LAB University of Applied Sciences
Technology, Lappeenranta
Mechanical Engineering and Production Technology

Pham Bui Anh Duy

# Turntable modification for 3D-scanner

Thesis 2020

# Abstract

Pham Bui Anh Duy
Rotary table modification for 3D-scanner, 29 pages.
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Instructor: Development Engineer Eero Scherman, LAB UAS.
Commissioner: Development Engineer Mikko Ruotsalainen, LAB UAS.

The subject of this thesis is to design a control system for the turntable which is to be utilized for 3D scanning. The purpose of the turntable is to rotate object to be scanned by a handheld 3D scanner.

The theory part will discuss about the utility of turntable and variation of the electrical components of the project, and methods to control stepper motors.

After this stage, the thesis will focus on a complete design of the system, which contain the circuit design for the electrical components, the 3D model of the modified frame with all the components attached, and a program to control the motor and display it through an simple LCD.

The result of the thesis is a complete design of a functional turntable suitable for its purpose. Electrical components will be selected with additional explanations and recommendations for modification. The 3D model will show the placement for the components along with all the necessary modification on the metal frame.


Keywords: turntable, 3D scanning, stepper motor, 3D model.

## Table of contents

# 1 Introduction

This thesis is about designing a turntable that are going to be used for the purpose of 3D scanning. The design will be based on some existing components, namely, a metal frame of a turntable with a stepper motor. This project will focus on two main things: to design an electrical system for the stepper motor that is suitable for 3D scanning, and to modify the existing metal frame so that it is suitable for the purpose of the project.

The electrical system must be able to operate the stepper motor in adjustable speed. The speed of the turntable must be controlled and shown through a display. The desired power source of the system is from wall socket. The speed of the turntable should be between 0-30 RPM. The project will also research optimal index for the speed of the turntable for the 3D scanning purpose. The modified frame will be designed to fit the electrical system. The frame is measured and modelled in a 3D design software.

# 2 Stepper motor types and how they work

Stepper motor is an electric motor use in many different industries. Stepper motors are DC motors use magnetic energy for accurate movement controlling. With different design, the motor can move accurately in small steps in a wide range of angle, depending on the use of it. (Electrical Technology, 2016)

Stepper motor are used widely in operation where precise precision control is needed. As well as the ability to move back and forth, it is typically use in robotics, 3D printing, Information Technology and many other advance industries. (Electrical Technology, 2016)

The stepper motors principle is to have a bar of iron or steel suspended to allow it to rotate freely in a magnetic field, the rotor will align itself with the field. If the direction of the field is changed, the bar will turn until it is again aligned, by the action of the so-called reluctance torque. (Hughes, A. 2006)

The two most important types of stepper motors are variable reluctance stepper motor and hybrid stepper motor. (Hughes, A. 2006). A third type of stepper motor is the permanent magnet stepper motor which is briefly introduced later.

## 2.1 Variable Reluctance stepper motor

A simplified stepper motor is shown in figure 1 with the main components: the rotor and the stator. Rotor may be a solid or laminated rotor, and, in the example, it has four teeth. The rotor has teeth that are offset to the stator poles to accomplish rotation. Each pole pair is connected to a separate power source for controlling. To increase the resolution of the motor, more teeth will be added to the rotor. (Hughes, A. 2006)

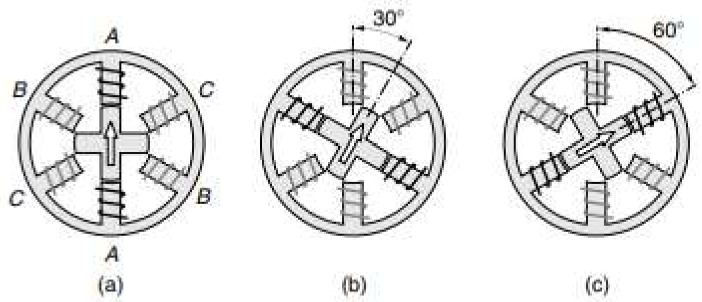


Figure 1. Principle of operation of 30° per step variable reluctance stepper motor (Hughes, A. 2006)

