How to make (almost) anything:
2-player pinball machine

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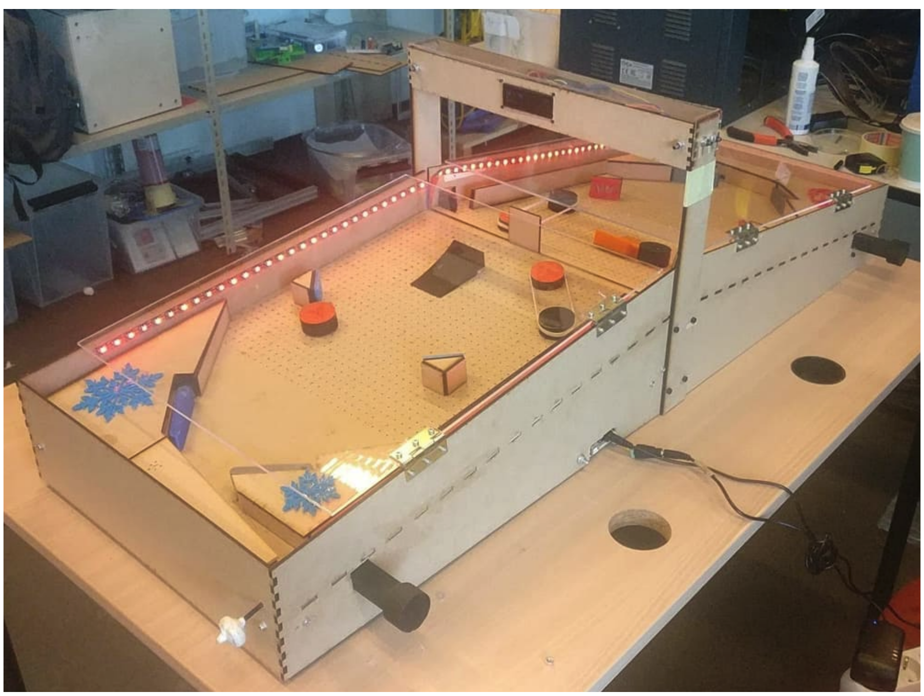


1 Introduction

This report documents the development of a 2-player pinball machine, where players compete against each other to achieve points by hitting certain objects on the playing field and scoring on the opponent's goal, accumulating towards a winning score. The device is made of various materials such as MDF, plastic, acrylic, aluminum, and is produced using various techniques learned in the HTMAA course; laser-cutting, 3D-printing, drilling, electronic wiring, soldering, among other. The final product contains working flipper - and launching mechanisms, LED lighting, automatic point display and a modular playing field allowing obstacles to be positioned differently from game to game. The motivation for making the product is of shear interest in the original pinball machine, and a desire to add our own twist to it.

2 Background

The group decided on the project without knowledge, that a 2-player pinball machine has been made by others. However, while the 2-player aspect of the game has been seen before, the use of electronics to track points and produce appropriate sound and lighting in such a game, is something we couldn't find elsewhere. Another original construct of our machine, is that the playing field is made modular so that players can change position of the obstacles from game to game. The intention is, that this introduces an aspect of change at each game play. This is made possible by a grid of small holes on both sides of the playing field, where obstacles can be inserted into using metal pins.

3 Requirements

Before we can create anything it is crucial to setup a set of requirements that the final product must satisfy to ensure that The requirements that we set are as follows:

- There should be 2 pinball fields, connected symmetrically on the upper parts.
- It should be possible to pass the ball from one field to the other.
- The flippers should be mechanical so players can decide with force how hard to shoot the ball.
- There should be a way to gain points, namely by hitting the ball into the opponents pit, or hitting special obstacles on the field which grants points.
- There should be an automatic system keeping score of the points, and a way to present these points to both players.

- There should be obstacles that a player will have to play around. These obstacles should be modular, so they can be positioned on the playing field as seen fit.
- There should be at least 1 motor in the product.
- The players should get some visual/auditory feedback when a game has been won.
- The whole playing experience should be achievable without having to move the ball around with ones own fingers.

These requirements guided us in the making of the product, however we did not want to limit ourselves to these requirements, and so possible extensions were taken into considerations during the development.

4 Description

4.1 Mechanics

4.1.1 Game board Design

The game board itself is made as two separate pinball fields that are joined in the middle by the score-display tower. The fields themselves are laser-cut out of 4 mm thick MDF material and all the parts are combined with finger joints, and fastened with metal brackets and glue. The center playing fields are angled at a symmetric 7 degree slope and contains a grid of more than 1000 holes each with a diameter of 1.4mm, for which obstacles can be inserted into (see figure 6 in appendix). On top of each side of the board is mounted two transparent acrylic lids to prevent the ball leaving the game board. The acrylic lids are mounted with hinges on one side so a player easily can access the playing field and alter the position of obstacles. The score-display tower is made of laser-cut MDF plates and assembled with finger joint and metal brackets. Two LCD screens are placed inside the top part of the tower, on each side. A laser-cut acrylic plate which has been bent in each end using heat, functions as a lid protecting the electronic wiring inside the tower

4.1.2 Flipper mechanism

The flipper mechanism consists of 5 parts; a *trigger handle*, a *moving mechanism*, a *pin*, a *rubber band*, and a *flipper head*. The *flipper handle*, *pin*, and *flipper head* are 3D printed using plastic as material whereas the *moving mechanism* consists of 3 laser-cut MDF boards stacked and glued on top of each other. The *trigger handle* is connected to one end of the *moving mechanism* with a m4 screw and a nut, which can move back and forth inside the *moving mechanism*. The *pin* is connected vertically to the other end of the *moving mechanism*. Through a small hole in the playing field, the *pin* is placed between the bottom and the upper part of the playing field, peaking out on the top part, and the *flipper head* is mounted and glued on top of the *pin*. Finally a *rubber band* is connected between the side wall and the screw in the *moving mechanism*, constantly pulling the entire mechanism towards the wall. When the *trigger handle* is pushed into the side, the *moving mechanism* is rotated away from the wall, and the *pin* is rotated around its own axis ultimately moving the *flipper head* from back to forth. Releasing the trigger handle will cause the rubber band to pull the entire mechanism back to starting position. See figure 10 in appendix for the assembled flipper mechanism, and figure 11 for individual parts.

4.1.3 Ball Shooter

The ball shooter or ball re-loader consists of a strong spring with a carbon rod inside it, the carbon rod when pulled back will make the spring curl together. To do this we drilled a hole in the rod, pulled a washer over the rod which is held back with a metal wire inside the hole in the rod. We also added a lump of glue on one end of the rod, to make a handle. The ball shooter can be seen on figure 22. The springs have been created using the 1.4mm wire that is also used for the pins on the obstacles see figure 23.

4.1.4 Moving Wall

The moving wall consists of a stepper motor, two laser-cut gears connected with a belt. The wall is mounted on the belt with a laser-cut mount. When the belt is pulled, the wall moves. Above each gear, a button is positioned to register if the wall has reached the edge of the space it can move between. When a button is pushed it signals the motor to change direction. The wall and mounting plate were also made using laser-cutting. A picture of the contraption can be seen in figure 7 in annexes.

4.1.5 Obstacles

There are a number of obstacles that a player will have to shoot the ball around in the form of round blocks with rubber bands between them. They simply consist of 3 laser-cut sheets of wood glued together, some of the sheets of wood have holes or tunnels in them, allowing us to run metal wire through them which is used to attach them to the game board. See fig 24.

4.1.6 Point-giving Obstacles

The point-giving obstacles are simply laser-cut sheets of MDF, glued together to form a triangle. They contain holes in the bottom part to send wires through. A button is glued to the bottom of the triangle with a rectangular piece of wood taped to the button. When the ball hits the rectangular wood the button is triggered which allows the points to be incremented. See figure 25.

4.1.7 Ramp

Ramps were added to allow a player to shoot the ball through the air. They were 3d printed with 0.4mm nozzle and 0.8mm nozle with good results. On the bottom of the ramps, we glued a laser-cut piece of wood with metal pins through, So that they can be attached to the board. The ramp can been seen on figure 16.

4.2 Electronics

4.2.1 Main Controller

We use Arduino Mega as the central controller to track all game states and mechanics. The reason why we use the Arduino Mega was due to it having a large number of sockets which was required because of the large number of electronic components needed to be connected. Thus smaller Arduinos such as the UNO would not be sufficient for the project. See figure 2 in annexes for schematics.

4.2.2 Power sources

We are using two external power sources to drive all components, 12V for the stepper motor and 5V for all other components in the system. All components have one common ground connected to the Arduino board.

