EG1311 Design and Make Report

B13 Group 4

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1. Introduction

This report documents our team's journey in designing and developing a self-powered robot capable of navigating an obstacle course (Fig. 1) and launching a ping-pong ball over a wall, all within the size constraint of 30 × 30 × 30 cm. Throughout four iterative designs, we refined key aspects such as movement stability, weight distribution, and payload delivery. Despite encountering multiple setbacks, each iteration significantly contributed to our learning and improvement, showcasing our design thinking process and the lessons gained along the way.

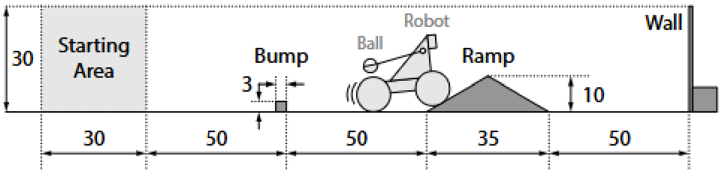


Fig 1. Obstacle Course

2. Abstract of Design

The template robot provided to us was not capable of completing any of the objectives. As we tested out the template robot, we identified the problems it faced and speculated on other potential issues from the current design. As we iterated through each design, adding and improving the functionalities, we set expectations for ourselves and followed the restrictions closely to overcome the challenges we encountered.

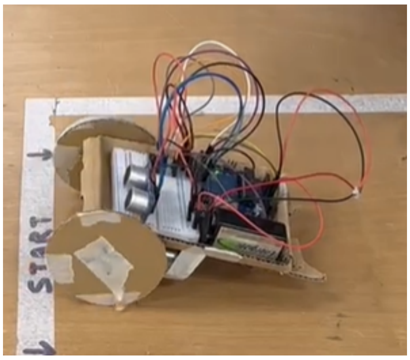


Fig 2. Template Robot

Expectations	Potential Challenges	Possible Designs
Traverse over the 3 × 3 cm bump and 10 cm ramp of 30-degree incline	If the diameter of the wheels is not wide enough, the chassis may collide with the apex of the ramp which can cause it to get stuck. Insufficient friction on the wheels will cause the robot to slip down the ramp.	Wheels should have a diameter higher than 8 cm and should be wrapped with a rubber band or anti-slip mat.
Launch the ping-pong ball over the wall	Due to the restrictions on the robot's dimensions and the 30 cm height of the wall, the ball has to be launched from a position below the top of the wall. As a result, it cannot be delivered in a straight line and must follow a parabolic trajectory.	Utilize the servo motor provided to construct a catapult with a launching mechanism.
Carry the robot components without toppling over	If the weight distribution is uneven, the robot will topple over when traversing the bump or ramp.	Ensure the heavy components are spread evenly on the robot with well-planned placements.
Ping-pong ball should remain in the catapult when traversing the obstacle course	When traversing the bump and the ramp, the ping-pong ball might fall out of the catapult bucket due to inertial forces.	The box containing the ping-pong ball should be deep enough. Materials that absorb shock may be padded within the bucket.
The robot's weight should be as light as possible	If the robot is too heavy, it may have difficulty in climbing the ramp.	Lighter materials such as cardboard and corrugated board can be considered. Acrylic is considered heavy.

2.1. Prototype 1: Four Motor Four-Wheel Drive with Cardboard Chassis

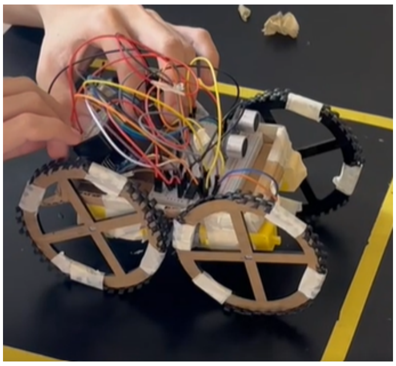


Fig 3. Prototype 1

Component	Template Robot	Challenge Faced	Prototype 1	Improvement
Motors and Wheels	2 motors and 2 wheels at the front of the robot	The back of the robot was dragging on the surface and the centre of mass leaned towards the rear, leading to instability on inclines.	4 motors and 4 wheels	The back of the robot was supported by 2 additional wheels. Even weight distribution increased movement stability.
Wheel Material	Cardboard wheels with an 8 cm diameter	The chassis would come into contact with the bump and apex of the ramp. The wheels also did not provide enough friction to clear the bump and ramp.	Acrylic wheels with a 10 cm diameter, wrapped with anti-slip mats	Provided the robot with greater clearance underneath the chassis and improved traction for traversing the bump and ramp.
Arduino Code and Wiring	2 motor pins	Arduino code and wiring only enabled 2 motor pins.	4 motor pins	Initialized 2 additional motor pins.