Figure 1 also shows how to control a variable reluctance stepper motor. It can activate up to two poles at the time to control the rotor in this example. The motor with the presented configuration is able to move accurately up to 30 degree per step. This is a very cheap and simple rotor to control. However, the torque capability of this motor type is quite limited when comparing to other variations. (Electrical Technology, 2016)

Due to the simplicity design, variable reluctance stepper motors are cheap to produce, but also provide low efficiency with no holding torque. Variable reluctance stepper motors are used for mechanical vibration applications such as clock timer, signalling devices, recording instruments. (Njr.com 2010)

## 2.2 Permanent magnet stepper motor

Permanent magnet stepper motor is one of the most popular stepper motor design. Permanent magnet stepper motors are small, reliable and cheap, with higher angle steps. (Scarpino, 2015)

Permanent Magnet motor has a similar system like the variable reluctance stepper motor, which use magnetic force from the stator poles system to control the rotor. The rotor, however, instead of having a muti-teeth soft iron gear rotor, use a permanent magnet poles of high retentivity steel and is cylindrical in shape. (Electrical Technology, 2016).

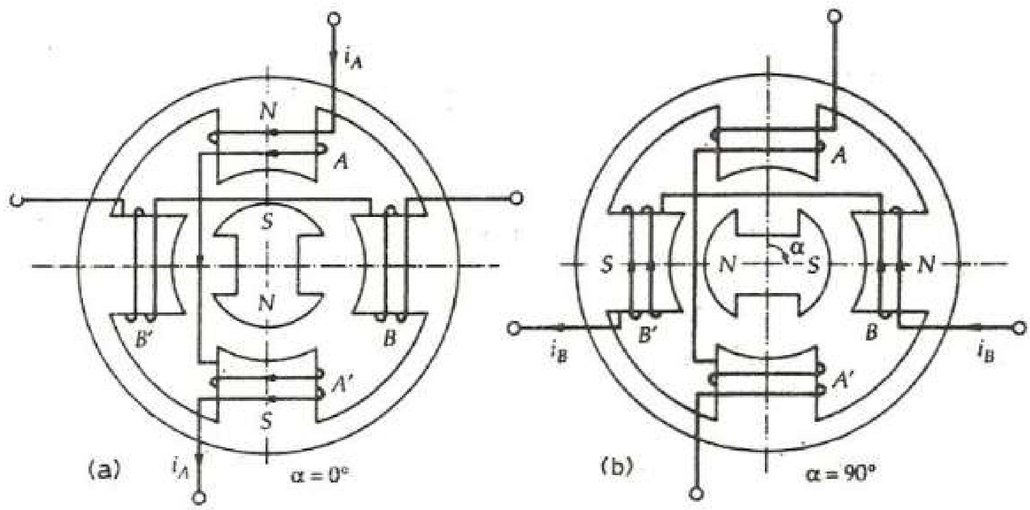


Figure 2. Principle of operation of 90° per step permanent magnet stepper motor. (Electrical Technology, 2016)

Figure 2 is an example of a basic permanent magnet motor. When pole A-A’ is activated, the pole holds rotor at position **α**=0°, when pole B-B’ activate and pole A-A’ deactivated, the rotor will turn and the angle of rotation at **α**=90°. When both poles are activated, **α**=45°. To reduce the angle of each possible step, more stator poles can be added to the stator. In comparison with variable reluctance motor, permanent magnet stepper motor has higher torque capability, but also higher price since the material for the magnetic rotor is more expensive. Also, permanent magnet stepper motors are more complicated to control. (Electrical Technology, 2016)

This type of stepper motor is a simple solution for low-powered drives with low or medium requirements in terms of dynamics. Because of the simplicity and inexpensive characteristic, permanent magnet stepper motors are widely used in automotive and construction industry for task such as windshield wipers. (Njr.com 2010)

## 2.3 Hybrid stepper motor

Hybrid stepper motor is the most advanced stepper motor of the most popular type of stepper motors. The hybrid motor is the technological combination between variable reluctance stepper motor and permanent magnet stepper motor. (Hughes, A. 2006)

