MEC-E1003

Teemu Laine 526254
Santeri Lähteenmäki 526597
Tuukka Lahenius 479767
Viljami Pirttimaa 480620
Juho Piilola 475088

Shuttlecock launcher

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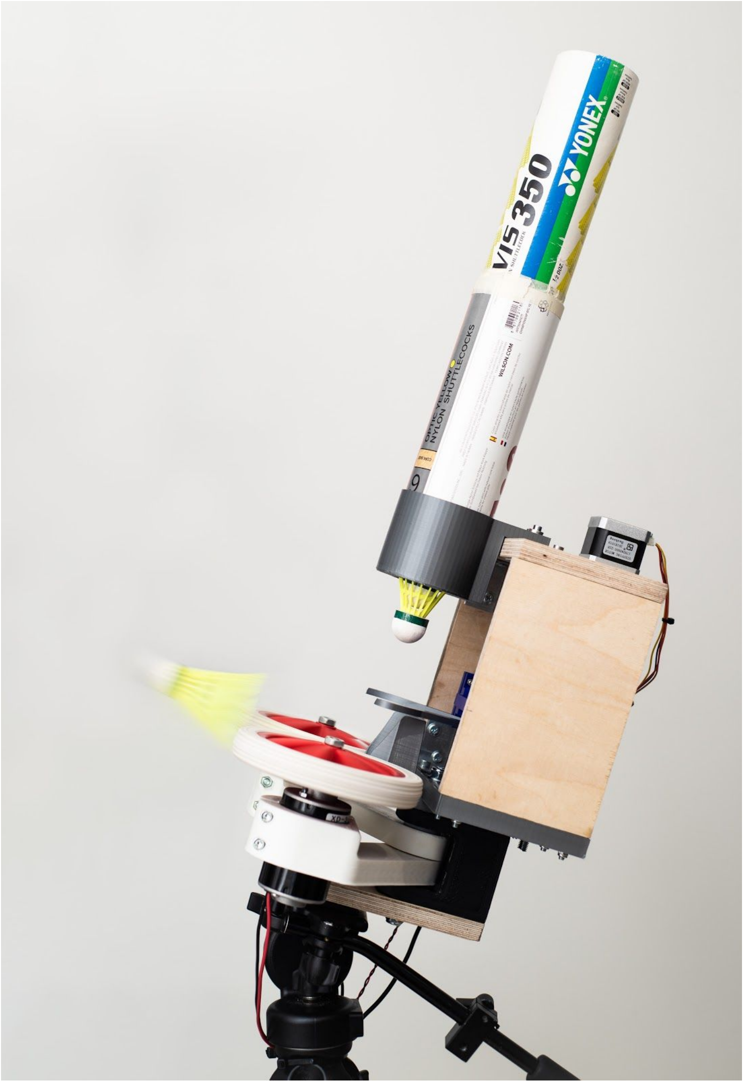
Introduction

The aim of the project was to build a mechanical machine that utilizes a minimum of 5 mechanical elements such as bearings, couplings and gears. The project topic was chosen to be a shuttlecock launching machine that is able to launch multiple shuttlecocks one after another. Shuttlecock machine was chosen since it was seen as an interesting topic by the group members and also the mechanical requirements would be easily exceeded. In addition to the mechanics, the machine included some electronics, but since these were not the main topic of the course, the electronics were made almost as simple as possible.

The machine was first modelled using Onshape, a browser based online CAD program. After the design was done the needed parts were ordered and the manufacturing of other parts started. The machine made use of many commercial parts, as well as parts made by hand and by additive manufacturing. The machine consisted of two modules, the shooter assembly and loading assembly which could be designed and assembled in parallel. After the assembly was finished some testing to adjust the spinning of the shooting wheels was made.

The machine has basically two functions, the loading of the shuttlecock and the shooting. The loading process grabs the shuttlecock from a shuttlecock tube inserted on top of the machine. After the shuttlecock is grabbed by the arms, the arms are moved downwards and the shuttlecock is dropped onto the slide. The slide guides the shuttlecock between the spinning wheels and the shuttlecock is shot through the wheels.

This report presents how the project was carried out. The designing process is described first after which manufacturing and assembly processes is discussed. The report ends in learning outcomes and thoughts of the project.