Overwhelmed by the plethora of challenges faced by the template robot, we set simple expectations for our first prototype. Our primary objective was to ensure our robot could clear the bump and ramp first before tackling other objectives. Retaining the cardboard chassis which was sufficient to support all the components, we equipped our robot with four motors and four wheels to enhance stability and generate enough torque to navigate the uneven terrain. The larger acrylic wheels increased sturdiness and ensured the chassis remained sufficiently elevated, preventing contact with obstacles while traversing the bump and ramp. To support the additional wheels, we modified the Arduino code and wiring so that all the motors could operate independently. After testing various materials, we found that the anti-slip mat reinforced with hot glue provided the best traction for the wheels.

2.2. Prototype 2: Four Motor Four-Wheel Drive with Catapult

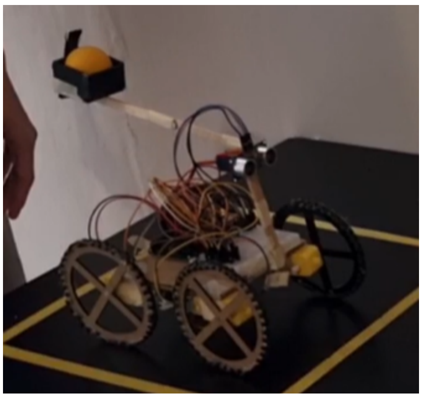


Fig 4. Prototype 2

Component	Prototype 1	Challenge Faced	Prototype 2	Improvement
Chassis	Rectangular cardboard cutout	Deteriorated in strength and stiffness over time, leading to misaligned wheels and collapsing of components.	2 pieces of 10 × 10 cm cardboard	The 2 identical pieces of cardboard were hot-glued together to increase stiffness and enhance durability.
Wheel Size	Acrylic wheels with a 10 cm diameter	The wheel's size leaves minimal separation between the adjacent front and back wheels, causing occasional contact. This configuration also raises the robot's centre of gravity, making it prone to flipping over on inclines.	Acrylic wheels with a 9.5 cm diameter	The wheels were sufficiently spaced apart and the centre of gravity of the robot was lowered to increase stability when traversing the bump or ramp.
Ultrasonic Sensor	Fixed onto the breadboard	The ultrasonic sensor detects the ramp when approaching it.	Detached from the breadboard and elevated using ice cream sticks, secured with rubber bands and tape to the servo motor.	The ultrasonic sensor was high enough to not detect the ramp.

After evaluating the issues encountered in Prototype 1, we found them to be minor and requiring only refinements. We raised our expectations for Prototype 2, aiming for it to clear the obstacle course and meet all project objectives successfully. To achieve this, we made the following improvements in Prototype 2 and introduced new functionalities. The next key objective was to launch the ping-pong ball over the wall. We constructed a catapult to contain the ball using a 4 × 4 × 2 cm corrugated board container mounted on an ice cream stick, which was taped to a servo horn. We chose the corrugated board because it provided sturdiness while remaining lightweight. The catapult was designed to generate a parabolic trajectory when launching the ball from an angle parallel to the ground. This was implemented by initializing the servo motor angle at 0 degrees and activating it to 45 degrees when a wall was detected. To ensure the robot returned behind the bump after launching the ball, we modified the Arduino code and rewired the motors to reverse infinitely once the catapult was triggered. This was executed by connecting the motors directly to the output pins of the L293D motor driver, allowing them to draw reverse currents by toggling the HIGH and LOW signals accordingly.

