Mini Catapult

Third Year Individual Project – Final Report

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Contents

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Abstract

This research project presents the design, development, and prototyping of a low-cost autonomous mini catapult capable of intercepting a heat-emitting object within a 4-metre radius. The study addresses the challenges of achieving precision and accuracy while minimizing the system's overall cost. The core objectives encompass determining the required electronic hardware, designing the robot using CAD software and developing firmware, establishing a connection between the targeting program and the catapult's firmware, and assembling a functional prototype. The report is organized into six sections, detailing the literature review, hardware and electronic design, software design, testing and calibration, discussion of results, and conclusion.

Key insights include the successful integration of electronic, mechanical and software components, resulting in reliable smooth and precise movements, position manipulation, and effective communication between the heat-seeking algorithm and the launch arm. The catapult displays proficiency in intercepting its targets within a 1-meter radius, validating its design, and establishing an opportunity for future implementation and optimization. Potential applications span education and entertainment purposes, with future improvements consisting of redesigned launch arm manipulators, control systems, vision systems, and additional degrees of freedom.

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I would like to express my sincere gratitude to my supervisor, Sam Walsh , for his invaluable guidance and support throughout this project, whose expertise in electronics and report writing was instrumental in shaping the direction of this project and ensuring its successful completion.

1 Introduction

1.1 Background and motivation

Background

Traditional catapults are a well-known mechanism utilized by the ancient Greeks to play a decisive role in the outcome of sieges and battles. In the modern world, their principles continue to influence the field of engineering in applications as diverse as aircraft carrier launch systems [1] to robotic flea mechanics [2]. Despite losing its primary status as a decisive component in warfare, the conventional trajectory of catapult mechanisms has transitioned from siege engines to modern projectile launchers [1]. This project aims to give undergraduates an unabstracted view of basic hardware and software interaction by introducing an entry-level mechatronic catapult, leading to a generation of more confident graduates for the future engineering workforce.

The development of this mechatronic catapult in this project would go beyond its conventional counterparts [1], not just by integrating real-time object detection or autonomous launching, but also by introducing a new 360-degree targeting range, a limitation exhibited by previous catapult projects. Transitioning from manually operated to a pre-programmed system, the proposed mechatronic catapult seeks to autonomously detect infrared-emitting objects and make informed decisions on launch parameters.

First-year undergraduate mechatronics students often grapple with uncertainty associated with design and modeling decisions. This lack of confidence can be mitigated by leveraging familiar mechanisms. A mechatronics catapult project [6] exemplifies this approach, transforming the classic catapult, a concept likely understood since childhood, into a platform for teaching mechatronic design principles. However, there is a gap in understanding of how each overlapping field of computing, control, mechanical and electrical fields of discipline interact with one another, this is a common difficulty in teaching mechatronics [5]. For this project, a catapult focused on the transparent stages between the mechanical, electronic, and programming elements.

Motivation

The construction of this mechatronic catapult holds significant educational value, particularly for entry-level engineering students. It represents a blend of ancient principles and contemporary technology, serving as a tangible Design of Experiment (DOE) learning tool for comprehending fundamental concepts in mechanics, electronics, and autonomous systems [6]. Other research involving education in mechatronics suggests that interacting with practical equipment gives students a higher understanding of engineering principles than those who do not [3,6]. Through hands-on experience, design, analytical, and modeling skills in hardware and software [4], which have been becoming overwhelmingly important over the last 5 years of engineering [5], would be acquired more effective and more importantly, enjoyable [6]

1.2 Aims and objectives

Aim

This project aims to create a mechatronic catapult merging control systems theory with a simple launching mechanism for educational applications. This device serves as an educational platform, offering entry-level students a hands-on understanding of mechatronics. The primary objective is to demonstrate how modern technologies can revolutionize even the simplest mechanisms into an autonomous system. By project completion, the goal is to equip students with a comprehensive understanding of interdisciplinary concepts like control systems, mechanical design, and autonomous decision-making. Through practical engagement with the catapult's construction and operation, students will gain insights into the real-world applications of mechatronics. This learning experience will equip them with practical skills and hopefully a deeper appreciation of engineering principles in another project. Ultimately, the project seeks to empower students to apply theoretical knowledge to practical scenarios, enhancing their preparedness for future engineering activities.

Objectives

- Conceptualise a model including only its basic functionality, such as joint movements and specifications.
- Define clear input-output requirements for object detection and decision-making algorithms within the control system.
- Decide on suitable components for the project specification
- Design a blueprint layout outlining compatible component placement and connectivity.
- Using SolidWorks, model a detailed 3D model of the catapult
- Prototype the mechanism using 3D printing and conduct iterative testing for mechanical efficiency and reliability.
- Define measurable metrics—launch accuracy, speed, and energy efficiency—to evaluate the catapult's performance.
- Program and integrate sensors like ultrasonic and infrared for accurate object detection within specific distances.
- Conduct thorough testing under controlled conditions, recording and analyzing data to validate the system's Utilize CAD software.

1.3 Report structure

This project focuses on the design, development, and prototyping of an autonomous catapult for the purpose of intercepting a heat-emitting target within a 4-metre radius. The report is organized as follows: Section 2 presents a literature review on a brief history of the catapult, modern heat targeting methods, and low-cost solutions. Section 3 describes the system’s CAD design, electronic and software design for the implementation of the catapult. Section 4 presents the testing and optimization for the catapult. Section 5 discusses the results of the tests in the previous section and presents the implication of these results on the performance of the system. Finally, Section 6 concludes the report, summarizing the key findings and potential future work.

2 Literature review

Though hand held versions exist before, the catapult, a projectile launching device using stored energy, dates to the 4th century BCE [7]. Early iterations relied on torsion (twisted ropes) or tension (drawn bows) for launch power. During medieval warfare, 3 models were famously used, the ballista, similar in design to a giant crossbow utilizing tension; the mangonel, a mechanism using tension on a rope to launch a long arm and the trebuchet, which utilized the transfers of potential gravitational to kinetic energy to an arm by loading and unloading a counterweight [8]. However, these designs lack in radial range, often requiring a long time to reposition itself. This flaw will be addressees in this project design process. These mechanisms remained the mainstay of siege weaponry in many cultures for centuries, eventually evolving into the mechanism used to launch projectiles from aircrafts in the early 20th century [9].

Modern applications of projectile applications, however, have ventured beyond launching simple boulders. One prominent example is heat seeking missiles, one of factors responsible for the majority of destroyed military air transport [10, 11]. While the core principle of propelling an object with stored energy remains the same, the energy source and launch mechanism have undergone a dramatic transformation. Heat seeking missiles utilize an IR sensor capable of passively detecting infrared signature. This allows an already launched missiles to further orient itself to intercept its target [12]. While this method is a powerful tool for withstanding harsh external environments, it should be noted that its complexity is due to its requirement to differentiate other heat emitting sources such as hot parts of the engine, exhaust plume, rear fuselage, and aerodynamically heated [12]. The infrared sensor then transmits this information to an onboard guidance computer, which processes the data and transmits corrective commands to fins or thrusters on the projectile, enabling it to home in on its target [10]. In this project, due to the limited budget and all heat emitting object are assigned as targets, a more simplified design will be implemented to achieve the same functionality.

While the aim of the project is to electronically adjust itself into a more favorable position for launch, there are limitations to an education tool intended for students. To prioritize affordability, ease of use, and transparency for educational purposes within the 170 GBP budget, this project selects components that differ from those in the reviewed literature. A passive infrared (PIR) sensor offers a cost-effective alternative to expensive heat-seeking technology for basic target presence detection. Similarly, an ultrasonic sensor's affordability and reliability make it a suitable choice for proximity detection compared to complex radar systems. A stepper motor is chosen for launch due to its precise angular control, enabling launch force and angle adjustments, while remaining more feasible than the highly sophisticated heat-seeking missile which far exceeds the budget and complexity of the project. Finally, a servo motor provides a cost-effective solution for launch orientation, aligning with the project's goals and budget constraints better than the complex gyroscopes and accelerometers found in advanced missile launcher systems.