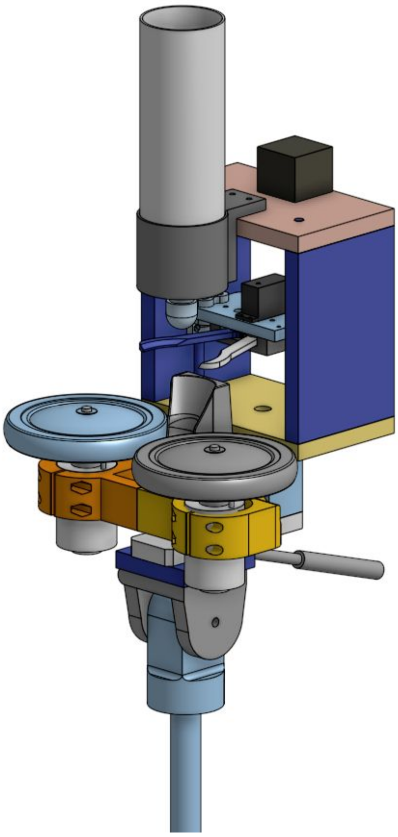


Designing process

CAD

Large part of the design process was the parametric 3D CAD model. We chose to use Onshape as our CAD environment. This made the modeling of the device by multiple people simultaneously possible.

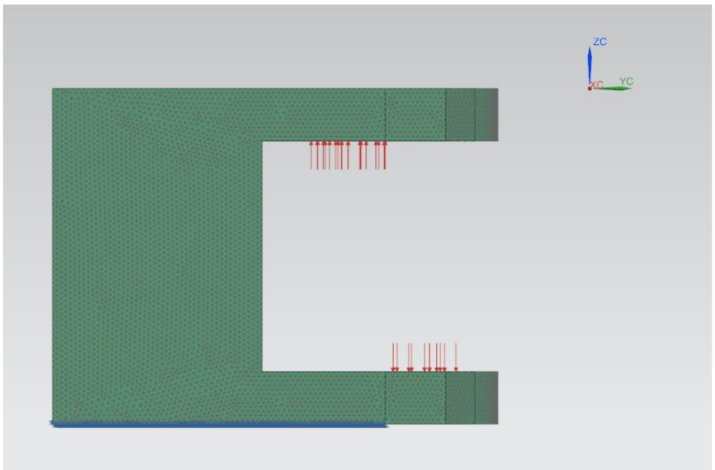
We chose to make the model parametric by utilizing global functions. This allowed us to make changes in the design without breaking the parts modeled earlier. For example the distance and thickness of the linear smooth rods were defined globally as well as the lead screw diameter.



FEM

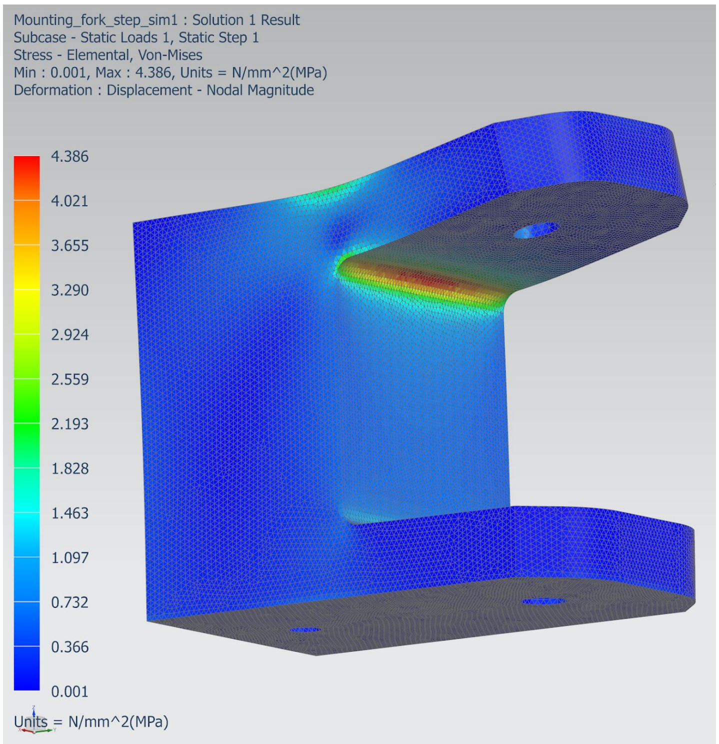
FEM analysis was done for the fork that supports the motor arms. The analysis was done with Siemens NX.

