EduFarm - Color Sensing Tractor

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Abstract
This paper is based on a project given in the Physical Computing course on Aarhus University 2021, where the assignment was to create a educational toy from scratch using sensors and actuators. We present the concept of EduFarm, which is divided into three components; tractor, attachments, and tiles. We argue that EduFarm helps children improve their inductive logic and fine motor skills. Furthermore the paper will focus on the main electronics and the processes in making the prototype and finally we will finish with future work and discuss which aspects of the design can be added or improved.

Author Keywords
Physical Computing; Tractor; Interactive toy; Color-sensor; Farming; 3D Prints; PCB; MCU; ATmega, Arduino; Plough; Seeder; Harvester; Fertilizer.

Introduction
This report is a documentation of the design and making of our prototype we call EduFarm. EduFarm is a toy mainly targeted towards children in the concrete operational stage around 7-11 years old. It is an educational toy that makes it fun for kids to learn about agriculture and what type of machinery is used in certain stages of the farming cycle. We have made a tractor which is able to have four different attachments on, one for each stage of a field. The game is

about choosing the right attachment for the field to make the tractor starts driving, the user then has to turn or swap the tiles when the tractor has driven over them, to the next stage of the field. The tractor then has to go over the field again with a new attachment to make it transform into a new stage. This is done four times and then the user is back to the beginning and can start over. We will explain more about the toy and the workings of it in the next sections.

Link for the demo of the prototype:
https://www.youtube.com/watch?v=aZiEggrXGDE

Link to the code of the prototype:
https://gitlab.au.dk/au665243/edufarm-tractor-project/-/tree/main/

Related work

The main idea for our project is inspired from the classic tractor and farming toys we played with as kids. We wanted to make something visual and interactive when playing with a tractor instead of imagining everything in the head. Thus we created the attachments and the tiles to add more complexity and a feeling of progression when playing with the tractor. This way we learn the children the step by step sequence of farming and how it is supposed to reflect in the real world. As mentioned the children are 7-11 years old at the concrete operational stage, which is just the age where they use inductive logic[1]. An example is how the users learn the constraints when manipulating with the different components and how they gradually understand what requirements are needed to make sure the tractor drives. Not only do we want the children to manipulate the objects, but with our system it also encourages problem solving and trying out new combinations of actions. The agricultural approach of our design is helping children inductive learning which are essential especially within STEM fields.

We argue that EduFarm covers both locomotor play and object play[2]. Locomotor play is applied as the kids are free to use the tractor how they like, just like an ordinary tractor toy, focusing on exercise play and motor skills. They are not bound to use the different tiles and attachments, these things are just extras to play with and therefore the tractor in itself is already a fine vehicle toy for even toddlers. Although with all components combined, the main feature is about building your own field, knowing what kind of attachment is on and making the tractor drive.

Following the basic idea of farming, we took inspiration from the video game series Farming Simulator[3] where the user can take on the role of a modern farmer. Similar to our concept it focuses heavily on the process of farming trying to be as realistic as possible. With the game in mind we tried to simplify it into the physical world with the same features that defines the core gameplay. We ended up reducing it all down to four farming actions; plough, seed, fertilize, harvest. Finally it is worth noticing that Farming Simulator is also a great source to look at when we want to find new possible ideas for further developing our prototype.

Figure 1: Full view of the EduFarm tractor prototype with fertilizer attachment and orange stubble field

Prototype design

The prototype is called EduFarm. The prototype design (see figure 1) illustrates a tractor driving through fields with an attachment at the back. The intent of the prototype is to give a simple visible representation of the farming cycle (see figure 2).

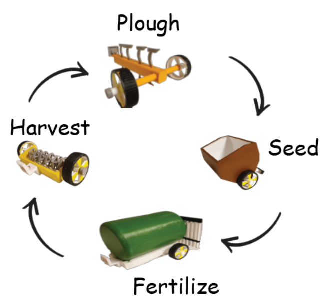

Figure 2: Farming Cycle

To play the game (see figure 3) the user first creates a field containing one color of tiles, this will be the starting of the farming cycles. Each tile has one color on each side, one type is orange and brown the other is green and yellow. These tiles represent the different states of the farming cycle, orange represent a stubble field, brown a plow field, green a sown field and yellow a fertilized field ready for harvest. The user places the tractor on top of the first tile of the field, the tractor starts reading the color. To make the tractor drive the user needs to connect the attachment that matches the state of the field(see figure 4), if the field is brown it means it has already been plowed. The next logical step would be to seed the field, so the brown seeder would be the correct choice of attachment on the brown tile to make it green. This gives feedback with LEDs at the back of the tractor, if the tile and attachment matches, the green LED will light up, the buzzer will give a positive beep and the tractor starts driving. However if the tile and attachment does not match the red LED will light up, a negative beep will sound and the tractor stands still. Having buzzer and LED we use the benefits of multi sensory learning through auditory and visual feedback[4]. While driving, the tractor reads the color of the tiles and gives feedback with LEDs on the top of the tractor on what tile to place next, this once again follows the farming cycle. When the tractor and attachment has passed a tile the user turns or swaps the tile to make it match the LED on top of the tractor to make the field reach the next state in the farming cycle.

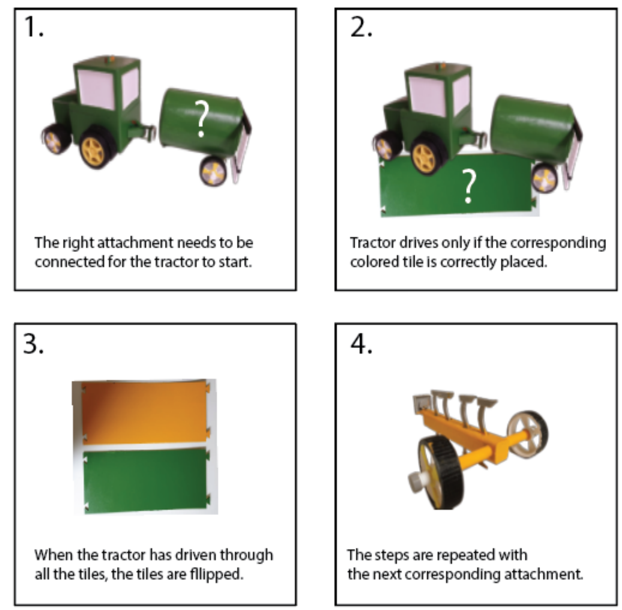

Figure 3: User manual

We have designed and 3D-printed the tractor and all the attachments ourselves. We used Fusion 360 to design the 3D-models to make them look as close to real life models as possible (see appendix C for all the 3D renderings). We then used a 3D-printer (Prusa mini) which was given to us by the university to print the models. When printing we had to split up the attachments and tractor as they were to big to print in one piece and to get the best possible result. We printed everything in PETG because we wanted to make it sturdy so it would not break if a kid were to play with it. We used sandpaper on the tractor to give it a more smooth feel and less rough edges. We used mostly white filament for the 3D-models because we wanted to paint everything and a white canvas makes it easier to paint. To get the paint to stick we sprayed the attachments and tractor with primer three times to give it a layer where the paint is able to stay to give it a better finishing look.

The attachments connect to the tractor by magnets. The magnets are quite strong and gives the user a satisfying snap when connecting. A byproduct we did not think of before installing the magnets was that the attachments can not attach to each other only the tractor because the attachments has the same poles of their magnet pointing out. The magnet holding the tractor and attachment together also does so the resistor from the attachment touches the wires on the tractor. This makes the tractor able to recognize what attachment the user has put on and if its matches the field, the tractor starts going.

We made the tiles from 3mm MDF wood, because its cheap and easy to cut through with a laser cutter. An unexpected disadvantage with the 3mm wood was it was easy to bend, which meant some of the tiles were arced and therefore hard to put together with the rest of the tiles. Especially after they were painted on only one of its sides did they get a big arc, but straightened out a bit when paint was applied to the other side. The paint also resulted in an extra layer so that the tolerance when connecting the tiles were too tight.

