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Autonomous Basketball Court Creation Robot

Bryce Haldeman
bah163@uakron.edu

Tyler Gray
The University of Akron, tjg96@uakron.edu

Dalon Vura
The University of Akron, dav28@uakron.edu

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Project Final Report

Tyler Gray

Bryce Haldeman

Dalon Vura

Faculty Advisor: Mohammed Ali

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Abstract

The Autonomous Basketball Court Outlining System presents a comprehensive solution for precision court marking. Powered by a 24V lithium-ion battery and driven by a single ST microcontroller, the system autonomously marks the outline of a half basketball court using predefined algorithms. User-friendly features include easy loading of marking material, actuated by gravity or a small servo motor depending on material of choice, ensuring intuitive operation. Safety is prioritized, with the servo motor eliminating high-pressure concerns, and the system maintains a controlled speed accounting for user well-being. Two step and direction servo motors enable accurate linear displacement, facilitating straight lines, and continuous arcs. Distance measurement and user feedback are achieved through encoder feedback. The system's efficient operation allows completion within a full battery charge, offering up to 50 minutes of runtime. Weighing less than 20lbs, it is portable, meeting torque considerations for optimal performance. The integration of a 24V to 3.3V switching circuit on the PCB ensures compatibility, while the chosen microcontroller provides centralized control and computational power. This project harmonizes technological precision, user convenience, and safety, delivering a sophisticated solution for basketball court outlining.

1. Problem Statement

1.1 Need

According to a survey done by Utah State University, parents with kids ages 6-18 identified basketball as the most popular sport amongst their children. The Statista Research Department estimates that over 27 million people play basketball each year and with the global basketball gear market size of roughly $800 million each year, basketball is very popular amongst casual “backyard” players. Although not a requirement, each court should be outlined with a 3-point arc, free-throw line, and restricted area amongst other things. A system is needed to allow players to outline their courts at home with precision and accuracy.

1.2 Objective

The objective of this project is to design a device that will autonomously spray the outline of a basketball court. This device will be placed in the desired area for the court and will spray the perimeter, three-point line, baseline, key, low post area and other lines to create an accurate half basketball court.

1.3 Background

The basic theory behind an autonomous robot that will spray the outline of a half basketball court involves several key components: sensing, planning, and actuation. While sensing, the robot needs to be equipped with sensors that allow it to perceive its environment. For example, it may use cameras or lidar sensors to detect the location and shape of the basketball court. It may also use inertial sensors or encoders to track its own movement.

For the planning phase, once the robot has gathered information about the basketball court and its own position, it needs to plan a path for itself that will enable it to mark the outline of the court. This may involve using algorithms such as path planning, obstacle avoidance, and motion control (Alzahrani 2018). Finally, the robot needs to actuate its movements to physically apply the outline of the court. This may involve controlling the speed and direction of its movement and the spray mechanism to ensure the outline is sprayed accurately. The key idea behind an autonomous robot that can spray the outline of a half basketball court is to use sensing, planning, and actuation to enable the robot to navigate its environment and perform the specific task autonomously.

One of the design's goals is to allow organized basketball games to be more accessible to everyday consumers and casual players. This will be achieved by marketing the product in a way that allows it to encourage the youth to get outside and get involved with physical activity. According to Dayna Reich in her article “Basketball” that appeared in the Women’s Sports and Fitness magazine, “It's a full-body workout that builds strength and increases agility.” (Reich 2000). According to the CDC, one in five individuals aged 2-19 are considered obese. Basketball is proven to burn around 500 calories per hour, and being the most popular sport amongst children, it is an effective way to stay active and social (Reich 2000). This device would promote higher activity levels in children by allowing them to play a more organized version of basketball in a residential setting.

There are similar autonomous robots that are designed to perform tasks such as marking the outline of various sport fields on the ground with paint which are currently being developed and used by a couple of organizations. For example, companies such as Intelligent Marking and Turf Tank (Sorensen 2018) are producing autonomous line-marking robots that use GPS technology to accurately mark sports turf fields with paint. Additionally, other research and development organizations are working on developing autonomous robots for a variety of tasks in the field of transportation. The direction and importance of automated vehicles (AVs) and the role they will play in future transportation systems is outlined in an article by Yu et al (2021). Although an autonomous robot outlining a basketball court is not itself a vehicle, it will use similar technologies to become automated as do AVs. The use of autonomous robots has the potential to increase efficiency, reduce costs, and improve safety in a wide range of industries.

While the Turf Tank robotic line marking system and other similar systems offer many advantages over traditional manual line marking methods, there are still some limitations and challenges that need to be addressed. The first limitation is the cost. The initial cost of purchasing and implementing a robotic line marking system can be high and may not be feasible for smaller organizations or individuals (Khanam 2019). The complexity of the technology involved in autonomous navigation, obstacle avoidance, and accurate line marking can require specialized skills to operate and maintain. The accuracy of these systems can still have limitations in certain conditions, such as uneven or bumpy surfaces or inclement weather conditions. Though, in ideal conditions GPS accuracy is approximately ±2cm (Hameed 2011) in autonomous vehicle systems. Lastly the maintenance of robotic line marking systems requires regular upkeep and may have parts that need to be replaced or repaired, which can add to the overall cost of ownership. These limitations are common challenges faced by many autonomous robotic systems in various fields. However, as technology advances and these challenges are addressed, it is likely that these systems will become more accessible, affordable, and reliable for a wider range of applications.

There are quite a few similarities and differences between established devices already in the industry and this proposed concept. Turf Tank, a robotic device used for painting lines, is used for turf fields and grass. The Turf Tank is marketed toward football, soccer, baseball, and lacrosse as well as rugby, all of which are played on grass or turf fields (Sorenson 2018). Some similarities the proposed concept shares with the Turf Tank are that both would be used for painting lines to create a playable field for the given sport, which in this case for the proposed concept is basketball. Both devices are also self-contained and do not require human interaction once the process of painting has begun unless the reservoir needs to be refilled with paint. A difference between the proposed concept and Turf Tank, however, is the weight difference. Turf Tank weighs 132 pounds with a full paint reservoir, which holds five gallons of paint. The proposed concept would weigh much less since it will not utilize paint as it's marking material. Turf Tank can paint an entire football field without refilling, whereas the proposed concept only needs to outline half of a basketball court and utilizes a marking material that does not get utilized as quickly as paint. The Turf Tank is also marketed toward commercial use whereas the proposed design would be marketed toward residential use.

The proposed concept shares similarities and differences as well with the Roomba. The concept needs to be able to turn with a radius of zero and this is what the Roomba does to make movement smoother and more efficient. The Roomba accomplishes this by having two wheels on independent motors that can move in reverse directions of each other to achieve a zero radius turn. The proposed design will require a similar approach in movement; however, the proposed concept will have bearings to allow it to balance properly on the surface. This type of movement will simplify the programming and engineering required to outline the court because it eliminates the need for a reverse mode. A difference between the Roomba and the proposed design is that the Roomba uses ultrasonic sensors to prevent collisions since it does not use a predetermined movement path. The proposed concept will utilize a predetermined movement path so ultrasonic sensors are not required. Another difference between the two systems is that the Roomba is lighter, only weighing seven pounds with an empty canister. The proposed design will need to utilize motors and other hardware that can handle the extra weight of the proposed design while still maintaining zero turn capability. Roomba also utilizes a charging station that the device knows how to locate and can dock itself whereas the proposed design will need to be recharged via conventional methods due to feasibility (Cohen 2014).

There are multiple systems that are relevant to the proposed concept. As previously mentioned, the patented product Turf Tank completes a similar goal. However, it is meant to be used on a larger scale and more for turf managers and companies instead of recreational use. Another similar product that has been mentioned is the Roomba. The Roomba is a robotic vacuum cleaner that uses navigation technology to complete the task of cleaning the floors inside a room. Using this concept, it is possible to adjust the design and create a machine that will mark the ground instead of cleaning. Another design that can be used for inspiration is the automatic paint sprayer developed by GRACO. This machine aims to reduce material consumption versus what would be used by the average person completing the same job. This concept will be used when completing the design of this concept. Allowing for this to become an affordable alternative to other solutions. One final inspiration for the idea is the addition of an anti-spill paint canister holder used in Black and Decker's paint sprayer design. Black and Decker has described their side filling canister to "[allow] for quick, clean refilling" (Black and Decker 2012). Taking advantage of this design, the robot would have a simple and efficient way to be cleaned and stored for the consumer to quickly use it and stow it away when not in use. Overall, the proposed system will allow at home players to outline their courts with precision and accuracy in the most efficient way possible.

1.4 Marketing Requirements

1. The system should be lightweight and portable.
2. The system should be rechargeable.
3. The system should be able to determine its location relative to the desired court.
4. The system should be able to create an entire half-court without the need to refill.
5. The system should be user-friendly and intuitive.
6. The system should be refillable.
7. The system should be relatively low cost.

2. Engineering Analysis

The system should be able to complete the outline within a full charge of its battery. Assuming the device is running off a lithium-ion battery with the following specifications:

- Battery Voltage: 24V
- Battery Capacity: 22,400mAh
- Battery Energy Capacity: 82.88Wh

Power consumption needs to be considered while spraying the court outline. Motors, paint dispensing mechanism, and any other electrical components all draw power and need to be considered. Assuming all the components draw 100W in total, the total on-time of the device can be calculated.

$$Time = \frac{Battery\ Energy\ Capacity\ [Wh]}{Power\ Requirement\ [h]} \qquad (1)$$

Using equation (1), the time can be calculated to be 0.8288 hours, or about 50 minutes. This means the system can operate for 50 minutes on one charge. This is enough time to complete the outline of a half basketball court.

The system should be able to operate from a 24V source. This fundamental specification sets the primary voltage level for the entire system. The PCB is designed to interface with a 24V voltage level, meeting this requirement ensures compatibility between the system’s components and the power supply. Within the PCB, there is a 24V to 3.3V switching circuit, which provides power to the microcontroller. This voltage regulation is crucial as the microcontroller is operated off a 3.3V supply.

The system is designed to facilitate user-friendly loading of marking material for operational ease. Instead of being pneumatically driven, the material dispensing process is actuated using a small servo motor. This servo motor is responsible for pressing down on a can of spraying material. The design ensures a straightforward and intuitive approach to loading material, offering convenience to users. The servo motor's controlled action eliminates the need for pneumatic components. The system operates within a safe pressure range of the servo motor, guaranteeing a consistent and continuous spray without posing any risk of punctures or bodily injury.

The system must be able to maintain a straight and accurate line. By utilizing two step and direction servo motors, two PWN signals will drive each motor to drive the device. In software, there will need to be a few things calculated, first being the linear displacement of the system via the servos.

$$Distance\ (m) = Number\ of\ Steps * Step\ Size\ \left(\frac{meter}{step}\right) \quad (2)$$

Using equation (2), the distance can be calculated and used to maintain a straight and accurate line. Note that the "Number of Steps" corresponds to the total number of steps taken by the motors to move the system, and the "Step Size" is the distance each step corresponds to. To determine the step size, the motor's specifications are used and calculated by equation (3).

$$Step\ Size\ \left(\frac{meter}{step}\right) = \frac{Distance\ per\ Revolution\ (meters)}{Number\ of\ Steps\ per\ Revolution} \quad (3)$$

Note that the "Distance per Revolution" is the distance the wheel travels in one full revolution, and "Number of Steps per Revolution" is the number of steps in one full revolution of the motor.

The system must be able to complete a continuous and accurate arc. This requirement emphasizes that the system should be capable of executing a curved path, such as an arc or circular motion, without interruptions, abrupt deviations, or inaccuracies. To achieve continuous and accurate arc motion, the control system and mechanical design play a crucial role. The choice of actuators, motors, and control algorithms should be suitable for maintaining a smooth arc. As there are two servo motors acting independently, a drive system is developed to allow for such a motion.