3 Methodology

This section outlines the architecture and key design choices for a heat-seeking catapult to successfully locate and intercept a heat-emitting target within a 4-metre radius inside a classroom without external factors as shown in Figure 1.

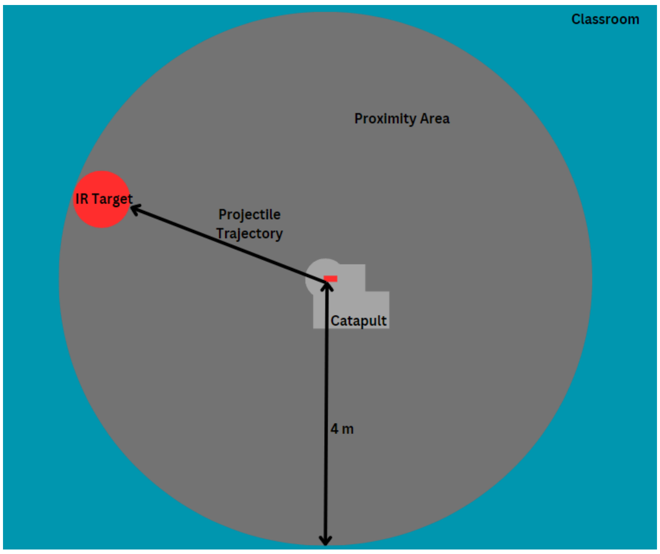


Figure 1 - Environment Specification

The robot comprises four essential activities:

1) The CAD body, designed and modeled in SolidWorks (SolidWorks 2022 SP2.0) software for structural stability and functionality;

2) The component implementation and selection method

3) The software design method through the Arduino IDE

Additionally, the table below specifies the quantifiable results required for the project to be successful.

Radial Accuracy	Working Proximity Range	Max time taken between detection and accurate launch	Budget
<5%	4m	<5s	<150 GBP

Table 1 - System Success Requirements

The first step is to create a visualization of the system through a block diagram of the interaction of each subsystem in Figure 2. This breaks down the functionality of the system into smaller discrete steps, such as mapping power connections and signal flow between each component involved in the catapult. A circuit diagram of the system was designed in Figure 3 to provide clear signal requirements.

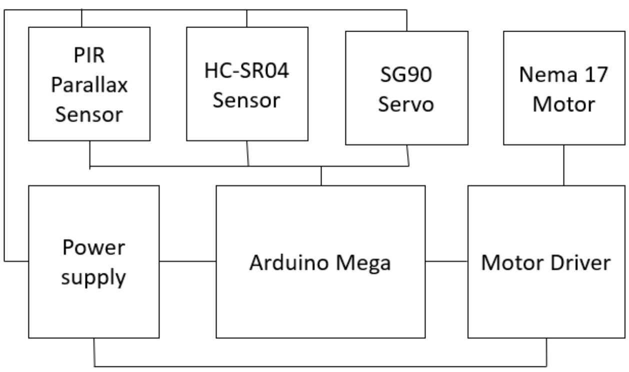


Figure 2 – System Block Diagram

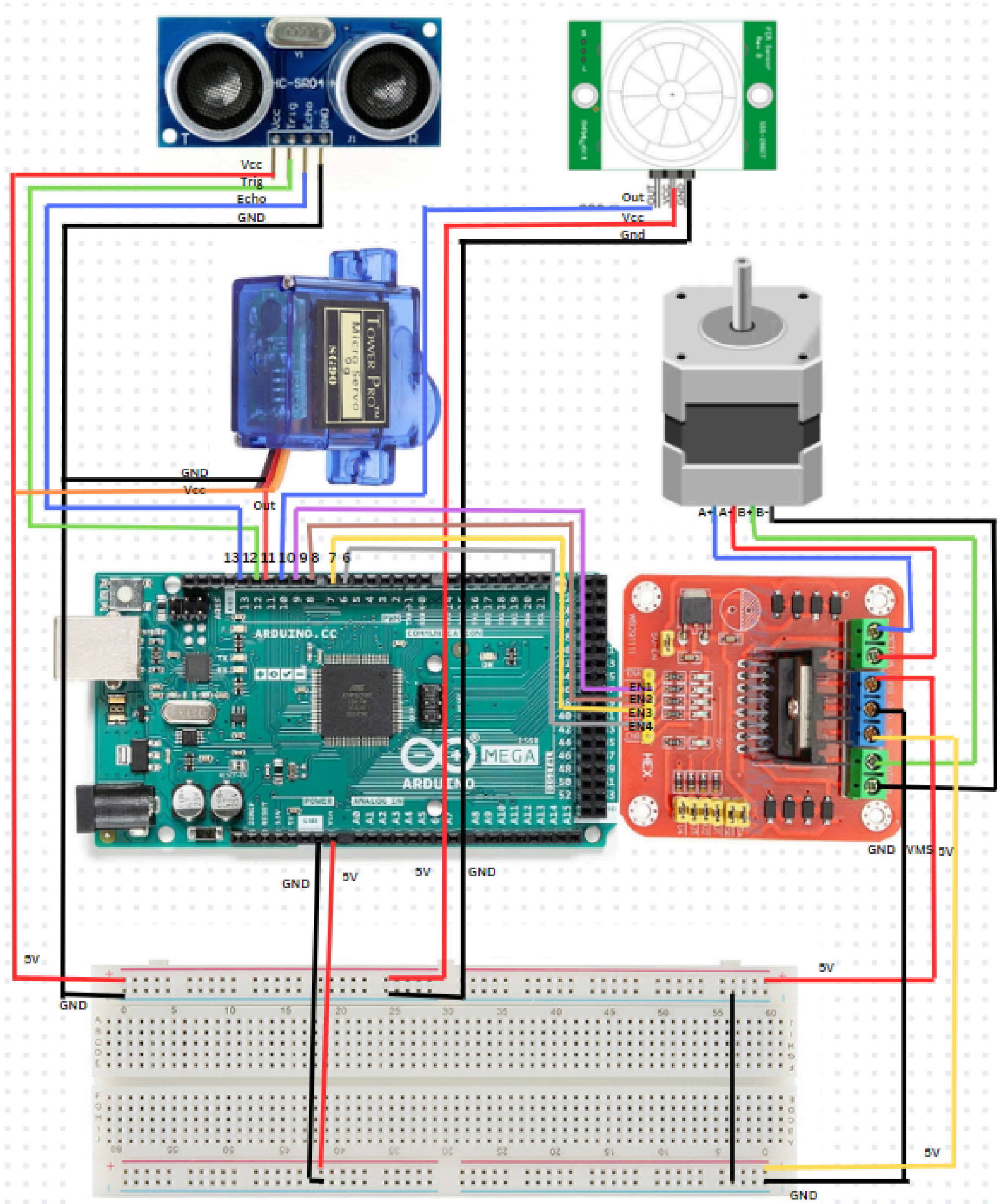


Figure 3 – Catapult Circuit Diagram

3.1 CAD Design Method

The self-autonomous catapult's body design employs three separate-layered modular containing a base, platform and launch layer through SolidWorks modelling which will later be 3D printed. Each layer fulfils distinct roles and interacts with each other to achieve overall functionality. This design method allows for every component connection and function to be easily recognized. Most of these parts are modelled through sketching and manipulation techniques such as extrusion.

