ECE 198 Design Document - Group 33 (Siddharth & Rayyan)

Needs Assessment

Client/Customer definition

- Demographics:
    - Employment: School authorities
    - Type: Elementary, Middle, and Secondary schools
- Economic:
    - School authorities (specifically the principal/person in charge of playground maintenance) must allocate a relatively high upfront payment, with the payment of maintenance being extremely low (since the robot only relies on being plugged into an outlet using a cable)
- Geographic
    - Location: School zones, places where schools are constructed
    - Specifically school playgrounds, ideally flat surfaces

Challenges:

- Excessive amounts of litter on the ground obstructs children from playing and engaging in recreational activities. [1] [4]
- Littering in school yards often occur daily - especially in an environment of children since some may not be educated about the repercussions of littering.
- The lifespan of a littered playground has been shown to be significantly lesser than a playground cleaned often.

Sources:

- [2] outlines the advantages of having autonomous dusting robots in schools (however our robot will be collecting physical garbage). The article outlines that the main advantage is to save money on workmen who take time & effort to dust the school (our project will help the school save money on workmen who put in the effort to go outside and clean up garbage). [5] outlines the importance of having/maintaining a clean school playground and demonstrates that this is a problem for children who regularly play at their school playgrounds - and shows that cleaning up regularly can reduce the risk of injury and also ensure the longevity of the playground.

[1] https://callmehannah.ca/the-top-10-things-i-found-cleaning-up-trash-in-the-schoolyard/
[2] https://www.techlearning.com/news/how-robots-can-clean-schools
[3] https://felton.net.au/three-ways-you-can-reduce-litter-in-the-schoolyard/
[4] https://www.allpeoplecanplay.com/blog/park-playground-waste-management/
[5] https://www.arihantplay.com/important-maintenance-cleaning-tips-for-school-playgrounds/

Competitive Landscape

1. [6] is a technological cleaning system created by braincorp to address a similar issue as us - cleaning up dust on floors. Their Robotic Floor Scrubber is used to clean hard floors within stores, malls, and schools. This system is similar to ours in the sense that the dust gets stored within the robot until it automatically goes to its docking station. However, the robot doesn't simply dump the dust, it requires a user to clean up the dust stored - unlike our robot which will simply dump the garbage at the predefined docking station.
2. [6] also outlines another technological cleaning system - robotic vacuums created by braincorp to clean up the dust on soft floors including carpeted areas in commercial areas such as office spaces, classrooms/lecture halls in universities and hospitals. Again, this is a similar system to ours since the dust gets stored within the robot until it goes to its docking station. However, similar to the previous one, the robot doesn't simply dump the dust, it requires a user to clean up the dust stored - unlike our robot which will simply dump the garbage at the predefined docking station.
3. [7] outlines the fact that it is the duty of custodians at schools to clean their school playgrounds. Although students in the school bear a responsibility not to litter at playgrounds, the responsibility falls toward the custodians to keep school playgrounds clean. This is an economic system funded by the school authorities, with their goal being to clean the school's playgrounds. The design for our robot will aim to minimize work done by school custodians through the means of collecting garbage around the playground.

[6] https://braincorp.com/applications/floor-care/
[7] https://nces.ed.gov/pubs2003/maintenance/chapter5_2.asp

Requirement Specification

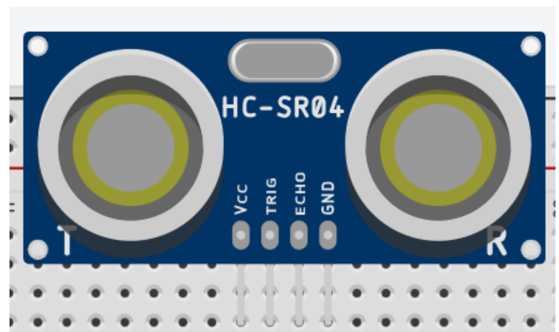
1. **Input definition of perimeter (must be a factor of 25cm):** This is a fully autonomous robot: We first define the entire perimeter of the area in cm^2 (For example 1000cm x 1000cm). The location of the garbage disposal as an (x, y) system will be represented as (0cm, 0cm)
2. **Size of robot:** 25cm x 30cm x 15cm (including height of bin & tires)
   Size of bin: 20cm x 10cm x 10cm
3. **No children must be present within 5m on either side of the predefined operating perimeter**: Due to children potentially being present on the predefined perimeter on the school yard/ground, we must make it a requirement that there are no children close to the predefined operating perimeter of the robot to completely prevent any accidents and to maximize student safety. For example: if the predefined perimeter is 1000cm x 2000 cm, there can be no children present within the area of 2000cm x 3000cm.
4. **Ultrasonic sensor (HC-SR04) range between 2cm - 350cm:**

a. US sensor senses objects directly in front of it, and gets a distance/proximity reading of the object in front of the robot.
b. Convert the time reading from the ultrasonic sensor into a distance measurement using the physics formula/principle outlined in the next section.
c. Average Power consumption at any given time: 0.006A*3V = 0.018W

❖ Range reading of US sensor: **2cm - 350cm**. This means that the robot will not be able to sense objects greater than 350cm (object too far away) and lesser than 2cm (object too close) away from the robot [8].