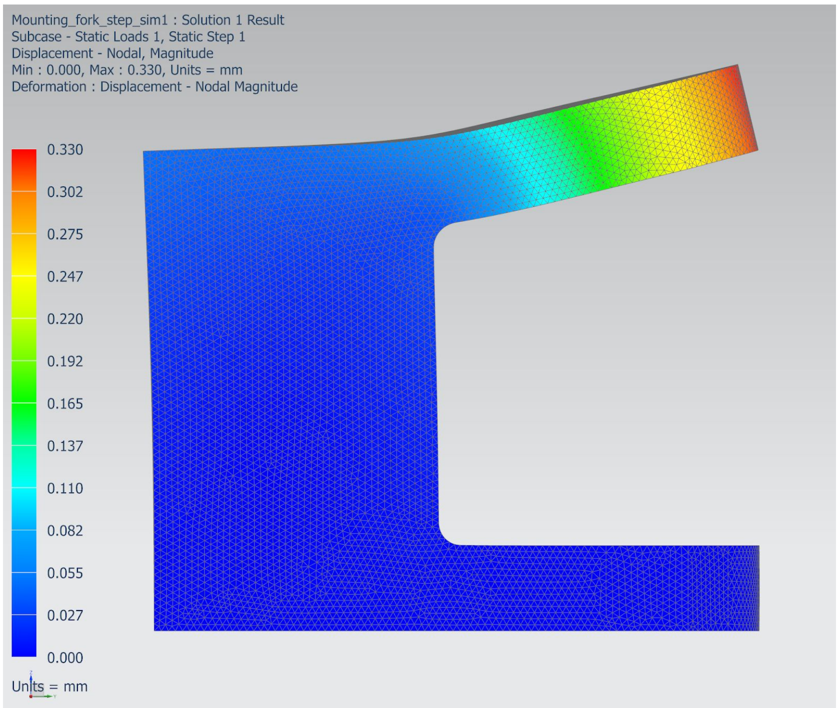
Bottom of the part was fixed. Forces simulating the torque produced by the hanging arms was applied to the fork as can be seen from the image below. The force was applied to half of the area of the M16 nylon washers that were used as a slide bushings.



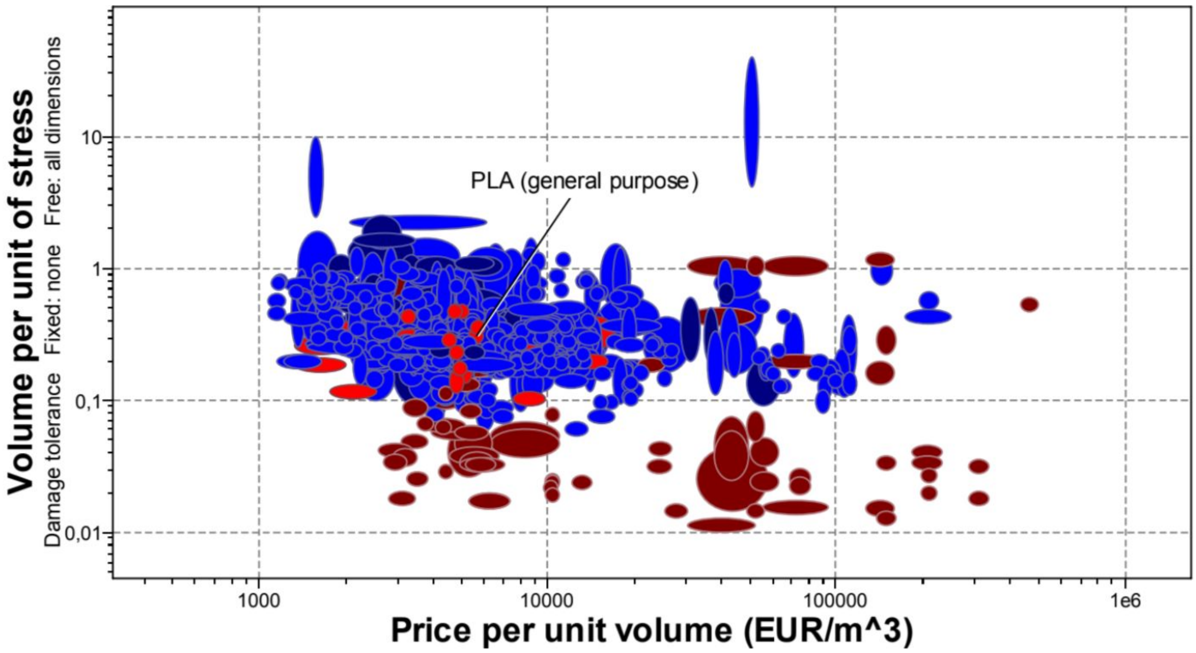
Based on the result the top and bottom parts of the forks were made 12 mm instead of 10 mm and a 3 mm radius was added to the inside corners to reduces stresses.