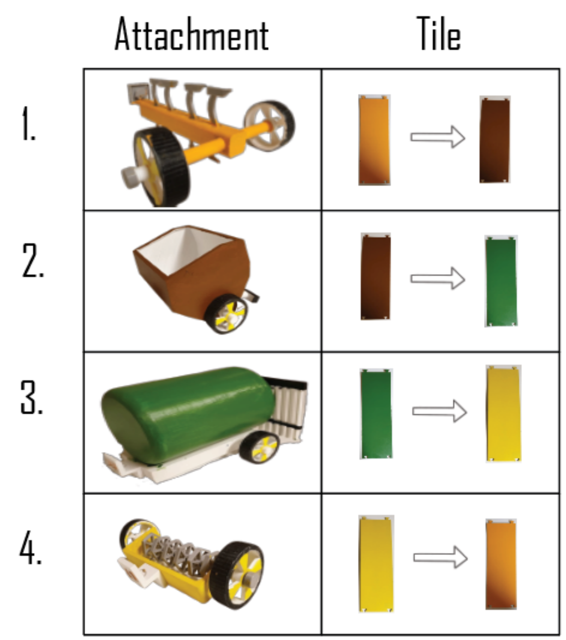

Figure 4: Overview of attachments and tiles

Main components

This sections is a description of components used for the prototype. It will include each components specification, power consumption and how it works within the system.

ATmega328P

We use two micro controller units which talks to each other through the I2C protocol. It draws 20mA and is operating from 2.7V to 5.5V. The ATmega328P has a maximum operating voltage of 6.0V and a maximum current draw per I/O pin of 40.0mA [5] The I2C protocol uses a two wire communication, analog pin 4 (pin 27 on the ATmega) and analog pin 5 (pin 28 on the ATmega). By doing this we are able to make the slave ATmega send values to the master ATmega. The slave is getting all the input from our system, it reads the resistor value for what attachment is on the tractor and reads what color tile the tractor is driving over. The input data gets send to the master which then lights up the corresponding LED's and makes the right buzz according to what data it receives.

Oscillator setup

The ATmega setup is using a Oscillator setup each containing two 22 picofarad ceramic capacitors, one 16 MHz crystal and one 10k resistor. This setup is used to help the ATmega calculate and keep track of time.

Reset button

A reset button is used in both circuits to make it possible to reset each circuit as unexpected errors can occur. This buttons are installed on the PCBs but could with benefit be installed at the button of the tractor to easily reset it without opening the prototype.

DC Motor with motor driver L293D

Two 3-6v DC motors are used to spin the wheels on the tractor. Each of these has a draw around 155mA [6] and operate at a voltage between 3V and 6V. The motor driver L293D is a quadruple high-current half-H driver. It can be used to drive bidirectional currents up to 1A when it operates at a voltage between 4.5V and 36V. It can drive inductive loads for DC motors and is used in the prototype to handle the use of two DC motors which drives the tractor forward, left and right. It draws around 24mA.[7]

Capacitor

Two 100µF 50V decoupling capacitors [12] are used in the motor circuit to make the motors more stable by reducing noise in the circuit.

Color Sensor GY-31 TCS3200

A GY-21 TCS 3200 color sensor is used in the prototype to read the RGB values of the field underneath the tractor. This is done by emitting light from a transmitter and then it detects the light reflected back from the block underneath with a color receiver. The LEDs turn on depending on what value the sensor reads. It operates at a voltage between 2.7V and 5.5V. The draw is around 25mA.[8]

Attachment resistors

In each attachment for the tractor is a resistor from which the slave ATmega are able to read values when connection is made. We use one resistor for each attachment all with different values. The different resistors are 5ohm, 380ohm, 1.000ohm and 10.000ohm. The readings are done by analog reading the voltage difference between the known resistor (1000ohm) and the unknown attachment resistor. We calculate how much the unknown resistor is by dividing the analog read with the volt input which is 3.96V and then times it by 1000 because off our known resistor, so the calculation looks like this: analogRead(A3)/3.96V*1000.

Buzzer
Inside the tractor is a LTE12 active buzzer that either buzzes with a successful or unsuccessful sound depending on the attachment connected to the tractor. The active buzzer has a current draw of 30mA[11] at a voltage between 2-5V, the active buzzer is connected through a 220ohm resistor to reduce the sound to an appropriate level.

LED Feedback System
As seen in Appendix D 26, the prototype uses six LEDs, two green 5mm LED, one yellow 5mm LED, one red 5mm LED, and two white 5mm LED which are painted orange and brown as RGB cannot show these. The draw is around 20mA [9] for each of these at maximum voltage, so around 120mA in total for the LED system. Four LEDs, brown, green, yellow and orange are used as a feedback system at the top of the tractor for the user to know which tile they have to place next on the field. E.g. If the tiles on the field is brown the green LED should light up and the brown tile should be replaced with a green tile once the tractor has passed, as the next state of a field when seeded is that it turns green. Two LEDs, green and red are used at the back of the tractor as another feedback system to know if the user has connected the correct attachment to the tractor, when the tractor stands on a tile it reads the color and each color has a associated attachment. If the tile is green which means that it has been seeded, then the next logical step should be to fertilize the soil, this is done by attaching the green fertilizer which makes the green LED light up and the tractor starts driving. If the wrong attachment were connected, the red LED would light up and the tractor would not move.

Battery
The prototype is using two 3.7 volt 1800mAh rechargeable batteries[10]. One to power the logic circuit through the slave PCB to the master PCB. This battery is connected to a step-up unit to increase the voltage from 3.7V to 3.96V so the volt from the battery to the color sensor is equal to the measured volt on the Arduino Uno's 3.3V pin to make the interval of the color sensor equal to what has been calibrated when reading sensor values through the Arduino. The second battery powers the DC-motor driver and the two DC-motors and is also connected to a step-up unit to increase the voltage from 3.7V to 6V.

This means the batteries has a lower capacity than their normal capacity of 1800mAh each[10]. The change in mAh for the battery powering the logic circuit is calculated by dividing 3.7V by 3.96V which equals 0.93. The battery capacity of 1800mAh is then multiplied by 0.93 which equals 1674mAh. Since step units are never 100 percent efficient, we calculate 20 percent off the mAh to make it more accurate, 1674mAh multiplied by 0.80 equals 1339mAh. Finally calculating the battery time, battery capacity(Amphours) of 1339mAh divided by max current draw(Amps) 215mA for the logic circuit including six LED's, one color sensor, two ATmega's and one active buzzer which equals a battery life of 6.2 hours. The same calculation is made for the motor circuit including two DC-motors and one motor driver. 3.7V divided by 6V equals 0.62, 1800mAh multiplied by 0.62 equals 1116mAh, 1116mAh multiplied by 0.80 equals 893mAh. Finally calculating the battery time by dividing the battery capacity of 893mAh with the max current draw of 334mA for the motor circuit which equals a battery life of 2.7 hours.

Schematics

The schematic seen in appendix A 5 covers the whole circuit. It is color coded to easily get an overview of the different components.

In the black square is the ATmegas(slave to the left, master to the right) which draws power from 3.7 volt battery (the leftmost red square). Before the ATmegas get the power from the battery it is connected to a step-up unit (the dark red square, right of the battery) because the power to the color sensor needs to be equal to the of the Ardunio Uno to calibrate the color sensor correctly.

The other battery (top left red square) is also connected to a step-up unit (dark red square right of the battery) as it needs to give 6 volts to the DC-motor driver (dark blue square) to make the wheel drive at adequate speed. The DC-motor driver is the one that distributes the power to the two DC-motors (light blue square). The DC-motors are the ones that make the tractor wheels spin and thereby making the tractor move.

The six LEDs (purple squares) are connected to the ATmega with a 220 ohm resistor in between each of them.
The color sensor (green square) is connected to the slave ATmega where it sends the color codes of the tiles the tractor is over, to the master ATmega.
If the color values is in between the right interval one of the four LEDs (bottom right purple square) will light up.
If an attachment (resistors representing each attachment lime square), is connected to the tractor through the attachment tow bar(yellow square), then one of the two LEDs (purple square) light up and the buzzer(pink square) will give a sound of successful or unsuccessful depending on the match of the attachment and the color of the tile.

Limitations & future work

In this section we will talk about what we could change to make the prototype better and what we would like to work more with in the future.