2.3. Final Prototype: Two Motor Four-Wheel Drive with Acrylic Chassis and Catapult

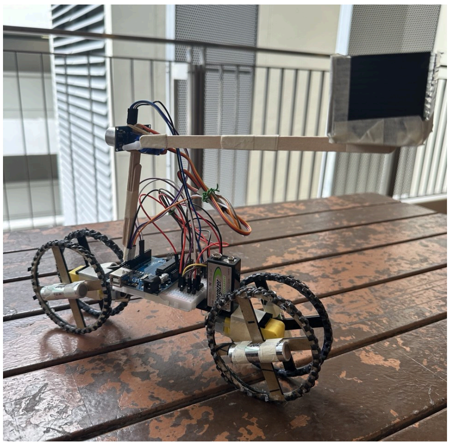


Fig. 5 Final Prototype

Component	Prototype 2	Challenge Faced	Final Prototype	Improvement
Chassis	2 pieces of 10 × 10 cm cardboard	Despite reinforcement, the cardboard eventually deteriorated with extended use, causing the robot to veer off course. The cardboard also flexed when traversing uneven terrain, compromising stability.	Thin 20 × 2 cm acrylic board	The rigid acrylic chassis proved to be reliable over multiple runs, showing no signs of wear and tear. Stability improved with almost no flex.
Motors and Wheels	4 motor with 4 wheels	The motors contributed significantly to the overall weight.	2 motor with 4 wheels	Weight was significantly reduced by 60g.
Catapult	4 × 4 × 2 cm corrugated board container	The ping-pong ball often falls out of the container when traversing the bump and ramp because of the catapult's recoil.	5 × 5 × 4.5 cm corrugated board container with anti-slip mat in the interior.	The larger container ensured the ball was fully contained and the anti-slip mat acted as a shock absorber.

Prototype 2 was successful, as it was able to clear the obstacle course and fulfil all the objectives consistently. However, it still faced reliability issues due to wear and tear of the chassis, an unsecured ping-pong ball, and occasional false detections from the ultrasonic sensor. Initially, we considered replacing the cardboard chassis with an acrylic one to address durability concerns. However, this conflicted with our goal of maintaining a lightweight design. At approximately 520g, Prototype 2 was already relatively heavy, and we were concerned that adding more weight might overload the motors.

While observing other groups in the lab, we noticed most robots were bulky and equipped with at least three motors. We reassessed our motor usage and realised that using only two motors was feasible, as their width provided adequate stability. Furthermore, the obstacle course posed more vertical challenges (bumps and ramps) than lateral ones. Hence, we made an ambitious but risky decision to significantly reduce the overall weight and drastically redesign the robot with the aim of minimizing weight while maintaining performance.

In our Final Prototype, we adopted a bicycle-like configuration. We reduced the motor count from four to two, with each motor driving a pair of wheels through a shared axle. This allowed us to maintain a four-wheel setup while halving the motor weight. The chassis was just wide enough to house the two motors, with the components placed centrally to ensure balanced weight distribution. However, the chassis could not accommodate the four 1.5V batteries, so we secured them to the wheels, effectively lowering the robot's centre of gravity and enhancing stability. We also improved the catapult by enlarging the container and lining it with anti-slip mats to dampen impacts. To address the issue of phantom detections caused by the sensitive ultrasonic sensor, we introduced a loop counter requiring three consistent readings before the robot stops.

2.4. Final Prototype Lite: Two Motor Four-Wheel Drive with Corrugated Chassis and Catapult

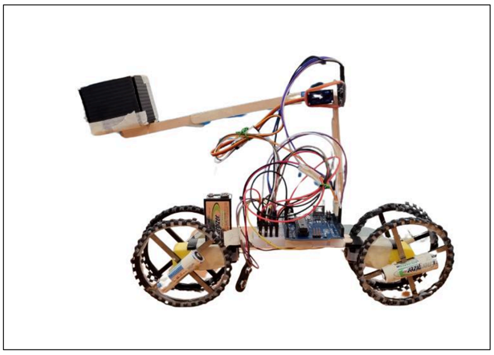


Fig. 6 Final Prototype Lite

Component	Final Prototype	Challenge Faced	Final Prototype Lite	Improvement
Chassis	20 x 2 cm acrylic board	The acrylic body weighed around 20g, which still contributed significantly to the overall weight.	20 x 2 cm corrugated board with ice cream sticks	Replacing the chassis with a corrugated board reinforced by ice cream sticks reduced its weight by approximately half.
Wheel Size	Acrylic wheels with a 9.5 cm diameter	The acrylic wheels also added considerably to the overall weight.	Acrylic wheels with a 9 cm diameter	Switching to slightly smaller diameter wheels still provided enough clearance for the chassis while shaving the overall weight by ~20g.

We managed to secure all the points for the Final Prototype, except for the "lightest robot" component in our second graded run, as another group had a lighter design. To reduce weight, we considered replacing acrylic parts while keeping in mind that this would compromise the robot's stability. We experimented with using only the corrugated board for the chassis, but it proved too unreliable due to excessive flexing over uneven terrain. To address this, we reinforced the chassis with ice cream sticks, which were both light and sturdy. By opting for smaller wheels, the robot's centre of gravity was lowered, reducing the risk of toppling over. This final improved version struck the best balance between weight and performance. We went ahead with the graded run, and it did not disappoint.

2.5. Conclusion

This project challenged us to go beyond just building a functional robot. Our team navigated a series of design challenges that required us to make deliberate trade-offs between weight, stability, and functionality. We adapted to setbacks and worked effectively as a team to iterate through four major prototypes, each driven by testing, reflections, and targeted improvements, leading us to the following key learning points.