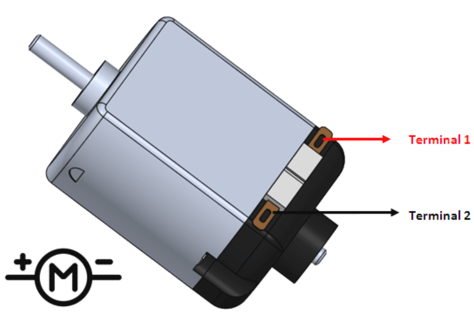
Pinout:

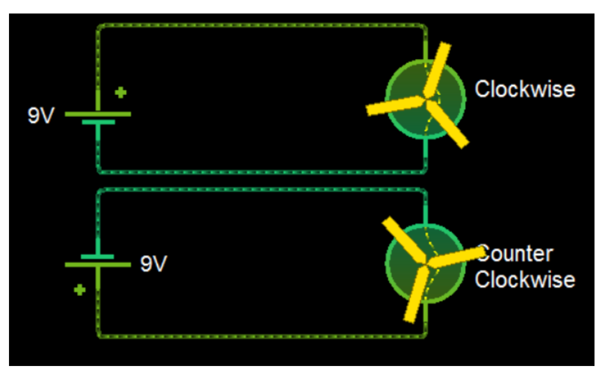
VCC: Powers the sensor, +5V
TRIG: Input pin, receives the ultrasonic wave
ECHO: Output pin, sends the ultrasonic wave
GND: Grounds the sensor



5. Two DC motors to control the motion of the robot - forwards, backwards, left turn, right turn

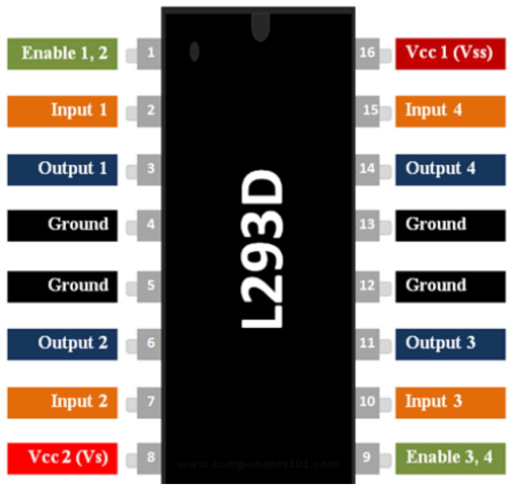
a. DC motors allow the robot to go forwards, backwards, left and right (using programs). We will require the robot to perform forward & backward motion along with right & left turns.
b. Reversing the connection of wiring in Terminal 1 and Terminal 2 will reverse the direction of the motor.
c. We plan to implement 2 DC motors in our robot design, and create separate void functions for the robot to make a left turn (setting the right motors to forward and left motors backward) and a right turn (setting the left motors forward and the right motors backward) [9].





d. The other 2 DC motors are responsible for operating the scoop that we will implement at the front of our robot.

e. Average power consumption of ONE DC motor: 3V*1.5amps = 4.5 Watts per motor. Therefore 18 Watts used to run all 4 motors at any given time, which is within our project's power requirements.
f. We will be using two H-bridge L293D IC to control the speed of each motor. Since each L293D IC can control two DC motors, plan to use two L293D motor driver ICs to control the direction (+ forward or - backward) and speed (based on voltage supplied) of four motors [11]. The images below outline the pinout and the schematic we will be using to connect each motor driver to each pair of our DC motors.



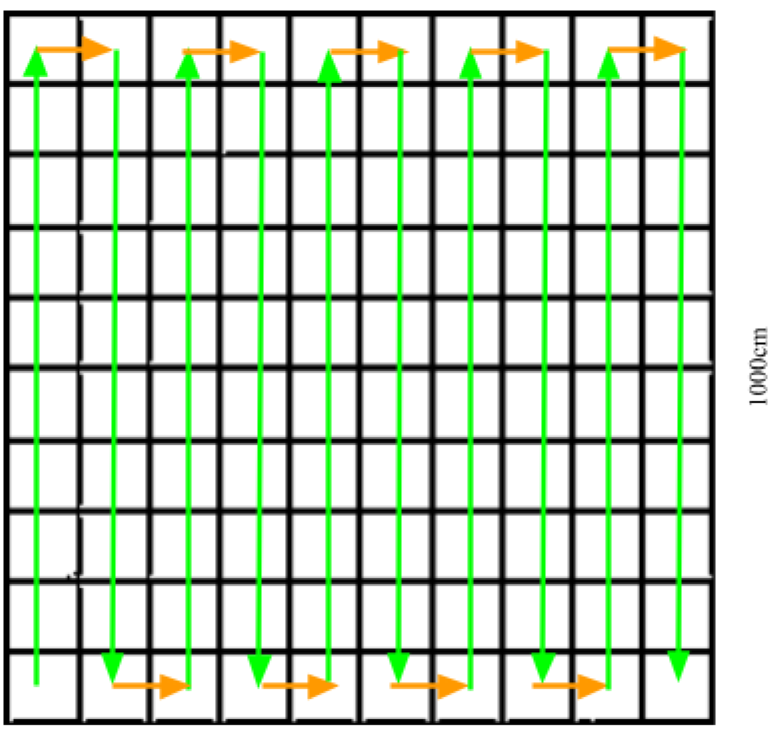
[8] https://www.omnicalculator.com/everyday-life/electricity-cost
[9] https://components101.com/tags/dc-motor
[10] https://components101.com/sensors/ultrasonic-sensor-working-pinout-datasheet
[11] https://components101.com/ics/l293d-pinout-features-datasheet