4.2.3 Stepperdriver and limit buttons

To move the wall we are using a Pololu A4988 stepper driver to control the speed and direction of the NEMA 14HS13-9804s stepper motor that drives the moving wall. Furthermore, two 3-pin-snap-action-lever-switches are used to track when the wall has reached its limit before it needs to change direction. That is when the wall touches one of the limit switches, the wall will change its direction. See figure 7 in annexes for schematics.

4.2.4 Goal Sensoring

For tracking goal scores we have utilized the KY033 optical IR sensor module to sense whether a ball has entered a players goal. We use the analog input to read the light reflected and compare the input to a threshold denoting whether a ball has crossed its sensor. This ensures that goals are tracked compared to if we use pressure plates controlled by switches that require x amount of force applied before the goal can be registered. See figure 3 in annexes for schematics.

4.2.5 Point-giving Obstacles Sensoring

The Point giving obstacles discussed in 4.1.6 uses the 3-pin-snap-action-lever-switches to track when a ball hits a point giving opstacle. Compared to a push-button, an action lever switch requires less force due to its extended lever arm and thus reduces the amount of force needed to track a hit. Finally, one can add additional point giving obstacles by connecting them to the breadboard located underneath the game board, thus adding a way to extend the number of point giving obstacles in the game. See figure 3 in annexes for schematics.

4.2.6 LCD screens

We utilize two 16x2 GDM1602K LCD screens to display the players' scores. These displays are mounted on the center tower to maximize visibility. Considering they all display the same data we have made a joint connection on all common pins on both LCDs to reduce the number of actual wires needed to be managed and connected. Specifically, only 12 wires needed to be managed instead of 24 wires. See figure 5 in annexes for schematics.

4.2.7 LED lights and Sound effects

To increase the entertainment value, we have used various lighting and sound effects. Here we are using buzzers to play different sound queues to represent a certain game event to let the player know when a point has been given or when a game has ended. It would be interesting to add a musical aspect to the project to further increase the entertainment value but was deemed out of scope. Finally, four light NeoPixel LED strips have been used where two of each are located at each players side. The LED strips emit random colors on each diode every 500ms passively until the game concludes where all LED diodes emit the color of the winner which is either RED or BLUE. See figure 4 in annexes for schematics.

4.3 Software

The deployed code on the Arduino Mega has been written in the Arduino IDE. The code contains all logic needed to track scores as well as handling all game events. Due to the sheer number of components as well as all of the states that need to be tracked, it was crucial to implement an architecture that separated state checking and setting from displaying states and firing events based on states. Thus two main methods are used where "*determineState()*" reads and sets states from all the inputs while "*showState()*" reflects the current state, such as playing sounds or updating the LCD display. Thus the separation of concern of states is critical since for example, the color of the LEDs have to change every 500ms, goals and points have to be tracked, sounds have to played, etc. All these events may occur at the same time or arbitrary from each other. So having the states mixed up would make the whole code-base extremely complex and hard to maintain and extend. Finally, each game states that are timer-based have their own timer to track whenever a given state or event is ready to be executed, instead of using the inbuilt delay function which would freeze the whole system.

5 Results

The goals of the project have been achieved for the most part, and we have created a product that we are satisfied with. The device meets the requirements for the minimum viable product, and also includes some extensions. The product was tested by playing the game; pressing and pulling various mechanism and hitting certain objects, achieving different game states.

5.1 Discussion

5.1.1 Shortcomings

- The stability of the push-to-shoot mechanism. This mechanism will often get stuck because of the friction between the wood and the plastic. We could have overcome this challenge if we used linear solenoids and ball bearings attached to the flippers, which would be activated by a button. However, this would prevent one to manually control the amount of force applied to the flippers since it would have been constant for every push.

- The requirement about achieving a playing experience without using your fingers to adjust the ball is only partly met, since often the ball will get stuck and the field will have to be tilted or you will have to push the ball. This can be partly fixed by arranging all modular obstacles in way to reduce the risk of getting a stuck ball.

- Another shortcoming is that that the point-giving obstacles need a to be hit quite hard with the marble ball in order for it to register the hit. This could be fixed if we use a heavier ball such as a metal ball. Currently the metals we have access to are unfortunately too big to fit through the goal and ball shooter alleyway.

- The LCD screen is not very bright and it is difficult to see what the score is. We could have used a bigger brighter display but none were available.

- it would have been nice to have a painted and more elegant product in the end, there is a lot of plain wood. One idea was to engrave all the surfaces, but we decided not to due to time constraints.

- With the Point-giving obstacles, we ran into problems in regards to making them modular in an effective way. The initial idea was to make a top part and a bottom part. The top part is the one the players interact with and the bottom part should have the wiring. The two parts should fit together like a socket and one would then be able to re-position the obstacle without having to unplug the wires (See figure **??** in annexes). We ran into trouble with how to do this without the use of custom Through-hole PCBs and time ended up becoming our constraint preventing us from developing this.

5.1.2 Strengths

- The modularity of the non-wired obstacles works very well and it is nice to redesign the game field from play to play.
- The flippers, when not stuck, work great, being able to adjust the force allows players to have a greater impact on the game.
- The lighting and the scoring system very well in creating a more entertaining game-play.
- The overall stability of the product is good.

Overall the device meet the requirements that we set out to begin with. However we would have loved to improve the shortcomings given more time.

5.1.3 Mass production

If the device would be mass produced we would not use any 3d printing, we would get molds for the plastic parts, since the 3d printing was quite time consuming and the parts would also be visually better and robust. Also we would add holes for the screws to all the sheet designs, so we wouldn't have to drill them ourselves after.

6 Annexes

6.1 Bill of materials

Things to construct

- 4 side panels of 4mm mdf.
- 2 back panels of 4mm mdf.
- 2 field panels of 4mm mdf.
- 2 tower side panels of 4mm mdf
- 4 3d-printed flipper handles
- 4 3d-printed flippers heads
- 4 point-giving obstacles
- 2 3d printed ramps
- 6 round obstacles
- 2 acrylic panels 4mm
- 1 acrylic tower lid

- 1 rectangular 4mm mdf (moving wall)
- 2 gears of mdf
- 1 rubber belt

Electronics

- 10 3-pin-snap-action-lever switches
- 2 KY033 optical IR sensors
- 2 GDM1LCD displays
- 4 breadboards
- 1 Arduino Mega
- 2 Multicolor LED strips
- 4 Speakers
- 1 NEMA 14HS13-8804s Stepper motor
- 1 Stepper driver
- 1 Potentiometer
- 6 10k resistors
- 1 DC port adapter
- 1 12V dc power supply
- 1 5v dc power supply
- Wires

Miscellaneous

- 4 hinges
- 6 L brackets
- 8 m4 20mm screws
- 34 m4 15mm screws
- 30 m4 bolts
- 16 m4 washers
- 4 m3 10mm screws
- Glue and glue gun glue