Balancing and Compromising	Iterating and Prototyping	Improving our Soft Skills
Designing within constraints of size, weight, and component limitations meant that every decision involved trade-offs. We constantly had to weigh the benefits of durability against the need for weight reduction. Decisions such as reducing the number of motors, switching to lighter materials, and downsizing our chassis were all calculated risks. Each compromise was carefully considered with the end goal of optimising performance without sacrificing reliability.	Across four prototypes, our robot improved through continuous testing and refinement. Each failure taught us something new, revealing the gap between our initial plans and real-world implementation. We were initially hesitant to make drastic changes, especially with the leap from Prototype 2 to the Final Prototype, but even small tweaks, such as adding an anti-slip mat to the catapult bucket, made a huge difference. Iterating and prototyping were the hearts of our improvement process.	This project sharpened our collaboration and communication skills. Making collective decisions and coordinating tasks under time pressure highlighted the importance of teamwork and adaptability. We encountered many hardware issues in the early design stages, including a faulty Arduino board and broken connections. Through guidance from our tutors and the lab personnel, we learnt how to debug effectively using tools like the multimeter and the Serial.println() function. Surprisingly, our Final Prototype Lite was fully assembled in under two hours during the graded run session.

2.6. Acknowledgements

We would like to extend our appreciation to the following staff for their guidance in this project:

Lecturer: Dr Jason Ku

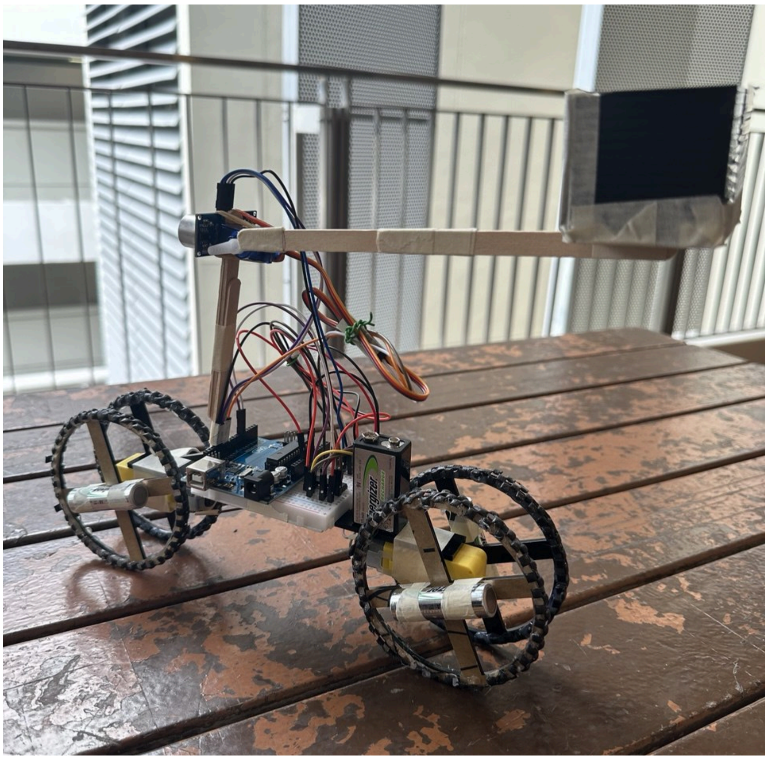
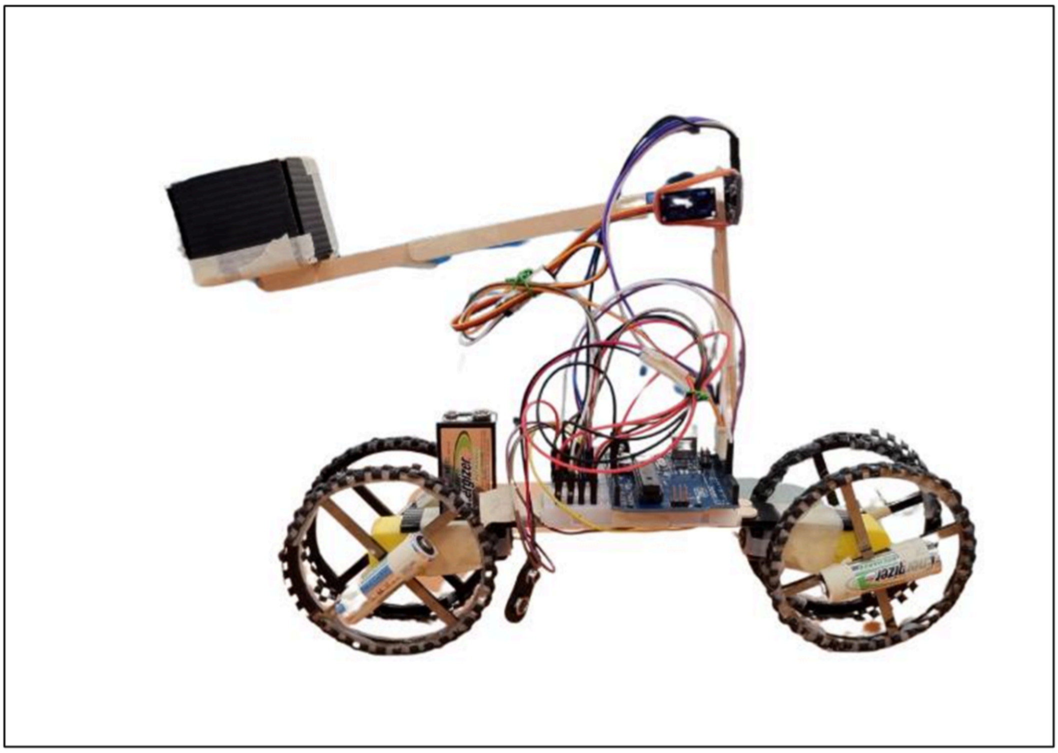
Tutor: Dr Mark Chong