Analysis

Design

Implementation & Operation - User instructions & Robot functionality

- The user must first define the entire perimeter of the area in cm^2 (For example 1000cm x 1000cm). The length and width must both be a factor of 25cm to minimize margin or error. must be The location of the garbage disposal docking station expressed as an (x, y) coordinate system will always be (0cm, 0cm).
- Next, the user must place the robot at the docking station - the origin (0cm, 0cm) and plug the robot into the STM32 microcontroller connected by a USB port. The robot is now powered on and starts to map its perimeter from this point- and goes forward while picking up garbage on its way.
- Logic (perimeter): The robot has been programmed to turn right after it reaches the end of the length (1000cm). After turning right it then goes forward precisely 25cm. The robot then turns right again and goes forward (1000cm) until it covers the length once again. This process repeats over and over until the entire perimeter is covered.
- After covering the entire perimeter, the robot will come to a full stop, and the user is free to unplug the robot from the USB port connecting to the STM32.
- The below image provides a visual of the robot's 2D mapping, given the input perimeter of 1000cm x 1000cm.

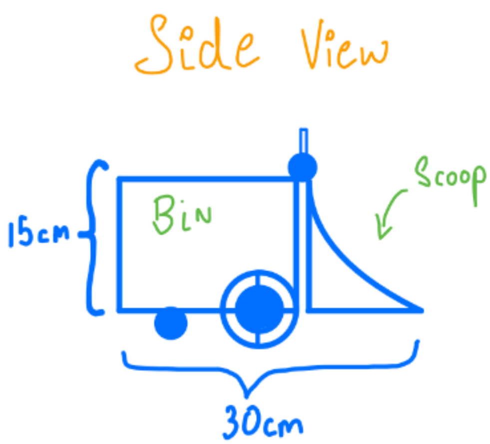


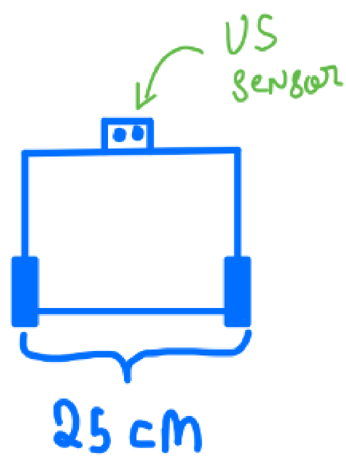
1000 cm

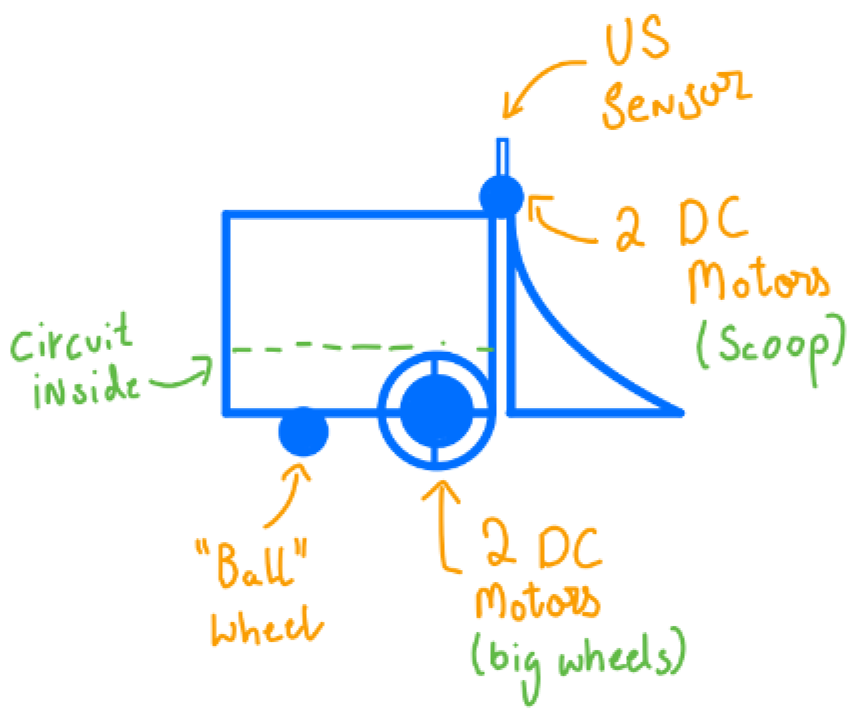
Implementation - Programming logic

- While the US sensor receives max reading, or 0 reading - the robot moves forward. Once US sensor gets a distance reading less than the max, the robot stops 2.5cm in front of the object.
- At this point, the US sensor stops measuring object distance in front of it (since the scoop will be blocking it) - and then the scoop takes the garbage and puts it into the robot's bin, and comes back to its neutral position. The robot then continues on its path.
- When the robot approaches the end of the perimeter, it will know to turn since the distance covered by the robot will be modelled as a function of time.
- The robot proceeds to scoop the garbage, and
- Right turn: left motor forward, right motor backwards (delay 1000ms)
- Left turn: right motor forward, left motor backwards (delay 1000ms)
- Forward: both motors forward (delay uses the input length of the perimeter)