- 2m 1.4mm Ø metal wire
- Strips
- Heat shrink tube
- 4 industrial rubber bands

6.2 Schematics

This subsection contains all electronic schematics for the project

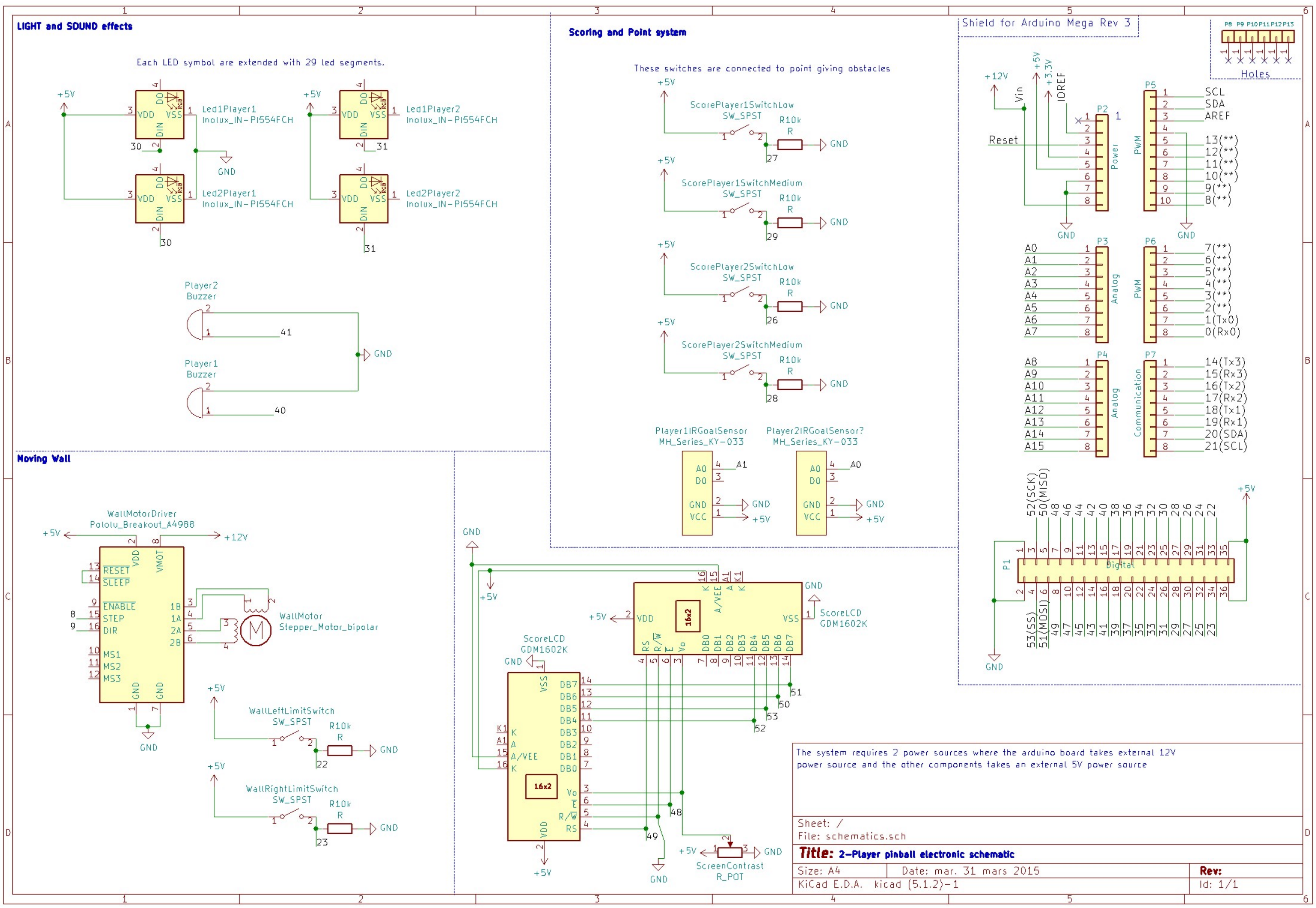
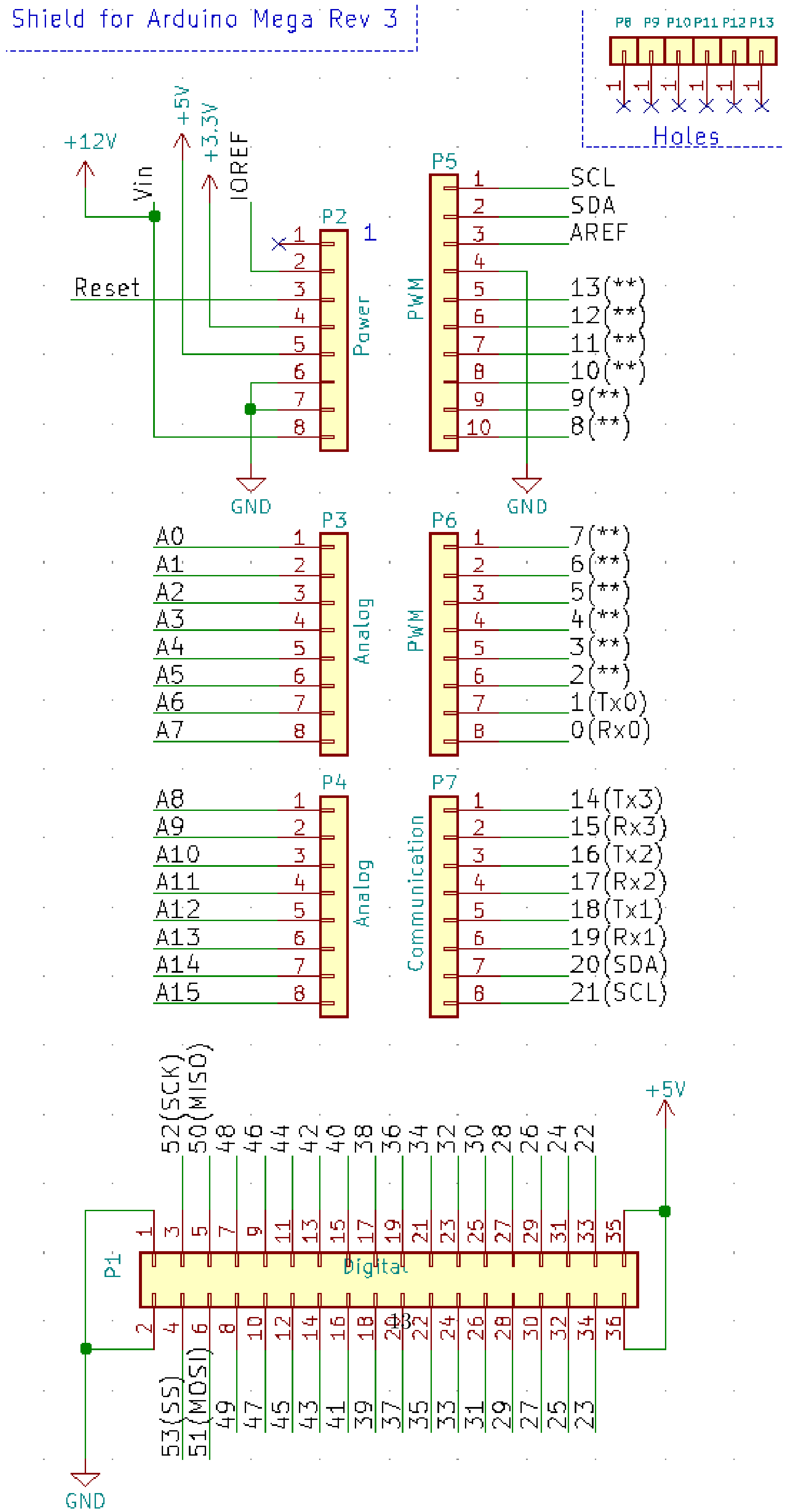

LIGHT and SOUND effects
Each LED symbol are extended with 29 led segments.
Led1Player1
Inolux_IN-PI554FCH
Led2Player1
Inolux_IN-PI554FCH
Led1Player2
Inolux_IN-PI554FCH
Led2Player2
Inolux_IN-PI554FCH
Player2
Buzzer
Player1
Buzzer
Scoring and Point system
These switches are connected to point giving obstacles
ScorePlayer1SwitchLow
SW_SPST
ScorePlayer1SwitchMedium
SW_SPST
ScorePlayer2SwitchLow
SW_SPST
ScorePlayer2SwitchMedium
SW_SPST
Player1IRGoalSensor
MH_Series_KY-033
Player2IRGoalSensor?
MH_Series_KY-033
Shield for Arduino Mega Rev 3
Holes
Moving Wall
WallMotorDriver
Pololu_Breakout_A4988
WallMotor
Stepper_Motor_bipolar
WallLeftLimitSwitch
SW_SPST
WallRightLimitSwitch
SW_SPST
ScoreLCD
GDM1602K
ScreenContrast
R_POT
The system requires 2 power sources where the arduino board takes external 12V power source and the other components takes an external 5V power source
Sheet: /
File: schematics.sch
Title: 2-Player pinball electronic schematic
Size: A4
Date: mar. 31 mars 2015
Rev:
KiCad E.D.A. kicad (5.1.2)-1
Id: 1/1

Figure 1: Full Schematic


Shield for Arduino Mega Rev 3
P8 P9 P10 P11 P12 P13
Holes
+12V
Vin
+5V
+3.3V
IOREF
Reset
P2
Power
GND
P5
PWM
SCL
SDA
AREF
13(**)
12(**)
11(**)
10(**)
9(**)
8(**)
GND
P3
Analog
A0
A1
A2
A3
A4
A5
A6
A7
P6
PWM
7(**)
6(**)
5(**)
4(**)
3(**)
2(**)
1(Tx0)
0(Rx0)
P4
Analog
A8
A9
A10
A11
A12
A13
A14
A15
P7
Communication
14(Tx3)
15(Rx3)
16(Tx2)
17(Rx2)
18(Tx1)
19(Rx1)
20(SDA)
21(SCL)
52(SCK)
50(MISO)
48 46 44 42 40 38 36 34 32 30 28 26 24 22
+5V
P1
Digital
53(SS)
51(MOSI)
49 47 45 43 41 39 37 35 33 31 29 27 25 23
GND