Lab Staff: Mr Vincent Bay

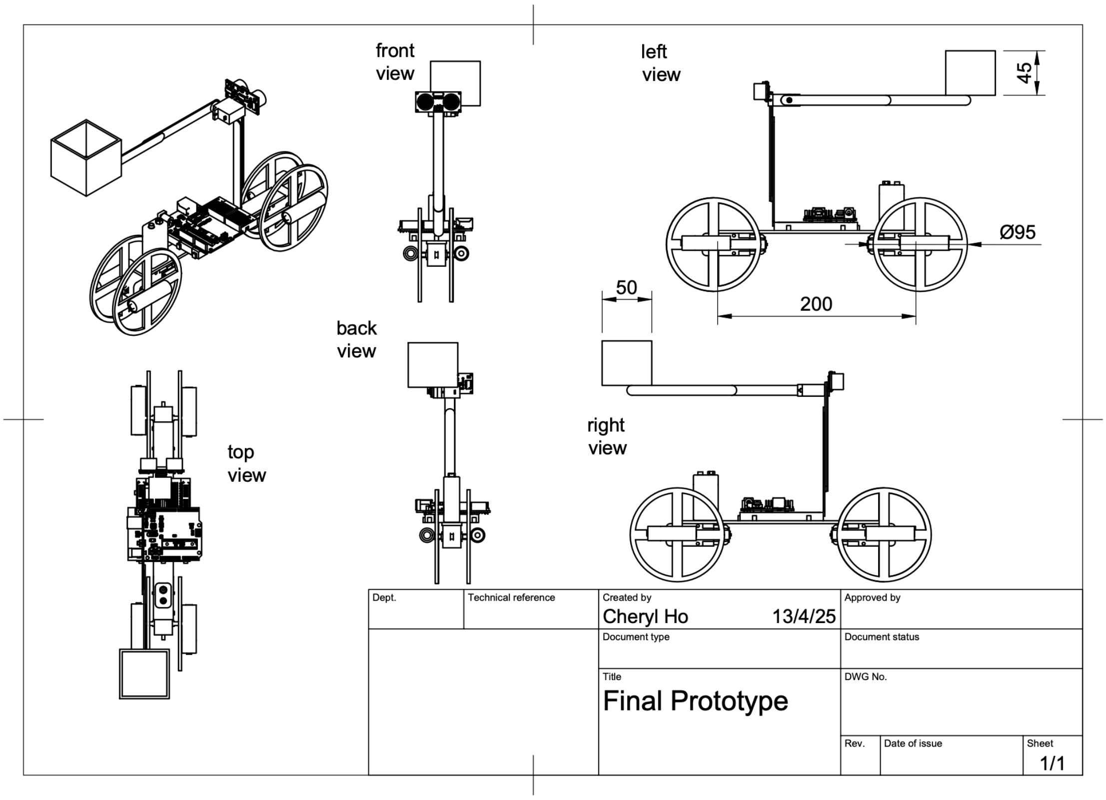
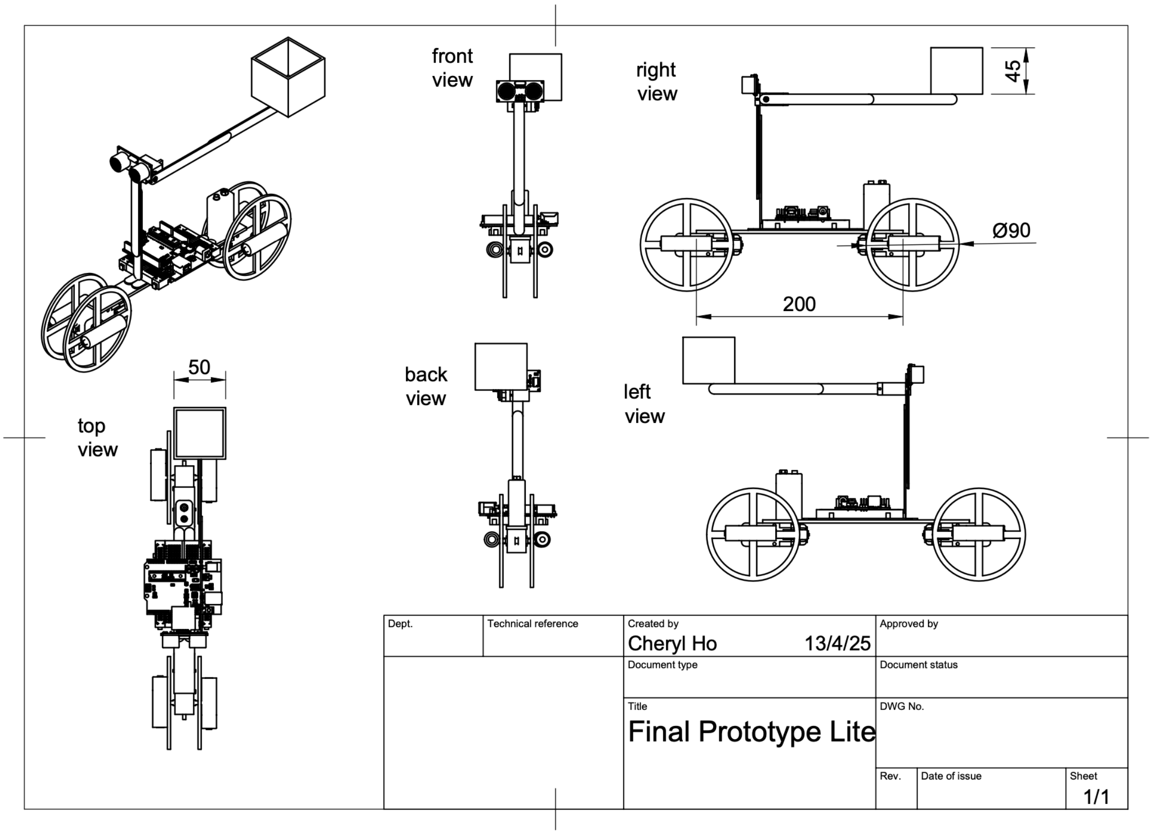
Teaching Assistants: Aakash Jayadeep & Joe Tien You