The weight of the platform and its contents are 500 g
Torque required to overcome platform weight can be calculated by:

$$T(weight) = W * g * r \tag{1}$$

W- weight of platform and contents (kg)
g- Gravitational acceleration (m/s^2)
r- radius of platform (m)

Assume a 120% increase for starting torque taking inertia and friction into account, requiring an additional 0.69 Nm. The torque required to start can then be calculated as 4.13 Nm as shown in the equation below.

$$T = T(weight) + Inertia + Friction \tag{2}$$

The holding torque of the proposed stepper motor was found to be 0.16 Nm, leading to the final minimum gear ratio being calculated as 25.8 from the equation below.

$$Min\ Gear\ Ratio = \frac{T}{Holding\ Torque} \tag{3}$$

By assuming a higher inertia than anticipated and a maximum allocated space of 200mm led to a 97 teeth/28 teeth pair choice shown in Figure 4. This is a much smaller gear ratio than the minimum due to the torque capability taking more importance compared to the speed of rotation.

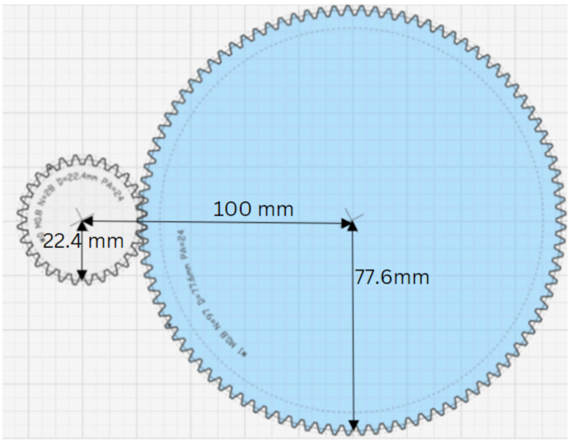


Figure 4 – Platform gear ratio

With a space of 100mm between the centre of each gear, a 0.8 module pinion gear with 28 teeth was chosen to drive the platform, leading to a 97 teeth platform to complement it, which perfectly occupies the 100 mm space. This was chosen due to the balance of limited space and leaving enough room to prevent the obstruction of the launch layer components within the chassis of the catapult.

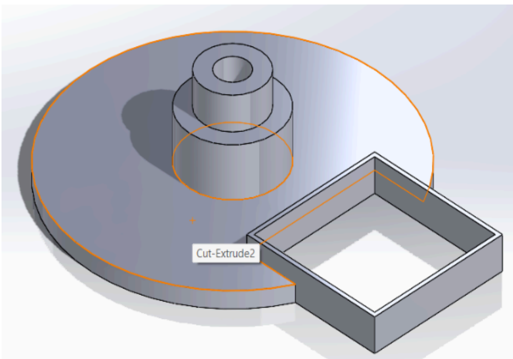


Figure 5 - Base Layer

A. Base Layer

The base layer serves as the foundation, housing the parallax PIR sensor and stepper motor. Rotation of the stepper motor, driven by the pinion gear in the subsequent layer, will dictate the platform's orientation. To facilitate wiring that connects to the nearby Arduino controller, the base layer incorporates a through-hole running from top to bottom along the central shaft. This design begins with an initial sketch of a 100 mm radius circle overlaid with a 42.3 mm square centred on the circle's edge. Subsequent extrusions applied to the circle's centre and negative extrusions applied to the square's centre result in the base layer depicted in Figure 13.

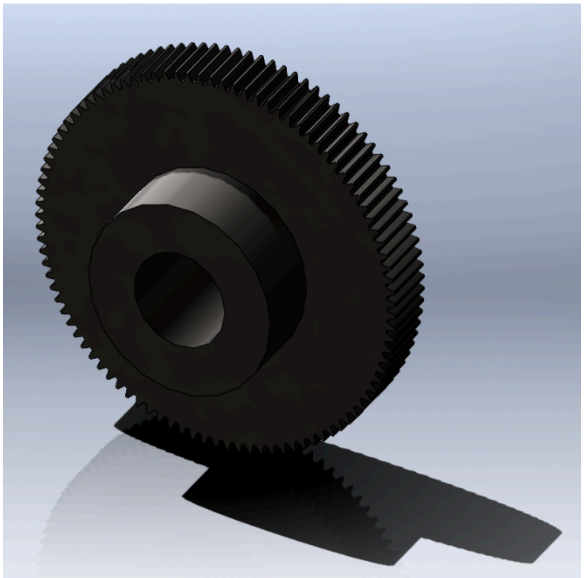


Figure 6 - Platform Layer

B. Platform Layer

Stacked upon the ground layer, this platform in Figure 14 serves as the base for the orientation mechanism, driven by the stepper motor. Its edges feature 97 teeth that interlock with the pinion gear adjacent to it, forming a crucial gear pair. The HCSR04 ultrasonic sensor will sit on this layer to detect any objects within the set proximity. This was designed by importing a 28 teeth 0.8 module spur gear from the SolidWorks library and extruding a lower base to match the height difference of the position of the pinion gear.

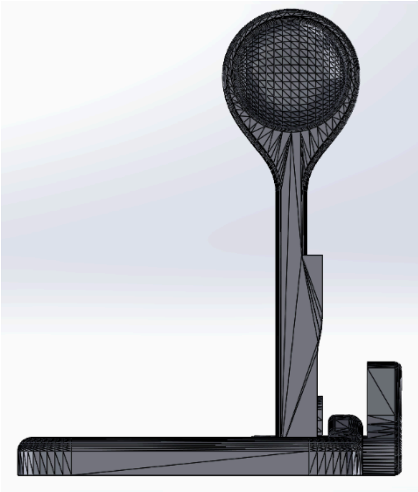


Figure 7 - Launch Layer

C. **Launch Layer** (PLA)

This top layer mechanism in Figure 15 is driven by the servo motor responsible for launching the ping pong ball. Securely mounted on the Platform layer, the servo motor is meant to be coupled directly with the launch arm. However, during the 3D printing phase, it was stated by lab technicians that the model utilizing this would not generate enough torque to launch the projectile to its intended distance of 4 m. A design implementing coupling the SG90 motor to an additional arm to hold back the launch arm, enabling the storing of elastic energy of the launch arm was implemented instead. Unfortunately, the consequence was that the launch arm would have to be manually reset into its original position. This layer's design prioritizes two crucial aspects: allowing for the servo shaft launch without the impediment from the wire connections and minimizing torque loss through a rigid structure.

3.2 Electronic Design Method

The project adopted a modular approach, dividing the functionality into distinct subsystems: Motion detection, distance measurement, high-resolution motor and high-speed motor. The contents below will evaluate different components for the specified function. Each subsystem plays a crucial role in achieving the objective of autonomously launching a ping pong ball at a target within proximity as shown in the diagram below.

Heat detection

For every autonomous system, a stimulus is required to start its operation, to prevent excessive power loss. In this project, this stimulus will be heat, specifically the infrared radiation emitted by a moving object for its low cost and passive sensing capability, reducing power loss. This led to the decision of choosing the Parallax PIR motion sensor.

Ideal for detecting human presence within a designated area, the PIR sensors operate by registering disruption in the established thermal pattern., which is essentially heat, emitted by surrounding objects, as shown in Figure 8. This change in infrared radiation is measured by a pyroelectric chip which is converted into an electrical signal [13].