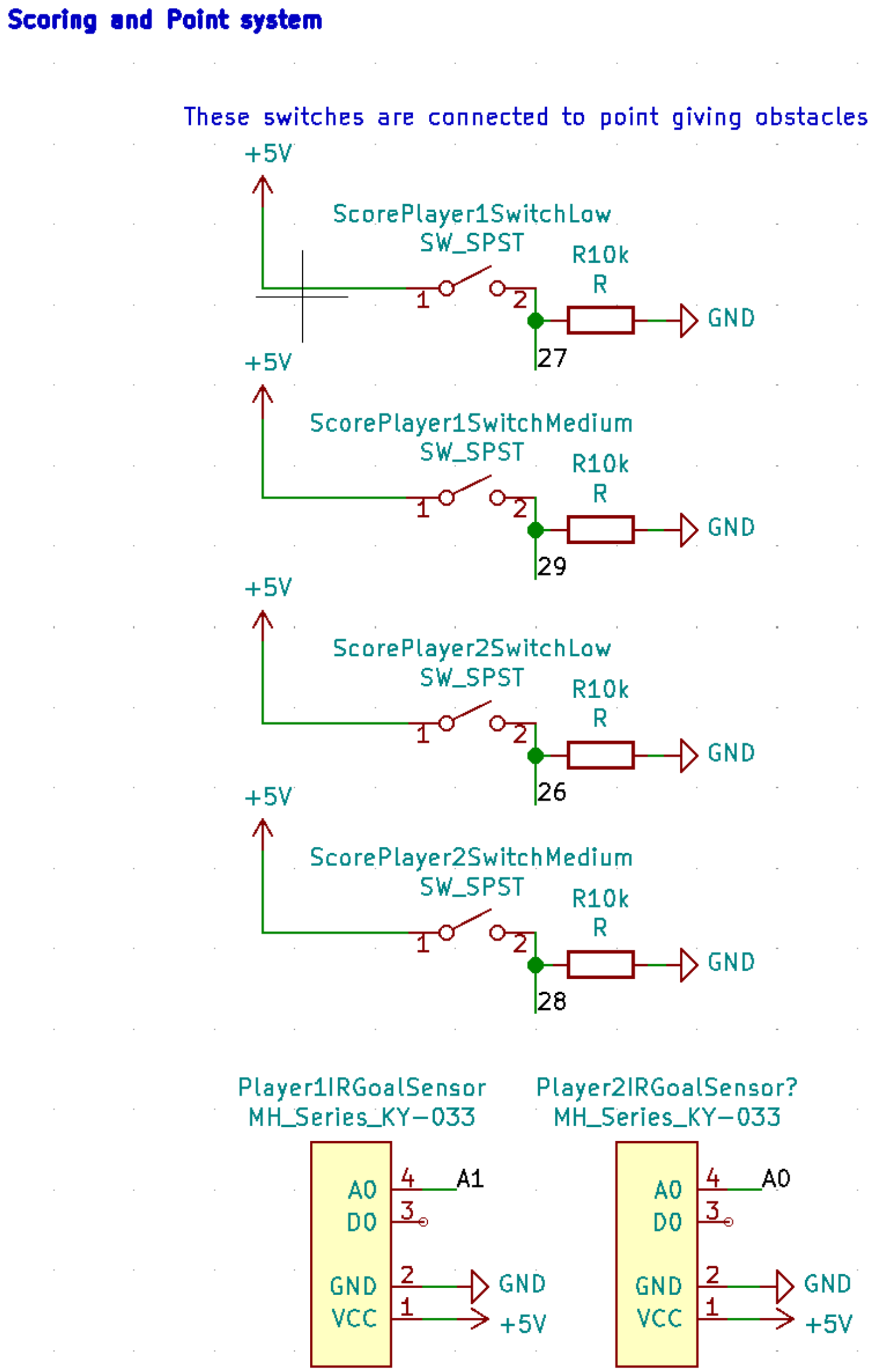


Figure 3: Schematic of point and score system

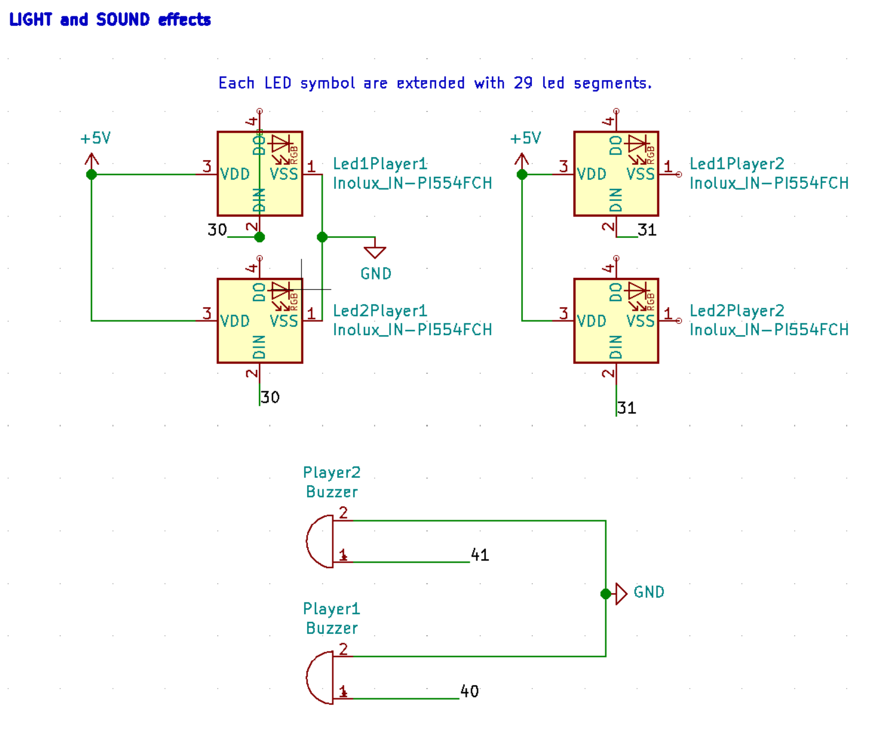


Figure 4: Schematic of light and sound system

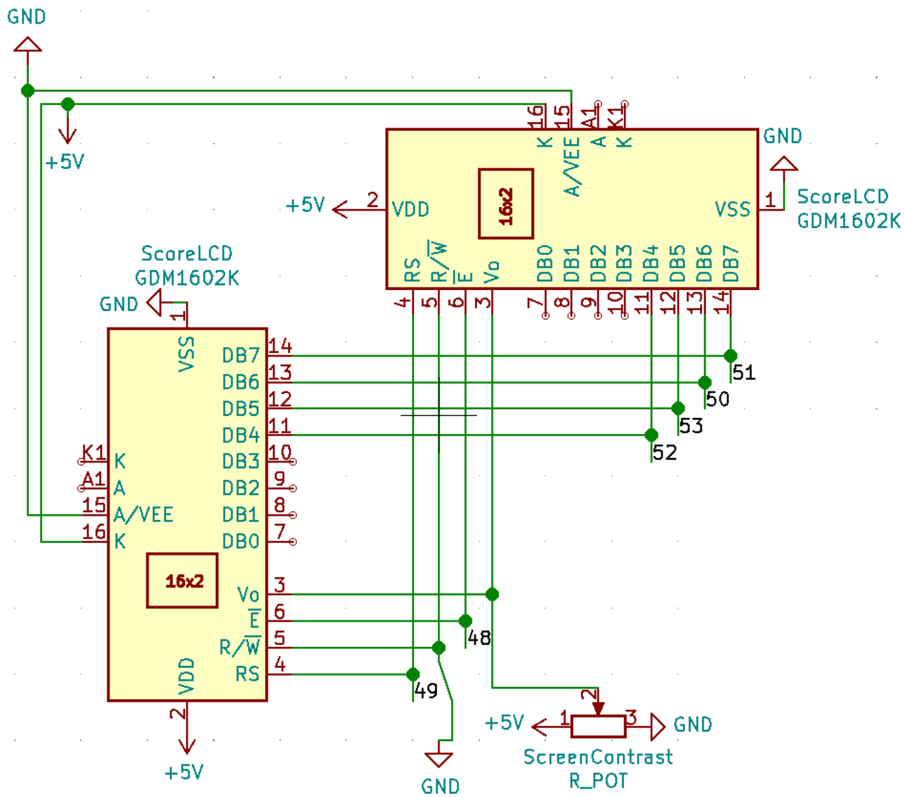


Figure 5: Schematic of moving wall

6.3 Figures

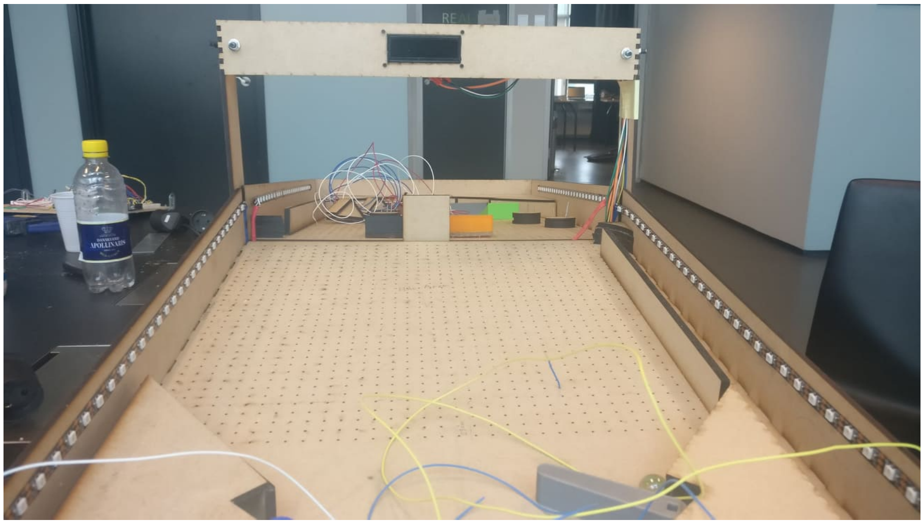


Figure 6: The game board

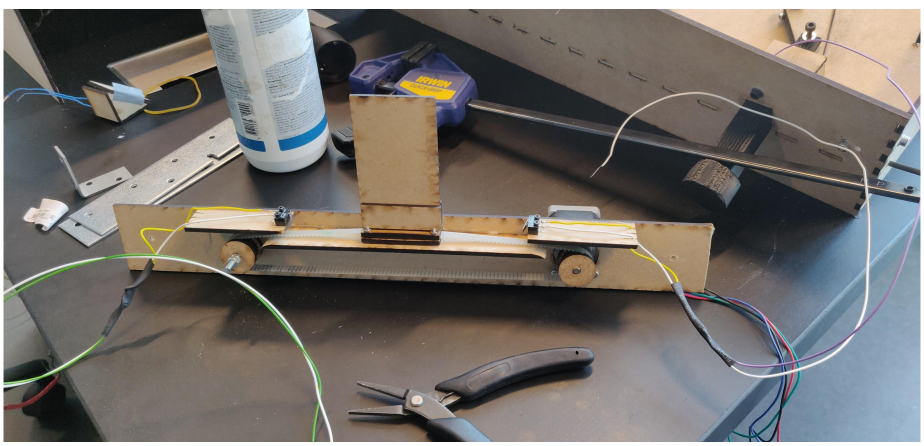


Figure 7: The moving wall

