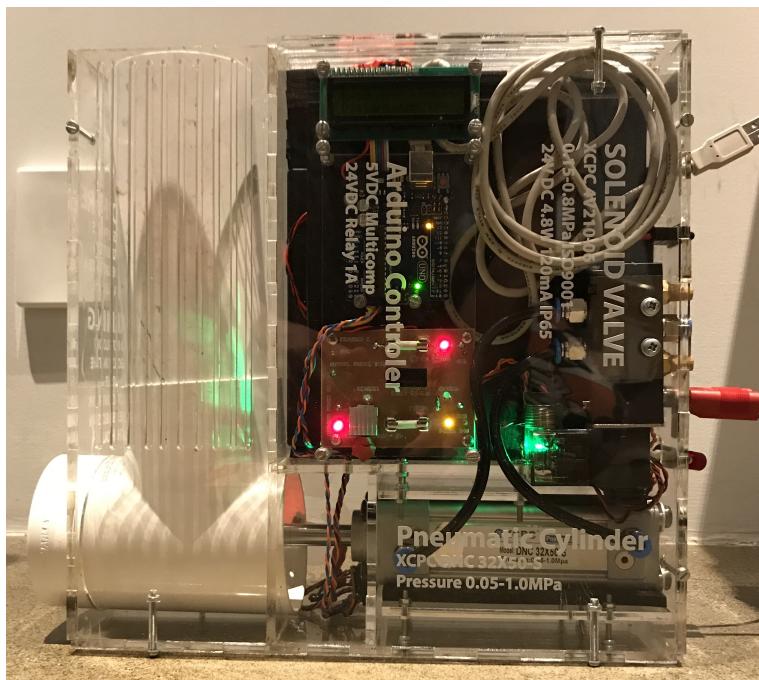


# Project 1: Pneumatic Cylinder

## Mechatronics 282 778

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### Abstract

Pneumatic actuation controlled project involving the projection of tennis balls. The projectiles are deployed from the actuation controlled device at fixed intervals and have an optional override to deploy manually.

The project involves constructing a frame in which will enclose and secure all parts in an orderly safe fashion; designing and building the PCB circuit with the consideration of controlling the solenoid, reading and displaying the extension of the actuator.

In this process, acquired Mechatronics skills are tested to build a devices which has mechanical, electrical and programming components with consideration of materials properties. To utilise all of the skills on a basic level of which can measure the performance and aptitude of converging these skills, and how things are done individually. While there are many methods to preform the task, consisting of different professional approaches is key for performance on an industry level.

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\*This work was not supported by any organization

†Faculty of Mechatronics Engineering, Massey University, Albany, Auckland, New Zealand Progress of project:  
<https://github.com/alex1vla/Mechatrnoics/>

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# 1. INTRODUCTION

The project is to utilise skills acquired, to build a mechatronic device that uses an actuation and sensing sub-system, with a control interface to time the interval in which it takes to deploy a projectile (tennis ball) from the hopper. The interface will display the extension of the actuator on an LCD display. The hopper can hold up to 3 projectiles (tennis balls) which are pre-loaded, and will deploy with a fixed time interval or manual override ejection.

## 1.1. Aims & Objectives

To build a mechatronic sub-system device, integrating actuation, sensing, and control sub-systems.

The key objectives to cover in this task includes

- Control the extension and contraction of a pneumatic cylinder.
- Measure the extension and contraction of a pneumatic cylinder.
- Integrate the mechatronic actuation, sensor, and control sub-systems in order to eject projectiles from a hopper with a fixed time period between deployments.

There are no constraints at which the design is to be achieved, leaving the best found method determined by the development. Therefore the process and development in the design is open for opinion given appropriate reasoning.

# 2. METHOD

A detailed description of what was done, how, and why.

## 2.1. Frame Material Selection

Planning in design for structural integrity is subject to the workspaces constraints, while there are many methods of which the design can be achieved, in a long life usage of the project using metals can prove effective; however in the projects scope the projectiles may be launched a minimum of eight times effectively without damage to the chassis. Therefore the design materials are chosen subject to a prototype friendly, cost effective method which will meet

the required eight successful launches for demonstration and any additional deployment during testing and compensation of the demonstration.