Most hybrid stepper motor has 1.8$^o$ step angle setting as default, which will provide 200 steps per revolution. There are also 0.9$^o$ step angle stepper motors which provide 400 steps per revolution, which make smoother rotation than the 1.8$^o$ step angle version. (Stepper Motor Basics)

A standard hybrid stepper motor with a 1,8$^o$ step angle will have a rotor with sets of two steel end-caps, each with 50 teeth, and separated by a permanent magnet. The rotor teeth have the same pitch as the teeth on the stator poles, and are offset so that the centerline of a tooth at one end-cap coincides with a slot at the other end-cap. The permanent magnet is axially magnetized, so that one set of rotor teeth is given a N polarity, and the other a S polarity. (Hughes, A. 2006)

Figure 3. A rotor of a 3-stack hybrid 1.8$^0$ stepper motor. (Hughes, A. 2006)

Figure 3 shows a typical rotor of a hybrid stepper motor with 6 end-caps. This type of motor can create a very small step for accurate controlling. It also has higher torque comparing to the other type of motors. For lower speed, this type of motor is very efficient and stable. However, due to its complex structure, the motor has higher cost when comparing to permanent stepper motor. The motor is also heavier and has more inertia due to its material and more complex structure. (Electrical Technology, 2016)

Hybrid stepper motor is considering the best motor in term of energy efficiency and performance parameters when comparing to the permanent magnet or variable reluctance stepper motor type. It is widely used in both small performance classes (printers, scanners) and higher performance classes (automation, robotics). (Njr.com 2010)

# 3 Stepper motor controlling

Stepper motor controlling system requires a set of electrical components which include a controlling device that consists of a processor, memory storage for the program and power supply for the system. More advance controlling system and program will require additional components such separate drivers. This chapter will discuss about the variation of stepper motor in term of electrical structure, and the methods and components needed to program and control stepper motor.

## 3.1 Step control

A hybrid stepper motor usually has two pole shoes, which are combined to create the rotor of the motor. In each pole shoe, there are two magnetized rotors with opposite pole. Each rotor in a pole shoe have 50 teeth, and they are not aligning perfectly with the one stay next to them.

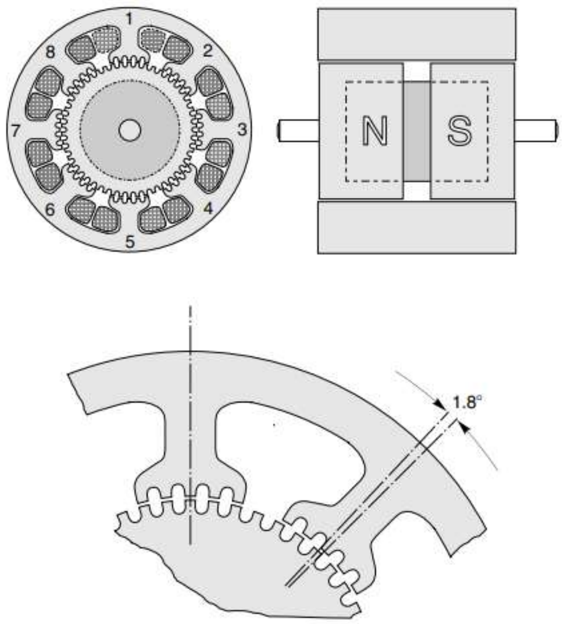


Figure 4. A cross-sectional view of a 1.8° hybrid motor. (Hughes, A. 2006)

Figure 4 shows a cross-sectional view of a 1,8° step angle stepper motor. To control the rotor, the stator of the motor is also toothed and separated into eight separate coils, which are four coils with each coil split in to two. In order to control the movement of the stepper motor, the current to the coils is controlled. A standard full-step rotation of a 1.8° step angle stepper motor will provide a standard resolution of 200 steps per rotation. To change the resolution of the motor, the number of steps per revolution of the motor can be change with wave driving method by using different current to the coils:

Half-step provide resolution of 400 steps/rotation

1/4 step provide resolution of 800 steps/rotation

1/8 step provide resolution of 1600 steps/rotation

(Scarpino, 2015)

## 3.2 Bipolar and Unipolar stepper motors

When discussing about controlling a stepper motor, there are two different types of motor which required different methods for the driving system: The Unipolar stepper motor and the Bipolar stepper motor.