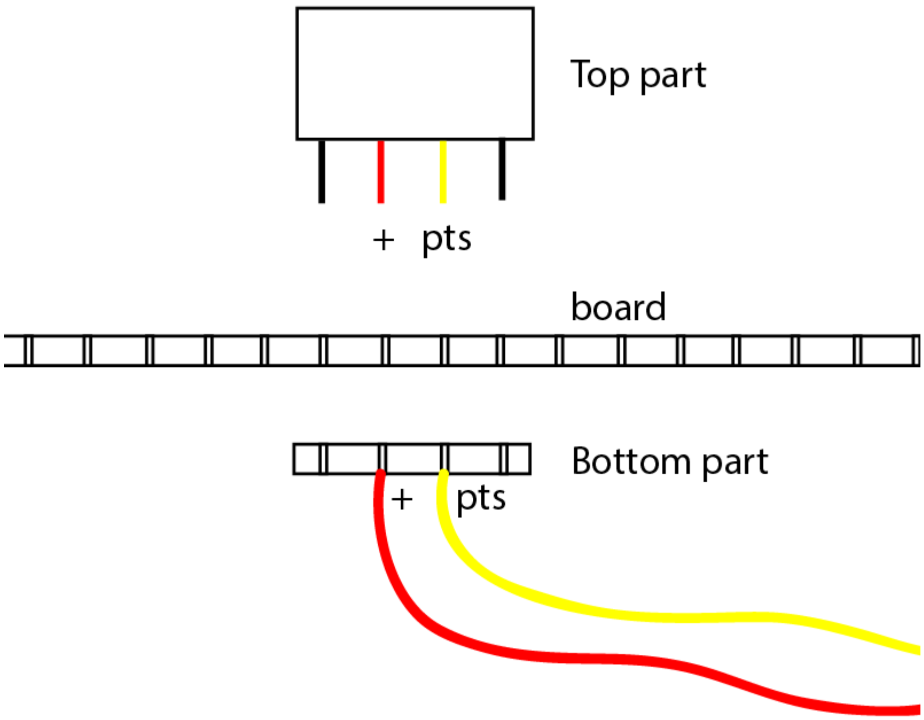


Figure 8: The idea behind Point-giving obstacles

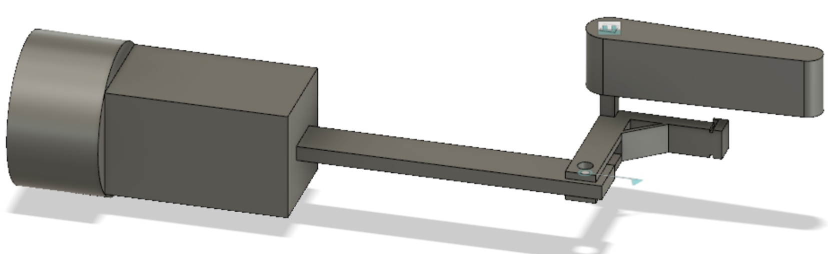


Figure 9: The initial flipper mechanism in Fusion360

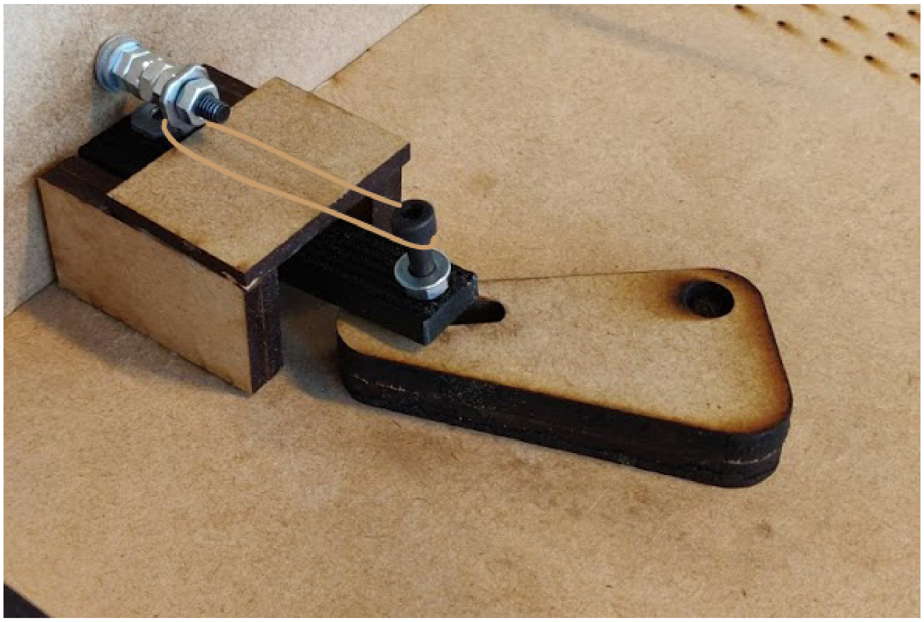


Figure 10: The flipper mechanism on the board

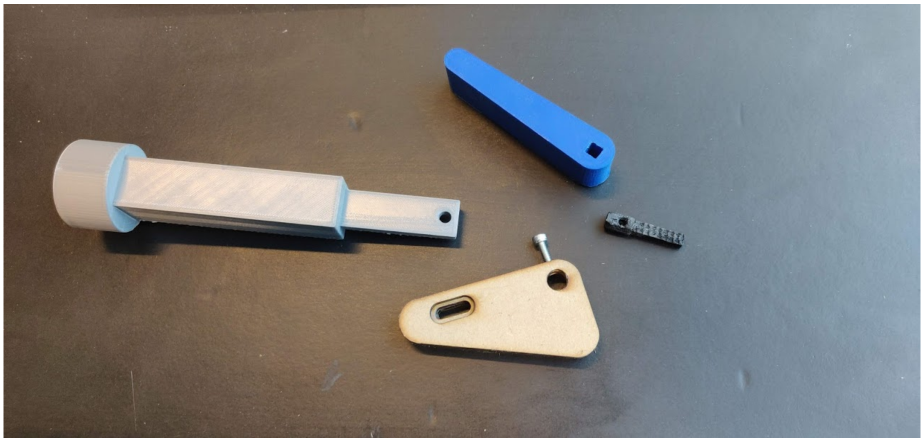


Figure 11: The flipper mechanism individual parts (without rubber band)