Stress and displacement of the optimized part. Based on the simulation the deflection is acceptable and the stresses are well below the yield strength of PLA plastic.





Material selection



Our first plan was to use PLA plastic in as many parts of the structure as possible. As can be seen from the chart from above, it's a great choice in both price and at handling stress. It is also commonly used in 3D printing, and it is readily available in our school's 3D printing facilities. Furthermore, our team member had his own 3D printer and the same PLA plastic for it as well. We knew from the start that we wanted to 3D print as many parts as possible and we modelled our device in such way that it would be possible.

In the end we had some trouble with the printers and the deadline of the project. This meant that a few parts that were supposed to be 3D printed ended up being made from plywood to finish the project on time. As the parts were just plates with some holes, 3D-printing them with plastic would not have been very beneficial anyway. Had we had more time we could have even used a laser cutter to manufacture all of the plates.

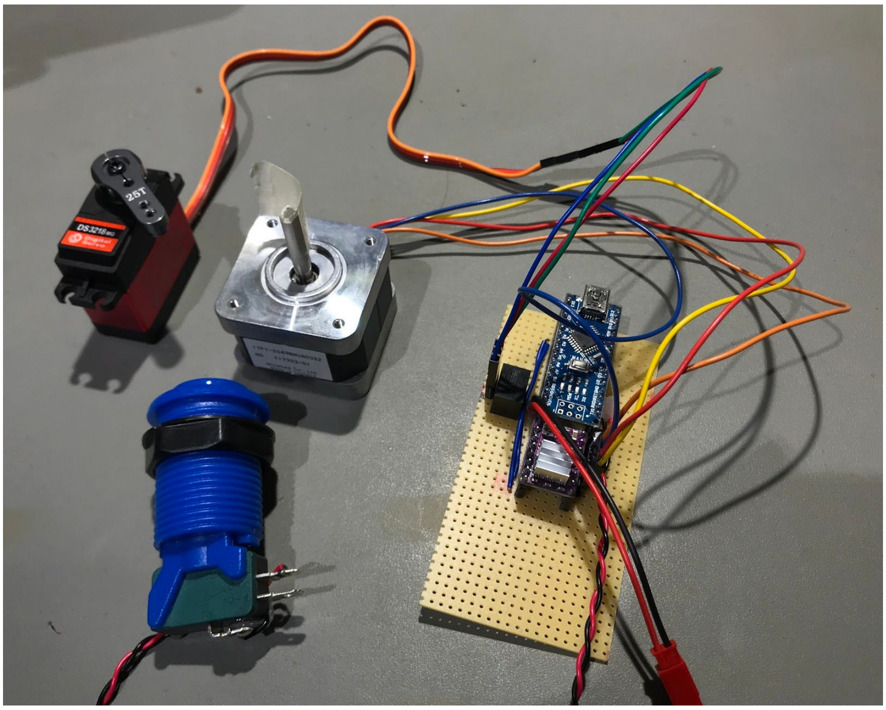
We selected plywood, because we had it available to us and plywood is easy to work with. Also, plywood is relatively cheap. In hindsight plywood ended up being a great choice because of its vibration dampening abilities. Higher than expected vibration of the spinning wheels was somewhat of an issue to us, because our construction was not big and sturdy enough to cancel the vibration on its own. This meant that we had to reduce our initial velocity to about half of the theoretical maximum. Utilizing plywood in the construction of the frame probably helped to dampen the vibrations a fair bit.

Electronics

Our design used 2 large 24 V DC motors, a hobby servo motor and a NEMA 17 stepper motor to automate the machine. The machine is triggered with a push button. Simple electronics was used to control the motors and detect the button press. For easy adjustability, a laboratory power supply was used for powering the drive wheels. The rest of the components were powered by a 12 V power supply that was regulated to 5V for the servo motor.

The stepper motor was controlled with a DRV8825 stepper driver. Arduino Nano controlled the stepper driver and the servo motor when it detected a button press. All of the components were soldered onto a prototyping board for better durability. The board was screwed onto the side of the machine. Hot glue was used for securing the connector so the connection stays solid even with high vibrations.