The system must be able to measure the distance it has traveled and the distance remaining to travel. By utilizing encoder feedback via the servo motors, an absolute position can be calculated and, along with it, the distance remaining can be calculated. This information can be used to provide the user with feedback on the progress of the task, among other things.

The system must have a user interface to control the state of ON/OFF. This requirement calls for a user interface that enables users to switch the system's power state between ON and OFF. This will be done using physical control and is designed specifically for ease of use. The user interface will be integrated into the microcontroller and other system circuitry to physically turn on and off the system. There will be no power consumed while the system is in the OFF state.

The system should move at a speed of less than 4 meters per second to not put anyone in danger during its operation. This requirement is in place for the users to maintain safety while using the device.

$$Safety\ Speed\ (m/s) = \frac{Safety\ Distance\ (m/s)}{Human\ Reaction\ Time\ (s)} \qquad (5)$$

To satisfy this requirement, a safety distance of 2 meters for the device is recommended while in operation. Assuming a human reaction time of 0.5 seconds, the device should not exceed 4 meters/second while operating as calculated by using equation (5).

The system should run off one ST microcontroller. Utilizing a single microcontroller for the system offers the advantage of centralized control. It simplifies the design and reduces the complexity associated with multiple controllers. The STM32G030K6T will be used with the pin configuration seen in Figure 1.

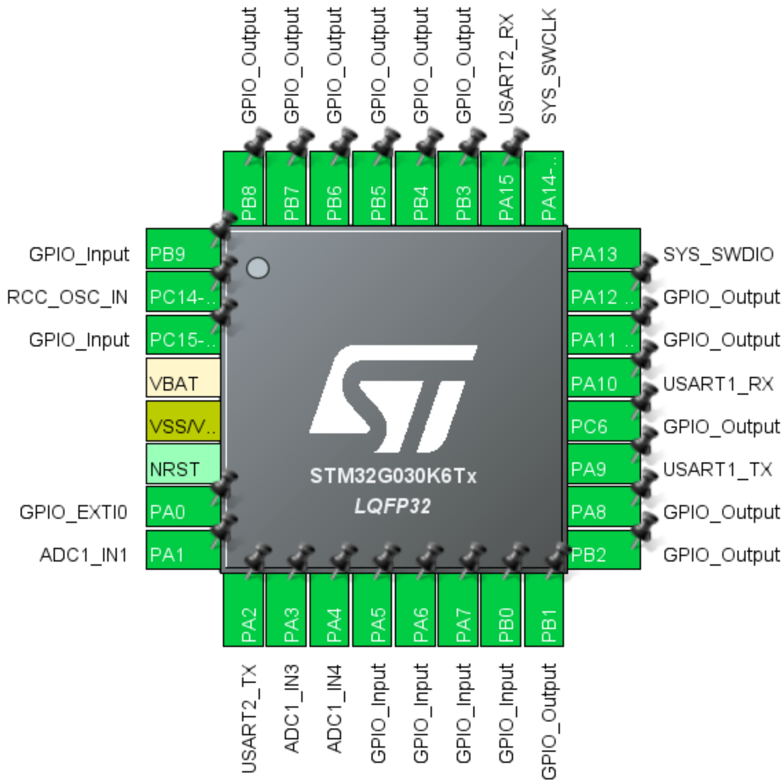


Figure 1: STM32G030K6T Pin Assignments

With 32 pins, there are more than enough to accommodate requirements the system needs. The core in the STM32G0 is an Arm® 32-bit Cortex®-M0+ CPU, frequency up to 64 MHz, which will provide more than enough processing power to satisfy our computational needs. As the input voltage to the system is 24V, there is a switching circuit in place that will drop the 24V to 3.3V to power the microcontroller at a safe voltage range.

The system should weigh less than 20lbs and be portable. The overall weight of the system is dependent on a few factors: material selection, component selection, compact design, etc. Material selection for the physical make-up of the device will be the main factor in overall weight. As the average quart of paint weighs 2.5lbs, this is the second largest source of weight to design around in the system. Using a Teknic ClearPath CPM-SDSK-2341S-ELN as the two servo motors, the constant torque out is 1.2N-m which can be used to calculate the maximum weight of the system.

$$Torque(Nm) = \frac{Force(N) * Wheel\ Radius(m)}{Gear\ Reduction} \quad (6)$$

Assuming a wheel diameter of 5 inches, no gear reduction, and constant total torque of 2.4N-m, the maximum weight the system can handle is calculated to be 9.7kg or 21.38lbs. By increasing the wheel radius or adding a gear reduction, the maximum weight can be increased.

In summary, the Autonomous Basketball Court Outlining System is designed to complete the outline of a half basketball court within the full charge of its 24V lithium-ion battery, providing up to 50 minutes of operation. The system is engineered to efficiently operate from a 24V source, incorporating a PCB with a 24V to 3.3V switching circuit for microcontroller power regulation. User-friendliness is emphasized, allowing users to load paint into the system easily, utilizing an electric servo motor for precise actuation of material. The system employs two step and direction servo motors to maintain straight and accurate lines, calculating linear displacement through precise control of the motors. Continuous and accurate arcs are achieved with the independent action of two servo motors. Distance measurement is facilitated by encoder feedback, providing user feedback on task progress. Safety considerations dictate a maximum speed of less than 4 meters per second, ensuring user safety with a recommended safety distance of 2 meters. The system is controlled by a single ST microcontroller, specifically the STM32G030K6T, offering centralized control and computational power. Weighing less than 20lbs, the system is portable, with the weight constraint calculated based on torque considerations from two Teknic ClearPath servo motors.

3. Engineering Requirements Specification

Table 1: Engineering Requirements

Marketing Requirements	Engineering Requirements	Justification
2, 4	The system should be able to complete the outline within a full charge of its battery.	Based on the user's need to be able to set this down and complete the court from one calibration.
1, 5	The system should be able to operate from a 24V source.	Based on the average weight and availability of a 24V source.
4, 5	The system must allow the user to load paint into the system for use.	Based on the user's need to be able to reuse the product.
3, 4, 5	The system must be able to complete a continuous and accurate arc.	Based on the user's needs to have an accurate basketball court.
5	The system must have a user interface to control the state of ON/OFF.	Based on the user's need for the system to be simple and intuitive enough for the average person.
3, 4	The system must be able to maintain a straight and accurate line.	Based on the user's need to have an accurate basketball court.
3, 4	The system must be able to measure the distance it has traveled and the distance remaining to travel.	Based on the user's need to have a basketball court with correct dimensions.
5	An intellectual property search will be conducted to ensure that there is no infringement on prior patents.	Based on the legality of not infringing upon prior inventors' rightful patents.
5	The system should move at a speed slow enough to not put anyone in danger during its operation.	Based on the user's desire to remain safe while operating the system.
7	The system should run off one ST microcontroller.	Based on the idea to keep the cost of manufacturing down and keep the design as simple and intuitive as possible.
1,5	The system should be lightweight and portable.	Based on the user's need to transport the system to wherever they need a basketball court.
Marketing Requirements 1. The system should be lightweight and portable.		

2. The system should be rechargeable.
3. The system should be able to determine its location relative to the desired court.
4. The system should be able to create an entire half-court without the need to refill.
5. The system should be user-friendly and intuitive.
6. The system should be relatively low cost.

4. Engineering Standards Specification

The purpose and scope of these standards and specifications are established to ensure the successful design, development, and implementation of the Autonomous Basketball Court Outlining System, focusing on precision, safety, and reliability. The project shall adhere to all applicable industry standards, regulations, and safety guidelines. The system shall consist of a central microcontroller, two drive motors, a spraying mechanism, and position feedback. All components shall be integrated seamlessly for reliable operation. The system shall not exceed a total weight of 20 pounds, including the device and any associated accessories. Portability shall be a priority, with the device designed for easy transportation. The system shall operate from a 24V Lithium-ion battery pack. The power system shall be designed to maximize operational time while ensuring safety. A user-friendly interface shall be provided, allowing users to control the ON/OFF state of the system. This interface should be intuitive and accessible. The system shall have the capability to complete continuous and accurate arcs and maintain straight and accurate lines. The maximum deviation from desired paths shall not exceed 2 cm. The system shall accurately measure the distance it has traveled and the distance remaining to travel. The system shall operate at a speed slow enough to ensure the safety of individuals in its vicinity. The maximum speed shall be defined based on a safety analysis, considering human reaction time. The materials used in the system shall be lightweight and durable. The system shall be designed to operate in a variety of environmental conditions, including outdoor settings with varying temperatures and humidity levels. Comprehensive documentation shall be maintained, including system specifications, design drawings, user manuals, and test procedures. Proper record-keeping is essential for future reference and maintenance.

5. Accepted Technical Design

5.1 Hardware Design

Block Diagrams and Functional Tables

Level 0 Block Diagram and Functional Tables

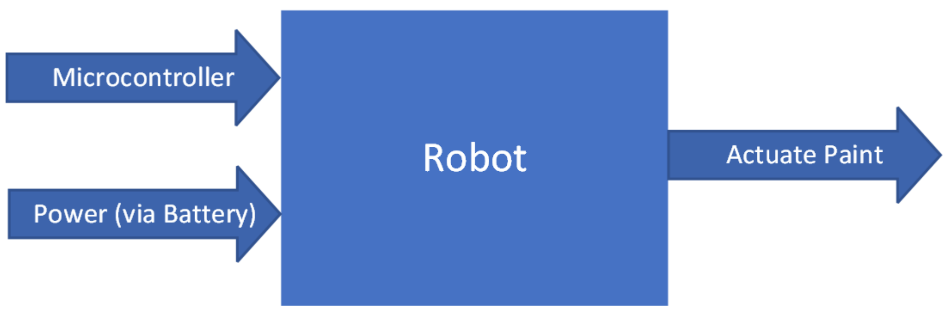


Figure 2: Level 0 Block Diagram

Table 2: Robot Module - Level 0 Block Diagram

Module	Robot
Designer	Tyler J. Gray, Bryce A. Haldeman, Dalon A. Vura
Inputs	Microcontroller Power (battery)

Outputs	Actuate Paint: Signal to cause robot to dispense paint and create the desired Basketball courts
Functionality	The robot will receive information from the Microcontroller and a power supply (remaining charge, battery health), decode them and allow the robot to navigate a sport court while dispensing sprayable chalk on the ground to make it visible for the user.