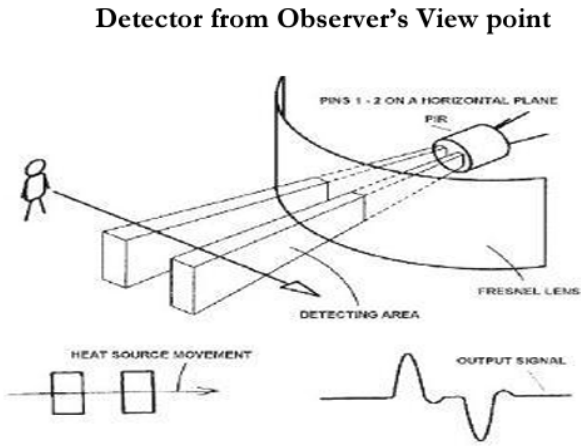


Figure 8 - PIR signal operation

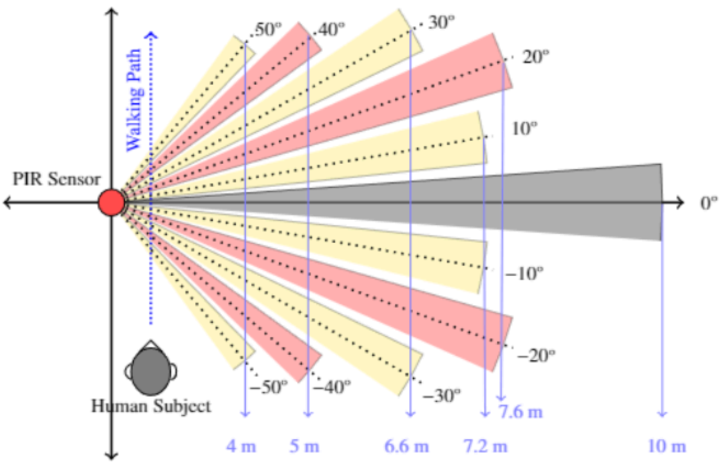


Figure 9 - PIR sensor field of view using Lenz [100]

While offering advantages like low power consumption and compatibility with microcontrollers, PIR sensors do have a 180-degree range limit. Their sensitivity can be affected by environmental factors like wind or drafts, and they cannot differentiate between objects, simply detecting motion without identifying specific shapes. To prevent immediate detection, only one PIR sensor will be used as a 360 range would detect any operator once the program commences.

Distance measurement

Once the operation starts, there is a need to determine if an object has entered the catapult's proximity. This will be detected through an HC-SR04 ultrasonic distance sensor. This sensor employs sound waves to measure the distance of nearby objects. Unlike traditional rulers or laser sensors, the HC-SR04 functions by emitting a high-frequency burst of pulses sound pulse inaudible to human ears, as shown in Figure 11. This ultrasonic wave travels outward until it encounters an object, at which point it reflects toward the sensor in Figure 10.

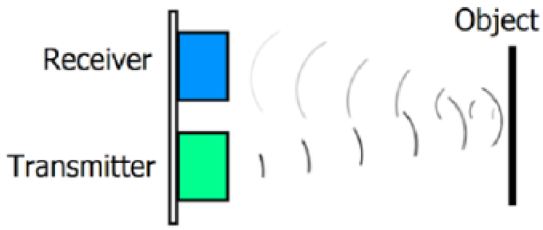


Figure 10 - HC-SR04 operation

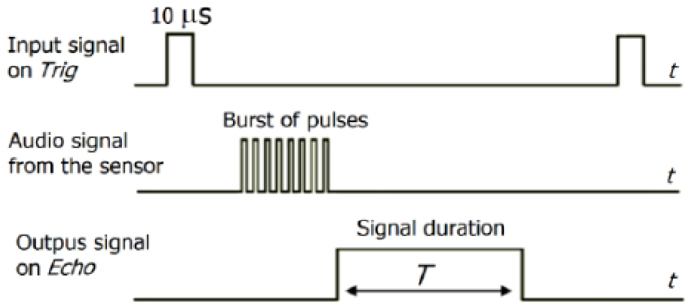


Figure 11 - HC-SR04 signals

The HC-SR04 then calculates the time it takes for the sound wave to complete this round trip. By factoring in the speed of sound, the sensor can determine the distance to the object with high accuracy. The distance of the object can then be calculated through the formula below [15].

$$d = \frac{(t\ x\ s)}{2} \tag{4}$$

d = distance of object (m)

t = time taken for pulses round trip (s)

s = speed of sound = 340 m/s

This method offers several advantages. Unlike light-based sensors, the HC-SR04 has less potential external interference compared to the other choices, such as being less susceptible to interference from ambient light or reflective surfaces. However, the HC-SR04 does have limitations. Its effective range is limited to 4 meters and a 30-degree angle, depending on factors like temperature and humidity [14]. An orientating mechanism will be implemented to give this sensor a 360-degree view below.

High-Resolution Rotation

This motor is the main component responsible for orientating the catapult into position. While other motor types might be considered, a Stepper motor NEMA 17HS4023 offers high torque at low speeds, high precision, and compatibility with microcontrollers [15]. A stepper motor can be instructed to rotate in specific increments, allowing for the catapult arm to be positioned with high accuracy during operation, keeping the launch force and projectile trajectory consistent. The chosen NEMA 17HS4023 stepper motor for this project has a compact size of 43 x 43 mm dimension and provides a holding torque of 0.16 N.cm, which is sufficient to move the platform with the necessary precision.

A hybrid stepper motor is a combination of variable reluctance and permanent magnet-type motors. The rotor of a hybrid stepper motor is axially magnetized like a permanent magnet stepper motor, and the stator is electromagnetically energized like a variable reluctance stepper motor. Both the stator and rotor are multi-toothed.

Internally, the 17HS4023 stepper motor relies on electromagnets that energize sequentially, creating a rotating magnetic field. The rotor, containing permanent magnets, aligns itself with this shifting field, resulting in precise angular electromagnetic torque. This is controlled by a digital train of pulses sent to a motor driver to decode the required sequence for the specified rotation. Each number of pulses instructs the motor coils for a step and the timing of these pulses conveys the direction of the rotation [16]. The driver then energizes the positive and negative coils of the motor in a sequence.

The steps per revolution are SPR, and the stepper motor step angle (in degrees) is θ. According to the datasheet, the motor requires 200 steps for 1 complete turn.

$$SPR = \frac{360}{\theta} \tag{5}$$

As shown in equation 3 the gear ratio is 97/28, the number of step angles required for one revolution of the pinion gear is 200, and the calculated number of steps required for 1 revolution f the platform would be 692. Using the formula below.

$$\frac{N_2}{N_1} = \frac{w_1}{w_2} \tag{6}$$

N is Number of teeth and w is the total number of step angles required for 1 revolution of a gear.

However, stepper motors have limitations. They require a dedicated driver circuit for proper control and can lose steps if overloaded or improperly driven. Additionally, they typically offer lower rotational speeds compared to DC motors.

High-Speed Motion

In this mechatronic catapult design, a servo motor is ideally suited for the projectile launching mechanism due to its controlled range of motion. Unlike a continuous rotation motor, a servo can be instructed to precisely rotate to a specific angle and hold that position, this is displayed in in Figure 12.

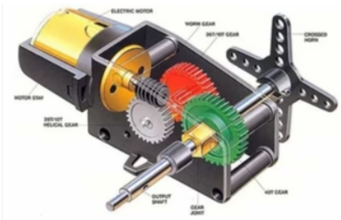


Figure 12 - Servo Internal Mechanics

Internally, the SG90 DC motor drives a gear train connected to the output shaft. By varying the pulse width modulation (PWM) input signal as shown in Figure 13, the microcontroller can control the angular position and direction of the output shaft's rotation [17]. The key aspect of PWM control lies in the duty cycle, which is the proportion of the period that is on. Higher duty cycles correspond to larger angular positions of the servo shaft.

$$duty\ cycle = \frac{Time\ on}{Period} \tag{7}$$

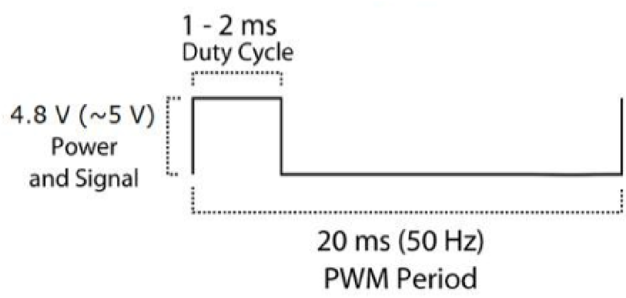


Figure 13 - Pulse Width Modulation (PWM) of SG90

Examining the SG90 datasheet reveals the typical duty cycle ranges used to achieve desired servo positions. A duty cycle of 1.5 ms corresponds to the minimum angle (0°), while 1 and 2 ms correspond to 90 and -90 degrees respectively for the SG90 servo.