Construction - Prototype sketches of robot





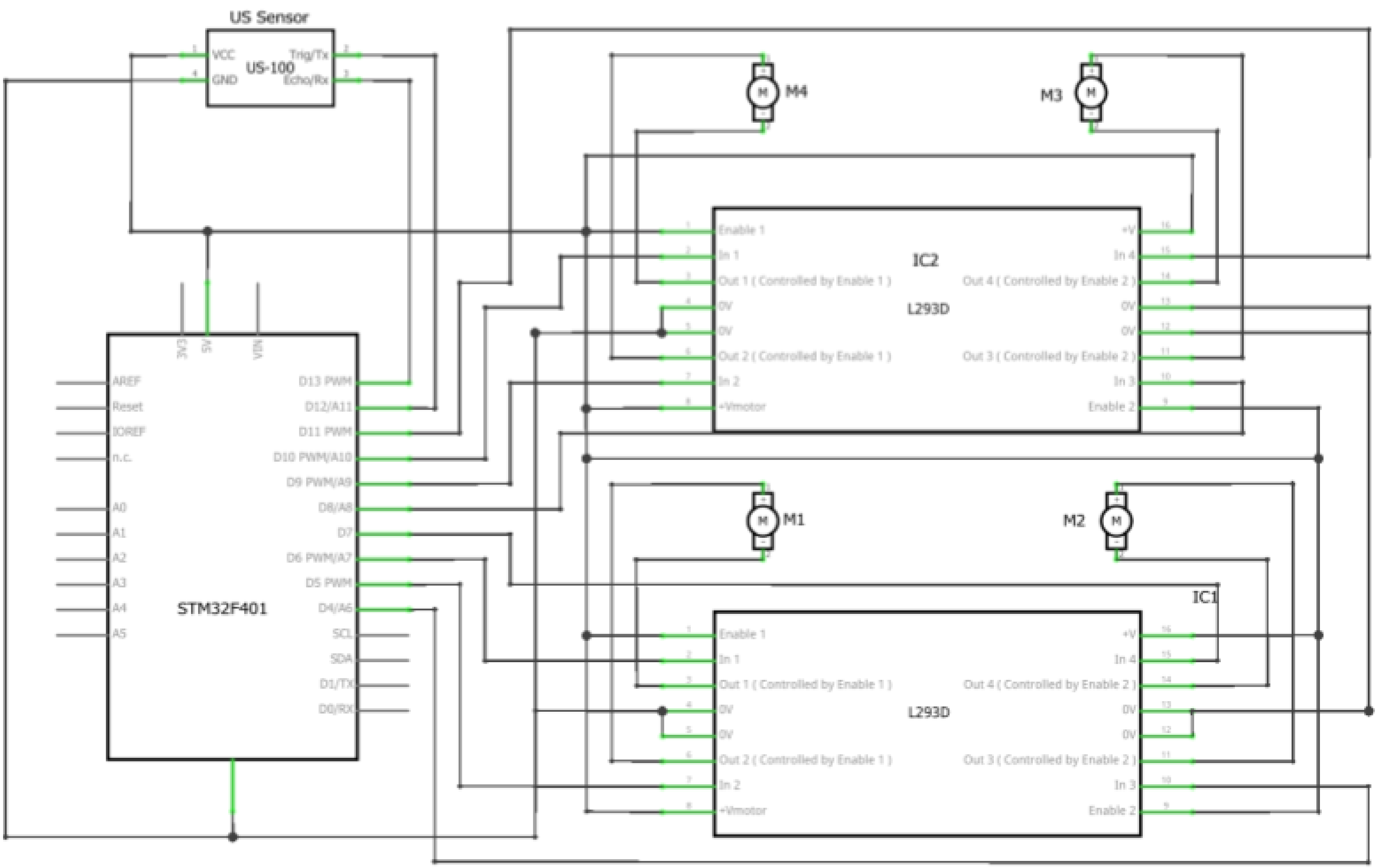


Construction - Key features

- Scoop to temporarily store garbage, DC motors attached to scoop to dump the garbage into the bin
- “Ball Wheel” to minimize traction, maximize the efficiency of the 2 big wheels controlled by DC motors
- The breadboard and circuit will be located underneath the bin, and a USB plug will be present to connect it to power.
- US sensor just above the scoop

Ball Wheel

Schematics, functions of components

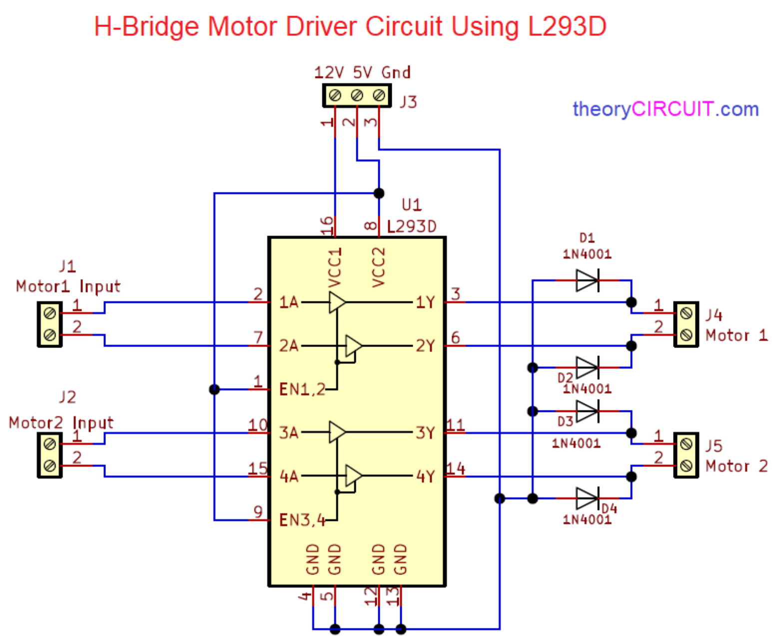


1. **Ultrasonic Sensor**

The ultrasonic sensor sends an acoustic wave (between 20-45kHz, above the audible range for humans) through its echo pin and receives the wave through its trigger pin. As outlined in the mathematical principles later, we can implement a formula using the time taken by these pulses to return to the trigger pin - in order to get a reading of the proximity of an object away from the robot.