Level 1 Block Diagram and Functional Tables

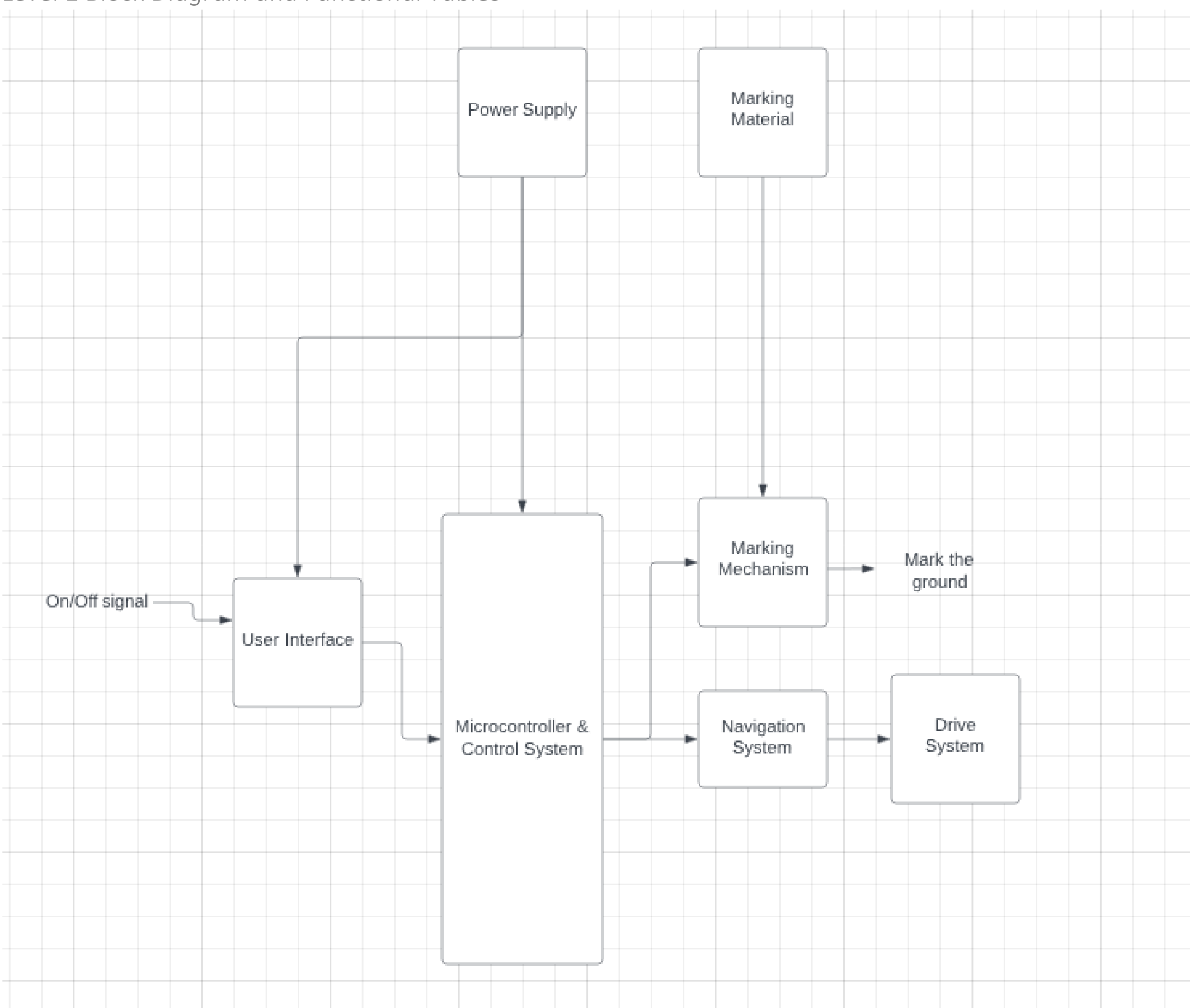


Figure 3: Level 1 Block Diagram

Table 3: User Interface Module - Level 1 Block Diagram

Module	User Interface
Designer	Bryce Haldeman
Input	Power User Variable Control (2 buttons) 1. System On/Off 2. Perimeter On/Off
Output	Digital Signal: 3.3V to microcontroller
Functionality	A simple user interface will be implemented to provide a digital signal to the microcontroller toggling the system on/off and toggling whether the perimeter is drawn.

Table 4: Power Supply Module - Level 1 Block Diagram

Module	Power Supply
Designer	Tyler Gray
Input	Battery Charger
Output	Output voltage
Functionality	Powers electrical components

Table 5: Marking Mechanism Module - Level 1 Block Diagram

Module	Marking mechanism
Designer	Tyler Gray
Input	Pneumatic Power Active/unactive signal from microcontroller
Output	Signal to release paint.
Functionality	A Marking Mechanism designed to deploy the determined substance on the ground to mark the court

Table 6: Paint Storage Module - Level 1 Block Diagram

Module	Marking Material
Designer	Dalon Vura
Input	Desired Marking material

Output	Supply marking material to the marking mechanism
Functionality	Store the designated material in a way that does not inhibit any functions of the robot

Table 7: Navigation System Module - Level 1 Block Diagram

Module	Navigation System
Designer	Dalon Vura
Input	Position information from microcontroller
Output	Outputs information to drivetrain
Functionality	Allows for the robot to navigate and paint a proper court

Table 8: Drive System Module - Level 1 Block Diagram

Module	Drive system
Designer	Tyler Gray
Input	PWM output to two Teknic motors to control the movement/direction of the wheels
Output	Robot movement
Functionality	Allows for independent operation of the wheels so the vehicle can move and steer

Table 9: Microcontroller Module - Level 1 Block Diagram

Module	Microcontroller
Designer	Tyler Gray, Bryce Haldeman, Dalon Vura
Input	User Interface, Calibration System, Power Supply
Output	Information to the navigation system on how to maneuver. Information to the spraying mechanism on when to activate and release paint.
Functionality	The brains of the project, controls everything based on the information it is presented with.

Level 2 Block Diagram and Functional Tables

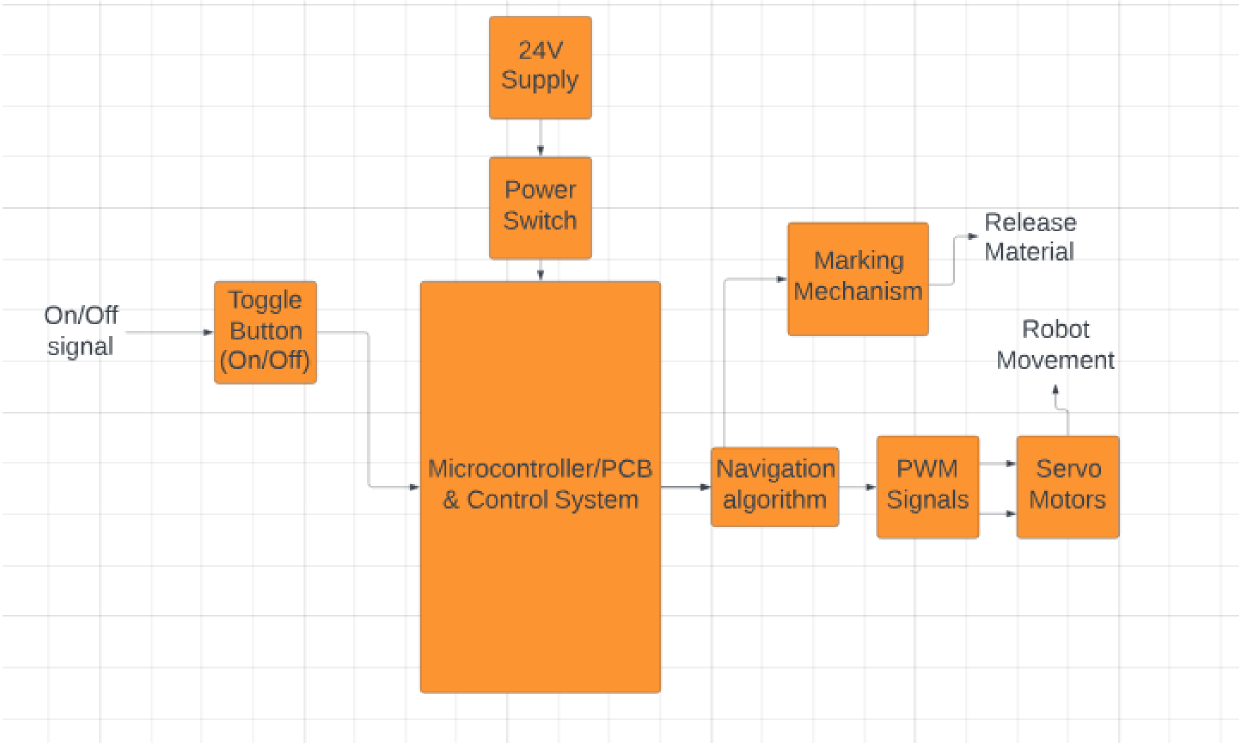


Figure 4: Level 2 Block Diagram

Table 10: Pneumatic Sprayer Module - Level 2 Block Diagram

Module	Marking Mechanism
Designer	Tyler Gray
Input	Signal from microcontroller
Output	Marking Material
Functionality	Functionality to deploy the material to mark the court

Table 11: Navigation Algorithm Module - Level 2 Block Diagram

Module	Navigation Algorithm
Designer	Dalon Vura
Input	Position information from microcontroller
Output	Outputs information to drive system

Functionality	Implements functionality for accurate movement of vehicle to paint a court

Table 12: PWM Signal Module - Level 2 Block Diagram

Module	PWM Signal
Designer	Tyler Gray
Input	Signal from navigation system
Output	Signal to drive system
Functionality	Implements a control method for the drive system

Table 13: Servo Motors Module - Level 2 Block Diagram

Module	Servo Motors
Designer	Tyler Gray
Input	PWM output from microcontroller
Output	Rotational movement
Functionality	Provides motorized movement for the wheels

Table 14: Power Switch Module - Level 2 Block Diagram

Module	Power Switch
Designer	Tyler Gray
Input	Power On/Off Switch
Output	Power on to system
Functionality	Give the user the ability to enable or disable power to the system.

Table 15: 24V Supply Module - Level 2 Block Diagram

Module	24V Supply
Designer	Tyler Gray
Input	Lithium-ion battery pack
Output	Output voltage
Functionality	Power the electronic components

Table 16: Toggle Button (on/off) Module - Level 2 Block Diagram

Module	Toggle button (On/Off)
Designer	Bryce Haldeman
Input	Power User initiated on/off state.
Output	Digital Signal: 3.3V to microcontroller
Functionality	Allow the system to functionally start and stop when prompted

Table 17: Microcontroller Module - Level 2 Block Diagram

Module	Microcontroller
Designer	Tyler Gray, Bryce Haldeman, Dalon Vura
Input	Toggle Button (On/Off) Toggle Button (Perimeter On/Off) Calibration laser Power: 3.3V
Output	Information to the navigation system on how to maneuver. Information to the spraying mechanism on when to activate and release paint.
Functionality	The brains of the system, controls everything based on the information it is presented with.

Circuit Analysis

I/O Circuit Design and Analysis

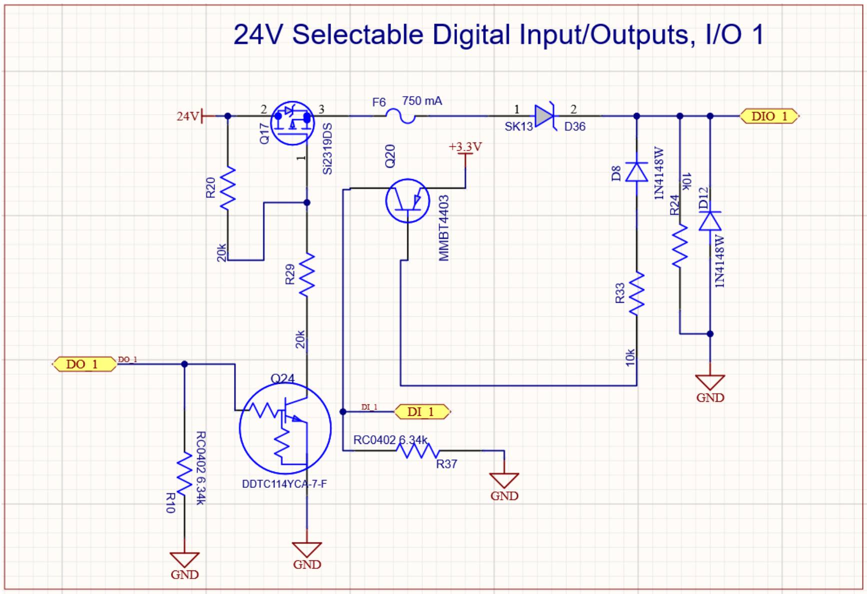


Figure 5: 24V Selectable Digital I/O Circuit

Figure 5 shows the circuit that drives the 24V output from the 3.3V microprocessor signal. The circuit works as either an output or an input. When the microcontroller sends a 3.3V signal to DO_1, Q20 turns on. This allows current to flow from the 24V source to DIO_1, now the circuit is acting as an output. When the microcontroller leaves DO_1 at 0V, Q20 turns off. This prevents current from flowing from the 24V source to DIO_1, which makes the circuit act as an input. The PCB itself has 10 of these identical circuits, which functionally makes 10 selectable I/O points.

The following table lists the components in the circuit and their functionality.