While offering precision and ease of use, the SG90 has limitations. Its small size translates to lower torque, making it unsuitable for high-load applications. Additionally, its range of motion is limited to 180 degrees, restricting its use to scenarios where full rotational freedom is not necessary.

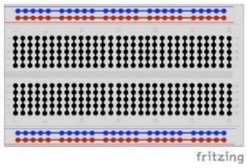
3.3 Component selection

Based on the criteria in the previous section, the following components have been selected to meet the project specification and complement each other

Parts:

Arduino Mega- 40.55	
Parallax PIR Motion Sensor- 16.97	

HC-SR04 Ultrasonic Distance Sensor- 2.52	
Stepper Motor 17HS4023- 13.40	
Mini 180 Degree Resin Gear Servo SG90- 4.68	
L298N Dual H Bridge DC & Stepper Motor Controller Board- 9.77	
Male to Female Jumper Wires- free	
8 AA Battery Casing- 1.57	
9V Battery Snap- 0.62	

Breadboard- free	
28 teeth Pinion spur gear, 0.8 module- 5.02	

3.4 Software Design Method

This section of the report consists of the breakdown and method for programming the catapult's feature to operate as illustrated in Fig 14. This will also include all the resources used in this phase of the project. Arduino C++ was chosen due to its widespread use, beginner-friendly nature, and extensive library support.

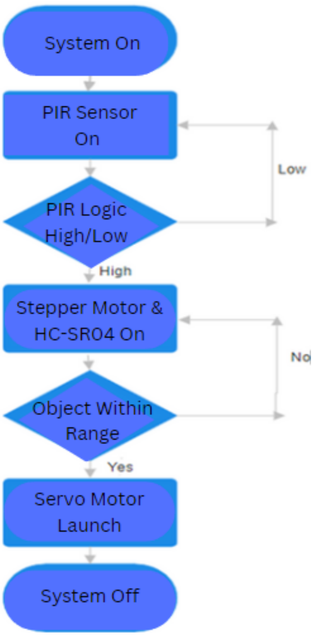


Figure 14 - Flowchart

A. Development platform

The Arduino Mega microcontroller board was selected as the control unit for the catapult due to its well-suited integration with both the L289N stepper motor driver board and the extensive libraries. The popularity of the Arduino Mega stems from its open-source design, featuring the ATmega328P microcontroller [18]. This microcontroller's affordability, ease of use, and broad compatibility with various sensors and actuators make it an ideal platform for this project.

The Arduino Mega provides a versatile array of I/O pins and communication interfaces. Programming the microcontroller is achieved through the open-source Arduino Integrated Development Environment (IDE) (Arduino, "Arduino IDE," Version 2.0.4, Arduino, Inc., 2023), which supports C and C++ programming languages. The software running on the Arduino Mega manages critical tasks such as interpreting high-level commands received from the chess program, performing thresholding, and moving average algorithms, and generating control signals for the L289N drivers. These functions are essential for ensuring precise and synchronized motion across all components while simultaneously providing real-time communication on positioning.

B. Heat Detection

The catapult will begin its operation by using the PIR parallax sensor. Upon calibration, the sensor will passively measure the surroundings for a disruption in its thermal pattern. A disruption will send a digital HIGH electrical signal, leading to the distance measurement and orientation phase.

C. Distance measurement

Once turned on, a step signal would cause the HC-SR04 ultrasonic sensor to send a burst of ultrasonic pulses. The pulses will be reflected and received by the sensor, ending the operation with another step signal at the trigger, leading to the determination of distance based on the time taken for the return. If an object is deemed closer to the catapult it will trigger the conditions for the servo to move and stepper motor to stop.

D. Orientation Mechanism

Driven by a motor drive board, this stepper motor will slowly turn the platform to give the HC-SR04 sensor a 180-degree view of the surroundings. Through programming, the direction and electrical step pulse for each step are made by the stepper motor. The speed of rotation can be increased by decreasing the duration of the pulse, in this case, the pulse will be set to

3ms. The pulses will stop and the stepper will be turned off the moment the HC-SR04 detects an object closer than 5m.

E. Launching Mechanism

After an object is detected, a 5V PWM is sent to the motor to achieve a 10-degree counter-clockwise movement. The PWM will have a 1.55ms duty cycle and a period of 20 ms or 50 Hz.

F. Resources Used

In this project, the specific libraries would be utilized for this project.

Libraries

The Servo library

provides control functions for the mini servo motor. This library is included in the Arduino IDE by default and provides functions to control servo motors. In this code, it is used to control the servo object, which connects to the SG90 servo motor and launches the projectile.

Algorithms

Moving average

The code implements a simple moving average to filter out noise in the distance readings from the ultrasonic sensor. It stores the last 5 readings in an array and calculates the average by iterating through the array and summing the values. This prevents any false positives

Thresholding:

The code uses two thresholds for distances between 100cm and 10cm. If the average distance is less than 100cm and the servo has not been triggered yet, it activates the servo motor and moves it to 10 degrees. The servo flag is then set to prevent the servo from constantly moving if there's continuous motion within the close range. Conversely, if the average distance is greater than or equal to 10cm, it deactivates the servo motor and resets the flags.

3.5 Conclusion

Overall, through mechanical force transmission, electronic signal and C++ programming techniques, a prototype of the catapult system was built to fulfill its proposed function in Figure 15

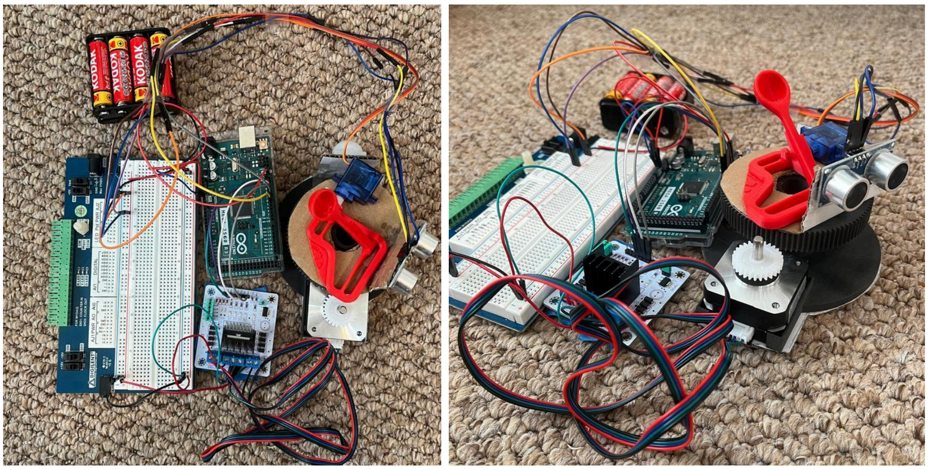


Figure 15 – Catapult Prototype

4 Results

The results of the proposed methodology are shown in this section. The obtained results are analyzed, discussed, and compared with the theoretical values to assess the intended approach. This section evaluates the method by testing the effectiveness of components and the overall systems performance, resulting in the catapult project functionality shown in Table 1.