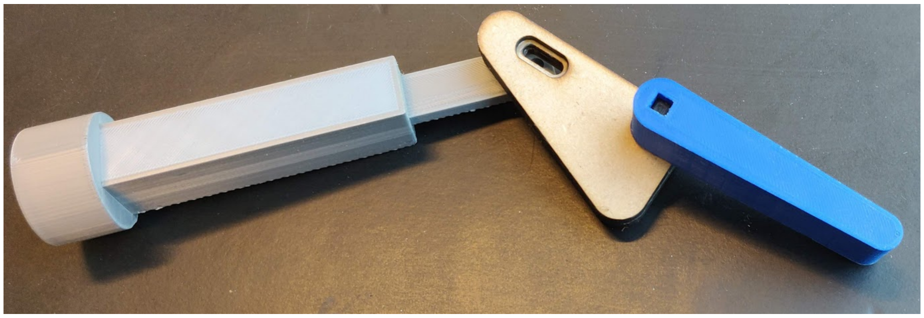


Figure 12: The flipper mechanism assembled

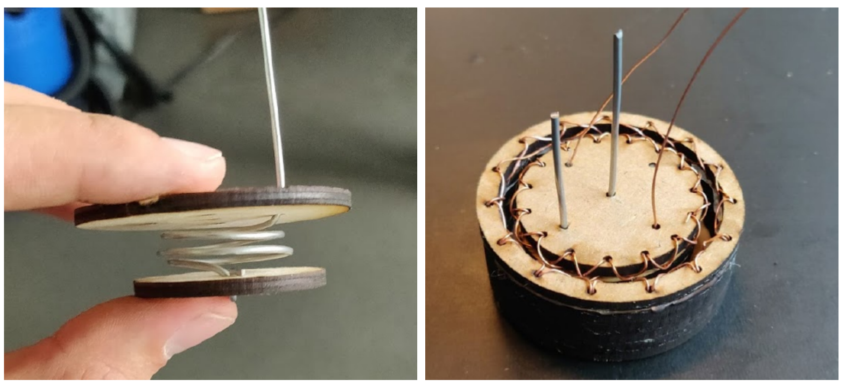


Figure 13: The idea for bonkers that did not make it into the game

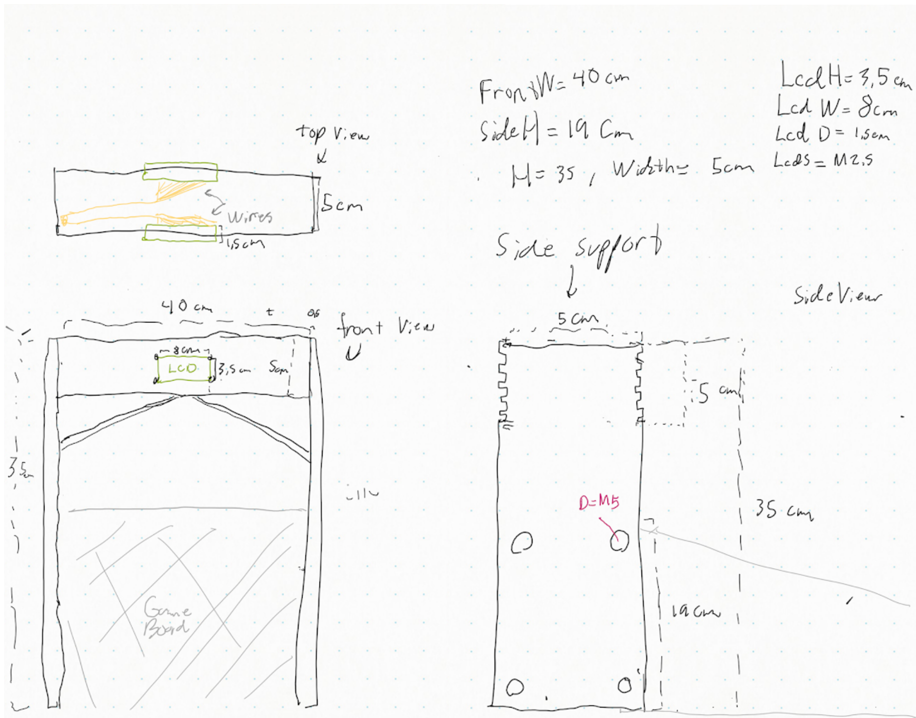


Figure 14: Sketches for the top display

Figure 15: An obstacle with wire inside it to place it on the field

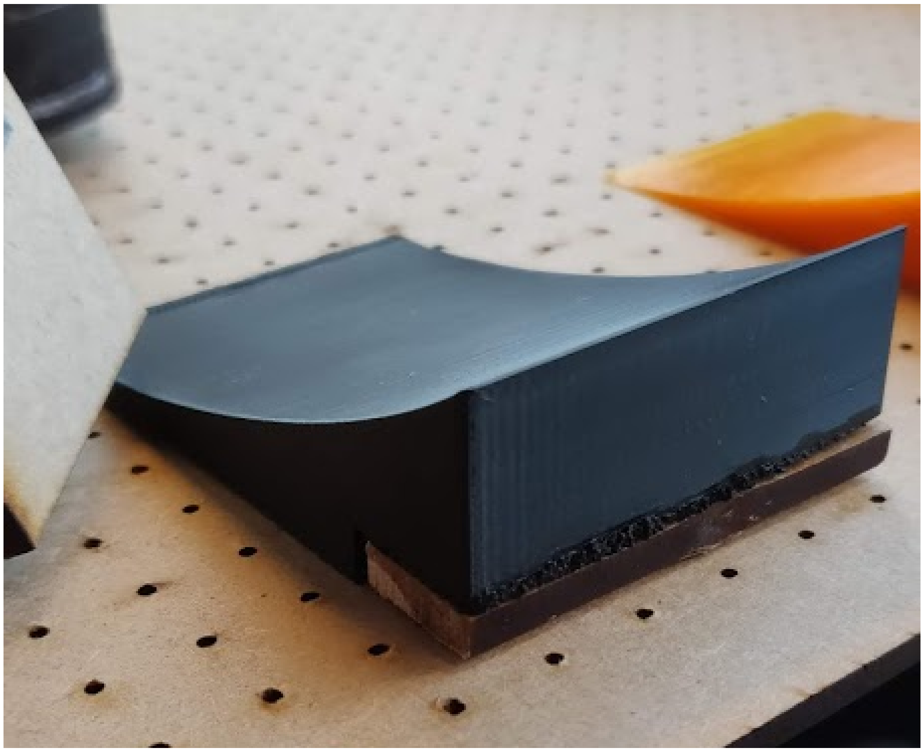