Table 18: I/O Circuit Components and Functionality

Component	Name	I/O Circuit Functionality
F6	Fuse	Protects the circuit from overcurrent conditions. If the current drawn from the circuit exceeds the rating of the fuse, the fuse will blow and open the circuit, preventing further damage.

D36	Zener Diode	Connected in parallel with the microcontroller's input pin. If the voltage on the input pin goes negative, the Zener diode will conduct current, protecting the microcontroller from damage.
Q17	MOSFET	If the voltage on the input pin exceeds a certain threshold, the MOSFET will turn on and short-circuit the input to ground, protecting the microcontroller from damage.
Q20	PNP Transistor	Controls the direction of current flow through the circuit. When the microcontroller sends out a 3.3V signal to DO_1, Q20 turns on, allowing current to flow from the 24V source to DIO_1. When the microcontroller leaves DO_1 at 0V, Q20 turns off, preventing current from flowing.
Q24	NPN Transistor	When the microcontroller sends out a 3.3V signal to DO_1, Q24 turns off, preventing current from flowing from DIO_1 to the microcontroller. When the microcontroller leaves DO_1 at 0V, Q24 turns on, allowing current to flow from DIO_1 to the microcontroller.
D12, D8, D37	Diodes	Prevents current from flowing in the wrong direction through the circuit
R10, R20, R24, R29, R33, R37	Resistors	Limit the current flowing through various components in the circuit and provide pull-up and pull-down voltages

STM32G0 Microcontroller Schematic and Analysis

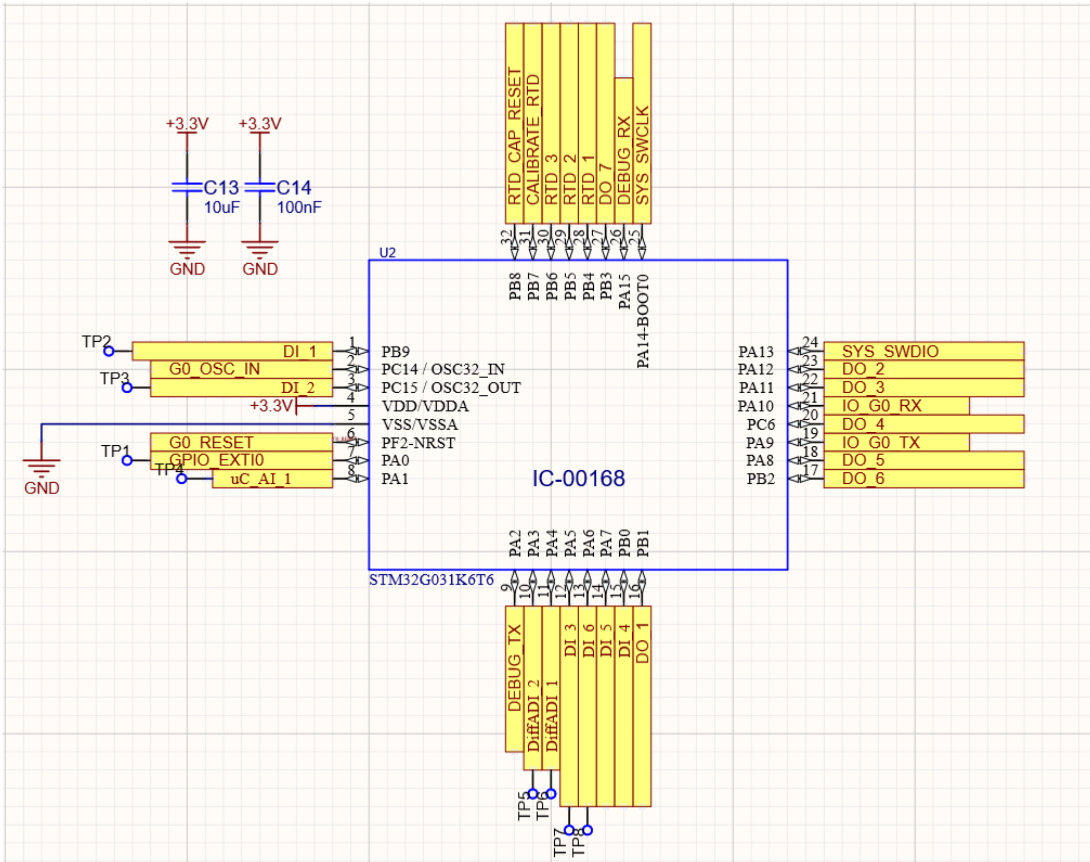


Figure 6: STM32G031K6T6 Schematic

The STM32G0 is a 32-bit microcontroller based on the ARM Cortex-M0+ core. It is a low-power microcontroller that is suitable for a variety of applications, including embedded systems, industrial control, and consumer electronics.

In the selectable 24V input/output circuit, the STM32G0 processor is used to control the direction of current flow through the circuit. The processor sends a 3.3V signal to DO_1 (or any of the other 9 I/O circuits) to enable the circuit to act as an output, or it leaves DO_1 at 0V to enable the circuit to act as an input.

Logic Power Supplies Design and Analysis

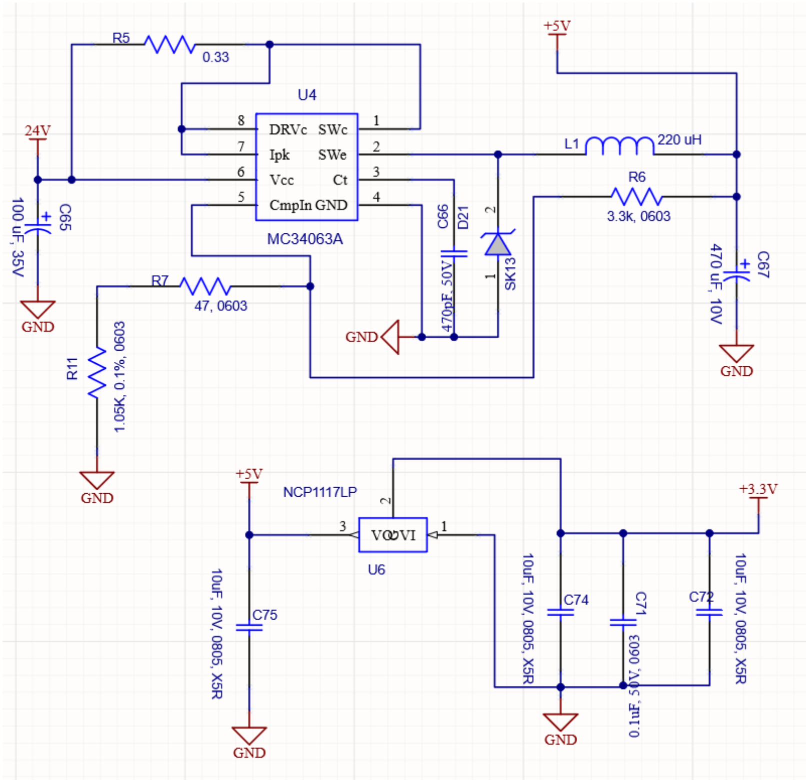


Figure 7: Logic Power Supplies

In the first circuit in Figure 7 is a boost-buck converter, which is a type of DC-to-DC converter that can decreases the voltage of its input supply. This circuit is designed to convert a 24V input voltage to a 5V output voltage. The MC34063A IC directly controls the switching process, maintaining regulation of the output voltage. The inductor L1 and the output capacitor C66 play crucial roles in storing and releasing energy during the switching cycles, ensuring a stable output voltage. The diode D21, connected across the inductor L1, serves as a snubber diode, protecting the MC34063A IC from the high voltage spikes that occur during switching. The resistor R35 provides feedback to the MC34063A IC for regulating the output voltage.

In the second circuit in Figure 7 is a simple voltage regulator circuit using the NCP1117LP linear regulator. The NCP1117LP is a low-dropout (LDO) regulator, which means that it can maintain a regulated output voltage even when the input voltage is only slightly higher than the output voltage. The circuit works as follows:

The +5V input voltage is applied to the VIN pin of the NCP1117LP. The NCP1117LP regulates the input voltage down to +3.3V at the VOUT pin. The output voltage is filtered by the two 10uF capacitors (C74 and C75) in parallel. The 0.1uF capacitor (C71) is a decoupling capacitor that helps to reduce noise on the output voltage. The circuit is designed to provide a regulated output current of up to 1A. The two 10uF capacitors in parallel provide a large amount of filtering for the output voltage. The 0.1uF decoupling capacitor helps to reduce noise on the output voltage caused by the switching activity of the NCP1117LP. So, this is a simple and effective voltage regulator circuit.

Table 19: Logic Supply Circuits Components and Functionality

Component	Name	Supply Circuit Functionality
U4	Boost/Buck Inverting Switch Regulator	This integrated circuit serves as the heart of the converter, providing the control circuitry and internal switching element.
U6	Low-dropout (LDO) regulator	Maintains a regulated output voltage even when the input voltage is only slightly higher than the output voltage. The NCP1117LP regulates the input voltage down to +3.3V at the VOUT pin
L1	Inductor	The inductor stores energy during the switching cycles and releases it to the output capacitor, maintaining a stable output voltage
C65, C66, C67, C71, C72, C74, C75	Capacitor	Used for input/output filtering of noise.

R5, R6, R7, R11	Resistors	Limit the current flowing through various components in the circuit and provide pull-up and pull-down voltages