Color sensor

The GY-31 TCS3200 color sensor has had its limitations for the project as the sensor values has a very tight interval when measuring the four different colors of the tiles. This meant that we were only able to use two different colors at the same time e.g. green and yellow to make sure the sensor read correctly.
The setup did also make it impossible to read the sensor values when powered by batteries. The sensor values varies drastically when powered with different voltage so the voltage from the Arduino Uno and the battery needed to be identical.

Another obstacle were the impact of light, light or shadows meant the sensor fluctuated in values and made the calibration of the tractor very inaccurate when used in different locations. That is why we tried to make a box for the color sensor to make it darker so the light would not interfere as much with it(see appendix C 15). It helped a bit which is why we used it in the final prototype, but not enough for us to be able to have good readings on all four colors.

To make this prototype more complete we would have to get a sensor which is more stable than the GY-31 TCS3200 color sensor or have to work out a new way to read what tiles the tractor is driving over. If we still wanted to use a color sensor we would have to get the sensor only millimeters away from the tiles and it would have to be completely dark around it.

Turn tiles
For future work we would like to make turn tiles for the kids to be able to make a more put together field, where the tractor are able to turn by itself. This could be done by having a color that tells the tractor to drive left and a color that tells the tractor to drive right. The software is already developed for this but needs calibration together with a set of turn tiles made of MDF to connect with the original tiles.

Insides of the tractor
In the future we would like to add an on/off button to make it easier for the user to turn the tractor on and off. At the moment the tractor is turned on by inserting the batteries to the correct cables, this is not user friendly. Furthermore the tractor could have a hole for a BMS(battery management system) to make the recharge of the batteries easier so the batteries never had to be taken out for recharge. Better cable management and attachment of the PCBs is also high priority to make sure wires and components does not get unplugged when opening the tractor.

Harvester
Another adaptation of the game could be to add a harvester as the concept of the harvester attachment does not convert into real life. This would make the game more realistic and with further adaptation of the tractor these two machines could drive the field simultaneously to harvest and fill the loading platform on the tractor to show how a real harvest works.

Conclusion
Our EduFarm prototype has not yet been user tested, which makes it hard to judge if the toy fulfills its purpose of being a fun and interactive way of learning the agricultural aspects of STEM. Through playing the EduFarm game the user should become more aware of the farming cycle, what field to use which attachments on with the visual and auditory feedback guiding the user through the cycle with limited chance of failure. Adding the agricultural aspect, we aim to improve children's inductive logic and fine motor skills through locomotor play and object play. The prototype has not reached its end goal because of various limitations such as an inaccurate color sensor which makes the game unable to be played to its fullest potential.

Division of labour
Idea generation and all early development such as the first low-fidelity[13] prototypes were made by all group members. All group members contributed to the created code for the prototype. The more physical aspects of the prototype were split between us. Henning made the tractor 3D print and two attachments, Dennis made two attachments while helping Patrick who had main focus on schematics and PCBs. All members were involved in the post processing of the 3D prints while Dennis laser cut and painted the tiles. Patrick calibrated the color sensor while everyone helped put the prototype together.

REFERENCES

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[2] Gelman, D. L. (2014). Design for kids: Digital products for playing and learning. Rosenfeld Media.

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[5] ATmega328p data sheet https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf

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[7] L293x Quadruple Half-H Drivers data sheet https://www.ti.com/document-viewer/L293/datasheet/

[8] Color Sensor data sheet https://www.openimpulse.com/blog/wp-content/uploads/wpsc/downloadables/TCS3200-Datasheet.pdf

[9] LED lights data sheets
Red: http://www.farnell.com/datasheets/1498852.pdf
Green:
http://descargas.cetronic.es/WW05A3SGQ4-N.pdf
Yellow:
http://descargas.cetronic.es/WW05C3AYP4-N2.pdf
White: http://craftofelectronics.org/downloads/bright-white-led-datasheet.pdf

[10] LiPo Battery 3.7V 1800mAh data sheet https://www.li-polymer-battery.com/wp-content/uploads/2021/03/LP103450-3.7V-1800mAh-Datasheet.pdf

[11] Active buzzer data sheet http://www.electronicoscaldas.com/datasheet/LTE12-Series.pdf

[12] Capacitor 100µf 50V data sheet https://www.electron.com/media/15283/datasheet-123-759.PDF?&key=ZGpmIyQwNUZfMTUyODM=

[13] Marion Buchenau and Jane Fulton Suri. 2000. Experience prototyping. Proceedings of the Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques, DIS, 424–433.

Appendix A - Schematics

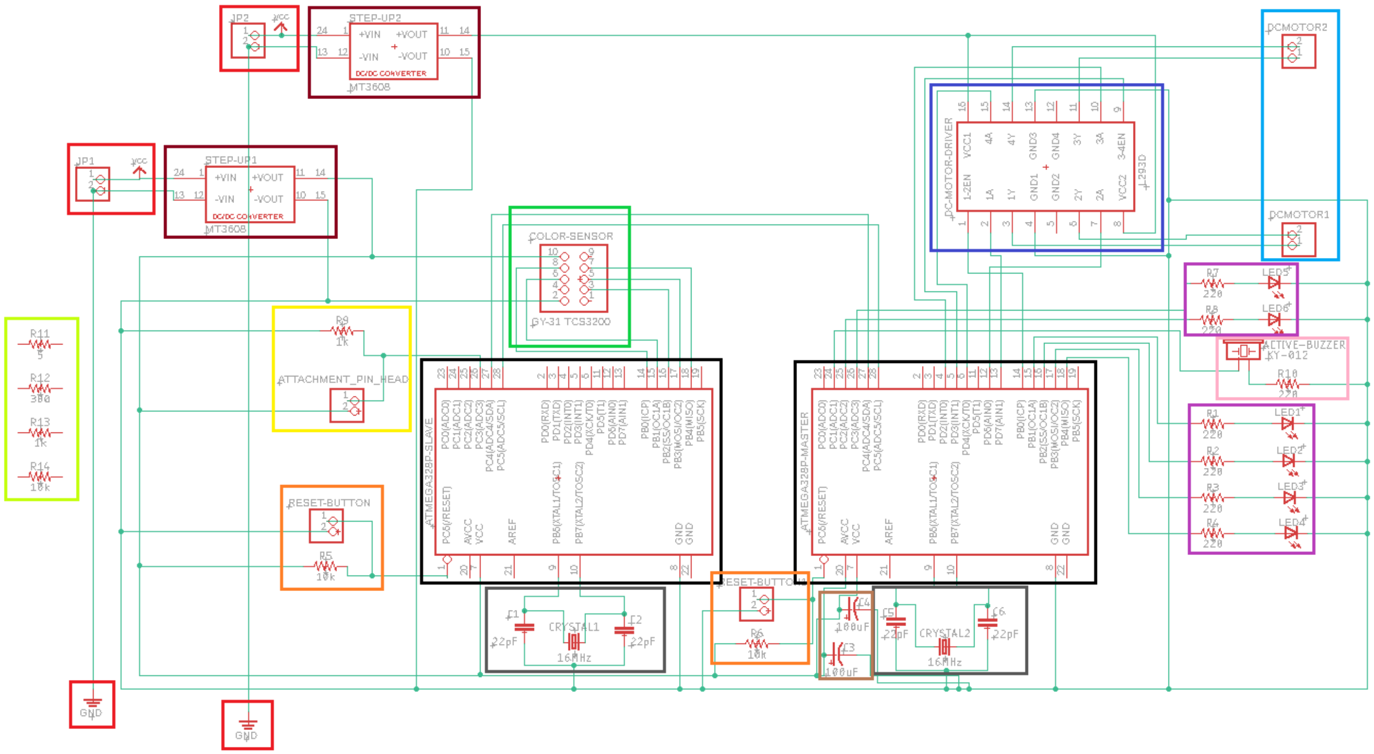

Figure 5: Full color coded schematic
Red: Battery - Dark red: Step-up - Black: ATmega
Gray: Oscillator setup - Orange: Reset button
Blue: DC motor driver - Light blue: DC Motors
Green: Color Sensor - Yellow: Attachment input
Lime: Attachment resisters - Purple: LED Feedback System
Pink: Buzzer