A limit switch would have been a good addition to make the homing of the stepper motor easier. As the electronics didn’t get much attention during the design phase, no mounting point for a limit switch was designed in CAD. To home the vertical axis on startup we decided to just drive the axis upwards and let it hit the top plate that prevents it from moving. As the system doesn't know when to stop it just keeps on going until the axis must have hit the top most position. The stepper motor starts to lose steps when the top position is reached which limits the torque generated by the motor to a low level that doesn’t damage the mechanism. This solution is not very elegant and sounds quite bad during startup but it works reliably.



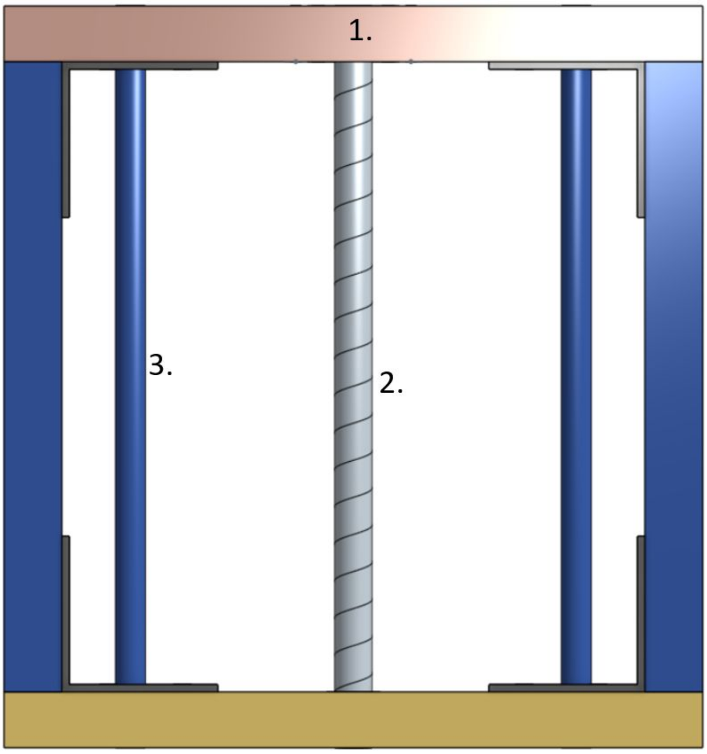
Manufacturing and Assembly

The launcher consists of two main features: gripping and launching mechanisms. These components were manufactured separately and eventually combined together with a camera tripod.

The gripping mechanism consists of the actual gripping claws powered by a hobby servo motor, the vertically moving base plate for the gripping claws, a stepper motor as well as the supporting structure for the mechanism. One gripping claw is driven by the servo motor and the other is connected to it via a gear wheel. The gear wheels were first designed as separate parts but in the end the gearing was designed directly on the claws. This reduced the part count and the added complexity of the parts didn't make manufacturing any more complicated due to 3D printing of these parts. Also the base plate for the servo motor was manufactured with a 3D printer along with the bearing clamps.

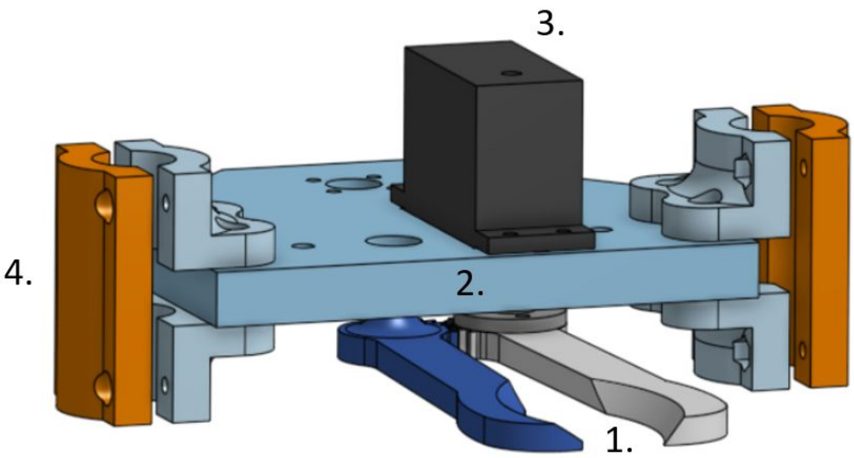
The supporting structure was manufactured using plywood except for the base plate of the structure that was 3D printed. The supporting structure was assembled using angle brackets to gain the needed stability and strength in use. The base plate of the gripping claws is powered by a stepper motor located on top of the supporting structure. The motor is connected to the gripper base plate with a lead screw allowing the gripper plate to move vertically in the structure. The gripper plate is anchored to the supporting structure with two smooth rods and linear bearings so that the vertical movement of the plate is as smooth as possible.