Figure 16: A ramp attached to the board

Figure 17: Linking the two displays together

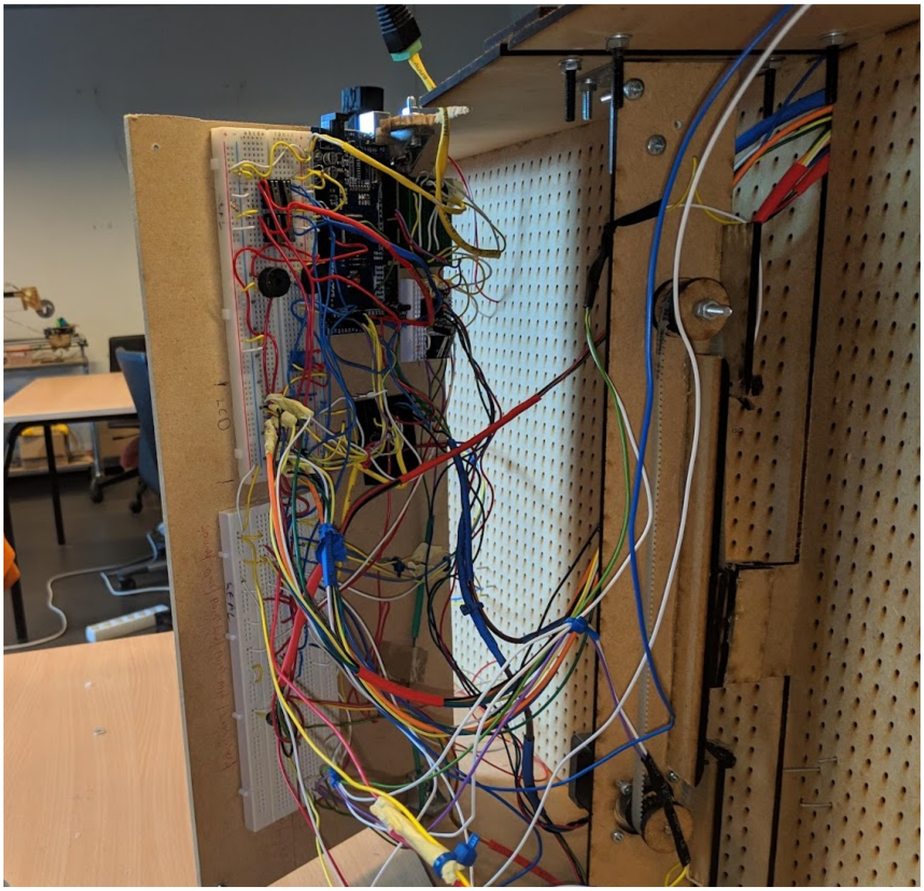


Figure 18: The wiring under the playfield

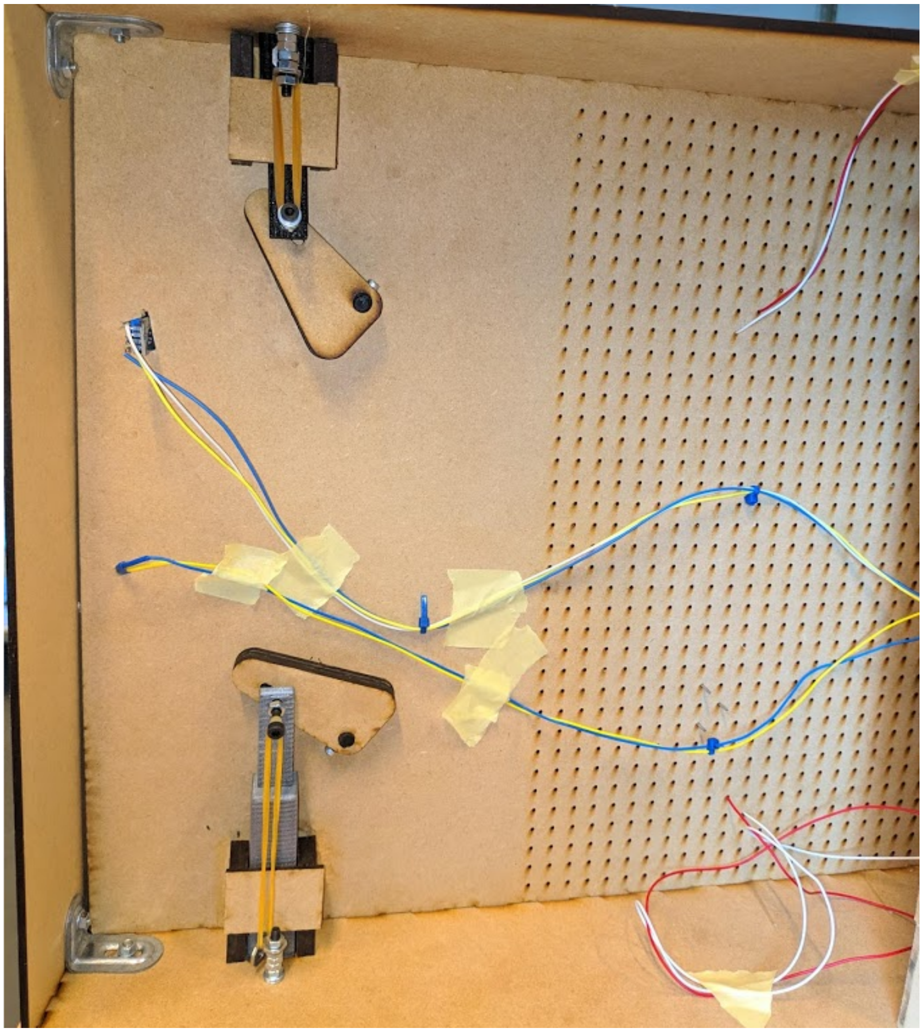


Figure 19: The flipper mechanism under the board

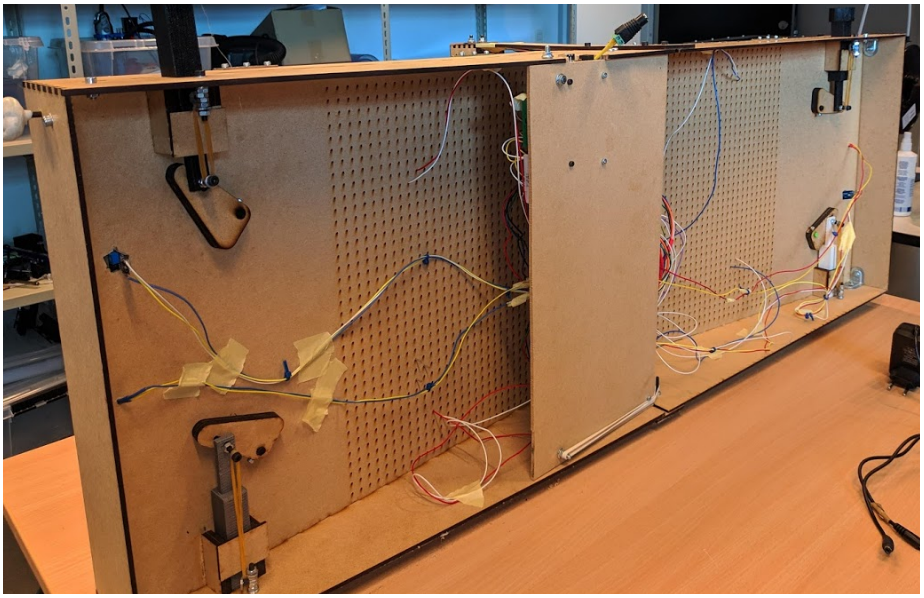


Figure 20: All the mechanisms and wiring under the board

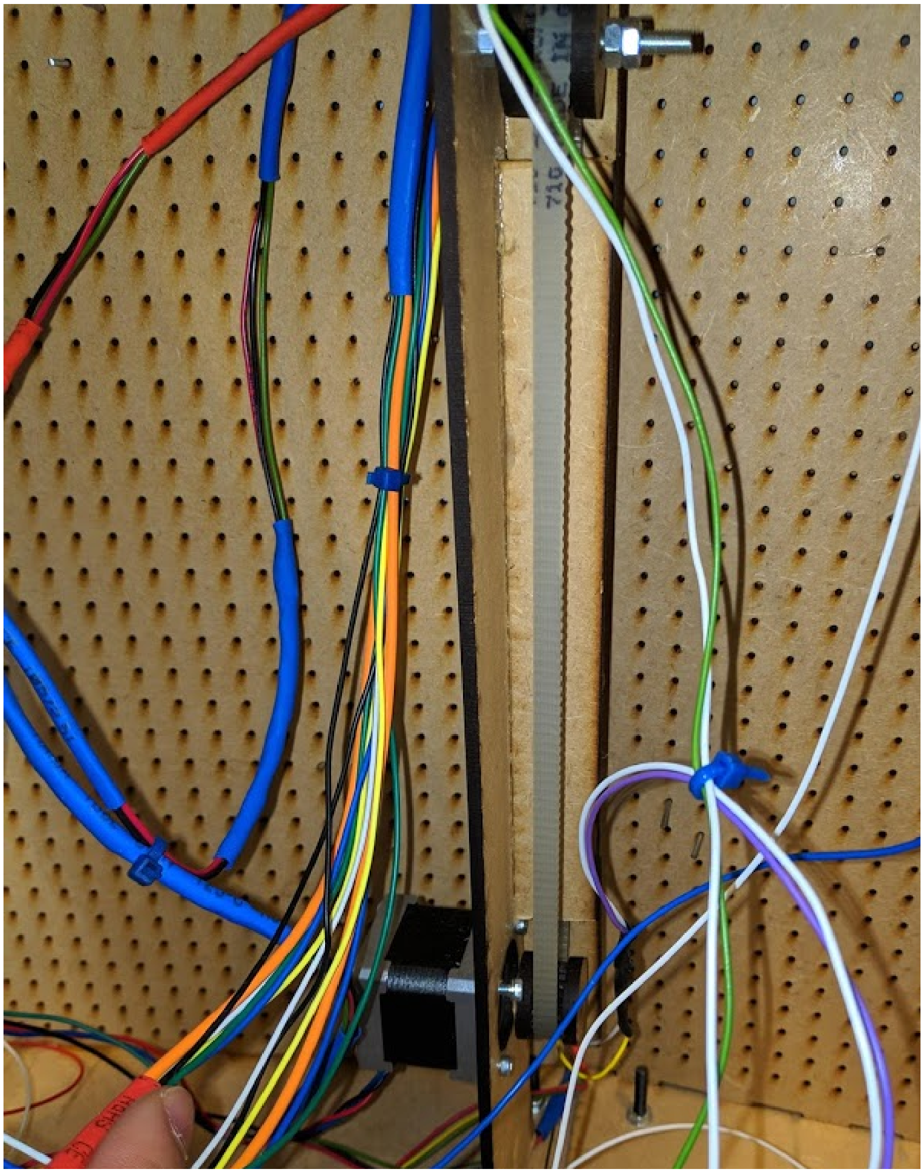