The estimated reasonable number of ejections required used is 100 cycles of both extension and contraction for the pneumatic cylinder, as this is the highest action point of the device, while all other parts remain fixed except the projectiles themselves.

With considerations of this, and analysis provided such as FEA strain tests over 200 (double the required) cycles with Solidworks 2015 and the isolated actuation frame the selected material chosen is entirely based on acrylic with the exception of PVC piping (explained further in frame design for the hopper pre-load).



**Figure 1. Isolated actuation frame**

While acrylic is more brittle than other ready available materials such as MDF, acrylic has the beneficial key feature of being fully transparent, so a full display of all parts can be monitored, and the full demonstration of all internal parts can be observed. Another key reason for this choice in material is the bonding of surfaces in the respect that with specific chemicals applied the surfaces fuse together and become bonded, almost in the sense they were moulded that way which with correct design can spread force through the entire chassis.

## 2.2. Frame design

For the frames design it is important to have a clean and functional, practical layout, so that all components have an appropriate amount of space and remain somewhat easily accessible. The enclosure should be safe with no hazardous features such as electric safety and sharp edges to be cut on. As this is not a final manufacturable product, and rather more towards a prototype model the features are not

strict on including mould casting and perfect rounded edges, but still somewhat of a safe standard with no edge lifting and fused surfaces to maintain integrity.

The frames design will be used as not only the containing housing, but also as a key point in the systems integrity. This is due to the force load's shock being dissipated over a compression surface rather than stressed all on a single point. The design features this to allow the acrylic to slightly expand on each deployment of a projectile, and in the expansion stage to lengthen the duration of the force to ensure the enclosure will not crack for the expected life cycles. This is the fundamental key aspect when designing the enclosure, along side the secure fitment and spacing of all components.

The material selection of acrylic and PCV piping is a cheap and effective way for rapid prototyping, and has not only has great functionality in this design, but also allows assessment of the internal design with the transparent enclosure. The selected PVC pipe (80mm) for hopper to contain the pre-loaded projectiles, and a more accurate deployment has been chosen as it is a cheap and effective method of storing, with a compensation of 6-10mm each side (An internationally recognised tennis balls diameter is 65.468.6mm) [1] of the projectile. While it has been difficult to cut the piping accurately a 'T' pipe has be used rather then assembling a custom joint as this was found to be a better method.

Below is a figure of the rapid prototyping process. The parts are laser cut, and another beneficial aspect of this is that if any part shall unfortunately break for whatever reason, a replacement part can be cut with little effort.



**Figure 2. Laser cutting the frame**

Shown below is the base frame assembly with the solenoid and pneumatic actuator.



**Figure 3. Basic stripped frame before popula-  
tion**

## 2.3. Bonding & Linkages

To secure the frame M3 30mm bolts and nuts were used with 8xM6 bolts securing the pneumatic actuator. All mounting and fastening of internal components is also achieved with M3 size bolts, while dampening foam has been used to cushion some surfaces.

The primary influence in structure bonding is C105 also known as acrylic weld but not to be mistaken with C502 also known as super glue for plastics and rubbers, which offers a different method of molecular bonding of surfaces. The advantage of C105 is that it is extremely thin comparable with water and preforms quick bonding which results in two or more surfaces being fused like overlaying corrugated iron.

The 105 Acribond contains

- U.N. 1593 METHYLENE CHLORIDE CAS No. 75-09-2
  - U.N. 1710 TRICHLOROETHYLENE STABILIZED CAS No. 79-01-6
  - U.N. 1247 METHYL METHACRYLATE MONOMER CAS No. 80-62-6

PG III, HAZCHEM CODE 2Z, Class 6.1

For a more in depth discussion on bonding materials and useful chemistry for plastics and rubbers ePlastics website is linked in the reference section [?]; the 105 Acribond Link [?] is also provided.

## 2.4. Power Supply

The available option of a 24VDC bench power supply is provided, however for ease of use in testing and probability an internal power supply has been integrated.

The selected cells are 2x 12VDC 7AH Gel AGM SLA batteries connected in series to provide a stable constant reliable power source which does not require frequent charging.