3. Appendix

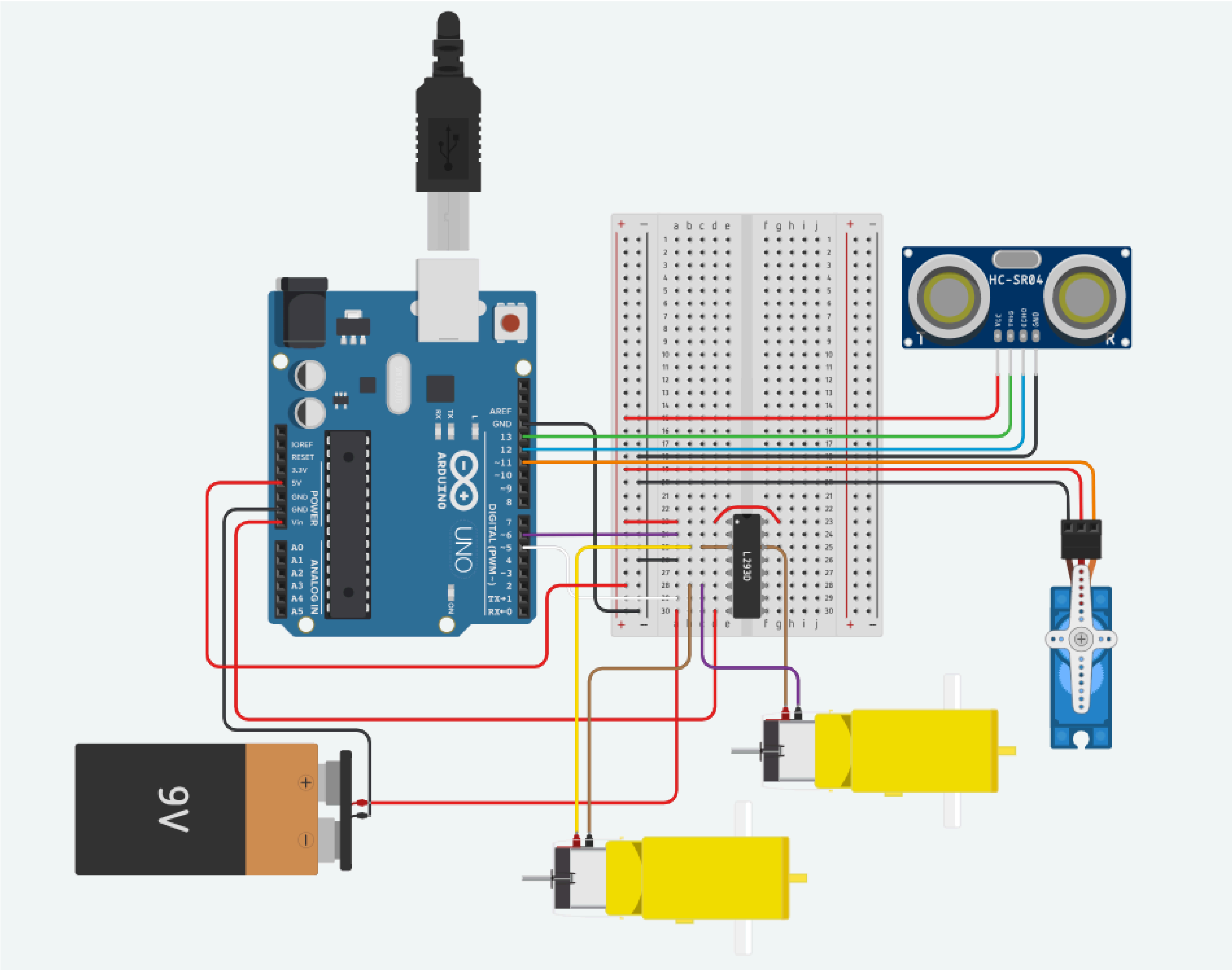
3.1. Photograph of the Final Prototype and Final Prototype Lite

Final Prototype

Final Prototype Lite


3.2. CAD Rendering of a Model for the Complete Final Prototype and Final Prototype Lite

Final Prototype

Final Prototype Lite


3.3. Image of TinkerCAD Diagram Corresponding to the Circuitry of the Complete Final Prototype and Final Prototype Lite



3.4. Arduino Source Code Deployed on Final Prototype and Final Prototype Lite

```
/*
  // EG1311 B13 Group 4
  // AY24/25 Sem 2, 14 April 2025
  // This file contains the source code that was deployed in Final
  Prototype and Final Prototype Lite, capable of commanding a robot
  to move forward, stop when a wall is detected, launch a ping-pong
  ball via a catapult, before reversing indefinitely.
*/

#include <Servo.h>

Servo servo;
int TRIG_PIN = 13;
int ECHO_PIN = 12;
int SERVO_PIN = 11;
int MOTOR_PIN1 = 6;
int MOTOR_PIN2 = 5;
float SPEED_OF_SOUND = 0.0345;
int catapult_launched = 0; // Initialise catapult launched to be false
int counter = 0;

void setup() {
  pinMode(MOTOR_PIN1, OUTPUT);