- *Bipolar motors* have four wires. *Unipolar motors* have five or six.
- *Bipolar motors* require two H bridges, which are electronic circuits that switches the polarity of a voltage applied to a load for control. *Unipolar motors* control is less complex.
- *Bipolar motors* are significantly more efficient because they utilize the entire length of each winding when energized. (Scarpino, 2015)

Figure 5 is an example of an opened bipolar stepper motor. As can be seen, the motor has four different wires, each is connected to a different pole.

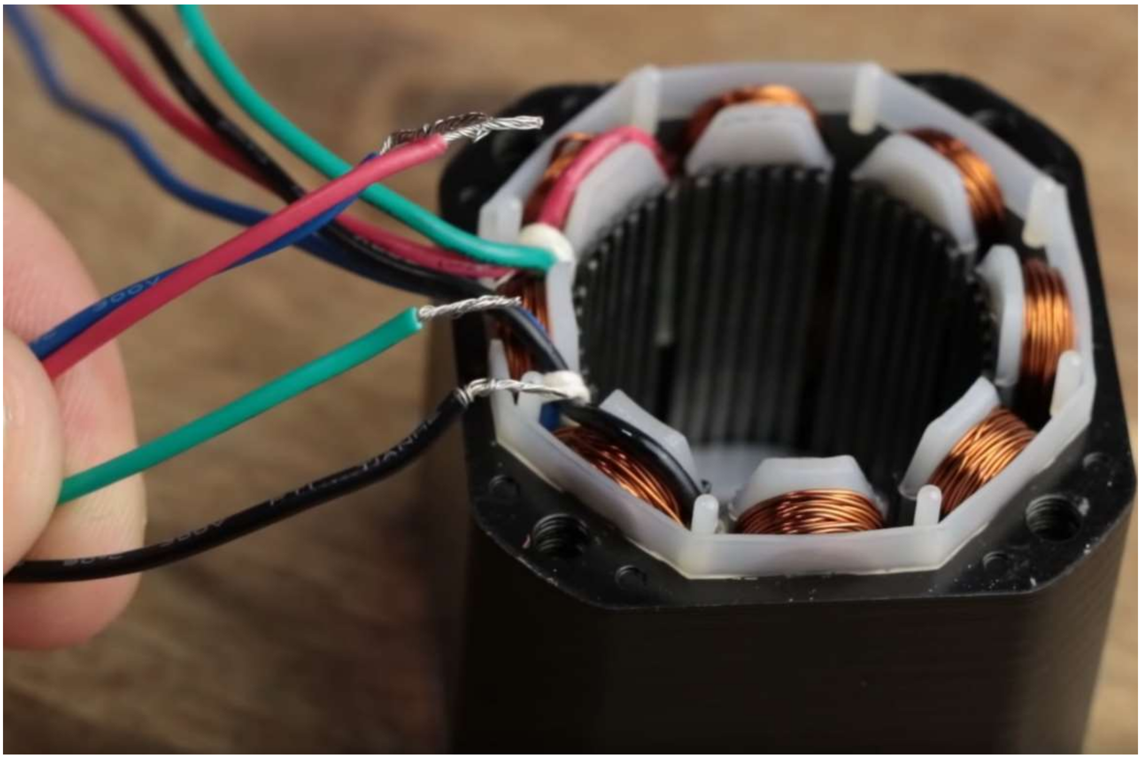

Figure 5. Inner look of a 1,8° bipolar stepper motor. (GreatScott!, 2016)

## 3.3 Controlling system

For controlling of stepper motors, there are two popular type of device: The programmable logic controller (PLC) and the microcontroller board system. They both share many similarities in term of architecture and have their own language for programming, however, they are made for different purpose with different capability.