The resultant supply is 24VDC 7AH for reference.

There is a built in universal charge port using banana sockets of which any appropriate SLA 24V charger can be used. Due to the nature of the batteries and the self maintenance hydrogen gas released the frame includes vents for any build up of gas or excess heat from components.



**Figure 4. Tree Battery 12VDC 7AH Gel AGM SLA**

## 2.5. Eagle PCB

Using Eagle CAD-soft from Autodesk [3] a PCB is designed and implemented. Eagle was the preferred method demonstrated in class and thus the chosen for this development.

There was also the choice of Altium however due to the accessibility of a Mac computer the Eagle Autodesk software has been found preferred.

Physical LED indicators have been implemented to assist with the user interface and a DIAG port provided.

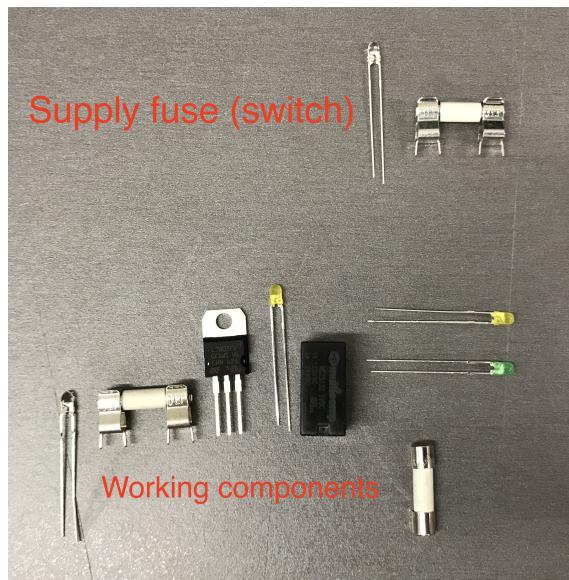
The PCB design includes the following

- Arduino controller
- Voltage regulator (24VDC to 5VDC)
- Relay from the Arduino to the solenoid (5VDC to 24VDC/120VDC 1A)
- Relevant LED's
- Safety features e.g. fuses (0.5A)
- Ground Core

The components are shown in a working order below. The LED's indicate the state of each action, with the red LED relating to power from the source at each stage 24VDC.

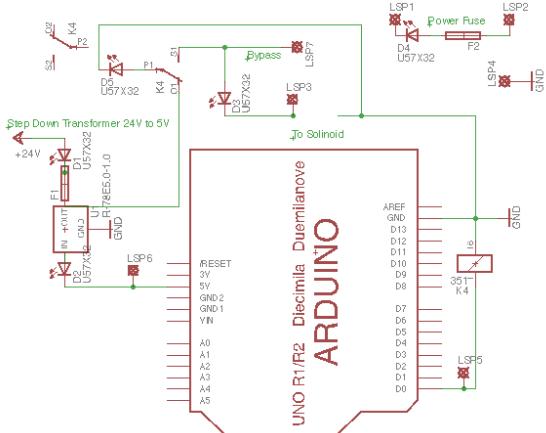
Yellow being the state of the stage after some processing, the first being the regulation from 24VDC to 5VDC, the second being the normally closed side of the relay or contraction of the actuation arm. Finally the green LED is for the extension state of the actuation arm.

These LED's are for status states only and debugging thus why they are not mounted and displayed on the enclosure although visible.



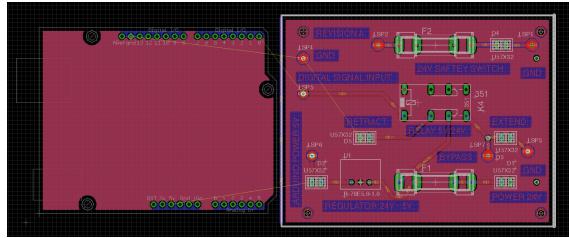
**Figure 5. Components of design**

A schematic of the design is given below. The design does not include capacitors after the regulator (or an attached heatsink) due to the current draw being less than 20% of the capacity of the transistor which is 1A and is not required.