Program and Debug Header Schematics and Analysis

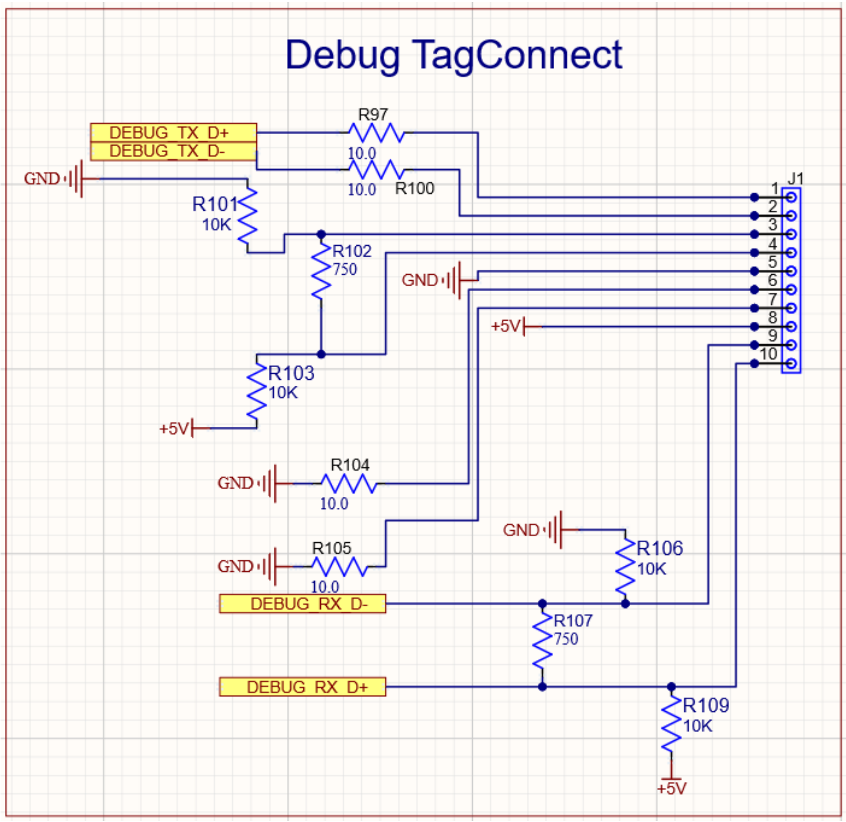


Figure 8: J-Tag Debugger Connection Schematic

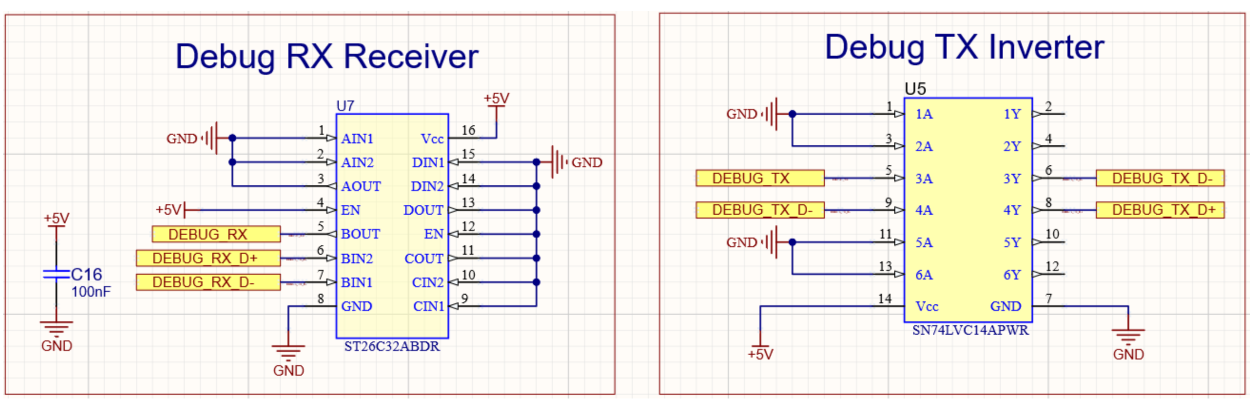


Figure 9: Debug RX/TX Schematics

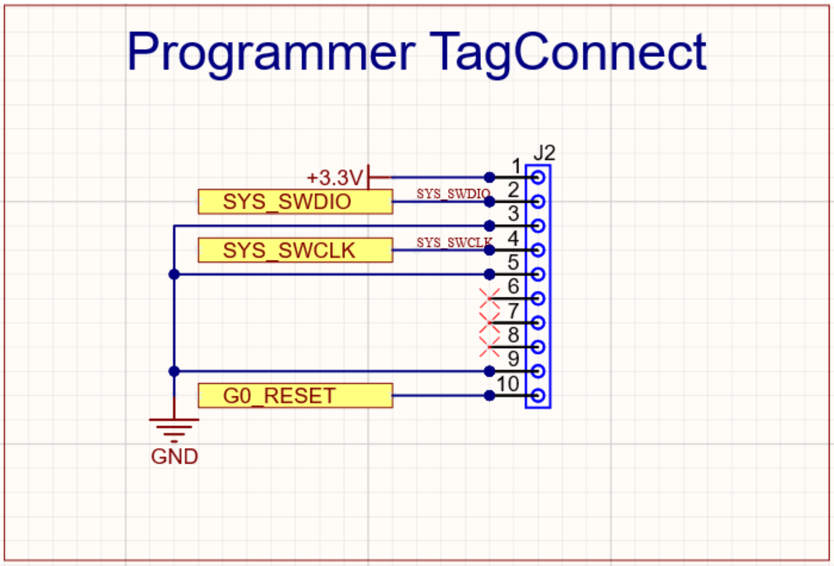


Figure 10: J-Tag Programmer Connection Schematic

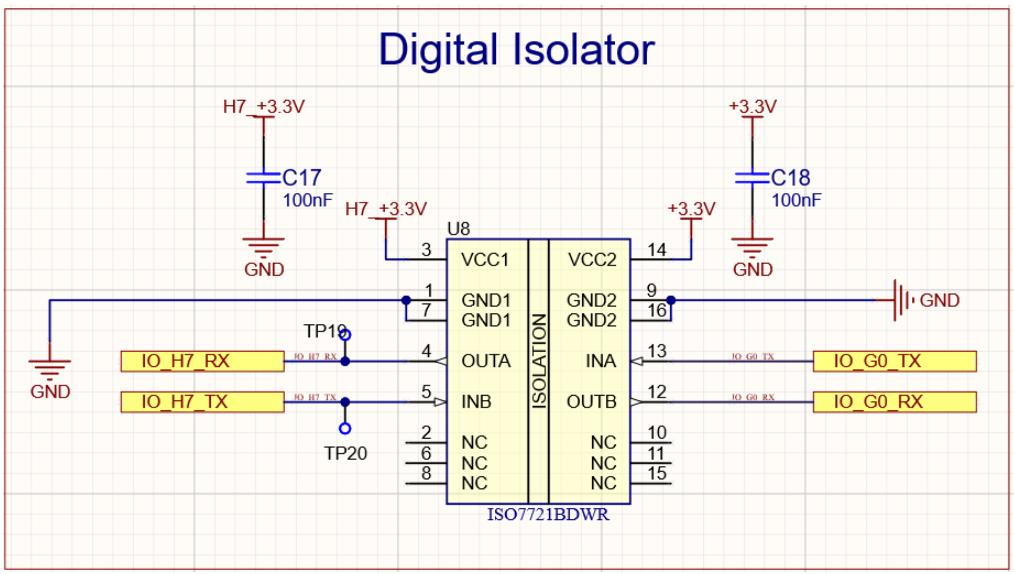


Figure 11: Digital Isolator Schematic

Figures 8, 9, 10 and 11 show the components needed to communicate with the microcontroller. The Debug Tag Connect is the physical connection that is routed to the RX receiver and the TX inverter. These components are routed directly to the microcontroller so data can be sent back and forth for programming and debugging purposes.

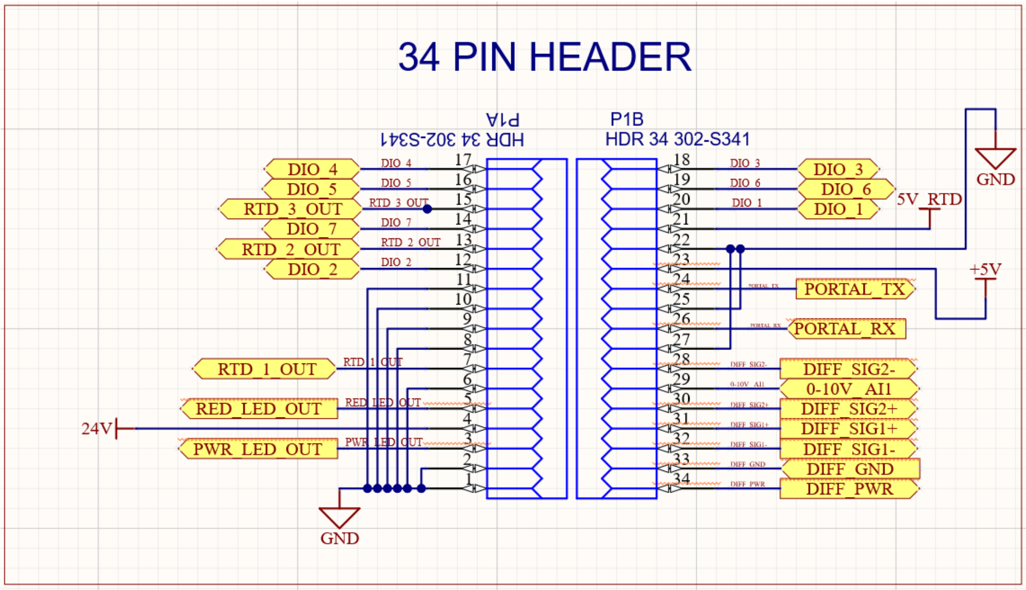


Figure 12: 34 Pin Header Schematic.

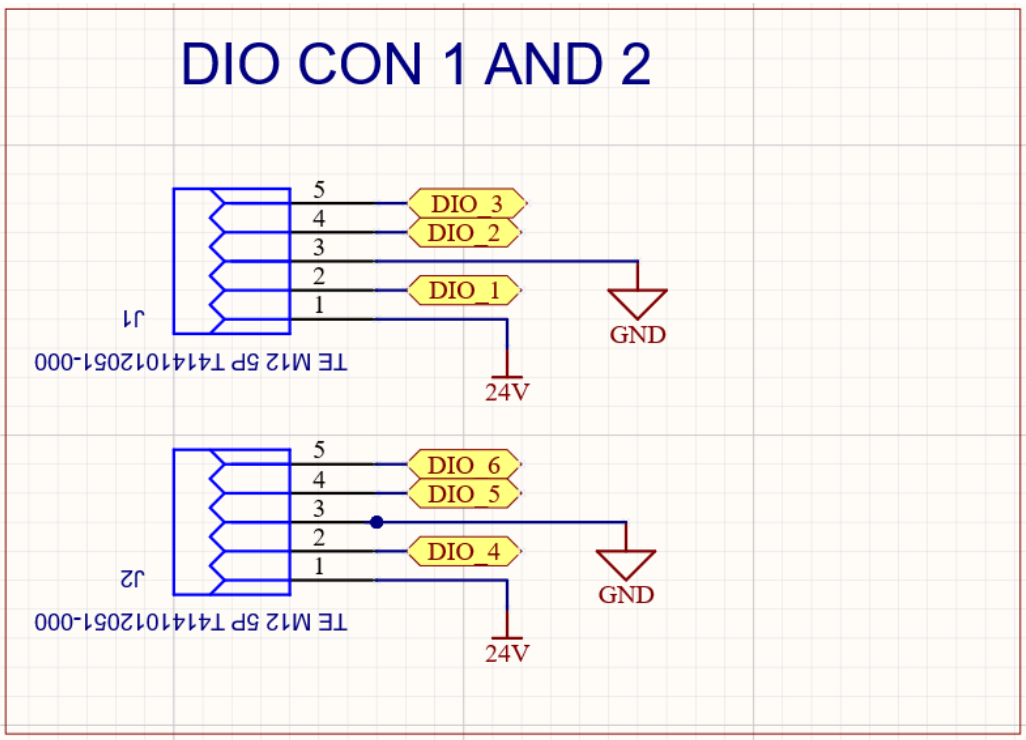


Figure 13: Connector Schematics.

To transmit and receive data from the outside world, a connector board is required. Signals from the I/O circuitry and other parts of the main I/O board are sent over via a 34-pin header. Once arriving at the other board, various M12 cables can be connected to receive each signal to a designated location. For example, the DIO 1 pin is a PWM signal and therefore should be wired to the 'Step' pin of the motor. Figure 12 shows the 34-pin header and the signals being sent to the outside world while Figure 13 shows the M12 connections where cabling can be plugged in to receive those signals. See Figures 14 and 15 for 3D models of each of these boards.