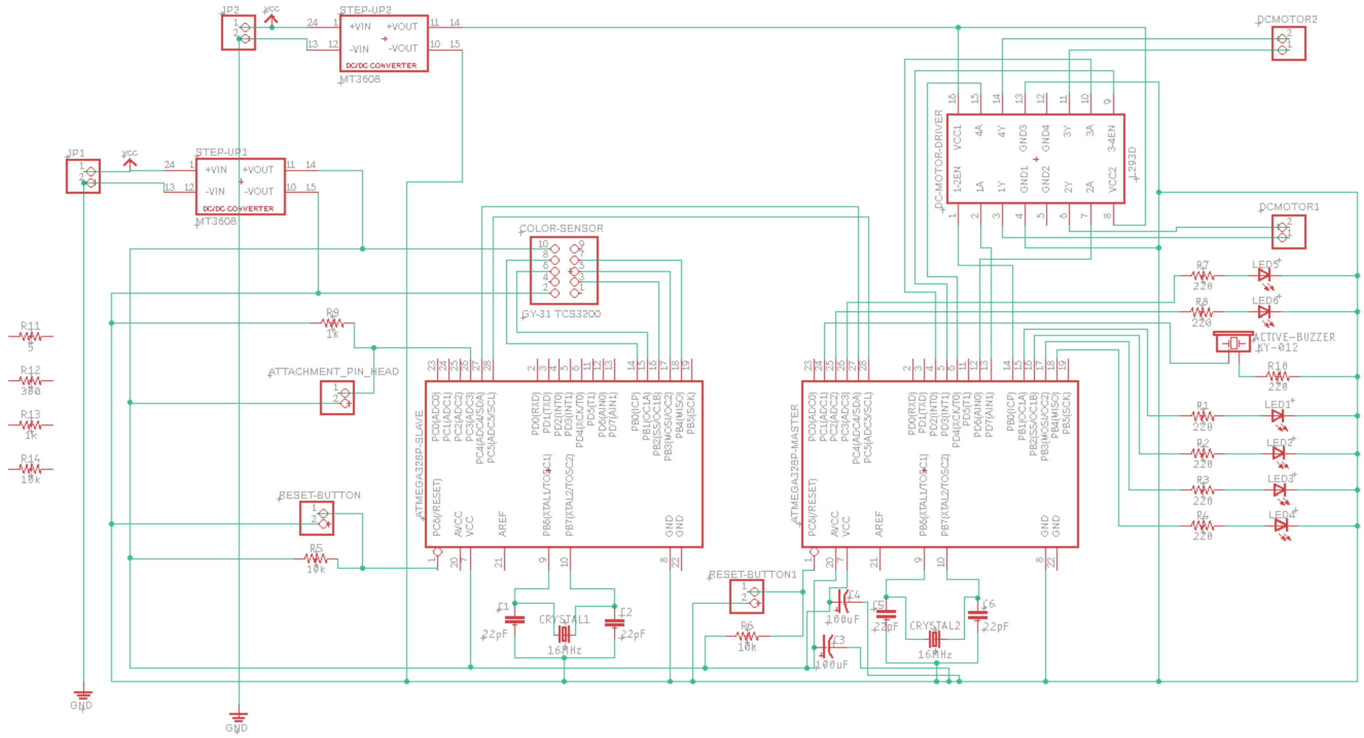

Figure 6: Full schematic of the prototype

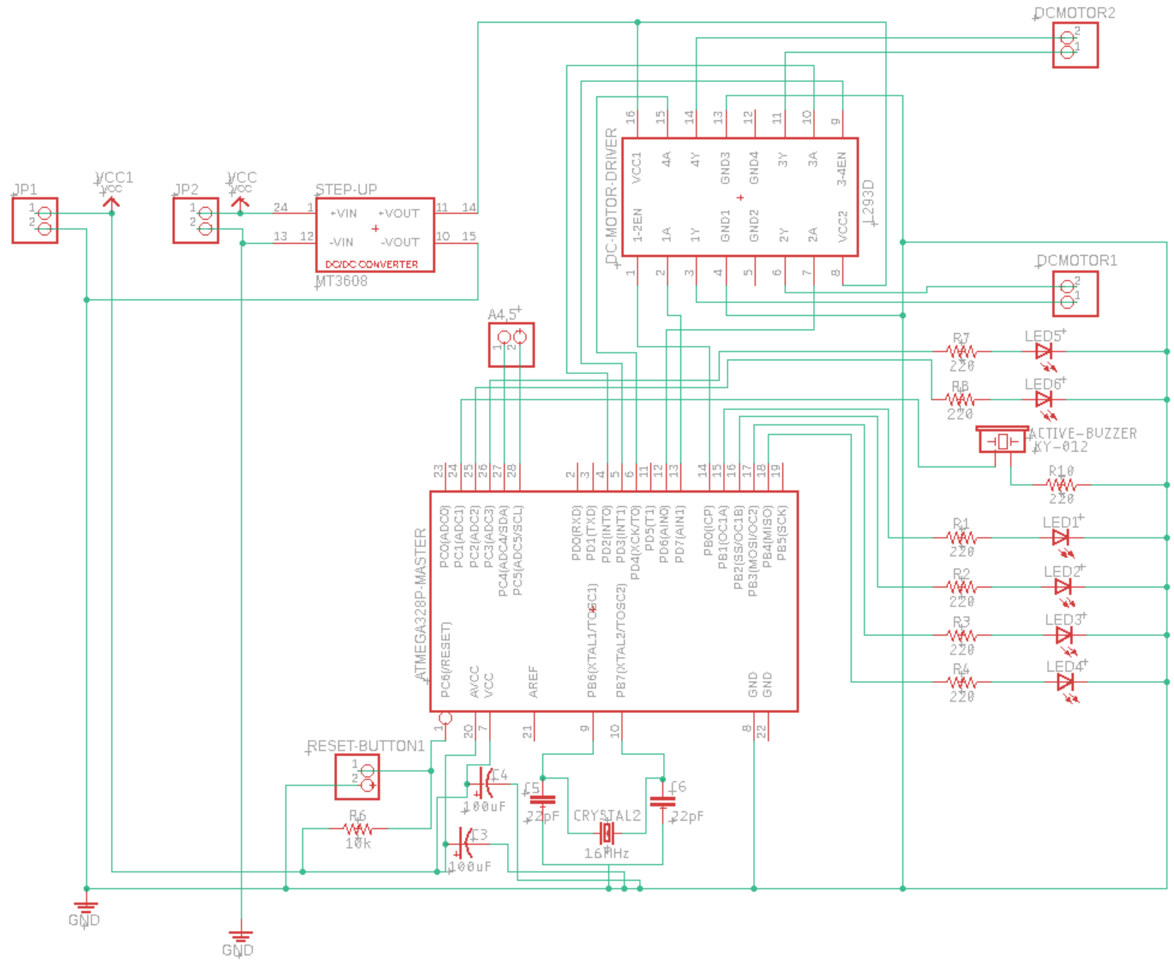

Figure 7: Schematic of master setup

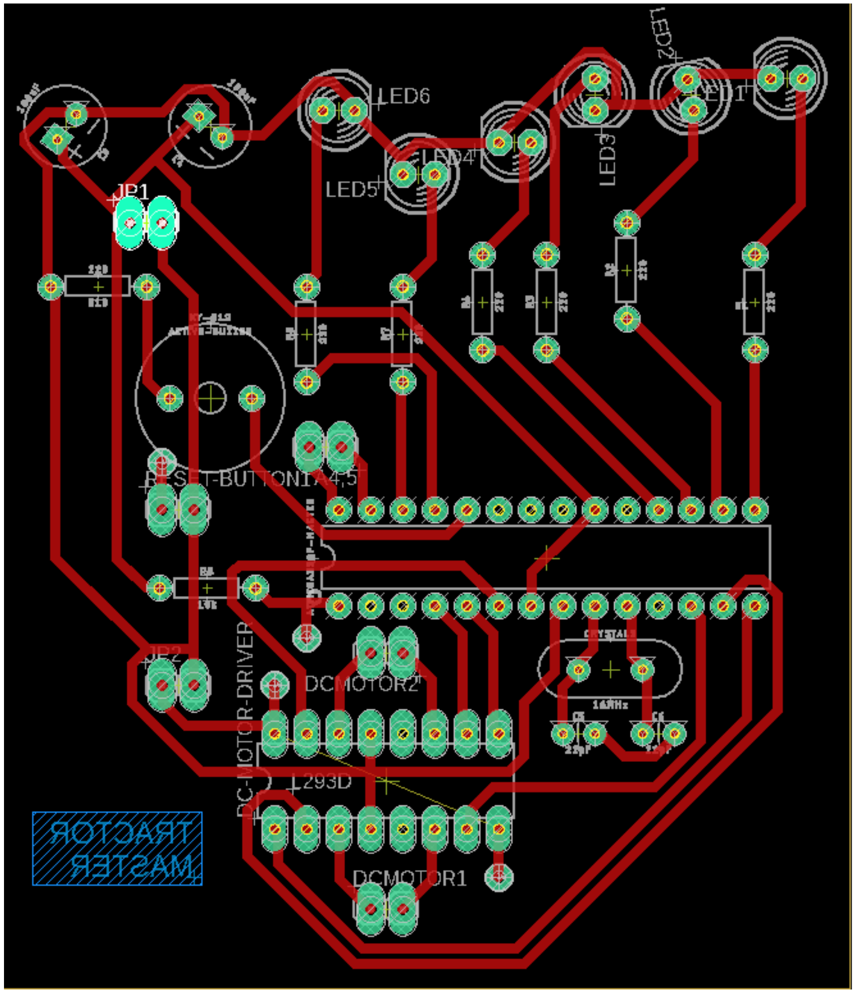

Figure 8: Board of master setup

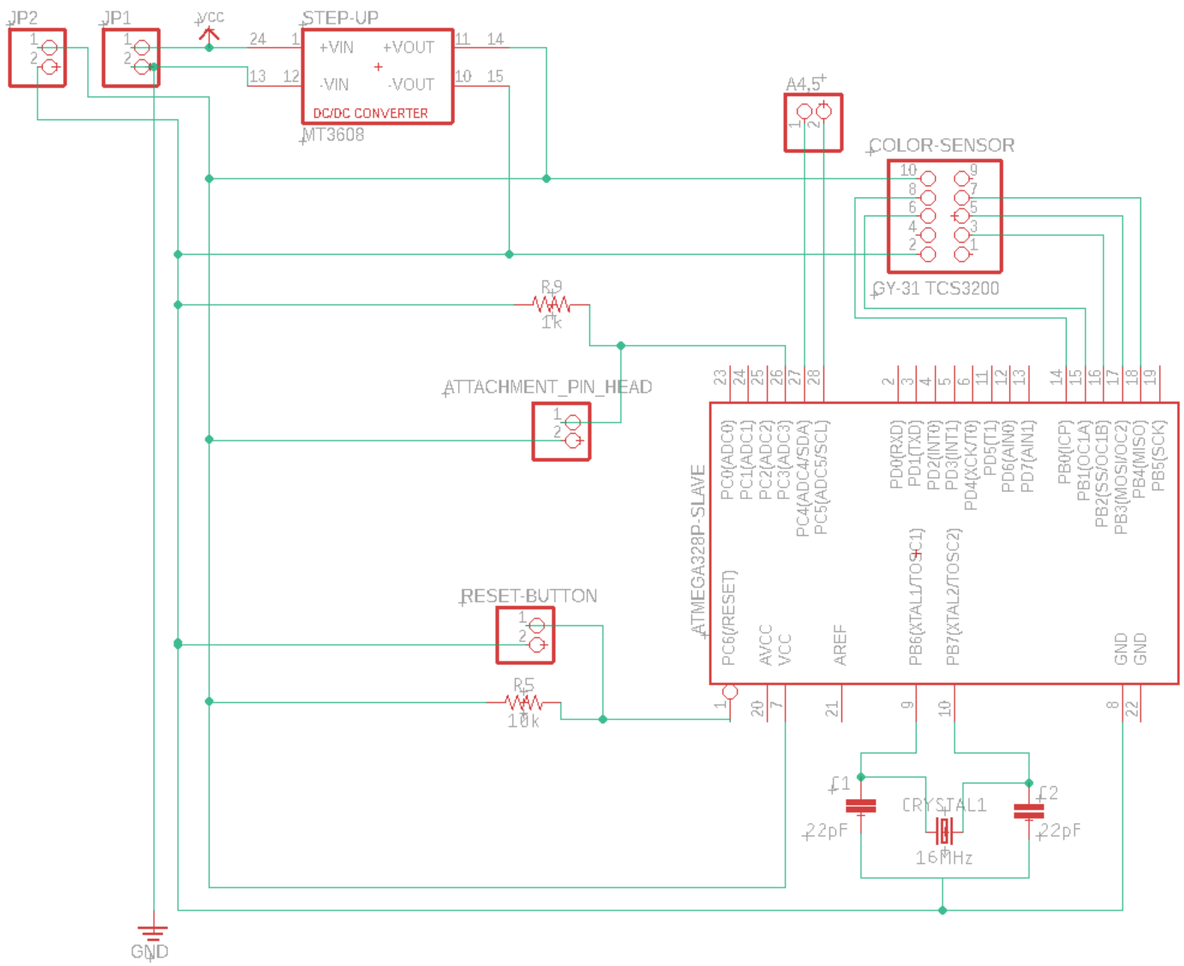

Figure 9: Schematic of slave setup

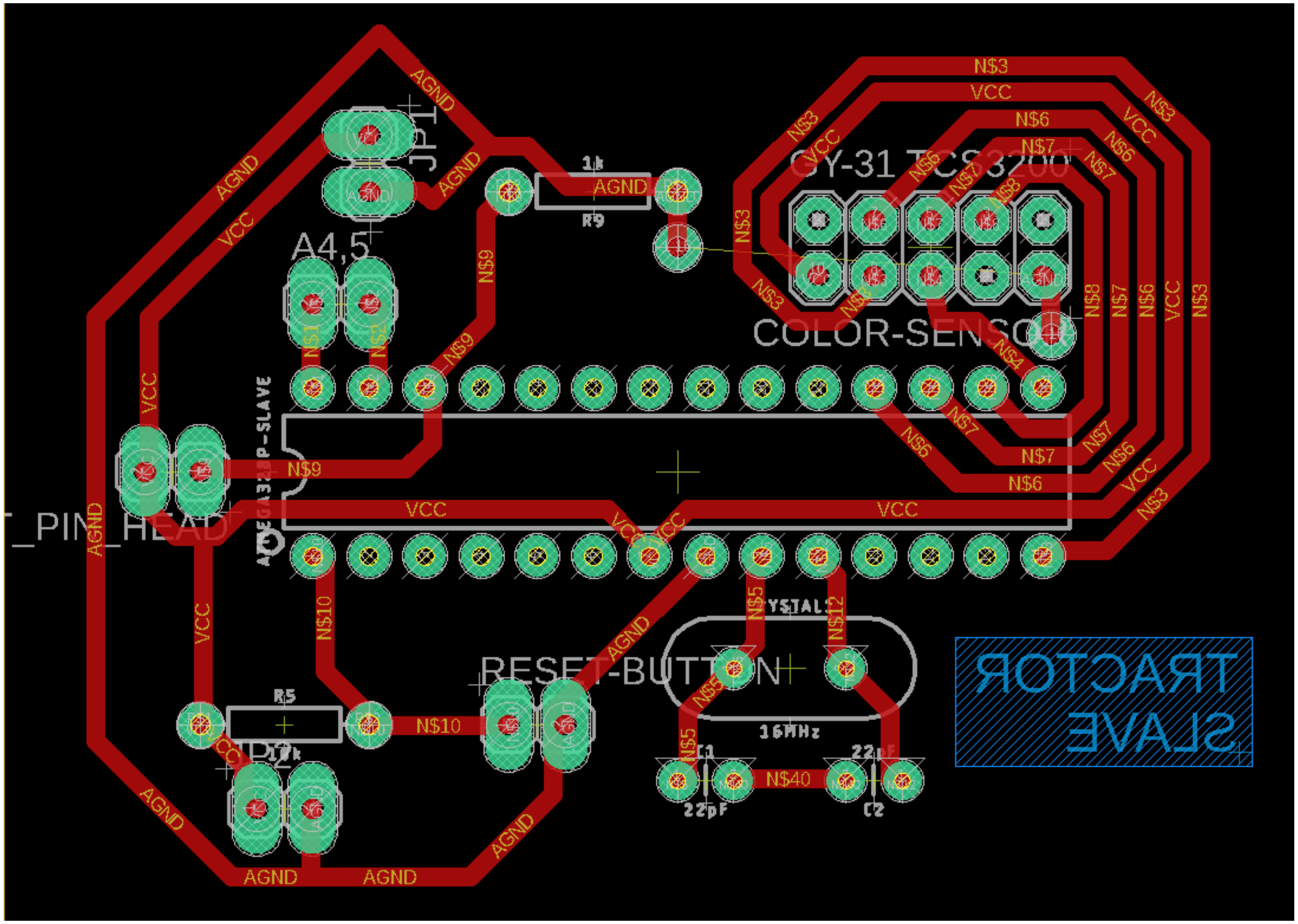

Figure 10: Board of slave setup

Appendix B - PCB

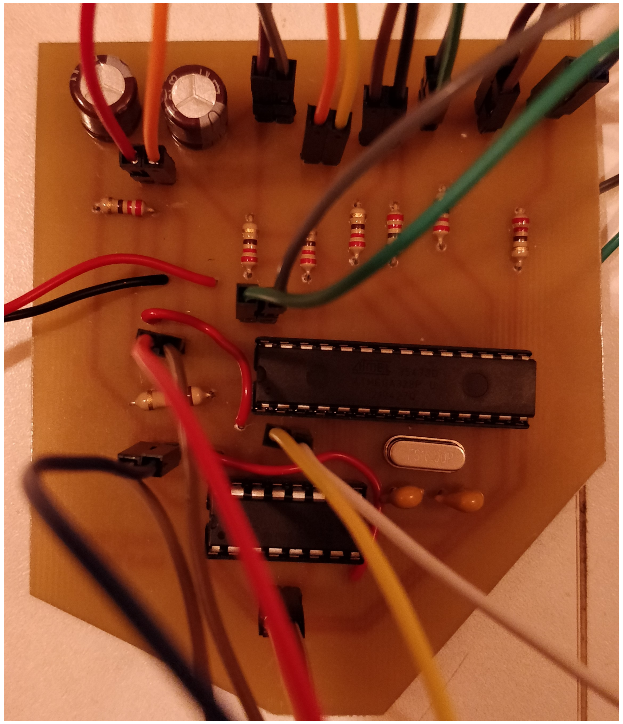