The tube containing the shuttlecocks is attached with a 3D printed holder on top of the supporting mechanism.



CAD front view of the supporting structure of the gripping mechanism.

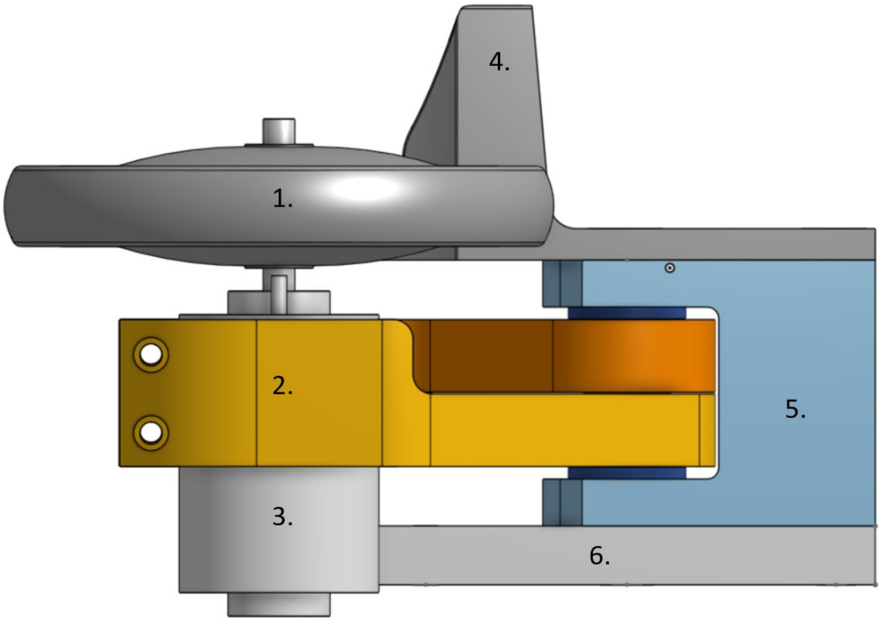
1. Supporting structure
2. Lead screw
3. Smooth rod



CAD picture of the gripping mechanism.

1. Gripping claws
2. Base plate
3. DC servo motor
4. Holders for the linear bearings

The launching mechanism consist of two launcher wheels powered by two DC motors, the structure holding the motors as well as the slide that guides the shuttlecock from the gripper mechanism to the gap between the launcher wheels. The arms for the motors are custom made with a 3D printer along with the fork connecting the holders together. Because the arms are moving in relation to each other a bit, a flat thrust needle bearing was attached in between the arms and the fork to gain minimal friction in the joint. There is also a spring attached in between the two arms so that they go back in their initial position after the launch. The fork is connected to the tripod via a plywood plate so that the place of attachment of the machine and the tripod can be adjusted. This means that the machine can be placed on the tripod close to its center of gravity to achieve the needed stability.