PCB Model

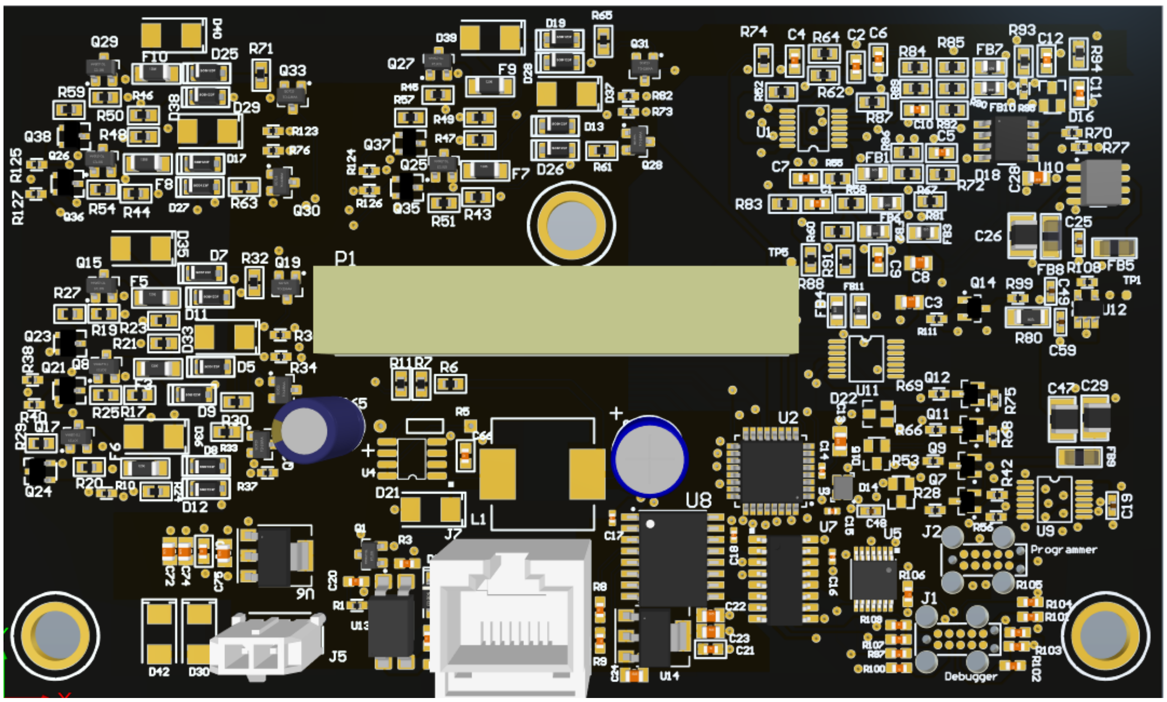


Figure 14: PCB Model

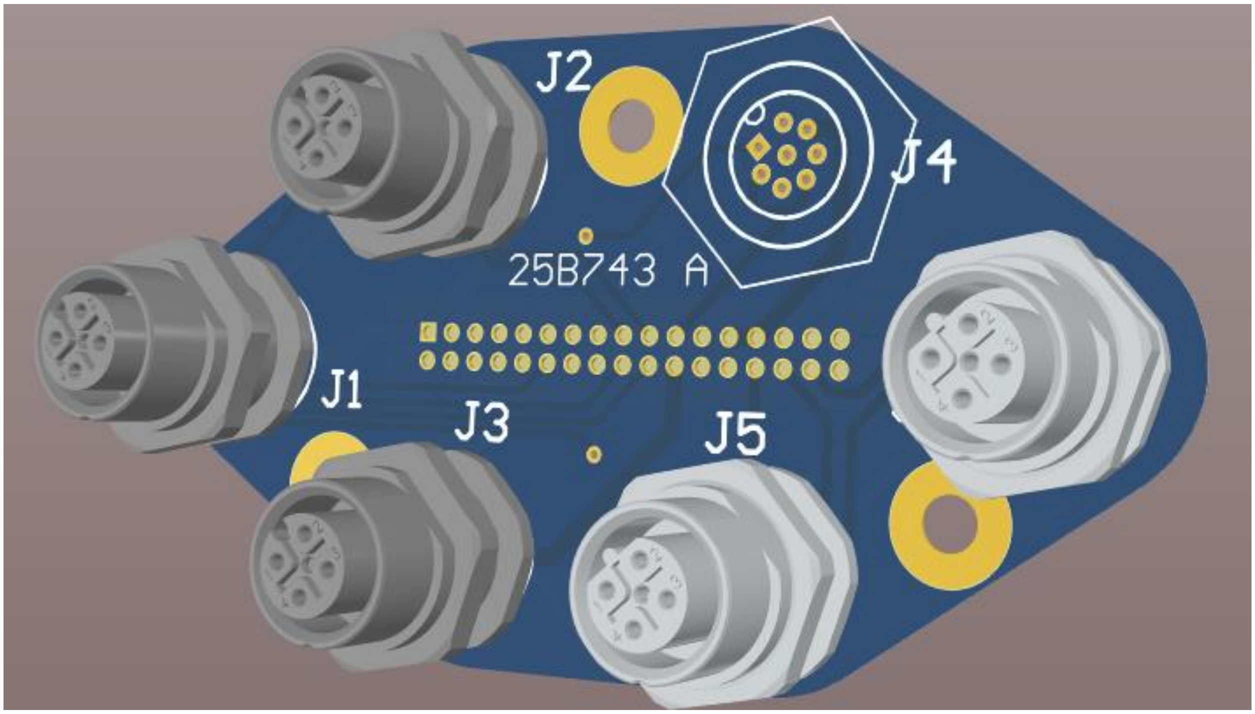


Figure 15: Connector Board PCB Model.

Motor Analysis

As previously mentioned, two stepper motors are used in tandem to drive each wheel independently. Two CPM-SDSK-2310P-EQN motors are used as shown in Figure 16.

Figure 16: CPM-SDSK-2310P-EQN Motor

This motor is a high-performance stepper motor from Teknic, Inc. It is a compact and powerful motor that is well-suited for a variety of applications.The CPM-SDSK-2310P-EQN motor has the following specifications:

- Step angle: 0.9°
- Torque: 112 oz-in (8 Nm)
- Speed: 4000 RPM
- Power: 110 W
- Voltage: 24-36 VDC
- Current: 3.0 A
- Weight: 1.2 lbs (0.54 kg)

The CPM-SDSK-2310P-EQN motor is a high-performance motor that can deliver precise torque and speed. It is also a very efficient motor, with a maximum efficiency of 80%.

Servo Analysis

To actuate material out of a spray can, an RC servo is needed to press the nozzle down. A Miuzei 20KG Servo Motor is used as seen in Figure 17.

Figure 17: Miuzei 20KG Servo Motor.

The Miuzei 20KG Servo Motor is a high-torque, waterproof servo motor. It features a metal gear train for durability and a waterproof design for protection against moisture and dust. The servo has a control angle of 270° and a maximum torque of 20 kg/cm, making it suitable for applications that require precise control and strong power.

Specifications include:

- Motor Type: Brushless DC servo
- Gear Type: Metal gear
- Torque: 20 kg/cm (270 oz-in)
- Speed: 0.12 sec/60° at 4.8V, 0.10 sec/60° at 6.0V
- Operating Voltage: 4.8V - 6.0V DC
- Control Angle: 270°
- Dimensions: 40.5 x 20 x 38.5 mm (1.59 x 0.79 x 1.52 in)
- Weight: 55g (1.94 oz)

The Miuzei 20KG Servo Motor offers several advantages for engineering applications: The servo's 20 kg/cm torque output makes it suitable for applications that require strong force. The metal gear train provides durability and reduces wear and tear, ensuring long-lasting performance. The waterproof design protects the servo from moisture and dust, making it suitable for outdoor use or in environments where exposure to water is possible. The 270° control angle allows for a wide range of motion, making the servo versatile for various applications. The servo's compact size makes it easy to integrate. In summary, the Miuzei 20KG Servo Motor is a reliable, high-torque servo motor with a wide range of applications.

Wiring Analysis

To receive signals out of the connector board from the microcontroller, various M12 5-pin cables are used. M12 5-pin cables are a type of circular industrial connector commonly used in automation, instrumentation, and other applications where reliable and robust connectivity is essential. These cables are characterized by their ruggedized design, which provides excellent protection against environmental factors such as dust, moisture, and vibration. They are also designed to withstand harsh mechanical stresses, making them suitable for use in demanding industrial environments.

Specifications include:

- Connector Type: M12
- Number of Pins: 5
- Cable Type: Shielded or unshielded
- Connector Material: Metal or plastic
- Ingress Protection Rating: IP67, IP68, or IP69
- Operating Temperature Range: -40°C to +85°C
- Current Rating: Up to 10A
- Voltage Rating: Up to 250V AC or 600V DC

5.2 Software Design

Flowchart

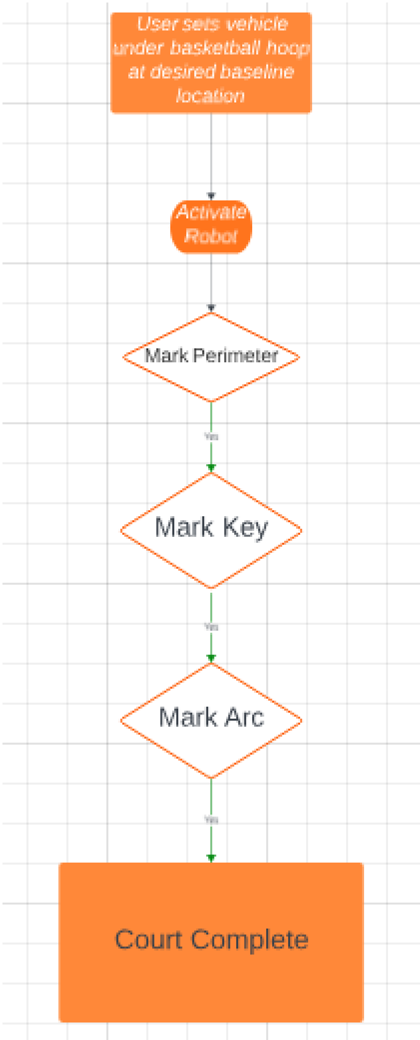


Figure 18: Software FlowChart

Mark Perimeter: The robot begins to paint the perimeter using feedback from the hardware to determine how many steps it has taken and when it should turn to begin new lines

Mark Key: The robot enters a new state in which is begins marking the key using similar logic to the perimeter state

Mark Arc: The robot begins to mark the arc by traversing to the location of the start of the arc then drawing the straight from the baseline to the beginning of the curve. Change the motor speeds to allow for a half circle to be smoothly created then finish the other straight of the arc

Court Complete: The robot enters an idle state in which the user can reset the robot to begin painting another court or turn off.

Subsystem Code

To communicate with the motors, the microchip must use a series of pulse width modulation (PWM) signals. However, the microchip in use does not allow for the default creation of PWM signals thus the code to create an artificial PWM signal was created as follows:

```
void TIM3_Init(void)
{
    // Enable the clock for TIM3
    RCC->APBENR1 |= RCC_APBENR1_TIM3EN;

    // Set the timer prescaler/autoreload timing for a 1 kHz PWM
    TIM3->PSC = 0; // No prescaler
    TIM3->ARR = 999; // Auto-reload value for a PWM frequency of 1 kHz

    // Enable the timer interrupt
    TIM3->DIER |= TIM_DIER_UIE;

    // Enable the timer
    TIM3->CR1 |= TIM_CR1_CEN;

    // Enable the TIM3 interrupt in the NVIC
    NVIC_EnableIRQ(TIM3_IRQn);
}
```

To begin the creation of the PWM signal a timer must be initialized for use. This is accomplished using the above code. The pre scaler is set to zero to make the PWM signal run as quickly as possible but including no divisions of the timer input clock. The auto-reload register is then set to 999 to create an overflow every one-thousand counts. Next the interrupt is enabled to trigger every time the overflow is reached. The final line gives the Nested Vector Interrupt Controller the desired action in which to take when an interrupt occurs.

```
void TIM3_IRQHandler(void)
{
    // Check if the interrupt is for this timer
    if (TIM3->SR & TIM_SR_UIF)
    {
        // Clear the interrupt flag
        TIM3->SR &= ~TIM_SR_UIF;
        //Increment the total step counts
        totalStepCount++;
        // Increment the PWM counter
        pwm_counter++;
        pwm_counter_servo++;
        // Reset the PWM counter if it exceeds the PWM period
        if (pwm_counter > PWM_PERIOD)
        {
            pwm_counter = 0;
        }
        // Set the PWM signal high if the counter is less than the duty cycle and
low otherwise
        if (pwm_counter < DUTY_CYCLE)
        {
            HAL_GPIO_WritePin(DO_1_GPIO_Port, DO_1_Pin, GPIO_PIN_SET);
        }
        else
        {
            HAL_GPIO_WritePin(DO_1_GPIO_Port, DO_1_Pin, GPIO_PIN_RESET);
        }
        // Reset the PWM counter if it exceeds the PWM period
        if (pwm_counter_servo > PWM_PERIOD_SERVO)
        {
          pwm_counter_servo = 0;
```

```
        }
        // Set the PWM signal high if the counter is less than the duty cycle and
low otherwise
        if (pwm_counter_servo < DUTY_CYCLE_SERVO)
        {
            HAL_GPIO_WritePin(DO_6_GPIO_Port, DO_6_Pin, GPIO_PIN_SET);
        }
        else
        {
            HAL_GPIO_WritePin(DO_6_GPIO_Port, DO_6_Pin, GPIO_PIN_RESET);
        }
    }
}
```