PLC has similar components to a personal computer: a processor, input and output modules and a mounting rack, which is similar to a computer motherboard: a metal framework with a printed circuit board backplane. The PLC programming unit allows its user to enter or edit the program to be executed. Depending on the complexity of the system, the programming unit can be in various form, advance system might required a separate personal computer for the programming task, simpler task might only required an simple display device such as a liquid crystal display (LCD) to operate. The programming language of the PLC is considering easy to execute, however, manufacturers of the PLC usually develop their own programming language for their products, therefore it is complicated to learn to program with PLC in general since one language cannot be learned that is applicable to all types. (Hackworth, J. R. & Hackworth, F. D. 2004)

PLC is the controlling system specialized for industrial environment. PLC systems are able to control complex automation system such as automotive industry, robotics or hydraulic system. (Sadegh & Amir 2011)

There are many different types of microcontroller boards is a programmable circuit board that are suitable for stepper motor controlling. The main different between these types are the capacity of the microcontroller chip (in voltage), architecture and bits. There are some companies that are popular for manufacturing microcontroller boards, which are *Arduino, Raspberry Pi, and BeagleBone*. These companies offer a wide range of microcontroller boards that are suitable for many different projects, from a small home-made one to industrial applications.

*Arduino* microcontroller boards commonly contain a microcontroller chip (ATmega) as its main component, with a USB type B port for program file. The simple structure of the board makes it easy to operate. The program is made for the board on a software that run on most popular OS (Windows, Linux, MacOS), then transfer it through the USB port on the board itself. (Massimo, 2011)

Due to the simplicity of the board, the Arduino company provide to the market a very wide range of products with different capability. Each product is made to be suitable for some different application, ranging from small-scale control to industrial automation and performance art. (Hughes, J., 2016.)

*Raspberry Pi*'s boards usually have these main components:

1. System-on-chip (SoC): including the central processing unit (CPU) and the graphics processing unit (GPU)
2. Random access memory (RAM)
3. Radio
4. Power management integrated circuit (PMIC)
5. USB 2.0 ports
6. Ethernet port
7. HDMI port
8. microSD card connecter

Through this list, Raspberry Pi board are appeared to be very similar to a board of the Personal Computer. Raspberry Pi operates on Linux OS like a computer, Raspberry Pi microcontroller boards requires a microSD card for storage, a monitor for action observation, mouse and keyboard for executing action as a minimum basic tool. Since the board is much more complex, it can also perform more complicate task when comparing to the Arduino boards. (Gareth, H. 2018)

*BeagleBone* microcontroller boards have an identical structure to the Raspberry Pi boards, which contain components of a small computer and run with the Linux OS. However, the specifications of the  BeagleBone board are very similar to a normal personal computer. For example, the popular model BeagleBone Black, have 1 GHz processor, 512 MB of DDR3 memory, which basically equal to a cheap computer at the time it was released (2013). Due to the powerful hardware, it is considered too complex to used for general audience. (Molloy, 2015)

# 4 Design

The purpose of the design is to create a turntable for 3D scanning based a frame of a turntable with a stepper motor. Figure 6 and 7 display the existing components of the turntable used in the thesis.