  pinMode(MOTOR_PIN2, OUTPUT);

  pinMode(TRIG_PIN, OUTPUT);
  digitalWrite(TRIG_PIN, LOW);
  pinMode(ECHO_PIN, INPUT);
  servo.attach(SERVO_PIN); // Not <500 or >2500
  servo.write(0);
  catapult_launched = 0;
  Serial.begin(9600); // For debugging, comment out during actual run
}

void loop() {
  digitalWrite(TRIG_PIN, HIGH);
  delayMicroseconds(10);
  digitalWrite(TRIG_PIN, LOW);
  int microsecs = pulseIn(ECHO_PIN, HIGH);
  float cms = microsecs*SPEED_OF_SOUND/2;
  Serial.println(cms); // For debugging, comment out during actual run

  digitalWrite(MOTOR_PIN1, LOW); // All motors to go forward
  digitalWrite(MOTOR_PIN2, HIGH);

  // This counter is deployed to eliminate phantom detections
  counter = 0; // Reset counter to 0 every loop
  if (cms < 18) { // Count to 3 when wall detected
    while (cms < 18 && counter <= 3)
    counter += 1;
  } // Exit loop when counter equal to 3

  if (counter >= 3) {
    digitalWrite(MOTOR_PIN1, LOW); // Stop all motor
    digitalWrite(MOTOR_PIN2, LOW);
    delay(1500);
    servo.write(70); // Launch catapult
    catapult_launched = 1;
```