Logic - if the US sensor detects an object in front of it, it must be garbage/trash that needs to be picked up. We will use time delays to ensure that the robot stops about 2.5cm before the garbage, goes forward to scoop it up, and dumps the garbage into the bin. Our program ensures that the US sensor will <u>not</u> be detecting objects in front of it, only while the scoop is in motion.

2. **L293D Motor Driver**



The above schematic showcases the logic and components used by the L293D motor driver. The L293D will receive signals from the STM32 microcontroller and will be used to transmit a similar signal to each of the motors that it will be connected to. As outlined earlier, this IC has two VCC pins - one draws current for the IC to work, and the other pin supplies voltage to both motors that it controls.

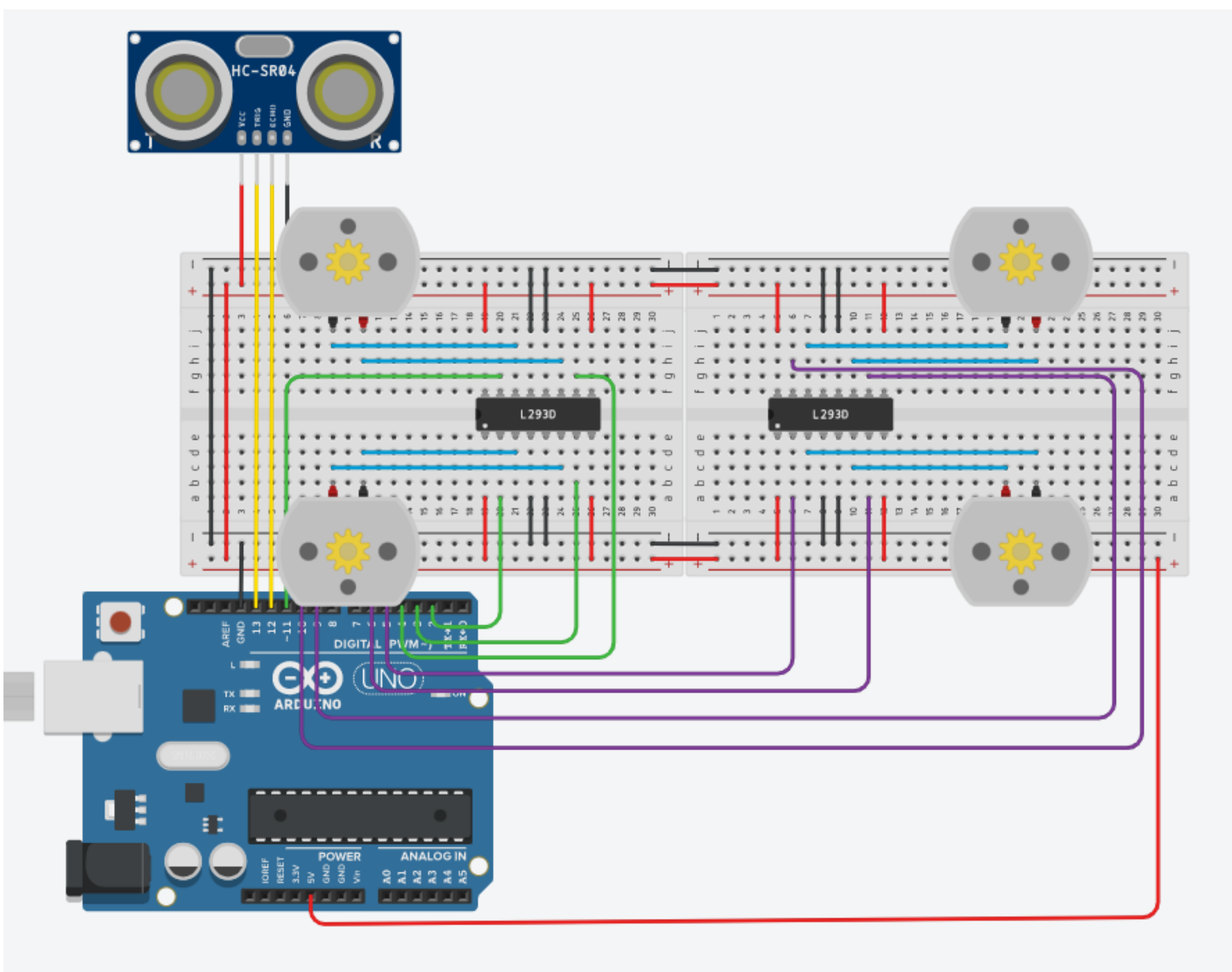
Logic - each L293D will control a <u>pair</u> of DC motors - allowing each of them to go forwards and backwards. This will be especially useful when our robot needs to take efficient left/right turns, even though the robot will never go in a backwards motion.