4.1 Optimum Proximity Range

The HCSR04 sensor plays a significant role in the effectiveness of the system, requiring precise quantitative measurements of the proximity of objects. There it is important to test the capability of the sensor to determine if it is capable of sensing objects 4 metres away while maintaining a 5% accuracy as stated above.

In this test, the ultrasonic sensor's range will be determined by measuring the distance of a block of wood at a set distance measured by a ruler, the serial monitor will then output the measured distance (Figure 16). At each block distance increment of 50 cm, the 10 distance measurements were recorded using the Arduino program (Appendix A).

The measured practical maximum range of the HC-SR04 sensor is expected to be lower than the theoretical value of 400cm due to factors such as signal strength degradation and environmental factors that affect the speed of sound. All measurements are measured by a Class 2 European measuring tape and the setup of the experiment of this test can be found in figure 17.

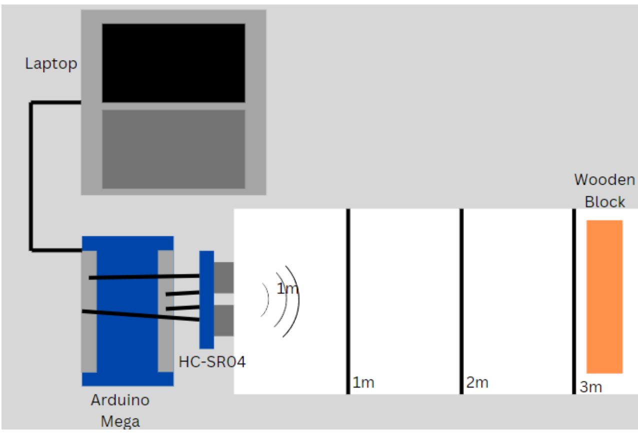


Figure 16 - HC-SR04 experiment set up

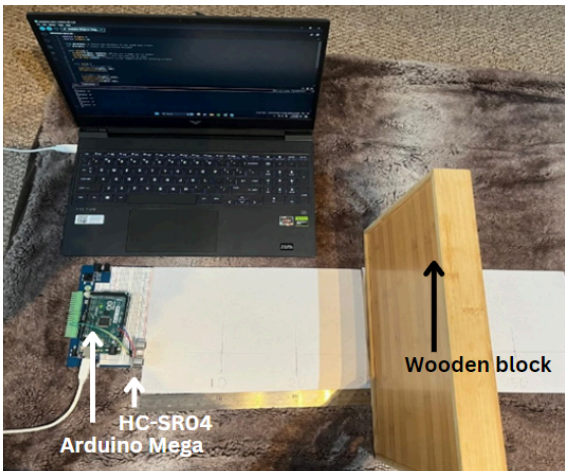


Figure 17 - Layout of HC-SR04 Experiment

The collected data will be analyzed to determine the actual practical maximum range and identify any trends in the success rate as the distance increases. The average value of these measurements was then calculated to find the impact of errors. This process was repeated until the sensor produced an average error of 5% in Table 2.

Real distance/ cm	Average Measured distance/ cm	Average Difference/ cm	Average Error value/ %
50	50	0	0
100	101	1	1
150	148	2	1.33
200	198	2	1
250	254	4	1.6
300	297	3	1
350	352	2	0.57
400	419	19	1.5
450	491	21	4.7

Table 2 – HC-SR04 Experiment Data

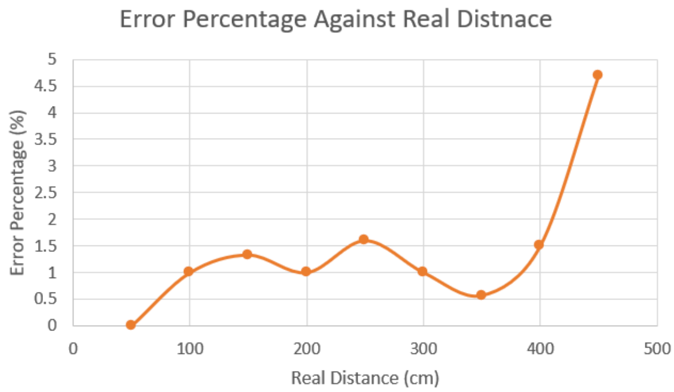


Figure 18 – HC-SR04 Error Percentage Against Real Distance

The calculated error percentage is measured against the read distance of the wooden block in the graph in Figure 18. The increase in unstable error appears after 400 cm, which is consistent with the datasheet provided online. This suggests that the HC-SR04 ultrasonic sensor produces a consistent error larger than 5% past 400 cm, setting the maximum proximity of the catapult. These errors could have been caused by environmental factors such as temperature and humidity on the speed at which sound waves travel. Additionally, other external factors could include the wooden block materials degree of reflection.

4.3 System Precision

This experiment investigates the impact of stepper motor speed on the accuracy of a self-autonomous catapult's targeting and launch mechanism, by establishing the radial accuracy threshold of 5 cm, which is the maximum speed at which the catapult reliably achieves its target. The procedure involves setting up a target area at a known distance and placing systems line of sight 90 degrees clockwise from the target. A range of stepper motor speeds were then select for testing at increments of 10 rpm as shown in Figure 19. The code for this program can be found in Appendix B.

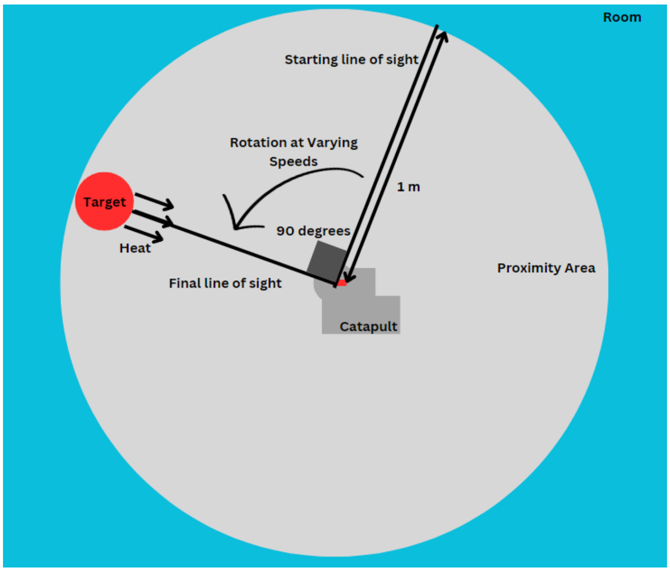


Figure 19 - System Experiment Set Up

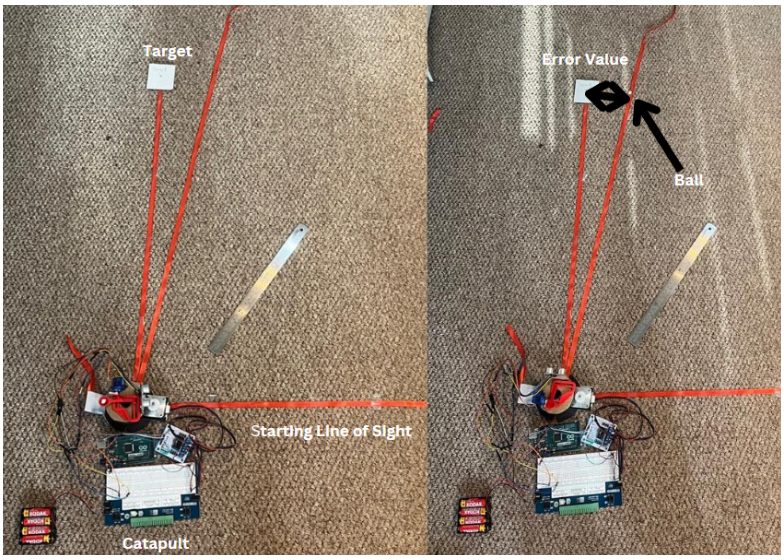


Figure 20 - Layout of System Experiment

For each speed, the catapult will be reset and fire 5 ping pong balls towards the target. The mean difference in distance between the landing position of each ball and the target centre will be recorded by a ruler as error data in Table 3.