Figure 11: Front of master PCB

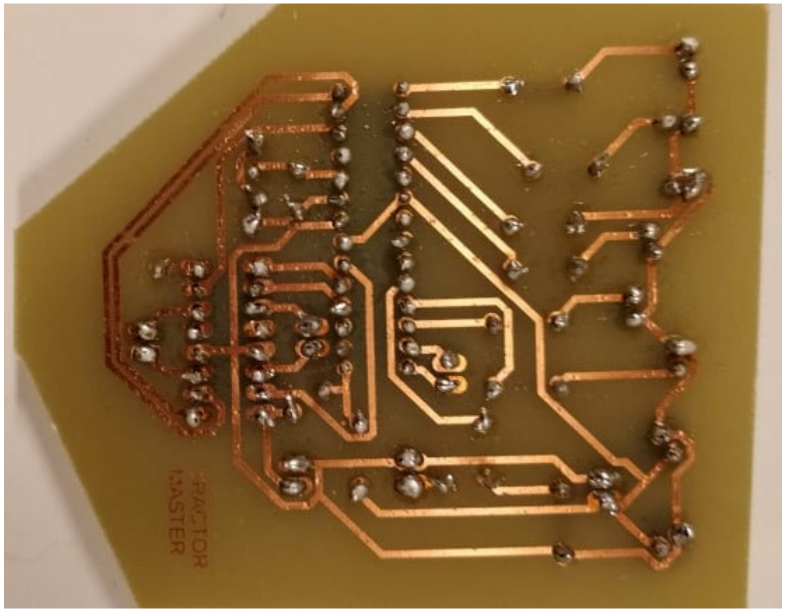

Figure 12: Back of master PCB

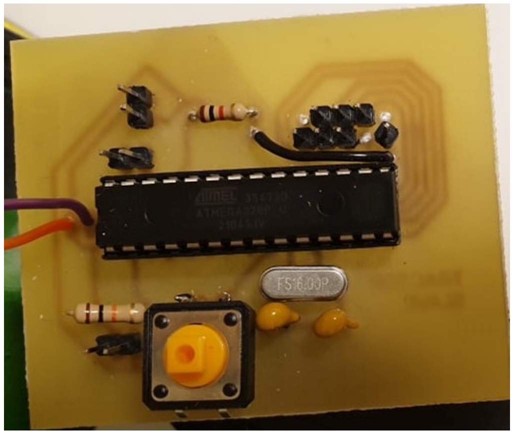

Figure 13: Front of slave PCB

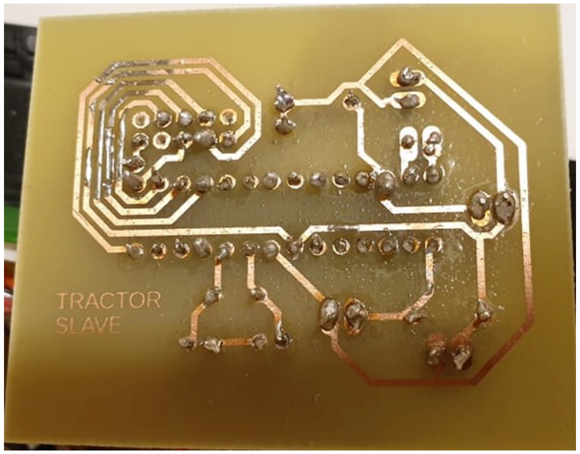

Figure 14: Back of slave PCB

Appendix C - 3D Rendering

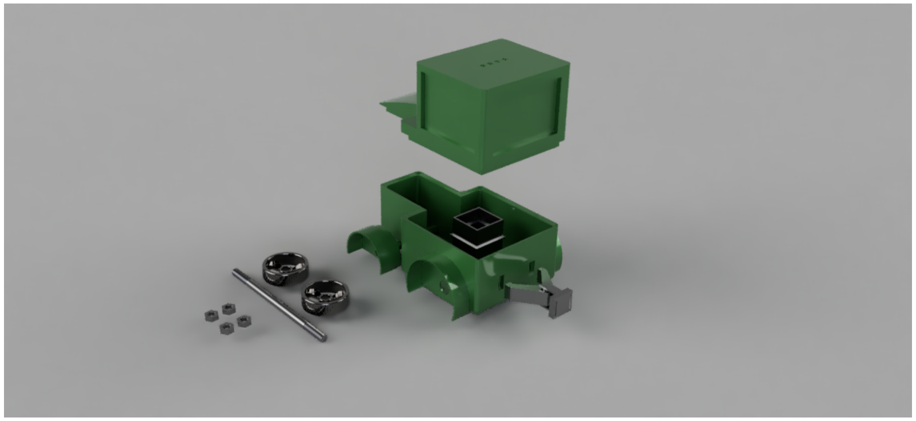

Figure 15: Side view of the tractor

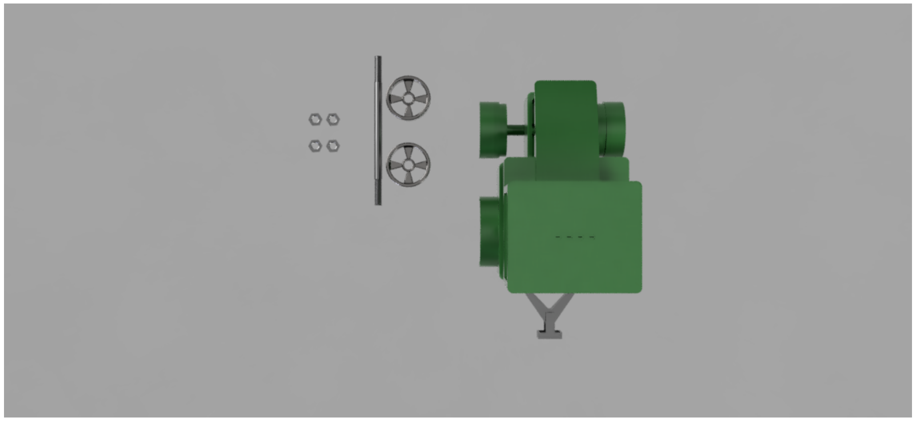

Figure 16: Top view of the tractor

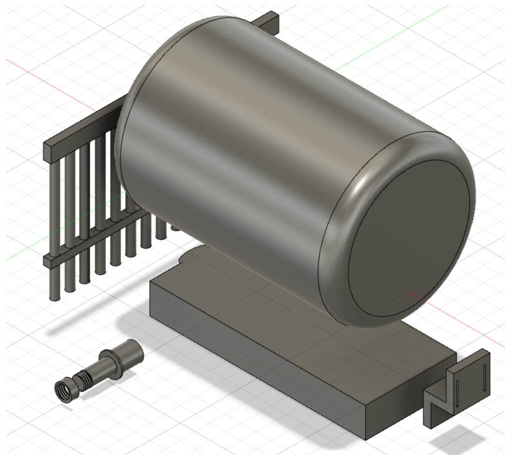