3. **Motors**

Our design implements two pairs of DC motors. One pair of motors is responsible for the motion of the robot (go forward, stop, turn right, turn left). The other pair of motors is responsible for the operation of the scoop (the scoop goes up to dump the garbage into the bin, comes back down and the robot resumes its operation).

Construction - Materials

- The scoop of the robot will both be constructed using layers of cardboard to provide stability and minimize costs. The chassis of the robot will be made up of ABS plastic, with holes cut through it to fit in the wheels and the breadboard/circuit. The bin of the robot will also be constructed using ABS plastic to provide stability and minimze costs.
- The image below provides one way that the schematic can be turned into a fully functioning circuit. Instead of using the Arduino UNO in the image below, our project will use the STM32 - simply follow the same connections as outlined in the circuit below onto the digital/analog pins of the STM32. All other connections remain exactly the same.



Scientific & Mathematical Principles

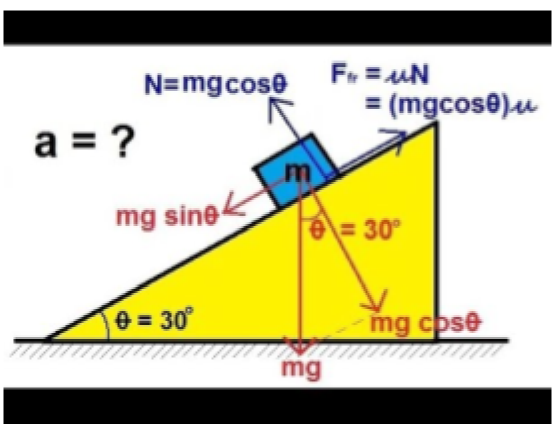
1. **Physics Principle:**

Understanding & Application:

A challenge of maintaining safe speeds being travelled by our autonomous robot is using tires that have more grip so when our device goes down any sort of slight ramp or small hill, speeds too great are not picked up to avoid any external or internal damages.

The physics equation for when something is going down a ramp: $acceleration = mgcos\boldsymbol{\theta}$ is an equation which displays how (though the angle of a ramp on any playground is generally quite small) our device will begin to move much faster and at a speed that can cause some form of damage.

The understanding of this principle helps us resolve our problem exceptionally well. As prior to knowing that there will be times when our device will begin to move too fast where things might become slightly dangerous, we did not consider making any changes to our tires. However, upon taking into account what the consequences of this physics principle are, we realize that we need to use wider tires which have more grip in them to avoid our device from moving too fast where damage may occur.



Stronger/thicker tires which should be used

References:

"Inclined planes," *The Physics Classroom*. [Online]. Available: https://www.physicsclassroom.com/class/vectors/Lesson-3/Inclined-Planes. [Accessed: 23-Oct-2022].

C. Perkins, "Do wider tires give you more grip? not all the time," *Road & Track*, 28-Jul-2020. [Online]. Available:

https://www.roadandtrack.com/car-culture/buying-maintenance/a21776425/wider-tires-more-grip/. [Accessed: 24-Oct-2022].

comes at the expense of wet performance, so you need to pick which you want more of. And while wider tires generally provide more grip in the dry on track, their road manners might

2. Mathematical Principle:

Understanding & Application:

In using US sensors, to be able to determine how far an object/piece of garbage is, we need to be able to calculate, through using ultrasonic waves, how far an object is, so the autonomous robot may know where to pick up garbage from.

This is possible through the use of a mathematical algorithm which can be applied in our code to determine how far an object is.

```
digitalWrite(TRIGGER_PIN, LOW);
delayMicroseconds(2);
digitalWrite(TRIGGER_PIN, HIGH);
delayMicroseconds(10);
digitalWrite(TRIGGER_PIN, LOW);
duration = pulseIn(ECHO_PIN, HIGH);
distance = duration * 0.034/2;
```

Ultimately, this algorithm will allow the device to know how to determine a piece of garbage's location.

This principle is an absolute necessity in allowing our device to even be operational. The equation we use solves our issue of knowing when something is a piece of garbage, when our robot needs to rotate, and when our robots should continue to move forwards or backwards. Without this equation, our device is not able to work.

References:

Anonymous and D. Kruger, "HC-SR04 ultrasonic sensor," *Components101*. [Online]. Available: https://components101.com/sensors/ultrasonic-sensor-working-pinout-datasheet. [Accessed: 23-Oct-2022].

HC-SR04 Sensor Features

- Operating voltage: +5V
- Theoretical Measuring Distance: 2cm to 450cm
- Practical Measuring Distance: 2cm to 80cm
- Accuracy: 3mm
- Measuring angle covered: <15°
- Operating Current: <15mA
- Operating Frequency: 40Hz

3. Mathematical Principle:

Understanding & Application:

An issue of optimization arises upon our bin getting filled to its limit and needing to return to a docking spot to unload all of its garbage. Our device, in most situations, will need to travel a large distance to unload all of its garbage. However, we want to use pythagorean to calculate the shortest distance from where the device is, to where the garbage needs to be unloaded.

The equation is simply the distance formula derived from pythagorean theorem: $d = \sqrt{x^2 + y^2}$. Through the coordinates, we can plug in the x and y coordinates to find the shortest distance for the device to travel.

Finally, travelling the shortest distance optimizes all of our operations. Travelling the shortest distance allows for lowering the chance of any garbage spilling out as it will now be filled to the brim for a shorter period of time. As well, using the shortest distance ultimately allows for the fastest cleanup.

