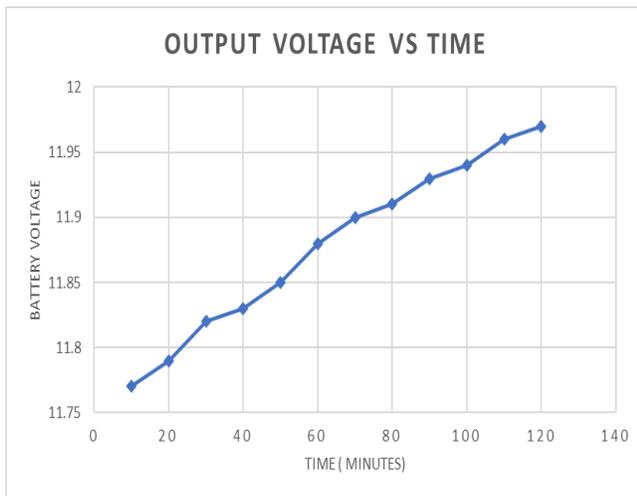

Figure X. Charging of the Battery over time

I.   Structure Design

The structure was completely built by the team. It consists of some wood panels 13" inches wide by 22' inches long. It uses two 2 35000 RPM (Revolutions Per Minute) Gearboxes for 12V motors and 2 5" inch Caster wheels on the back for better mobility. The wood was treated with a waterproof sealant to protect it from water as much as possible. The body is reinforced with 4-inch screws for better sturdiness. All the bolts and nuts were secured in place with glue as well, to prevent disassembly due to vibrations as it is moving through tougher terrain. The Plexi-glass allows for a good airflow to maintain the components as cool as possible while preventing water from coming in and allowing the user to see the inside with ease. The frame was able to withstand 35-lbs and move without any problem.

IV. COMMUNICATION PROTOCOLS

Serial communication is a communication method that uses one or two transmission lines and receive data. That data is continuously sent and received one bit a time through a single bit of data through a channel sequentially, opposed to a parallel communication, which sends multiple bits of data over a number of channels simultaneously. It is widely used to transfer information between equipment and peripherals.

There are a few standardized serial communication methods that exist for sending and receiving data synchronously and asynchronously that will benefit this project. Synchronous serial communications such as I2C (Inter-integrated Circuit), and SPI (Serial Peripheral Interface) could be used for interfacing the microcontroller with other subsystems such as Bluetooth. Asynchronous serial communications such as UART (Universal Asynchronous Receiver Transmitter) are useful for transmitting and receiving data between the device and the external device without having to wait for the other electronic. This would benefit something like the GPS when it just sends the coordinates information when it needs to across the microcontroller. When connecting the other subsystems to the microcontroller we must make sure we use the correct communication protocol. This is because in order for a subsystem to communicate with the entire system it needs to be able to route its information through the correct buses. The ATmega328P, Arduino Uno board we are using has the three protocols. I2C, UART and SPI. Therefore, we can benefit from all three of these protocols.

A.   I2C

Two signals, clock, and data are used regardless of how many devices are on the bus. Both signals pull up to the power supply voltage through appropriate resistors. Every device interface to the clock and data signal through open-drain or open-collector output drivers. The open-drain for the SDA and SCL is what distinguishes the I2C from the SPI and UART. This means that an I2C can only assert a low signal, making it an active-low. Serial Data is

the data signal. This is the transmission line that data is transmitted between masters and slaves. Serial Clock is the clock signal. The clock signal is created by the master bus. Slaves have the ability to command those clock signals to a lower frequency for some extra processing time in case they are receiving too much data from the master all at once. The I2C of the board is used by the compass of the project. The SCL would activate the compass with the clock line and the SDA would be where the Compass transfers the data to tell the board which direction it is currently looking at. These pins are generally found on the analog pins of the ATmega328P board.

B. UART

The UART (Universal Asynchronous Receiver Transmitter) is something that enables serial communications. This is another interface that is commonly used by microcontrollers between parallel and serial connections. One side of the UART has a parallel bus with multiple data lines, and the other side has two serial lines: the receiver (RX) and the transmitter (TX). In two-way communication, we use two wires for successful serial data transfer. This can help with the need of less circuitry and wires, thus reducing the cost of this implementation. The UART is responsible for converting the data from the microcontroller received through the parallel bus into serial data sent through the TX serial line. It is also responsible for converting data received through the RX serial line into data sent over the parallel bus lines that were received by the microcontroller. It also helps with handling interruptions from peripheral devices. The Bluetooth is connected via these RX and TX pins for communicating with other devices and sending those signals to the MCU. The GPS is also declared in the code to use RX and TX pins on the MCU board. When uploading code, we do have to disconnect the Bluetooth module and the GPS module because when uploading code to the MCU board, there would be an interruption. Since UART handles interruptions, it does not proceed with upload. This is all because code is uploaded via UART as well.

C. SPI

The serial Peripheral Interface Bus, also known as SPI, was made to use over small distances and has been considered a standard embedded system communication method for some time due to its simplicity and versatility. The SPI is also synchronous just like the I^{2}C protocol. This means that the clock signal will also be used to synchronize data and transmission. Devices that use SPI transmit and receive data at the same time. This is referred to as full-duplex mode. The four SPI bus wires that are important are:
• Slave Select (SS): This is the signal that the master uses to choose which slave it will communicate with.
• Serial Clock (SCLK): This signal is generated by the master, and it synchronizes all SPI signals.
• Master In Slave Out (MISO): This is a unidirectional data signal that travels from the slave output pin to the master input pin.
• Master Out Slave In (MOSI): This is a unidirectional data signal that travels from the master output pin to the slave input pin.

The SPI protocol uses a single master but supports multiple slaves. For this project it was not necessary for us to use the SPI protocol, however it is beneficial to have. This gives us the option to connect 2 MCU boards together via the SPI bus wires. Doing this would expand the amount of pins we can use while building the robot. This is of course beneficial because the Motor Driver we have chosen has taken up many digital and PWM pins. This left a small amount of pins for other electronics to connect to including the LiDar sensor. When testing the LiDar sense we ended up using a separate but similar MCU board for testing to allow more pins for it.

V. CONCLUSION

The objectives and goals of this project are to design and build a path-finding carrier robot that is completely solar powered which assists the user in performing different duties to ensure a more convenient maneuver through daily task that requires the user move equipment or luggage from place to place. Since at its core the SPC robot is an autonomous robot, it will be moving around autonomously with the help of a LIDAR sensor which will be able to assist the user in completing certain tasks such as obstacle avoidance and help in carrying objects. This project was made with design goals to ensure durability, efficiency, and most importantly low cost so that it appeal to a commercial market.

BIBLIOGRAPHY

Deborah Campbell is currently a senior at the University of Central Florida and will be graduating with a Bachelor of Science in Computer Engineering in May 2022. After graduating, she will be pursuing a career in Software Engineering.

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