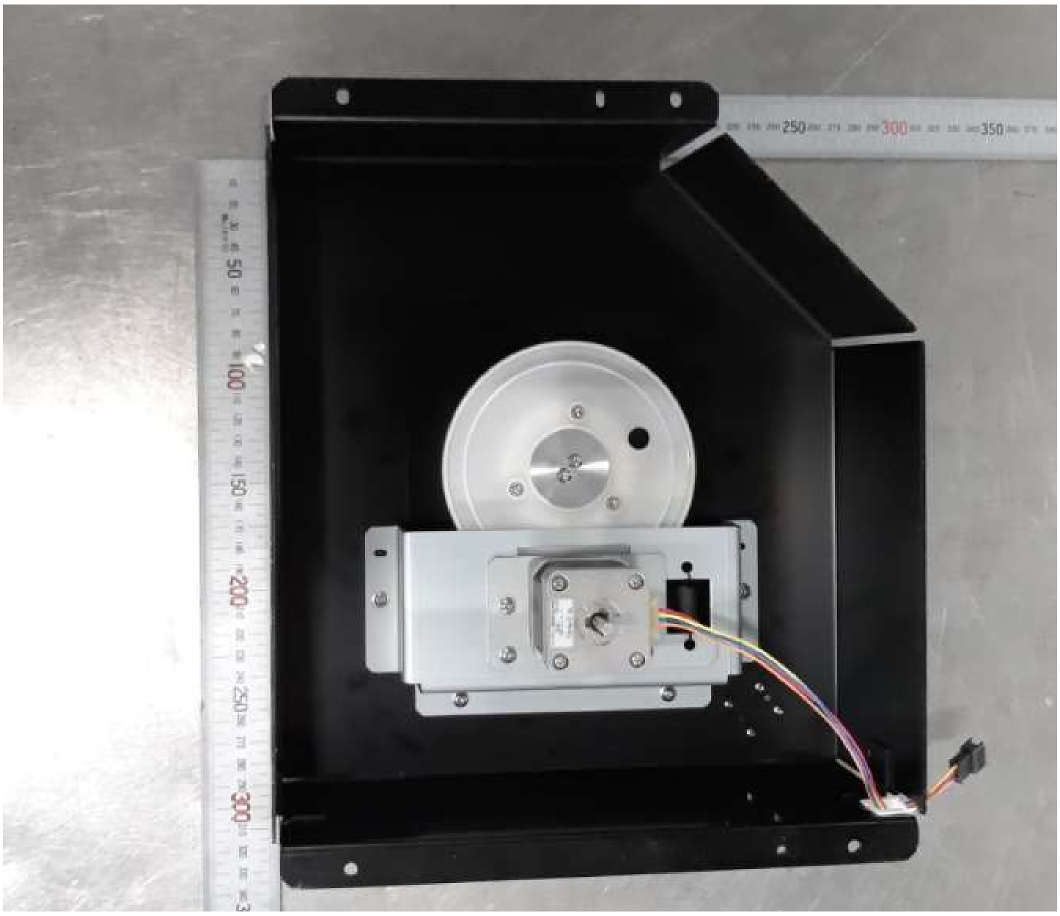

Figure 6. Underside of the turntable

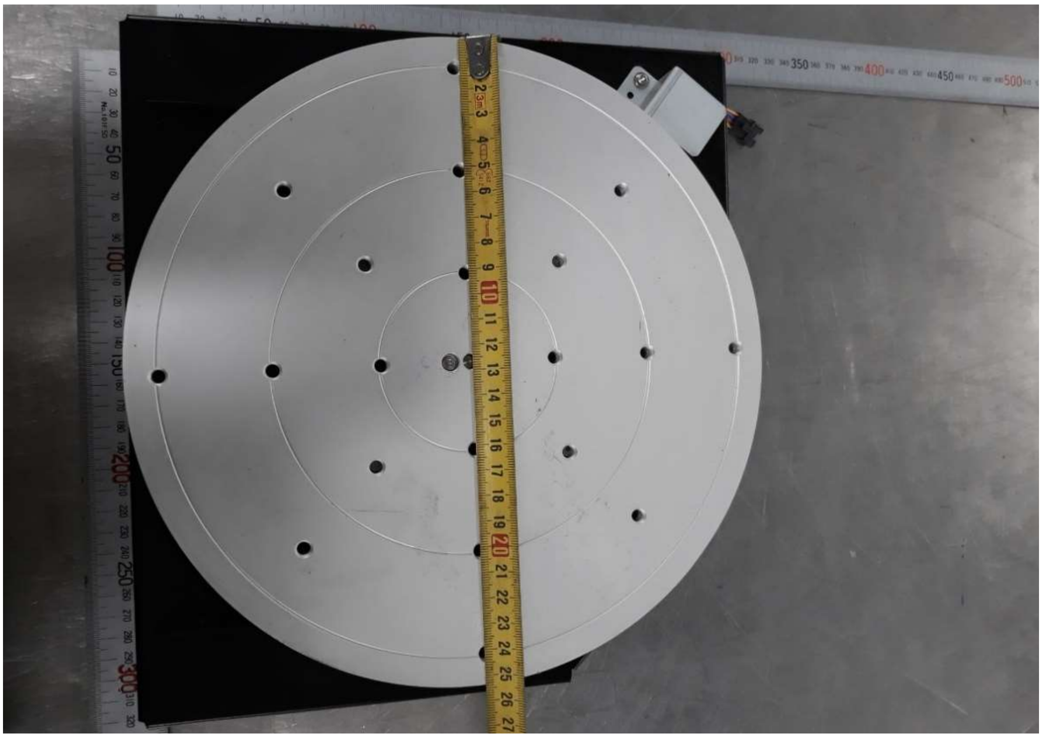

Figure 7. Top side of the turntable

Figure 8 displays the stepper motor in the project. The type of the motor is Sanyo Denki type: 103-594-8212, which is a bipolar hybrid stepper motor and support 0,9º step angle by default.


Figure 8. The stepper motor of this project

The aim of the project is to make the turntable to have an adjustable speed of rotation. The speed of rotation should be between 0-30 rpm. The speed must be shown through a display.

The 3D scanner that is going to be use with the turntable is an Artec Eva 3D-scanner. The Artec3D company also releases a model of Turntable that are compatible with their scanner, and that turntable have a fix speed of 13 seconds per round, which is about 4.62 rpm. The recommend speed for the user should be around 5 rpm. (Artec3D)