For the timer to replicate a PWM signal the above interrupt code must be utilized to store the value of the timer and change the signal from low to high depending on certain events that occur. First the code determines if the interruption occurred due to an update event occurring in the timer. Afterwards it clears the interrupt flag to acknowledge that the interrupt is being handled. Then the code records how many steps have been taken, as well as incrementing the PWM counter for each PWM this timer is currently creating. Then the PWM counter is determined if it is required to reset back to zero for exceeding the PWM period to maintain the desired frequency of the PWM signal. Followed by deciding if this interrupt is meant to set the signal high or low. This is done by deciding if the PWM counter is currently less than or greater than the duty cycle. The final snippet is then rewritten for each individual PWM signal that is being handled by this timer.

```
#define CLOCKWISE       (0)
#define COUNTERCLOCKWISE  (1)
#define STEPS_PER_ROTATION  (800)
#define RPM           (60)
volatile uint32_t PWM_PERIOD = 200;
// 5% duty cycle means the signal is high for 5% of the period
#define DUTY_CYCLE (PWM_PERIOD * 50 / 100)

volatile uint32_t pwm_counter = 0;
```

```
volatile uint32_t PWM_PERIOD_SERVO;
#define DUTY_CYCLE_SERVO  (PWM_PERIOD_SERVO * 50 / 100)
volatile uint32_t pwm_counter_servo = 0;
uint32_t totalStepCount;
```

The above code configures the symbolic constants for motor control, as well as defining the parameters for the PWM signals discussed previously. It also maintains the counters for tracking how many cycles the code has processed through. These parameters are used for fine-tuning the behavior of the PWM and keeping track of the system's overall progress.

```
void moveForward(void)
{
  PWM_PERIOD = 200;
  HAL_GPIO_WritePin(DO_2_GPIO_Port, DO_2_Pin, CLOCKWISE);
  HAL_GPIO_WritePin(DO_3_GPIO_Port, DO_3_Pin, CLOCKWISE);
}

void moveBackward(void)
{
  PWM_PERIOD = 200;
  HAL_GPIO_WritePin(DO_2_GPIO_Port, DO_2_Pin, COUNTERCLOCKWISE);
  HAL_GPIO_WritePin(DO_3_GPIO_Port, DO_3_Pin, COUNTERCLOCKWISE);
}

void moveLeft(void)
{
  PWM_PERIOD = 200;
  HAL_GPIO_WritePin(DO_2_GPIO_Port, DO_2_Pin, CLOCKWISE);
  HAL_GPIO_WritePin(DO_3_GPIO_Port, DO_3_Pin, COUNTERCLOCKWISE);
}
void moveRight(void)
{
  PWM_PERIOD = 200;
  HAL_GPIO_WritePin(DO_2_GPIO_Port, DO_2_Pin, COUNTERCLOCKWISE);
  HAL_GPIO_WritePin(DO_3_GPIO_Port, DO_3_Pin, CLOCKWISE);
}
void stop(void)
```

```
{
  HAL_GPIO_WritePin(DO_5_GPIO_Port, DO_5_Pin, GPIO_PIN_RESET);
}
void start(void)
{
  HAL_GPIO_WritePin(DO_5_GPIO_Port, DO_5_Pin, GPIO_PIN_SET);
}
```

The above code snippet is the declaration of basic functions in order to control the direction of the motors and give the option for the system to make turns. By changing the direction of the clockwise or counterclockwise pin the motor can be controlled in a manner that allows full control of the direction, as well as the start and stop functions giving access to control the go signal being sent to the motors.

```
typedef enum
  {
    WAITING = 0,
  PERIMETER_A,
  PERIMETER_B,
  PERIMETER_C,
  PERIMETER_D,
  RIGHT_FACE,
  LEFT_FACE,
  COMPLETE
  } STATES_t;

  STATES_t runState = WAITING;
  STATES_t runStatePrevious = WAITING;

  // Start timer
  HAL_TIM_Base_Start(&htim16);

  // Get current time (microseconds)
  timer_val = __HAL_TIM_GET_COUNTER(&htim16);
```

Above is another snippet use to establish an enumeration to represent different states the machine can be put into. This code also intiailizes variables to track the current and previous states, starts a timer, and retrieves the current timer value in microseconds to be used later.

```
while (1)
      {
        switch (runState)
      {
        case WAITING:

        if (__HAL_TIM_GET_COUNTER(&htim16) - timer_val >= 50000) //wait X seconds
to begin next line
        {
          runState = runStatePrevious + 1;
          timer_val = __HAL_TIM_GET_COUNTER(&htim16);
        }
        else
        {
          PWM_PERIOD = 0;
        }

          break;
        case PERIMETER_A:
          //time will be replaced by a step count
        if (__HAL_TIM_GET_COUNTER(&htim16) - timer_val >= 50000) //move for X
seconds to paint first perimeter line
        {
          runState = RIGHT_FACE;
          runStatePrevious = PERIMETER_A;
          timer_val = __HAL_TIM_GET_COUNTER(&htim16);
        }
        else
```

```
        {
            moveForward();
            PWM_PERIOD_SERVO = 150;
        }
          break;
```

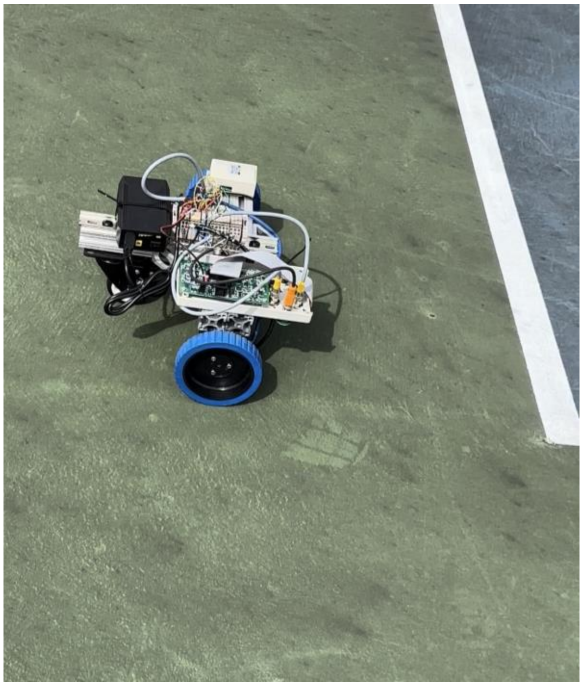
Above is an early implementation of the case statement that will determine the direction and speed of the system to accurately paint the desired basketball court. This code features the waiting state that the system will enter until given the command to start, as well as the first perimeter case. The perimeter case will be developed into more cases that describe each individual line that must be drawn to complete the half-court basketball court. This code currently uses an if statement paired with waiting for the timer to reach a specific value to tell the system when it is time to move on to the next case. In the final design this will be replaced with measured out rotations and steps that occur within the system. While in the waiting state the system stays idle until the desired timer value is reached in which case the system will then change its run state as well as update the timer value to keep the delay uniform into the next case. Once the system transitions to the next case which is Perimeter A it will send the signal to the motors to move forward by rotating both motors clockwise as laid out earlier in the function declarations. After the desired timer value is reached again the system will then record the current timer value, change the run state, and record what state it is leaving. This code will then be fashioned in a way to continue painting the court.

5.3 Testing Procedures

Due to the scope of the given project, testing was limited to near the end of the design period. Testing was mostly accomplished through allowing the robot to complete the entire court and then tweaking the measurements as were necessary. Since the algorithm was almost all based around mathematics there was little room for error on the side of the robot so once the driving code was completed it was a matter of small tweaks to complete the final design. To get our original code we placed two pieces of black tape 3 feet apart and tested to ensure the robot would drive in a straight line for 3 feet and then stop at the desired location. As soon as this was achieved testing outside began.

The location for the outdoor tests was the tennis courts on Wheeler St in Akron Ohio. The tests were conducted at this location for the group to have a straight line to start the robot on since a basketball hoop or desired baseline was not determined or necessary during the tests.

When testing, everything went smoothly except for fighting the friction on various surfaces. Due to the torque limit projected onto the robot by the motors the robot could not drive through all levels of friction at the start, but through testing different speeds as well as slowing down the turn speed the robot was able to overcome the friction and become extremely unlikely to fault out during a run.



6. Mechanical Sketch

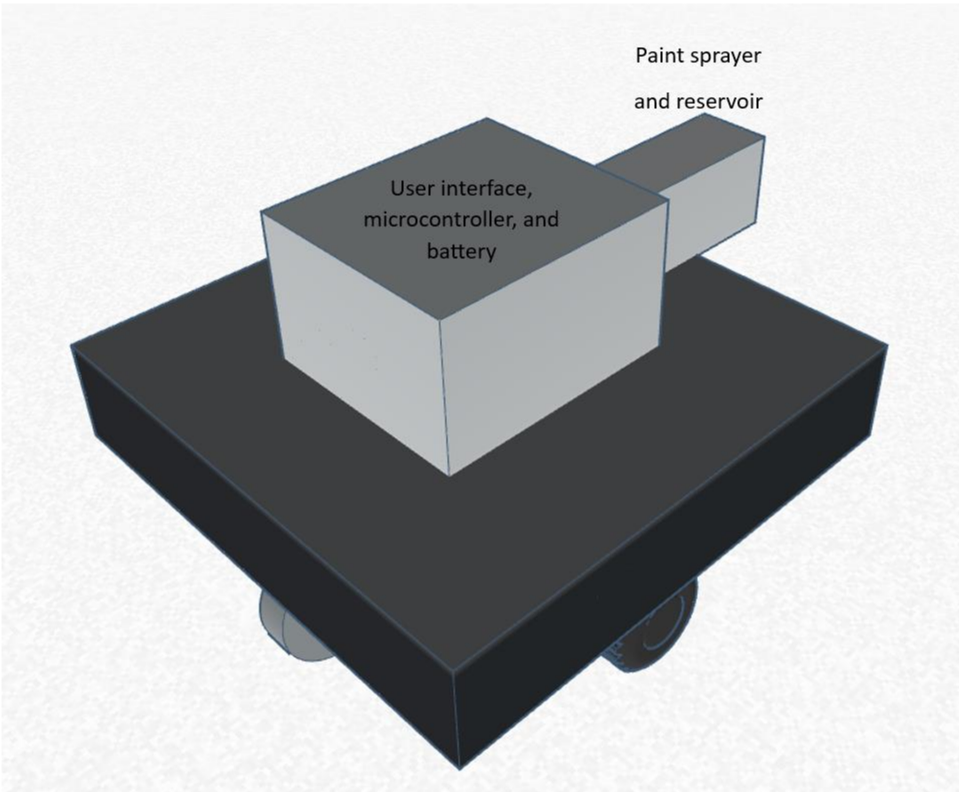


Figure 19: Mechanical Sketch

7. Team Information

Tyler Gray, EE: Project Lead, Hardware Manager

Bryce Haldeman, CpE: Software Manager

Dalon Vura, CpE: Data Manager

8. Parts List

Table 20: Parts List

Item	Quantity	Price	Description	Link
NEMA 23 Mounting Bracket	2	$ 15.74	STEPPERONLINE NEMA 23 Stepper Motor (Economy Geared Stepper Motor) Alloy Steel Mounting Bracket ST-M2	LINK
RC Servo Motor	1	$ 12.99	Miuzei 20KG Servo Motor High Torque RC Servo Metal Gear Waterproof for R/C Model DIY Car Robot, DS3218, Control Angle 270°	LINK
Teknic Motors	2	$ -	CPM-SDSK-2310P-ELN	Graco Inc. Sponsored
Motor Control Cables	2	$ -	CPM-CABLE-CTRL-MM660	Graco Inc. Sponsored
Motor Power Cables	2	$ -	CPM-CABLE-PWR-MM660	Graco Inc. Sponsored
M12 5-Pin Cables	2	$ -	1095966 Digi-Key Part Number 277-1095966-ND - Cable Assembly 16.40' (5.00m)	Graco Inc. Sponsored
Terminal Block	12	$ -	Digi-Key Part Number 277-15310-ND Terminal Block Connector 3 Position Feed Through Gray 12-26 AWG	Graco Inc. Sponsored
I/O Board	1	$ -	10 configurable input/output board	Graco Inc. Sponsored
I/O Connector Board	1	$ -		Graco Inc. Sponsored