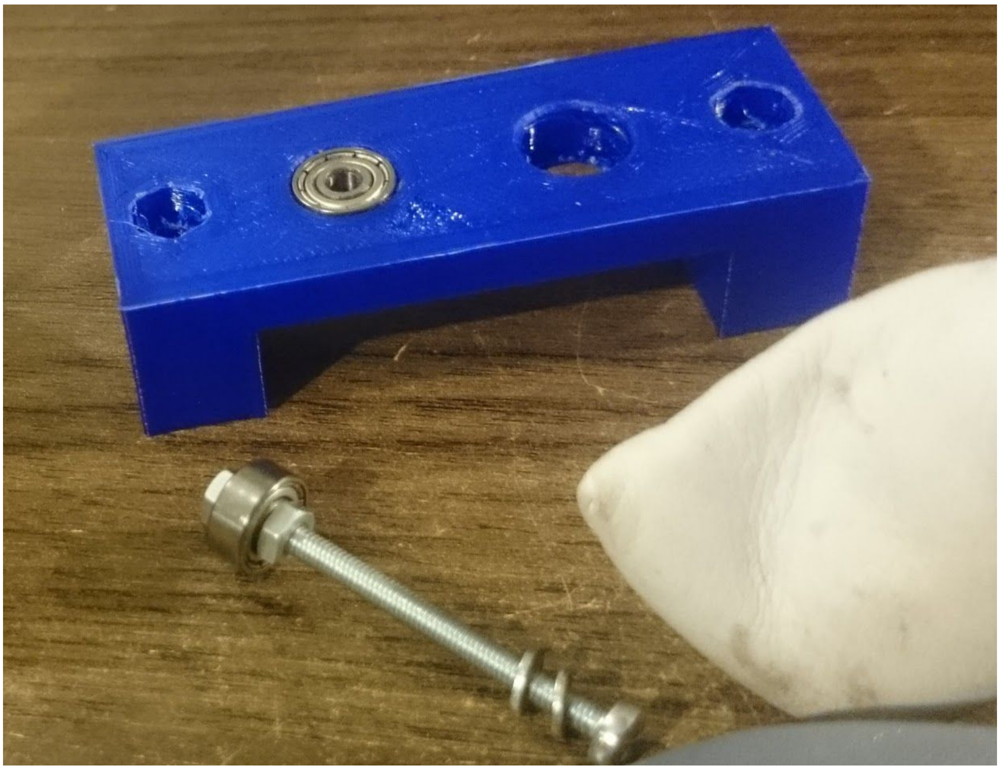


CAD side profile of the launching mechanism.

1. Launcher wheels
2. Arms
3. Motors
4. Slide
5. Fork
6. Base plate

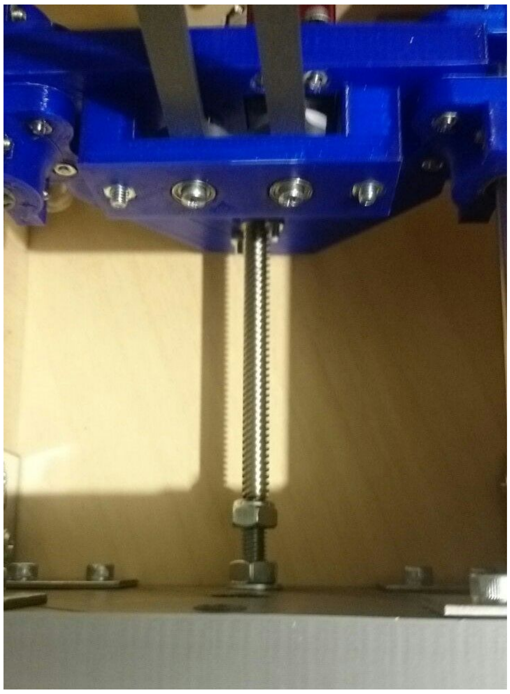
All manufactured parts were designed to be easily attached to each other using either screw or bolted joints. The holes for the joints were done in CAD for the 3D printed parts and drilled in other parts. Two bolted joints were used to eventually combine the gripper mechanism, the launching mechanism and the tripod together. Eventually, the prototyping board containing the electronic components was screwed onto the side of the supporting structure and the motors were connected to it.

One of the two launching mechanism wheels being milled to fit the modified shaft of the DC motor. After the machining the motors and wheels were connected with bolted joints using the original shafts of the motors. An M3 screw was used as a key that went through a hole motor' shaft and fit in the machined slot in the wheels.



Assembly of bearings on the top mount plate of the gripping mechanism. The bearing holes were made slightly undersized to achieve an interference fit. The idle gripping arm was fitted with bearings on both sides and the other one only from one side, since the servo motor end included own inbuilt bearing.

Learning outcomes and discussion



All in all the project taught us some general group working skills as well as project and time management skills. The project also thought us how effort in design saves effort in the actual manufacturing and building phase. Most of the things that gained good attention during the design phase worked as intended in the building phase. Even though the project was finished without any major flaws, some challenges were noticed during the building phase, which was not taken into account in the design. As mentioned earlier, we hadn’t thought about vibrations, but the use of plywood helped partly in the dampening. In addition to the vibrations two smaller design flaws were detected and fixed during the assembly.