**Figure 6. Schematic**

The board drill out design is shown below. The purpose of this layout being a separate entity rather than a shield of the Arduino, this is for display purposes only, and to perform visual inspection from the exterior of the enclosure for assessment and debugging.



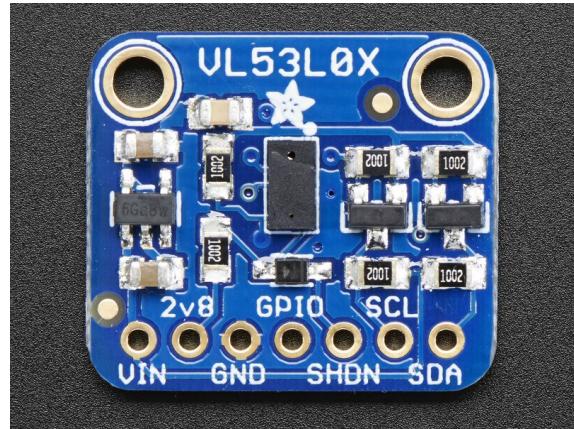
**Figure 7. Board design**

## 2.6. Sensor Selection

In order to measure the distance of the pneumatic actuation arm a form of sensor is acquired. The sensor chosen is the Adafruit VL53L0X Time of Flight. This was selected due to the linearity of the detection with high accuracy and the linear properties of the sensors measurement, without issues from depreciation due to limited cycles.

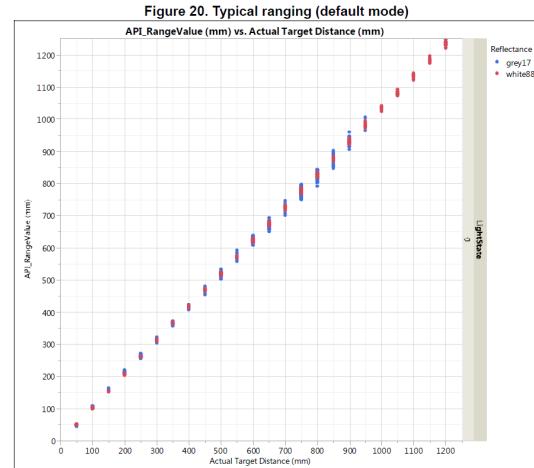
The benefits of the Time of Flight sensor is that being light dependant it does not rely on physical boundaries like that of a potentiometer, while also being far more accurate. These and few IR sensors were entertained as the only sensors looked into and the development for the projects designs. The head of the actuator also has an optional adaptor to measure the arm with more accuracy, however due to the fixed nature and known length of the extruded arm this was unnecessary and the max value had been overwritten. The device comes with the adaptor and commented code to further examine for the precise measurements.

The Actuation is measured with the VL53L0X sensor and sent to the Arduino via the SDA SCL pins A4 and A5; which in turn translates the read value decimal and is displayed in millimetres on the mounted LCD display located above the Arduino and PCB on the inside of the enclosure. The measurement is also recorded on the Serial input monitor with baud rate 9600 - For this sensor the Adafruit VL53L0X header library is called.



**Figure 8. Selected sensor**

The linear features of the sensor with range 50mm 1.2m is shown below



**Figure 9. Linear features graph with distance of the Adafruit VL53L0X Time of Flight sensor**

## 2.7. IR Ball Detection

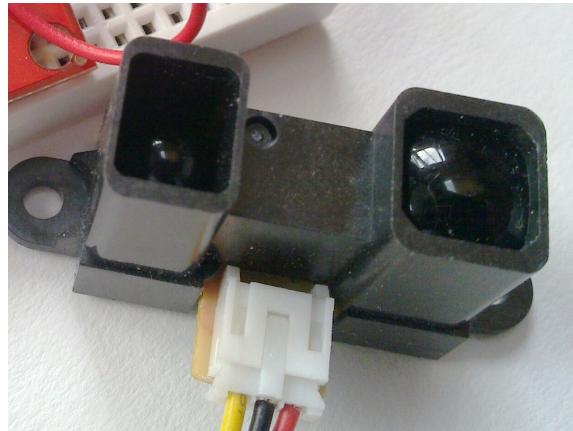
A Adafruit IR sensor is used for detection of the projectile. Once the chamber is occupied the operation can commence. The signal is passed to the Arduino as a digital high and if detection is successful the run function is called to preform the process, a

flag is set to be interrupted when cycle is complete and continue to scan.