## 4.1 Components for the controlling system

Since the stepper motor will be used to operate a 3D scanner turning table, a microstepping driver is used for smoothest rotation. The components should be suitable for the project, convenient for programming, maintaining and future development and adjustment.

### 4.1.1 Control board

For this type of project, the microcontroller is chosen from the Arduino family. The board is going to drive one stepper motor, and run one particular program that is design for it, a PLC system or a complex circuit board such as Raspberry Pi or BeagleBone are unnecessary and they will make the design of the project more difficult and expensive.

The board that is chosen is an *Arduino Nano* microcontroller board due to its compact and functional design, which also help fitting the electrical components inside the frame easier.

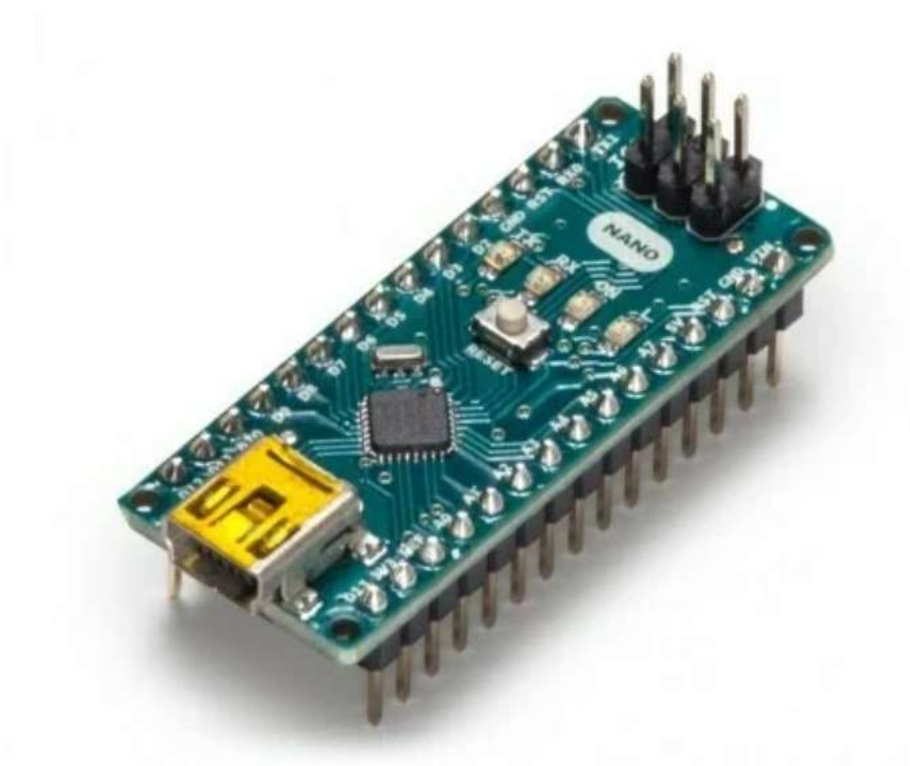


Figure 9. Arduino Nano (Verkkokauppa)