Figure 21: The steppermotor mechanism under the board for the moving wall

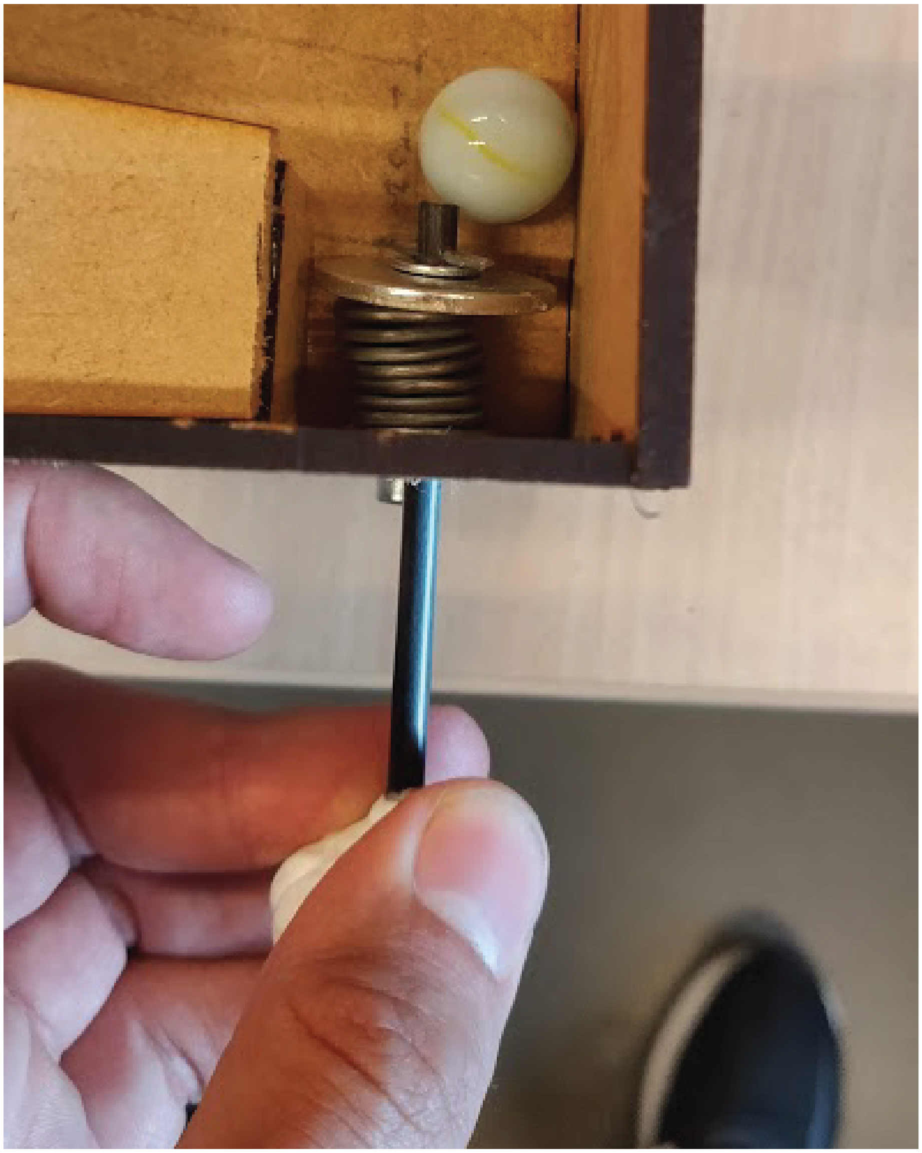


Figure 22: The firing mechanism

Figure 23: The spring created using the 1.4mm wire

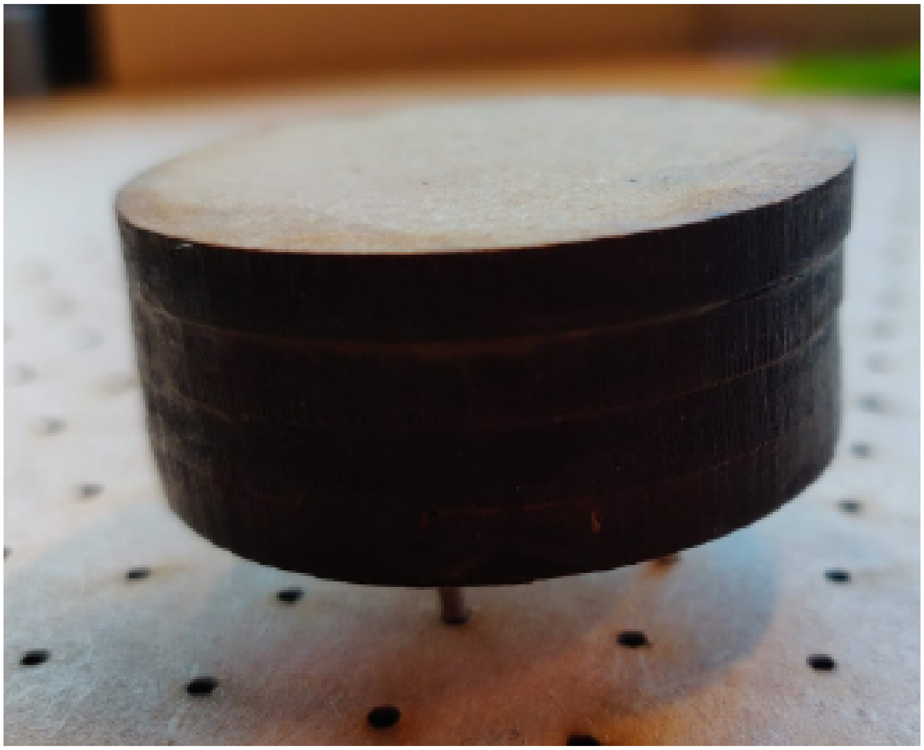


Figure 24: A static obstacle

Figure 25: A dynamic obstacle

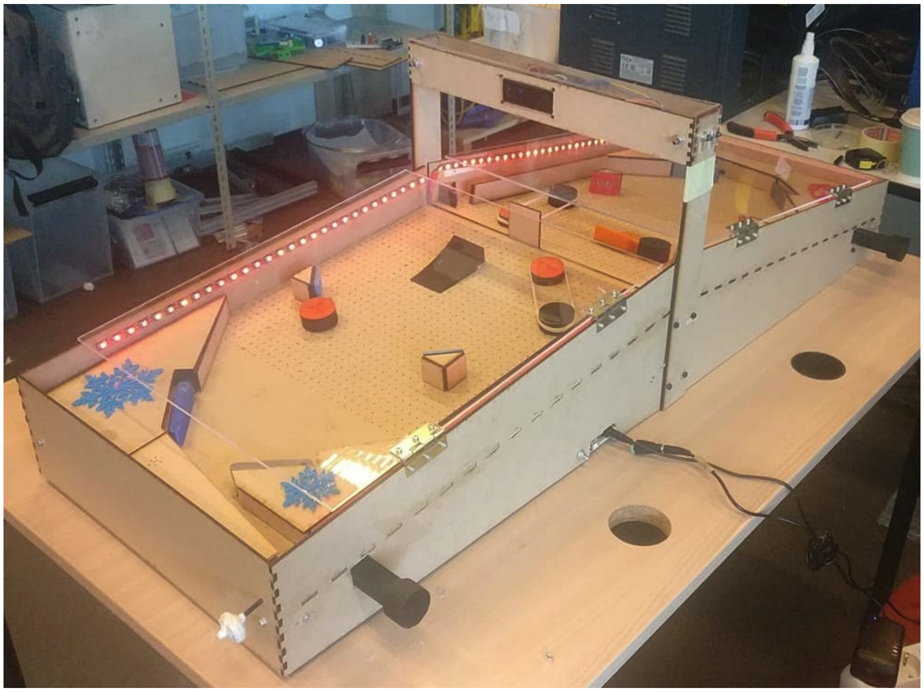


Figure 26: The final result