80/20 T-Slotted Aluminum	8ft	$ -	Digi-Key Part Number 4876-1010-48-ND	Graco Inc. Sponsored
Din Rail	1	$ -	Digi-Key Part Number 277-5375-ND Din Rail Top Hat 1.378" W x 0.295" H (35.00mm x 7.50mm) Slotted Steel 29.724" (755.00mm)	Graco Inc. Sponsored
24Vdc DIN Rail Power Supply	1	$ -	MEAN WELL MDR-100-24 slim line DIN rail power supply	Graco Inc. Sponsored
5Vdc DIN Rail Power Supply	1	$ -	MEAN WELL MDR-20-5 slim line DIN rail power supply	Graco Inc. Sponsored

9. Project Schedules

SDP I 2022				
Project Design	46.38 days?	Wed 8/30/23	Sun 10/15/23
Midterm Report	47.38 days	Wed 8/30/23	Mon 10/16/23
Problem Statement	399.38 days	Wed 8/24/22	Wed 9/27/23
Engineering Analysis	33.38 days?	Wed 8/30/23	Mon 10/2/23
Accepted Technical Design	24.38 days	Fri 9/22/23	Mon 10/16/23
Hardware Design: Phase 1	24.38 days	Fri 9/22/23	Mon 10/16/23
Software Design: Phase 1	24.38 days	Fri 9/22/23	Mon 10/16/23
Software Behavior Models Levels 0 thru N (w/FR tables)	7.38 days	Fri 9/22/23	Fri 9/29/23
Mechanical Sketch	10.38 days	Fri 9/22/23	Mon 10/2/23
Team information	1.38 days	Wed 8/30/23	Thu 8/31/23
Project Schedules	5.38 days	Fri 9/22/23	Wed 9/27/23
Midterm Design Gantt Chart	5.38 days	Fri 9/22/23	Wed 9/27/23
References	10.38 days	Fri 9/22/23	Mon 10/2/23
Midterm Parts Request Form	47.38 days	Wed 8/30/23	Mon 10/16/23
Midterm presentation file submission	33 days	Wed 8/30/23	Mon 10/2/23
Midterm Design Presentations Day 1	0 days	Wed 10/4/23	Wed 10/4/23
Midterm Design Presentations Day 2	0 days	Wed 10/11/23	Wed 10/11/23
	0 days	Wed 8/30/23	Wed 8/30/23
	0 days	Wed 8/30/23	Wed 8/30/23
	0 days	Wed 8/30/23	Wed 8/30/23
Project Poster	14 days	Tue 10/17/23	Tue 10/31/23
Final Design Report	47 days	Tue 10/17/23	Sun 12/3/23
Abstract	43.38 days	Tue 10/17/23	Wed 11/29/23
Hardware Design: Phase 2	47 days	Tue 10/17/23	Sun 12/3/23
Modules 1…n	47 days	Tue 10/17/23	Sun 12/3/23
Servo Moving	29.38 days	Tue 10/17/23	Wed 11/15/23
Motors Moving	22.38 days	Tue 10/17/23	Wed 11/8/23
Software Design: Phase 2	47.38 days	Tue 10/17/23	Sun 12/3/23
Modules 1…n	47.38 days	Tue 10/17/23	Sun 12/3/23
PWM Wave Creation	15.38 days	Tue 10/17/23	Wed 11/1/23
Motors Controlled movement	22.38 days	Tue 10/17/23	Wed 11/8/23
Parts Lists	47.38 days	Tue 10/17/23	Sun 12/3/23
Parts list(s) for Schematics	47.38 days	Tue 10/17/23	Sun 12/3/23
Materials Budget list	47.38 days	Tue 10/17/23	Sun 12/3/23
Proposed Implementation Gantt Chart	47.38 days	Tue 10/17/23	Sun 12/3/23
Conclusions and Recommendations	47.38 days	Tue 10/17/23	Sun 12/3/23
Parts Request Form for Subsystems	32 days	Wed 9/27/23	Sun 10/29/23
Subsystems Demonstrations Day 1	0 days	Wed 11/15/23	Wed 11/15/23
Subsystems Demonstrations Day 2	0 days	Wed 11/22/23	Wed 11/22/23
Parts Request Form for Spring Semester	0 days	Fri 12/8/23	Fri 12/8/23

Figure 20: Project Gantt Chart

Hardware Implementation	**43 days?**	**Mon 1/15/24**	**Mon 2/26/24**		
Aquire Hardware	**16 days?**	**Mon 1/15/24**	**Tue 1/30/24**		
Choose and order wheels	8 days	Tue 1/23/24	Tue 1/30/24		Tyler
Design paint can housing	22 days	Tue 1/23/24	Tue 2/13/24		Bryce,Tyler,Dalon
Finalize frame design	8 days	Tue 1/23/24	Tue 1/30/24		Tyler,Dalon,Bryce
Choose and order laser for calibration system	8 days?	Tue 1/23/24	Tue 1/30/24		Bryce,Dalon,Tyler
Design enclosure	36 days	Tue 1/23/24	Tue 2/27/24		Bryce,Dalon,Tyler
Choose and order battery	14 days	Tue 1/23/24	Mon 2/5/24		
Assemble Hardware	**21 days?**	**Wed 1/24/24**	**Tue 2/13/24**		
Build frame	14 days	Wed 1/24/24	Tue 2/6/24		Tyler
Attach servos & wheels	14 days	Wed 1/24/24	Tue 2/6/24		Tyler
Mount PCBs	14 days	Wed 1/24/24	Tue 2/6/24		Tyler
Install and integrate calibration system	1 day?	Tue 2/13/24	Tue 2/13/24		
Wire/install battery pack (replace power supplies)	14 days	Wed 1/24/24	Tue 2/6/24		
Test Hardware	**7 days**	**Wed 2/14/24**	**Tue 2/20/24**	**17**	
Frame weight test	7 days	Wed 2/14/24	Tue 2/20/24	17	Tyler,Bryce,Dalon
Battery life test	7 days	Wed 2/14/24	Tue 2/20/24	17	Bryce,Tyler,Dalon
MIDTERM: Demonstrate Hardware Subsystems	0 days	Tue 2/27/24	Tue 2/27/24		
Software Implementation	**43 days?**	**Mon 1/15/24**	**Mon 2/26/24**		
Develop Software	**43 days**	**Tue 1/23/24**	**Tue 3/5/24**		
Create code to drive wheels	15 days	Tue 1/23/24	Tue 2/6/24		Bryce
Create code to actuate paint	8 days	Tue 1/23/24	Tue 1/30/24		Bryce
Code perimeter	8 days	Tue 2/13/24	Tue 2/20/24		Dalon
Calibration system code	22 days	Tue 1/30/24	Tue 2/20/24		Bryce
Code arc	36 days	Tue 1/30/24	Tue 3/5/24		Dalon
Test Software	**10 days**	**Wed 2/14/24**	**Fri 2/23/24**	**23**	
Test perimeter	14 days	Wed 2/14/24	Tue 2/27/24		Tyler,Bryce,Dalon
Test the paint dispense system	14 days	Wed 2/14/24	Tue 2/27/24		Bryce,Dalon,Tyler
Test the arc	28 days	Wed 2/14/24	Tue 3/12/24		Dalon,Bryce,Tyler
MIDTERM: Demonstrate Software Subsystems	0 days	Tue 2/27/24	Tue 2/27/24		
System Integration	**49 days**	**Mon 1/15/24**	**Sun 3/3/24**		
Assemble Complete System Integration	**14 days**	**Tue 2/27/24**	**Mon 3/11/24**	**33**	
Copy code onto board	14 days	Tue 2/27/24	Mon 3/11/24	33	Bryce,Dalon
Finalize frame components and assemble fully	14 days	Tue 2/27/24	Mon 3/11/24	33	Tyler
Test Complete System Integration	**7 days**	**Tue 3/12/24**	**Mon 3/18/24**	**35**	
Test the frames ability to drive the full perimeter length	7 days	Tue 3/12/24	Mon 3/18/24	35	Tyler,Bryce,Dalon
test frames ability to drive arc	7 days	Tue 3/12/24	Mon 3/18/24	35	Bryce,Dalon,Tyler
test the spraying capability of the perimeter	7 days	Tue 3/12/24	Mon 3/18/24	35	Dalon,Bryce,Tyler
test the spraying capability of the arc	7 days	Tue 3/12/24	Mon 3/18/24	35	Bryce,Dalon,Tyler
Revise Complete System Integration	**23 days**	**Tue 3/19/24**	**Wed 4/10/24**	**38**	
bugfixes	23 days	Tue 3/19/24	Wed 4/10/24	38	Tyler,Bryce,Dalon
Preliminary Demonstration of Complete System	4 days	Mon 1/15/24	Thu 1/18/24		
Develop Final Report	**106 days**	**Mon 1/15/24**	**Mon 4/29/24**		
Spring Break	7 days	Mon 3/25/24	Sun 3/31/24		
Project Demonstration and Presentation	0 days	Tue 4/16/24	Tue 4/16/24		

[1]

Throughout the work period, the group stayed relatively close to the projected schedule within the GANTT chart, only making minor changes to smaller deadlines and getting rid of the calibration system due to time constraints. The other change that was made includes the mechanism used to mark the basketball court. As the semester continued, it was understood that

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using a mostly permanent solution like paint was out of the scope in this case. Thus, the group decided to pivot to using less permanent solutions such as chalk. This replaced our goal of designing and utilizing a spraying mechanism with designing and utilizing multipurpose marking system. This was done through gravity instead of using servo motors allowing the group to utilize materials such as chalk or markers while still maintaining the ability to complete the basketball court in one trip from start to finish.

10. Conclusion

In conclusion, developing a robot capable of marking a half basketball court with a given level of precision and efficiency represented a move forward in the world of automated technology in a small, budget-friendly package. This robot employed innovative and clever design ideas to perform the task of marking a court, fully automated. Efficiency for a user is greatly improved since they can set the robot down, enable it and then do other tasks themselves while the robot marks a court for them. Precision is improved also since the robot is much more accurate than a human trying to free hand paint the court. All the calculations and distances are coded into the motors at high precision. Consistency is at a very high level with a robot such as this due to the automation of most tasks, aside from turning the robot on/off for example. Safety of the users is further increased since people are removed from the process of painting which can pose chemical hazards. Movement of the robot is achieved by having two wheels driven by independent stepper motors via PWM and one castor wheel to maintain stability. By independently powering the wheels in either direction, we could achieve excellent levels of movement while having a near zero turn radius. The three-point arc was accomplished by setting the period of the outer motor such that it will rotate at a higher speed than the inner motor, allowing the robot to move in the shape of an arc. Marking was achieved by using chalk in a PVC tube with a spring to compress the chalk against the pavement. Overall, the robot operated as intended and produced consistent courts with a high level of accuracy. Recommendations from our group would include testing systems and parts much sooner. We did not have too much of an issue due to lack of field testing earlier on however timing could have proved not on our side if testing did go awry. We would also recommend having a sensor to ensure the robot stays on a straight path.

11. References

11.1 Article References

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11.2 Patent References

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