References:

Admin, "Pythagoras theorem (formula, proof and examples)," *BYJUS*, 06-Jun-2022. [Online]. Available: https://byjus.com/maths/pythagoras-theorem/. [Accessed: 23-Oct-2022].

How to use Pythagoras Theorem?

To use Pythagoras theorem, remember the formula given below:

$c^2 = a^2 + b^2$

Where a, b and c are the sides of the right triangle.

For example, if the sides of a triangles are a, b and c, such that a = 3 cm, b = 4 cm and c is the hypotenuse. Find the value of c.

We know,

$c^2 = a^2 + b^2$

$c^2 = 3^2+4^2$

$c^2 = 9+16$

$c^2 = 25$

$c = \sqrt{25}$

c = 5 cm

Hence, the length of hypotenuse is 5 cm.

Costs

Manufacturing Costs:

Qty	Component+ Source	Cost	Manufacturer	Location	Vendor/ Distributors	Location
1	US Sensor https://www.digikey.ca/en/products/detail/adafruit-industries-llc/3942/9658069	$6.22	Adafruit Industries LLC	New York, USA	DigiKey	Minnesota, USA
4	DC Motor https://www.digikey.ca/en/products/detail/vybronics-inc/VZ7AL2B1692612/7732322	$6.05 x 4	Vybronics Inc	New York, USA	DigiKey	Minnesota, USA
7	LED https://www.digikey.ca/en/products/detail/adafruit-industries-llc/4202/10130501	$4.65	Adafruit Industries LLC	New York, USA	DigiKey	Minnesota, USA
4	Wheel https://www.aliexpress.com/item/1005003514239354.html	$5.12	Cainiao Standard	Hangzhou, China	AliExpress	Hangzhou, China
1	L293D IC https://www.digikey.ca/en/products/detail/texas-instruments/L293DNE/379724	$6.76	Texas Instruments	Texas, USA	DigiKey	Minnesota, USA
1	Breadboard Kit With Wirehttps://universal-solder.ca/product/breadboard-830-starter-kit-with-wires-and-power-supply/?srsltid=AR5OiO3f5hjZ2JPvuo3K9kJWdeCqHtxMMstVVU_TB8bHxVrDWfwRlQYrx94	$9.95	Canaduino	Windsor, Ontatrio	Universal Solder	Windsor, Ontatrio

Implementation Costs:

Installation Manual:

Our device is exceptionally easy to install and get working. As it is still in prototype and is bound by the constraints of the assignment, the manual is at chance of alterations depending on the product upon prototype finalization. Regardless of this fact, installation of our device could not be easier. As it is based on the use of the STM32, our device will need to be connected to a computer in order to receive power to operate. Upon being connected with a computer through a USB, an extension cord may be needed depending on the length of the USB in order to more effectively complete the task of our device. You can now proceed to give the device input parameters to let it know how large the area it is cleaning is. Now that the device is properly connected, it can be set down in the children's play area, starting from the docking station, and complete the task of picking up garbage to make sure kids have a clean and safe place to play in!

User Guide:

Looking to use a great device which helps the environment and keeps children safe? Look no further! Our device sets up easily and gets its job done well even more easily. First, connect the device to a computer so that it can have a power supply to operate through. Next, determine if an extension cord will be required depending on the area that you wish to use the device in. Then, as your area requires, connect the extension cord to the device. Proceed to now give the device the parameters of the area it has to clean. Finally, make sure there are no children in the area and place the device at its docking station in the playground area you wish to have cleaned. Enjoy as your children have a clean and safe area to play in!

Finally, once the area has been cleaned and the device is sitting at its docking station since its job is no longer existent,

Risks

Energy Analysis:

1. Reference standards (baseline power levels)

The STM32F401 microcontroller can handle a max power supply of 5V (most I/O pins are 5V tolerant according to [12]).

2. Evidence that reference standard is appropriate for design: [12] is the official documentation that showcases the official power requirements/tolerance for the STM32F401 microcontroller. It states that most digital I/O pins are 5V tolerant provided VDDIOx is above 1.6V (which is true for our project).

[12] https://www.st.com/resource/en/reference_manual/dm00096844-stm32f401xb-c-and-stm32f401xd-e-advanced-arm-based-32-bit-mcus-stmicroelectronics.pdf

3. Scientific reasoning for whether energy storage could occur

Energy storage is unlikely to occur in our project since we are not using components such as capacitors. Capacitors are electrical components that store a charge. The only components we are using in our electronic circuit are DC motors, a US sensor, wires, breadboard, motor drivers, along with the STM32 and the USB cable. Aside from DC motors, none of the above components store any energy whatsoever. [13] states that “There is energy stored both in the inertia of the motor’s rotor and also in the mechanical system attached to the motor” which is almost negligible.

[13] https://www.monolithicpower.com/energy-recycling-in-dc-motor-drives

4. Quantify max energy stored

The maximum energy stored in our system will be close to ~ 0mJ. The only reason why this number is slightly over 0mJ is due to the mechanical energy stored by all the DC motors (again, the energy stored here is almost negligible - but slightly greater than zero).

Risk Analysis:

- **Possible negative consequences on safety or environment from using the design as intended:**
  If something such as an extension cord is used, it can end up being spread out across large areas of the playing area and can therefore result in a serious tripping hazard when putting the device away. However, due to the small size of our design, no negative

environmental impacts can be inflicted by it apart from negligible impacts caused by the use of technology as the power supply.