First of the two mechanical design flaws were the hanging of the blue gripper surface, which was estimated to cause too high axial force on the aluminum coupler between the stepper motor shaft and the lead screw. The coupler is designed to transmit torque but axially it is basically just an aluminium spring that might break due to fatigue. To fix this, we built an adjustable support below the loose end of the lead screw by using three M8 nuts and ca. 70mm of M8 rod. The support is presented on the picture below. The rod provides axial support so that the coupler is not stressed. Grease was used to lubricate the screw and the supporting nut to reduce friction and wear.

Second design flaw was in the wheel spring mechanism, which was built to achieve a better and longer grip of the shuttlecock when the shuttlecock moves between the spinning wheels. As the mechanism worked well in the simulation we had not realized how nothing was keeping the wheels positioned to the centerline of the shuttlecock machine. We had to fix the lower motor arm to the supporting fork with a screw, so that only the upper arm was able to move within the reach of the spring. Otherwise the spinning wheels would had possibly touched the frame of the shooter machine which could have broken the machine.

In addition to these design flaws also a quality problem was faced with the spinning wheels (which in a way is also a design flaw). The wheels used were cheap plastic hobby wheels with some softer outer material which were obviously not designed to withstand such high speeds as was used in the machine. The imbalance of the wheels resulted in quite strong vibrations especially with certain speeds due to resonance. To reduce the vibrations the soft outer material was glued on the inner plastic wheel and this helped somewhat but didn’t remove the problem completely. It was also discovered that high spinning speeds resulted to air flow on top of the wheels. The air flow was powerful enough to push the shuttlecock away before it even touched the wheels. The grooving on the rims of the wheels possibly affected the air flow, and smaller flows could have been achieved with smooth wheels. Since the wheels played a key role in the function of the machine, turning the wheels with lathe would have been a better option in terms of quality.

The ethical issues was also somewhat considered in terms of safety of the machine. Since the wheels resonated quite strongly, the presentation on friday was only done with very low rotation speeds, so that the machine wouldn’t frighten people and cause any possible harm to anyone around it. We aimed the machine towards a wall so we could launch the shuttlecocks without disturbing other groups.

All in all the project worked out well and as discussed it served us many good lessons about machine design, the possible challenges and how to deal with them.

Appendix A: Poster

Shuttlecock launcher

The shuttlecock launcher is a mechanism designed for firing shuttlecocks at high speeds. It's main purpose is to strengthen the weaker areas of the player. If you want to rise to top of the badminton world, then this is the thing for you.

The launcher is mounted on a tripod so that the angle and direction of the launched shuttlecock can easily be adjusted according to the preferred training situation. The speed of the wheels is adjusted, so that the initial speed of the shuttlecock matches that of a professional player.

Gripping mechanism:
- Grabs the shuttlecock from the tube
- Feeds it to the slide
- The gripper moves up and down using a stepper motor with a ball screw attached
- The gripping claws are operated with a DC motor

Launching mechanism:
- The slide catches the shuttlecock and guides it between the two launcher wheels operated by two DC motors
- The size of the gap between the wheels is adjusted by a spring set between the motor holders

Tuukka Lahenius
Teemu Laine
Santeri Lähteenmäki
Juho Piilola
Viljami Pirttimaa

Appendix B: Arduino code

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

AccelStepper stepper(1, A0, A1); // step and dir pins of the DRV8825
Servo servo;
int home_pos = 0; // -2500 after homing
const int stepper_top_pos = 50;
const int stepper_low_pos = 2030;
const int servo_open_pos = 67;
const int servo_closed_pos = 87;
const byte buttonPin = 2; // Trigger button pin

void setup()
{
  pinMode(buttonPin, INPUT_PULLUP);
  stepper.setMaxSpeed(5000);
  stepper.setAcceleration(1200);
  servo.attach(5); // servo signal pin
  homing();
}

void loop()
{
  if (digitalRead(buttonPin) == HIGH) {
    drop();
  }
}

void homing() {
  servo.write(servo_open_pos);
  for (int i = 0; i < 2500; i++) {
    stepper.moveTo(home_pos);  // Set the position to move to
    stepper.run();  // Start moving the stepper
    home_pos--;
    delay(1);
  }
}

void drop() {
  servo.write(servo_open_pos);
  stepper.runToNewPosition(home_pos + stepper_top_pos);
  servo.write(servo_closed_pos);
  delay(20);
  stepper.runToNewPosition(home_pos + stepper_low_pos);
  servo.write(servo_open_pos);
  stepper.runToNewPosition(home_pos + stepper_top_pos);
  servo.write(servo_open_pos);
}
```