The soft detection allows for consistent use of the device with no runtime issues. The assigned digital pin is D3 - This sensor was only used for close range detection due to the nature of interference of the sensor.

The IR detection is useful to know when the projectile is ready to be launched and therefore necessary deployment can be avoided. This is not in the projects scope, rather a side feature found useful and can be comment out in the following lines.

```
if (!digitalRead(3)) { // Ball
    Detection
    runFlag = 1;
}
if (runFlag){
    run();
}
```



**Figure 10. Adafruit IR sensor**

## 2.8. Interface

A serial monitor and LCD display is setup for reading the measured results of the actuator arm, while LED status indicators are implemented for easy debugging and safety features.

Below is the example of the LCD read out



**Figure 11. LCD display interface**

## 2.9. Programming

The selected device for use as the controller, and to measure and display the extension is the Arduino Uno. The reasons this was the selected microcontroller board is for no other than being cost effective, as this was taken from past years projects. As there were no specifications on what must be used this was the most appropriate solution.

A summary of the code is shown in the appendix which covers in full the method of deploying the projectiles, the override function, and displaying the displacement of the actuator.

Please see the comments embedded in the code for a more step by step detailed explanation for what is being processed.

It is important to consider the scope in this respect as the limitations are a fixed time interval between deployment. The stages are performed in sequence with the cycle use of the function loop run. This will perform each cycle and can display the extension and retraction distances.

If you choose there is also a live stream of continuous distance info available, however as there are only 2 modes with extended or retracted I have left this as a fixed term in the code. Easily changeable is required please use the DIAG PORT on the back of the device.

After the cycles are performed the detection will go back and check for more projectiles.

The **LCD display and Serial Monitor** will both give active values of all the recorded data simultaneously.

```

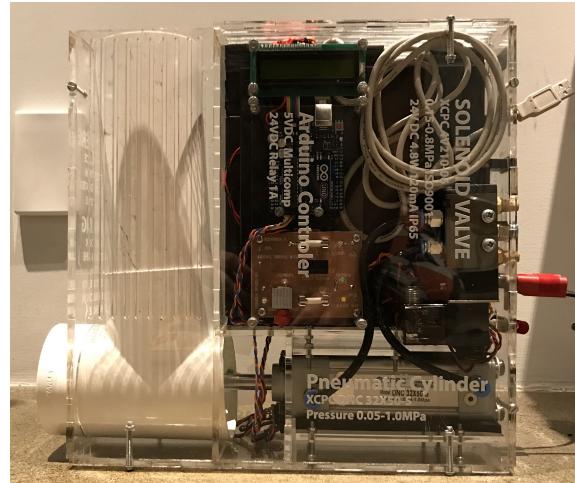
void run() {
    if (i < 3) {
        if (i % 2 != 1) {
            digitalWrite(2, HIGH);
            delay(500);
            Serial.print("Distance (mm):");
            ;
            Serial.println("54");
        //     Serial.println(dist);
        //     lcd.setCursor(13, 1);
        //     lcd.print(dist);
        //     lcd.print("54");
        } else {
            digitalWrite(2, LOW);
            delay(1000);
            Serial.print("Distance (mm):");
            ;
            Serial.println("21");
        //     Serial.println(dist);
        //     lcd.setCursor(13, 1);
        //     lcd.print(dist);
        //     lcd.print("21");
        }
        i++;
    }
    digitalWrite(2, LOW);
    runFlag = 0;
}