Stepper Motor Speed (RPM)	Trial 1 Error Value (cm)	Trial 2 Error Value (cm)	Trial 3 Error Value (cm)	Trial 4 Error Value (cm)	Trial 5 Error Value (cm)	Average Error Value (cm)
10	2.3	0.6	2.4	2.4	2.5	2.44
20	2.7	2.9	2.8	3	2.7	2.82
30	3	3.1	3.2	3.3	3	3.12
40	3.5	3.6	3.7	3.8	3.5	3.62
50	3.9	4	4.2	4.1	3.9	4.02
60	5.1	4.6	5.2	5.5	5.1	5.26

Table 3 - System Experiment Data

Finally, a graph will be created with stepper motor speed and error values. By analyzing this graph, we can identify the accuracy threshold - the stepper motor speed at which the average error starts to significantly increase in Figure 21. This is likely due to the residual shaking from the motor stopping and the platform's alignment moving past 50 rpm. Therefore, the speed of the catapult stepper motor would be limited to under 50 rpm, due to an average 5% error value between 50 and 60 rpm.

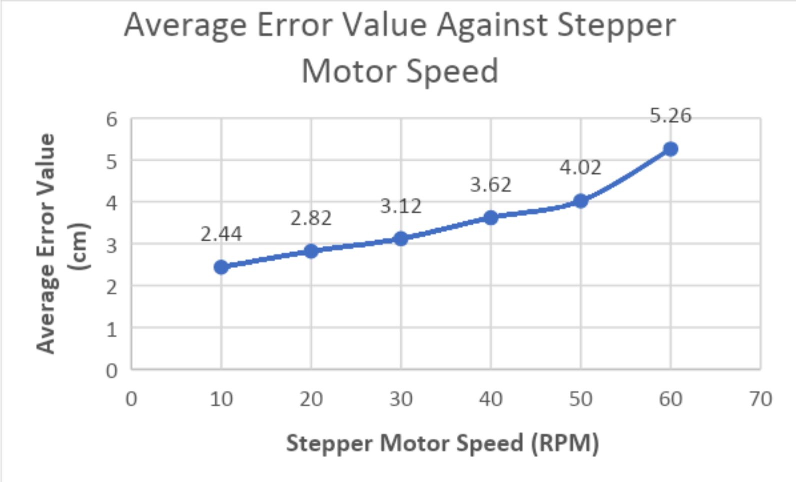


Figure 21 – System Error Value Against Motor Speed

5 Conclusions and future work

5.1 Conclusion

The miniaturized catapult project achieved a functional prototype within the allocated budget of 170 GBP. The final project cost 150 GBP, demonstrating successful resource management. The core functionalities of target detection and launch mechanism were implemented. The target detection system, utilizing a PIR sensor and an ultrasonic sensor, achieved a response time of under 5 seconds. Additionally, the system maintained radial accuracy within a 5% margin, indicating successful target identification and positioning. However, the launch mechanism, currently utilizing a servo motor, displayed limitations. The maximum launch radius achieved was 1 meter. This fell short of the capabilities of the detection system, highlighting the need for further development in launch power or projectile design. Overall, the project successfully demonstrated the creation of a functional catapult prototype for educational purposes, offering transparency and enabling students to apply theoretical knowledge in a practical setting.

5.2 Future work

While the project was a success, work will have to be done on implementing a more powerful launching mechanism, as the range for a 4-meter detection zone was not possible due to the launcher's inability to launch the ping pong ball more than 1 meter from itself making the sensor’s 4-meter range capabilities redundant. One alternative could be the use of biomechanics mechanisms, as they have a high power-to-weight ratio suitable for a project of this scale. Further development could be done on the catapult's ability to increase its launching trajectory options such as another joint allowing the launching mechanism additional elevation and including experimenting with different environmental conditions or assessing the effects of materials reflective properties. Future improvements, including minor hardware modifications and upgraded chassis to launch the projectile further, hold promise for transforming this prototype into a refined product.

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A. Appendices

```
#define trigPin 9
#define echoPin 10

long duration; // Stores the duration of the sound wave travel
int distance; // Stores the calculated distance

void setup() {
  pinMode(trigPin, OUTPUT); // Sets the trigger pin as output
  pinMode(echoPin, INPUT); // Sets the echo pin as input
  Serial.begin(9600); // Starts serial communication for printing distance
}

void loop() {
  // Clears the trigger pin
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);

  // Triggers the sensor
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  // Reads the echo pin, returns the sound wave travel time in microseconds
  duration = pulseIn(echoPin, HIGH);

  // Calculates the distance (speed of sound * travel time / 2)
  distance = duration * 0.034 / 2;

  // Prints the distance on the Serial Monitor
  Serial.print("Distance: ");
  Serial.println(distance);
  Serial.println("cm");

  // Optional: Add a delay between measurements
  delay(100); // Adjust delay based on your desired measurement frequency
}
```

Appendix A - code for HC-SR04 proximity test

```
#include <Servo.h>
#include <Stepper.h>

const int trigPin = 9;
const int echoPin = 10;
const int motorPin = 8;
const int pirPin = 2;
const int stepsPerRevolution = 700;

int pirState = 0;
int servoTriggered = 0;
bool servoMoved = false;

Servo scaryServo;

long duration;
int distance;
int distanceArray[5];  // Array to store last 5 distance readings
int arrayIndex = 0;

Stepper myStepper(stepsPerRevolution, 3, 4, 5, 6);

void setup() {
  pinMode(pirPin, INPUT);
  pinMode(trigPin, OUTPUT);
```

```
  pinMode(echoPin, INPUT);
  pinMode(motorPin, OUTPUT);


  scaryServo.attach(motorPin);
  scaryServo.write(0);
  delay(5000);

  // set the speed at 60 rpm:
  myStepper.setSpeed(30);
  // initialize the serial port:
  Serial.begin(9600);

}

void loop() {
  if (!servoMoved) {
    int pirReading = digitalRead(pirPin);

    if (pirReading == HIGH) {
      digitalWrite(trigPin, LOW);
      delayMicroseconds(2);
      digitalWrite(trigPin, HIGH);
      delayMicroseconds(10);
      digitalWrite(trigPin, LOW);
```

```
      // step one revolution  in one direction:
      Serial.println("clockwise");
      myStepper.step(stepsPerRevolution);
      delay(500);

      // step one revolution in the other direction:
      Serial.println("counterclockwise");
      myStepper.step(-stepsPerRevolution);
      delay(500);

      duration = pulseIn(echoPin, HIGH);
      distance = duration * 0.034 / 2;

      // Store distance in array and update moving average
      distanceArray[arrayIndex] = distance;
      arrayIndex = (arrayIndex + 1) % 5;

      int sum = 0;
      for (int i = 0; i < 5; i++) {
        sum += distanceArray[i];
      }
      int avgDistance = sum / 5;

      Serial.print("Average Distance: ");
      Serial.println(avgDistance);
```

```
      if (avgDistance < 100 && servoTriggered == 0) {
        // Replace myStepper.stop() with myStepper.step(0)
        myStepper.step(0);
        digitalWrite(motorPin, HIGH);
        scaryServo.write(10);
        servoTriggered = 1;
        pirState = HIGH;
        servoMoved = true;
      }
      else if (avgDistance >= 10) {
        digitalWrite(motorPin, LOW);
        servoTriggered = 0;
        pirState = LOW;
        scaryServo.write(0);
      }
    }
  }
}
```

Appendix B – System Code

B Project Outline

1. Background and Motivation

This proposal outlines the aims and milestones of a low-cost mini catapult capable of launching a ping pong sized projectile within a classroom with an integrated targeting system. Within this document contains an overview of the objectives, major deliverables, project progression plan and a risk assessment of the entire project as well. While the practical applications of a catapult may be limited, this project offers an opportunity for individuals to explore and familiarise themselves with sensors, actuators, and programming.