- **Possible negative consequences on safety or environment from using the design incorrectly:**
  A possible safety issue that can occur from being negligent in reading the device instructions is that children might remain in the play area while our device is cleaning the playground. This can result in not only children getting hurt, but possibly irreparable damage being done to the device. There are many potential negative impacts which can occur. Namely, if the device is not powered correctly through a computer, an overload of power can be given to the device which can cause its components to burn out and in a worst case scenario, start a fire! Which is an extremely dangerous turn of events which puts both the environment and safety of users in risk.

- **Possible negative consequences on safety or environment from misusing design in a manner not intended:**
  If the device is used to pick up garbage in an area not intended, not only will it not be of any use, it may try to collect garbage items which are beyond its ability to pick up. This can result in the device breaking and again, can put the device in risk of starting a fire which is a huge negative harm on the environment and to those around the device.

- **Possible ways design could malfunction:**
  There are definitely ways in which our device could malfunction, however, those will likely only be results of mishandling the device and not using it according to the instructions we have specified. For example, if incorrect parameters are given to device pertaining to the area of the playground, the device will likely not function as desired at all. The only scenario which could potentially occur where the device malfunctions is if an extension wire is used and the device tries to pick up the extension wire instead of garbage which could result in an endless loop of garbage not being collected.

- **Consequences on safety or environment for each specified failure mechanism:**
  Chances of fires happening are applicable due to negligence from the user which can result in the danger of not only the environment but obviously to those around the device if a fire breaks out. Tripping hazard is visible to users if they do not follow safety regulations if they choose to use an extension wire.

Testing and Validation

1. **Input definition of the perimeter must be a factor of 25cm**

- Test setup: The user must open the STM32 cube IDE (Integrated Development Environment). On the IDE, the program will prompt the user to enter a length, width value.
- Environmental parameters: None - a 50cm x 50cm perimeter to place our computer will suffice since this is a software test.
- Test inputs: The user must input a valid integer as a length and width for the perimeter mapping.
- Quantifiable measurement standard: The length and width must be entered in cm. There will be 2 prompts - one number for the length, one number for the width (must be greater than 25cm each).
- Pass criteria: The entered numbers must each be greater than 25, and must each be divisible by 25.

2. **Size of robot must be 25cm x 30cm x 15cm and size of bin must be 20cm x 10cm x 10cm:**

- Test setup: Ruler, pencil, paper, finished model of robot.
- Environmental parameters: A 100cm x 100cm perimeter.
- Test inputs: The length, width and height of the finished model of the robot, and the bin will be measured using the ruler and noted down on the paper.
- Quantifiable measurement standard: The robot (with the bin) must be no more than 25cm x 30cm 15cm and the size of the bin must be no more than 20cm x 10cm x 10cm. There will only be one trial conducted to measure each of these parameters (length, width and height) to a great level of precision.
- Pass criteria: As per our safety requirements on the proposal document, the dimensions of the robot can be no more than 25cm x 30cm 15cm, and the size of the garbage bin can be no more than 20cm x 10cm x 10cm. If these requirements are met, the test has been passed.

3. **No children must be present within 5m on either side of the predefined operating perimeter (This test will be conducted more manually and is more relevant to a user’s ability to safely operate the device)**

- Test setup: The user must scan the area they are going to place the device in and see if there are any children in the area, specifically 5m within the radius of the device.
- Environmental parameters: Children’s playground area and/or the area in which the device is expected to be used

- Test inputs: User will identify area, primarily area of 5m radius around device and locate if any children fall within that space. If a child falls within the radius, test failed
- Quantifiable measurement standard: Area must be scanned with meters in mind. Upon considering meters, a 5m radius scan of the device must be conducted by the user.
- Pass criteria: If no child is detected in the 5m radius of the device, the test has been passed. In any other case, the test has been failed.

4. **Ultrasonic sensor (HC-SR04) must measure accurately within the valid range in the documentation 2cm - 350cm**

- Test setup: IDE must be open, sample US sensor code (that performs this test) uploaded to STM32, plastic box, ruler.
- Environmental parameters: An open space in front of the sensor, ideally a 200cm x 500cm perimeter and no objects within 500cm in front of the US sensor.
- Test inputs: Upload the sample code to the STM32, run the code. Place the plastic box within varying lengths from the US sensor, note the lengths using a ruler.
- Quantifiable measurement standard: 6 trials - Place the plastic box 1cm, 2cm, 3cm, 330cm, 350cm and 400cm away from the US sensor respectively in each trial.
- Pass criteria: The US sensor must give the max distance reading (350cm) for when we place the box 1cm, 2cm, 350cm, and 450cm away from the sensor. The US sensor must give the actual distance reading for when we place the box 3cm and 330cm away from the sensor.

5. **Two DC motors to control the motion of the robot - backwards motion, forwards motion, left turn, right turn must be accurate**

- Test setup: IDE must be open, sample motor motion code (that performs this test) uploaded to STM32.
- Environmental parameters: A clear perimeter of about 500cm x 500cm to test these motion of the robot.
- Test inputs: The code will have the following as inputs: forward motion, backwards motion, left turn, right turn.
- Quantifiable measurement standard: The program tells the robot to go forward for 5 seconds, turn right for 1 second, go backward for 5 seconds, turn left for 1 second.
- Pass criteria: The robot must successfully accomplish the above tasks within a 12 second timeframe, and the motion of the robot must be accurate (must be perfectly straight, backwards, right, left).