```

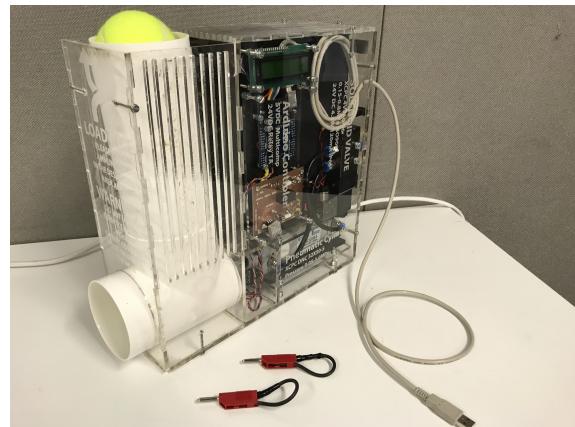
### 3. RESULTS

The products procedure resulted in a successful build of which a projectile is deployed and given information is passed to the user on a mounted LCD display. All of the objectives sought out to achieve have been completed. The projectiles average range was recorded at 2.2m when launched from the ground and 6.8m when launched from 1m above ground level. Below is the finished product captured from two angles.

The final product comes with the banana plug charge adaptors and USB DIAG cable, everything else is inclosed. The cartridge can load up to 5 projectiles at any one given time, where only 3 are required in the scope.



**Figure 12. The final product**



**Figure 13. The final product side 2**

### 4. OUTCOMES

Successfully achieved and built a mechatronic sub-system using the following

- Sensing elements and signal conditioning used within a mechatronic device
- Pneumatics and hydraulics
- Mechanical and electrical actuators
- Integrated mechatronic sub-systems to build a mechatronic device
- Configured and use PC and PLC control systems

## 4.1. Fine Tuning

While the process is rudimentary there is much room for fine tuning, this could be in the design of the enclosure, the rate of actuation, the speed, and angle, of which the projectiles are deployed and so on.

The range is highly subject to these parameters and is significantly effected from initial launch height so therefore an optimum combination of these can be found depending on the use of the product. After these parameters are established the settings can be tuned and set to random if chosen for a more unexpected distance result if required.

All pins and any loose wiring is solder fixed to their boards in all allocated sections and all safety features and shrink wrap checked, and exposed contacts sealed and stand offs secured accordingly.

## 4.2. Testing

The main aspects of testing is to show that the device works and meets the objective criteria. After the projectiles are launch and LCD displayed, details of range can be recorded.

A not necessarily obvious, but extremely key part of very necessary testing is the question of practicality; how easy it is to use and understand, is everything simple to understand and labeled correctly, and most importantly, how intuitive is the device. These features are checked over to make sure the device is simple and easy to setup and use, coming all in a single enclosure with enough information to determine functionality with no additional support.

The device is checked for standalone use, as well as being run via a computer interface terminal. It is easy to update and diagnose, and is simple to connect.

After all the results are finalised, the outputs confirmed with objectives complete, the project is simplified for clarity and ease of use for future development and reference. Making the build stable and concise, and as robust as possible prompts for a good design.

Checking over the functions and any redundant features, ensure a good user interface is easily workable and the outputs are all correct and comprehensive.

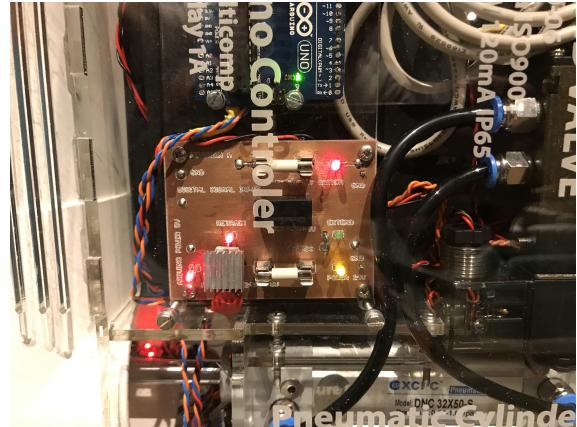


Figure 14. Testing the retract with signal LED



Figure 15. Testing the extend with signal LED

## 4.3. Finalising

As this is a prototype build a further recommendation coming to a final product design would be to use an ABS mould with rounded edges and an integrated handle with an adjustable deploy angle fitment and 1.5m portable stand.

A bluetooth remote would also be handy to start the sequence 0-15m no obstruction range, as an official tennis court is 23.77m long and singles line distance is 10.97m [1] therefore the average range would not exceed 15m once setup; that is if the product were to be used for this purpose.

The main limitation of this device is there is no automatic rotation angle feature, meaning that if someone were to actually purchase this device it might be a key feature in which they seek.