Figure 17: Side view of the fertilizer

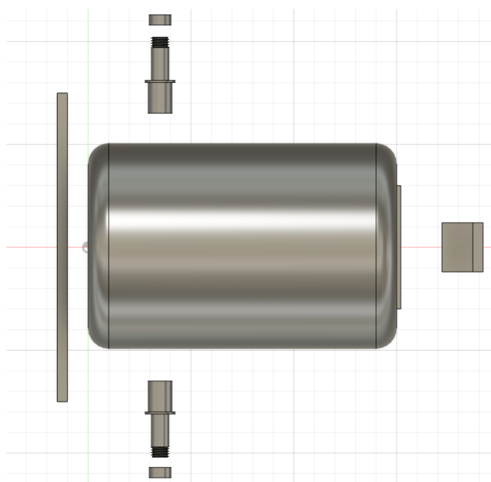

Figure 18: Top view of the fertilizer

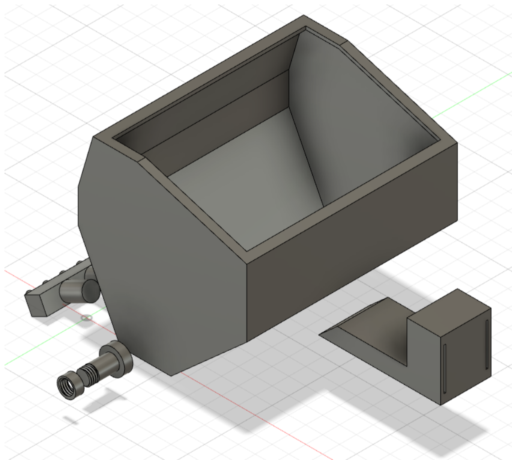

Figure 19: Side view of the seeder

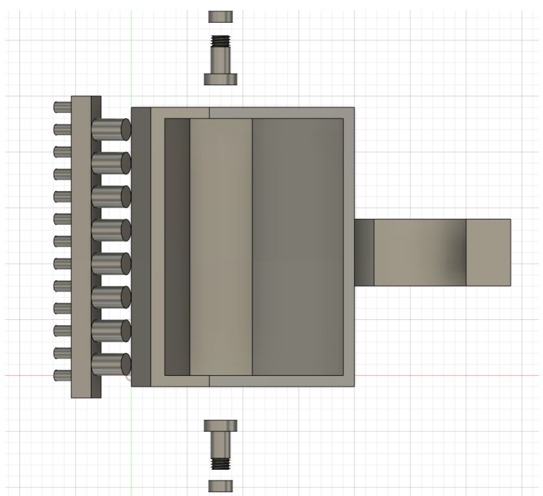

Figure 20: Top view of the seeder

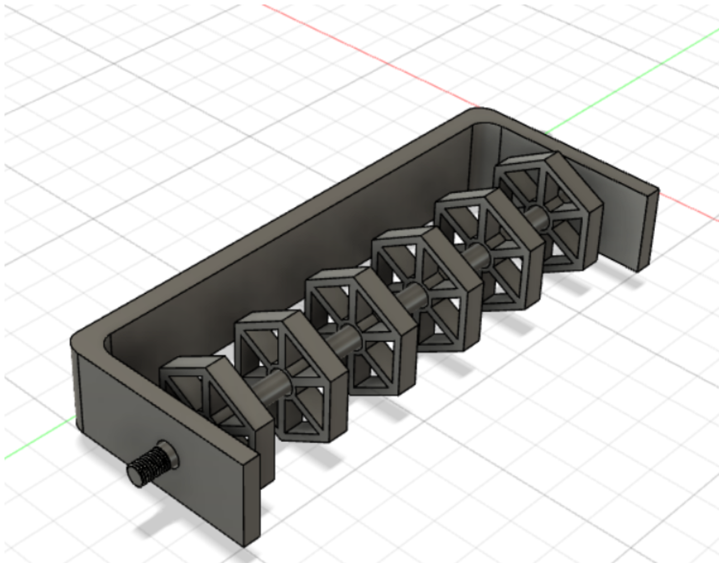

Figure 21: Side view of the harvester

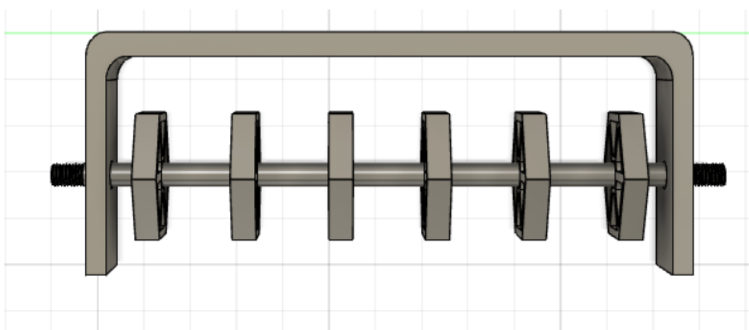

Figure 22: Top view of the harvester

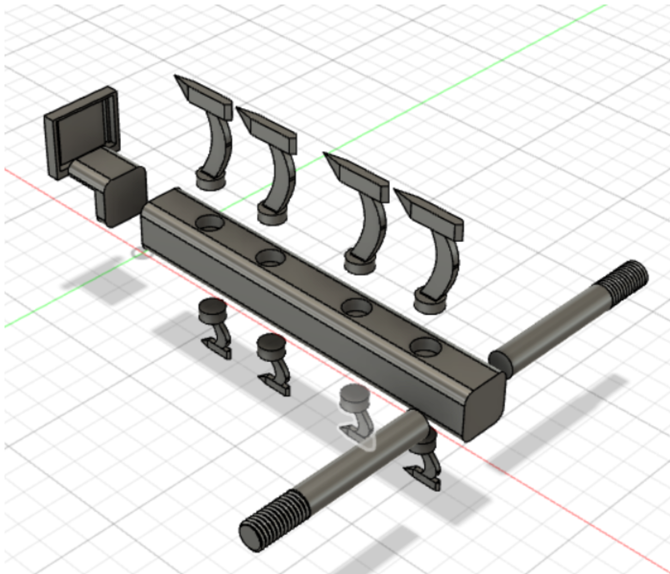