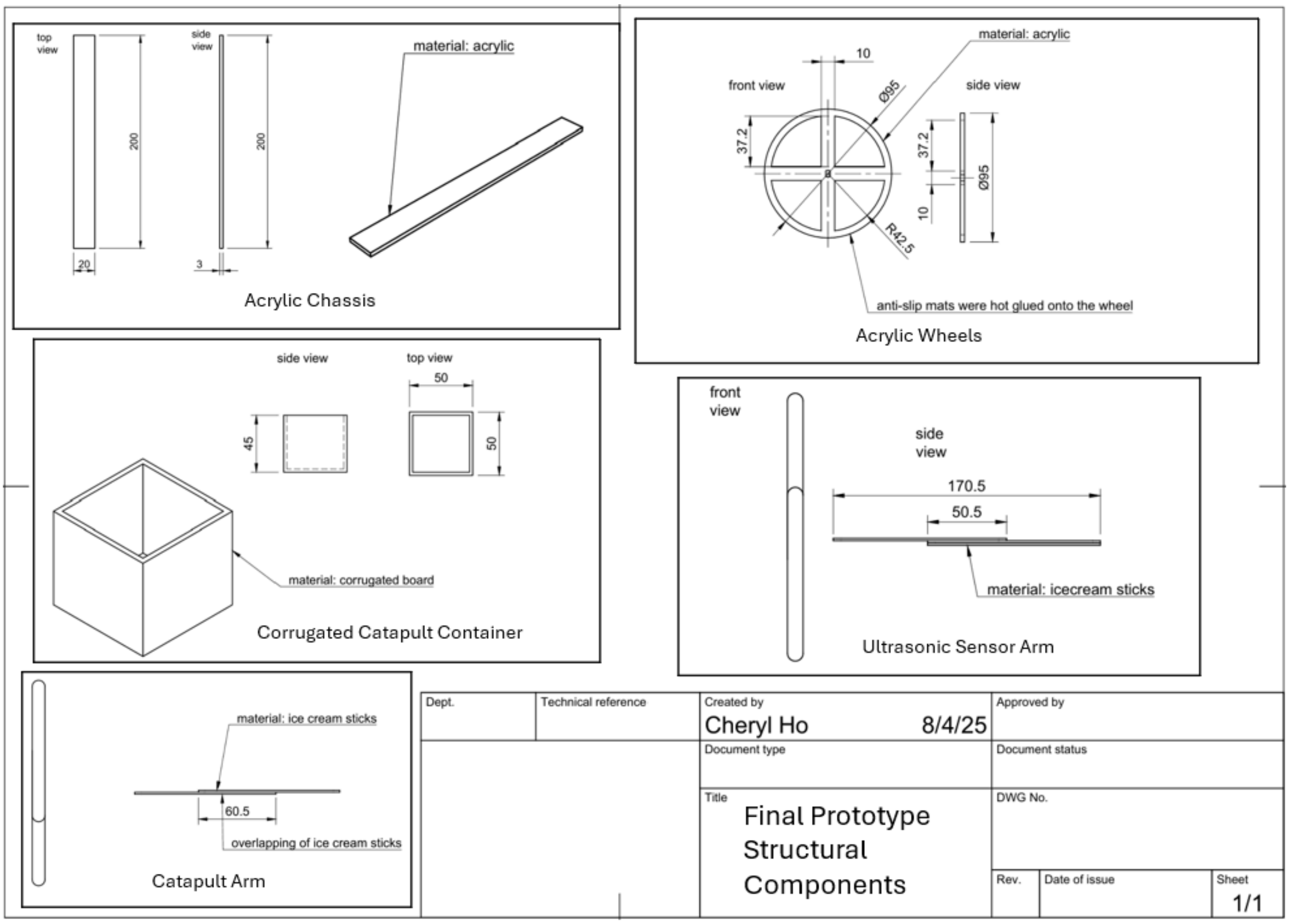
```
    delay(1500);

    // Robot will reverse indefinitely once the while-loop is entered
    while (catapult_launched == 1) { // Catapult launched set to true
      digitalWrite(MOTOR_PIN1, HIGH); // Motors draws reverse current
      digitalWrite(MOTOR_PIN2, LOW);
    }
  }
  delay(10);
}
```

3.5. Fully Dimensioned 2D CAD Drawing for Each Structural Component Made from Sheet Material Used in Final Prototype and Final Prototype Lite

The diagrams below depict how each structural component in Prototype Final and Prototype Final Lite was cut from sheet material, and the type of material used.

Final Prototype



Final Prototype Lite