Therefore an investigation of how to incorporate this might prove necessary, however due to the scope of this project it is unnecessary to go into details.

Finally, being as the device is pressure driven, the option of having a replacement induction driven actuator should be considered if used in final product, as it may not be particle to have a compressor or refillable canister always attached.

An override button has been implemented for a force override to the program in the result of a failure to read detection.

## 5. CONCLUSIONS

For any progress related to the report please see the public Github repo for alex1v1a or use the link in the cover page to be automatically redirected to this project.

The repo provides all laser cut, PCB, and other documentation as well as code for the entire design process and is open source, please feel free to review and make your own contributions, more images and live videos can also be found on the repo, enjoy.

### 5.1. Critical Evaluation and Methodology

The final methods found to be successful are of a high quality design. Further revision cans be better made, however on a whole the method met all the required targets in the scope and met all aims and objects set out to achieve.

The final design prototype had little to flaw and possible minor updates to be made before a second revision e.g. mould housing, and secure mount the IR sensor.

### 5.2. Discussion

This project has helped to exercise the skills in designing from scratch a fully automated device.

From here the fundamental methods of this project can be applied to numerous manufacturing situations and being automated have the capability of time and co-dependant systems.

A great deal like the Festo project the key concepts to achieving the build of a manufacturing process have been acquired. The challenge was exciting and when the results were examined to be correctly working, pride took place.

## References

- [1] T. I. T. F. (ITF), “The official diameter of a tennis ball.” <http://www.itftennis.com/technical/balls/approval-tests.aspx>. [Online; accessed 16-May-2017].
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- [5] A. Plastics, “110 acribond.” <http://www.awardplastics.co.nz/shop/Plastic+Fabrication/Adhesives++Cleaners/Plastic+Glues/110+Acribond+100mL+Tube.html>. [Online; accessed 19-July-2015].

## APPENDIX

```
#include <Wire.h>
#include <VL53L0X.h>
#include <LiquidCrystal.h>
///#include "Adafruit_VL53L0X.h"
//
//Adafruit_VL53L0X lox = Adafruit_VL53L0X();

LiquidCrystal lcd(10, 9, 8, 7, 6, 5);
VL53L0X sensor;
///#define HIGHACCURACY

int dist;
int i = 0;
int runFlag = 0;

void setup() {
    Serial.begin(9600);
    while (! Serial) {
        delay(1);
    }
    Serial.print("\nReading actuator measurement ... \n");
    lcd.begin(16, 2);
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Read measurement");

    // Serial.println("Adafruit VL53L0X test");
    // if (!lox.begin()) {
    //     Serial.println(F("Failed to boot VL53L0X"));
    // }

    pinMode(2, OUTPUT);
    pinMode(3, INPUT);

    // sensor.init();
    // sensor.setTimeout(500);
    // sensor.startContinuous();

    delay(1000);
    lcd.setCursor(0, 1);
    lcd.print("Distance (mm):");
}

void loop() {
    if (!digitalRead(3)) { // Ball Detection
        // dist = sensor.readRangeContinuousMillimeters();
        // Serial.print(sensor.readRangeContinuousMillimeters());
        // Serial.println();
        // Serial.print("Distance (mm):");
        // Serial.println("");
        // lcd.setCursor(13, 1);
        // lcd.print(dist);
        runFlag = 1;
    }

    if (runFlag){
```

```

        run();
    }
    digitalWrite(2, LOW);
}

void run() {
    if (i < 1000) { // 5 cycles
        if (i % 2 != 1) {
            digitalWrite(2, HIGH);
            delay(500);
            Serial.print("Distance (mm):");
            Serial.println("54");
//            Serial.println(dist);
            lcd.setCursor(13, 1);
//            lcd.print(dist);
            lcd.print("54");
        } else {
            digitalWrite(2, LOW);
            delay(1000);
            Serial.print("Distance (mm):");
            Serial.println("21");
//            Serial.println(dist);
            lcd.setCursor(13, 1);
//            lcd.print(dist);
            lcd.print("21");
        }
        i++;
    }
    digitalWrite(2, LOW);
    runFlag = 0;
}

```