Figure 23: Side view of the plough

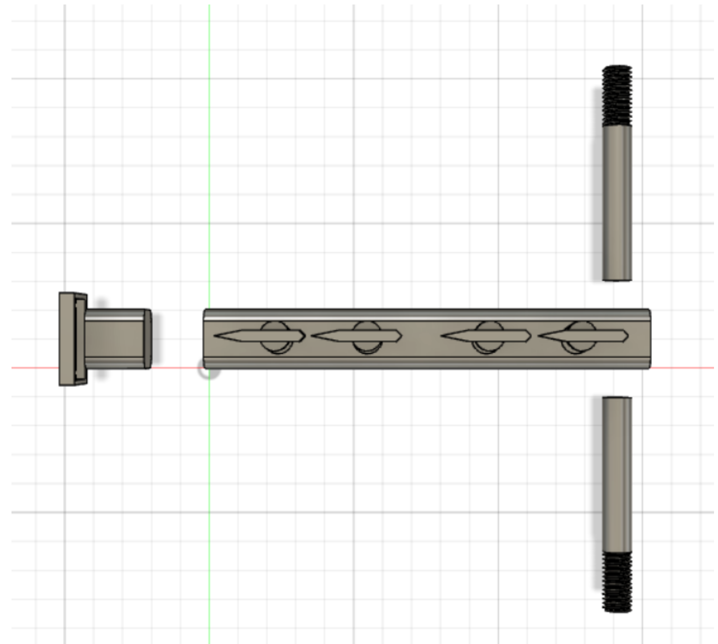

Figure 24: Top view of the plough

Appendix D - 3D Print

Figure 25: Front view of tractor

Figure 26: Back view of tractor

Figure 27: Side view of tractor with attachment

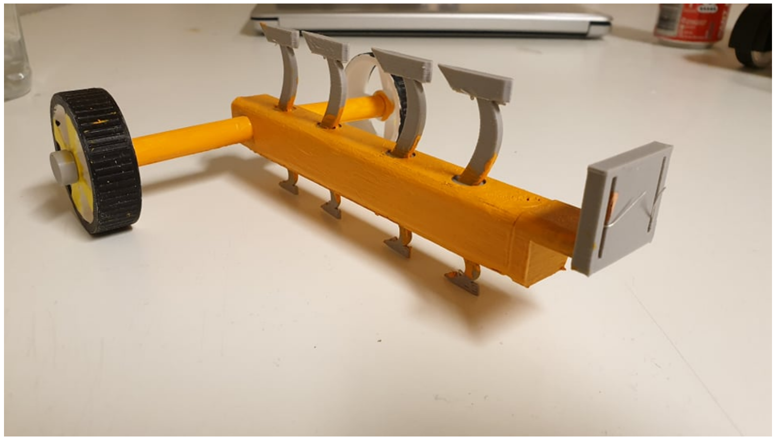

Figure 28: Front view of plough

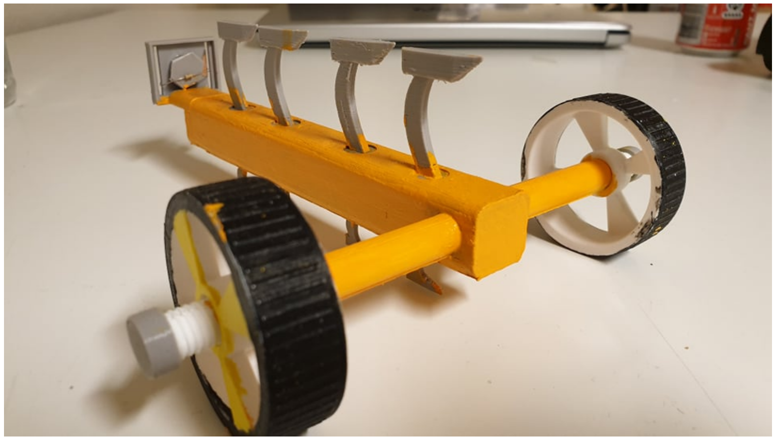

Figure 29: Back view of plough

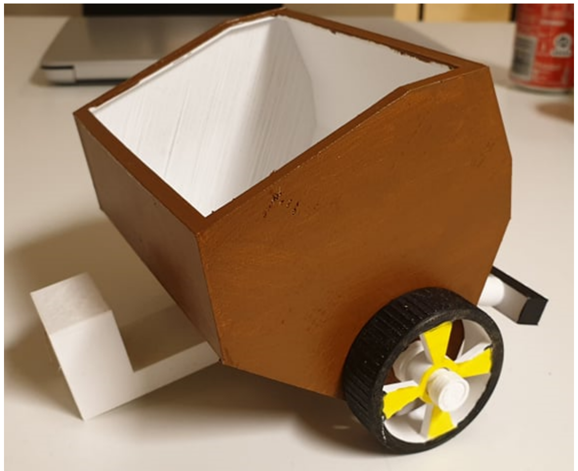