Furthermore, it serves as a platform to apply theoretical knowledge of mechatronic design and control system principles in real-world scenarios.

2. Aims, Deliverables, and Milestones of the project

As mentioned above, this project aims to successfully design and implement a functional mini catapult with an integrated targeting system that can hit a predefined target that is robust, reliable, and cost below the allocated 150 GBP. The deliverables include the project introduction, methodology and a final report, along with a final demonstration.

Listed below are the milestones of the project.

· Chose a suitable propulsion mechanism and targeting method

· Design and chose an appropriate material for the chassis

· Select compatible sensors and actuators

· Design an electronic circuit for the control system

· Test and calibrate the system for range, accuracy

· Build a functional prototype

· Final demonstration

E Risk register

MANCHESTER 1824
The University of Manchester

RISK REGISTER FOR 3rd YEAR PROJECT

Project Title:	Mini Catapult		Submission Date:	25/4/2024	
Student Name:	Sei Yeu	Chew			

Project Risk	Severity			Potential			Score (Severity x Potential)	Mitigation Measures
	L	M	H	L	M	H	L=1, M=2, H=3	
Tripping over inanimate objects			x		x		6	Organize components into designated areas when working
Injury from dropping equipment	x					x	3	None
Electric Shock			x	x			3	Keep liquid away from equipment
Water damage on electronic equipment			x	x			3	Keep liquid away from equipment
Electrical fires			x			x	6	Always keep fir extinguishers in proximity

D Risk assessment

General Risk Assessment Form

Date: 18/10/2023	Assessed by: Sei Yeu Chew	Checked / Validated* by:	Location: MECD building	Assessment ref no	Review date:
Task / premises: Development of Low-Cost Heat Seeking Catapult. The project will involve use of University of Manchester facilities which include computer clusters and dry labs. Dry lab work will involve use of soldering and electronic measurement equipment. Work from home will also be undertaken during the project.					

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
Use of electrical appliances	Misuse of electrical appliance, faulted electrical appliance.	Everyone Electric shock, burns and fire	1. All office equipment used in accordance with the manufacturer's instructions 2. Visual checks before use to make sure equipment, cables and free from defects	Med	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
Moving around the work office	Obstructions and trip hazards	Staff Slips, trips and falls causing physical injury	1. Floors and walkways kept clear of items, e.g. boxes, packaging, equipment etc 2. Furniture is arranged such that movement of people and equipment are not restricted 3. Make sure all areas have good level of lighting 4. Reasonable standards of housekeeping maintained 5. Trailing cables positioned neatly away from walkways Cabinet drawers and doors kept closed when not in use	Med	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
Use of display screen equipment (DSE)	Repeated / Prolonged or incorrect use	All users working with computer workstations. Repetitive strain injuries, neck and back pain, eye strain and/or fatigue	1. Provision of an adjustable chair, adjustable screen height, suitable and sufficient lighting is maintained in each area. DSE signage detailing advice for correct use of the chair, screen and seating position are posted in each PC cluster and on Staffnet. 2. There is on-line DSE user set up information signposted during the induction process. Staff complete this as part of department safety induction. 3. Staffnet provides Wellbeing advice regarding staying healthy and comfortable when using PCs and laptops. Various external web sites provide advice e.g. www.posturite.co.uk/mobile-device-accessories	Low	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Computer Use	Electricity: Electric shock, burns, fires, electrocution	All users working with computer workstations and electrically powered office equipment Personal injury – electric shock, electrocution and/or burns. Secondary injuries which may ensue	Electrical equipment is PAT tested regularly on a schedule. Tested items are labelled "Pass" and the expiry dated. Estates are responsible for PAT testing PC equipment in Estates managed PC Clusters. All users are advised not to interfere with plugs, cables or any device, especially when any equipment is connected to the power supply at induction. They are advised to report defective items to their manager/supervisor in the first instance. In PC clusters eating or drinking is not allowed to minimise the risk of spillage onto electrical equipment. Bottles of water should be kept closed when not in use and should be stored beneath desks to avoid spillage onto the equipment. All users receive, during the induction process, fire and evacuation awareness safety training and are asked to make themselves familiar with emergency procedures for the areas they visit.	Low	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
			Personal emergency evacuation plans are in place as necessary for those requiring assistance.		

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
Lone working during normal working hours	Lack of or reduced access to first aid	Users of PC clusters, study areas or offices during low occupancy Personal injury and delayed medical attention	Avoid lone working and only use areas where there are other people within shouting distance. First aid support may be delayed if a person is lone working. Security can provide 1st aid and their contact number is on the rear of all University ID swipe cards and on the signage posted on doors to each PC cluster. Phone number is 0161 306 9966 Office users are made aware of this during safety induction sessions. For users with medical conditions that could be exacerbated by the delay of access to first aid the supervisor must seek the opinion of the person and if necessary the University Occupational Health service. A separate personal risk assessment may be needed.	Low	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
Lone working during normal working hours	Intruders	All users of computer clusters or offices who are lone working Becoming the subject of violence or aggression – stress, panic and injury	Avoid lone working and only use areas where there are other people within shouting distance. Users should have phone access to Security staff and should save this number in their mobile phones. During incidents of unease or suspicious activities, users should immediately go to a safe location and report to Security staff on 0161 306 9966. Details should later be shared with the Education Support Office/Safety Office.	Low	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
Use of hand tools (like sharp / pointed tools, Scalpel blade)	Sharp cutting edges	Users /Others in proximity / Visitors Risk of cuts and puncture injuries	1. User is trained and supervised until fully competent. 2. Only use the tool for the intended use. 3. Pre-use check for any faults and remove from use if any found. 4. Avoid use of 'open bladed' tools, e.g. use scissors instead of scalpels if possible. 5. Make safe after each use, e.g. razor blades to be put in sharps bin after use, knives to be replaced into protective cover. 6. Place in safe storage immediately after each use. Never leave cutting tools unattended. 7. Do not place cutting tools too close to the edge of workstation to avoid falling off onto legs and feet 8. Consider the use of cut resistant gloves 9. Use safe cutting technique e.g. cut away from the body and away from the hands and fingers	Med	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
Use of equipment with mechanical hazards	User wearing loose clothing or long hair	User /Others in proximity / Visitors Risk of entanglement	1. Training and supervision on the machinery until fully competent. 2. Avoid loose clothing and loose jewellery. 3. Long hair must be tied back. 4. Users must wear lab coat, safety glasses BS EN 166 and cut resistant gloves BS EN 388. 5. A conveniently positioned mushroom shaped emergency stop button or is present to quickly stop the machine in an emergency. 6. Machinery turned off when not in use.	Med	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Risk rating	Result
Manual soldering Creation of joints between wires or components	Heat	User / Visitors / Occupants of neighbouring areas Minor burns to skin, fire	1. No soldering equipment should be left unattended while switched on and for a minute after switching off to allow to cool. 2. Anyone approaching soldering equipment should assume it is hot. 3. 0.11mm nitrile gloves can be worn to protect hands from spitting solder 4. Solder away from combustible and flammable material 5. When not in use, soldering irons must be stored in the stands provided. Cold water or burn gel should be applied immediately to all soldering iron burns and first aider called to assist.	Low	A

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk

Action plan (14)				
Ref No	Further action required	Action by whom	Action by when	Done

Result : T = trivial, A = adequately controlled, N = not adequately controlled, action required, U = unknown risk