Figure 30: Front view of seeder

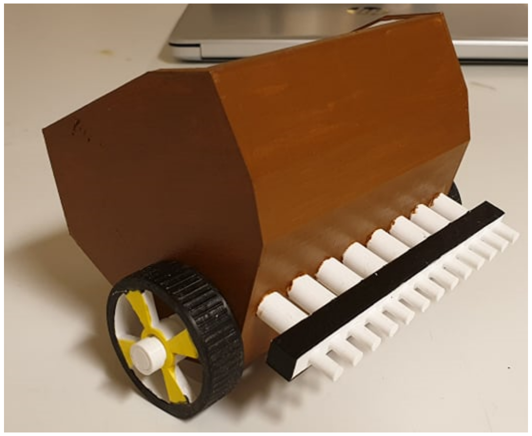

Figure 31: Back view of seeder

Figure 32: Front view of fertilizer

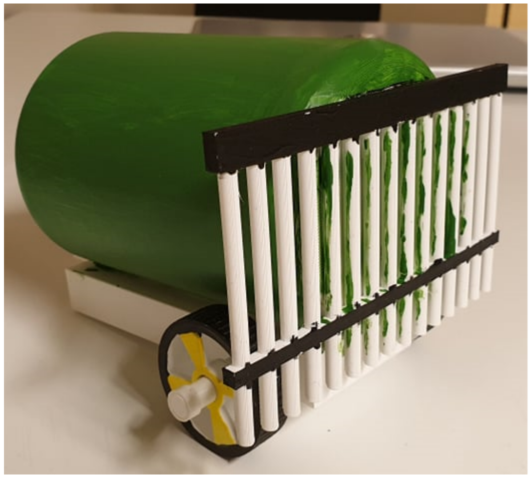

Figure 33: Back view of fertilizer

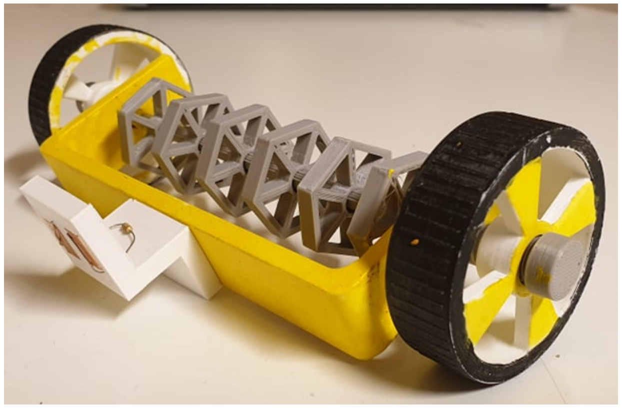

Figure 34: Front view of harvester

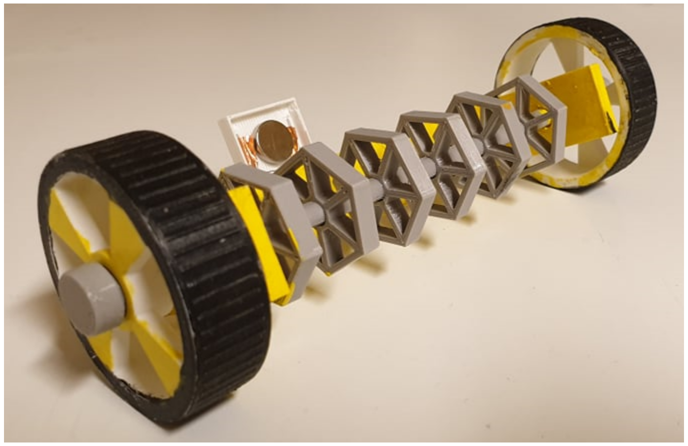

Figure 35: Back view of harvester

Appendix E - Laser cut tiles

Figure 36: First side of both tiles

Figure 37: Second side of both tiles