### 4.1.2 Stepper Motor Driver

For the motor driver, an *Easy Driver* (7V - 30V, 1/8 steps) is chosen for the system. Figure 10 is the Easy Driver

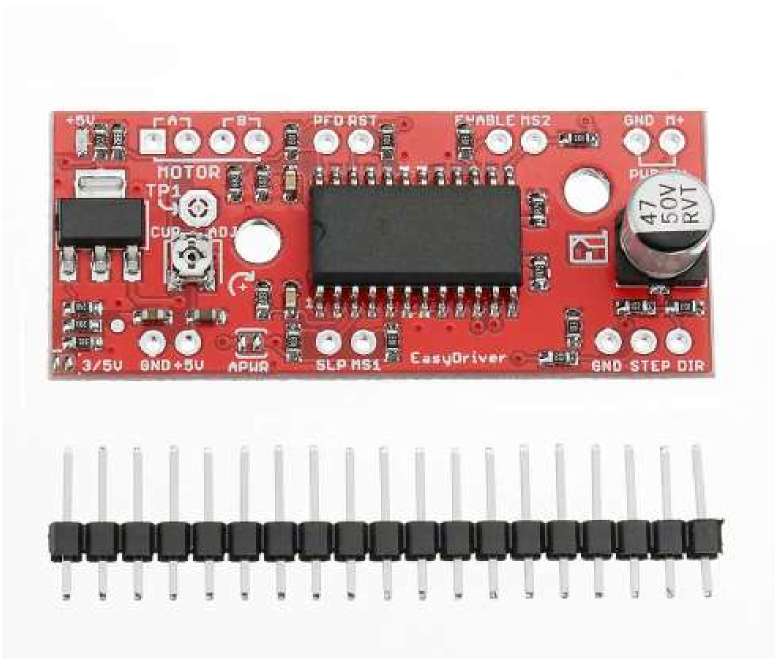

Figure 10. Easy Driver Stepper Motor Driver Board. (Banggood a)

Easy driver supports up to 1/8 steps controlling for the motor. The stepper motor of this project has a step of 0.9°, which mean the driver can help to turn the system into 3200 steps/rotation setting. (Banggood a)

### 4.1.3 Display

For the display, a **LCD1602** is chosen for simplification. The LCD can be link to the Arduino board and can be program on the same application provided by the Arduino. With two line of information, the LCD can provide information about the speed and the direction of the current state of the motor.

### 4.1.4 Power Supply

The recommended power supply for the Arduino Nano is 7-12V. Due to the low power requirement, the system can use either a battery power supply or a plug-in system. Since the request of this project is to use a plug-in system, a *12V DC Power Plug Jack Adapter Connecter* and an *12V adapter* were chosen for the system. Figure 11 shows an example of the adapter and the ports:

Figure 11. The power source for the system: 12V DC Power Plug Jack Adapter Connecter and a 12V adapter (Amazon)

## 4.2 Conclusion for components choice

The components selected for the project are very simple and popular for this type of project. The selected components are easier to modify and customize when comparing to a system that operates with Linux Operate system like Raspberry Pi. The price of this system is also relatively cheap, and easy to purchase in any local electronic store. This help future maintenance and development. The turntable speed will be control manual through a generic potentiometer, which allows the rotational speed to be controlled between 0-30 RPM. Table 1 below shows the price of the components:

| **Item** | **Price** (EUR) | **Source** |
|---|---|---|
| Arduino Nano V3 | 24.9 | Verkkokauppa |
| Easy Driver | 2.4 | Banggood a |
| LCD1602 | 2.8 | Banggood b |
| Power Adapter, 2A, AC 100-240V to DC 12V Transformer | 13 | Amazon |

Table 1. Prices of the components

## 4.3 Electronic design and components set up

The figure 12 display a system with similar components that has been chosen with Arduino nano and easy driver. The wiring position for power supply will be identical to the set up in figure 12. The system in figure 12 also does not have an LCD, the pins set up for the LCD will be described in detail in the next chapter.

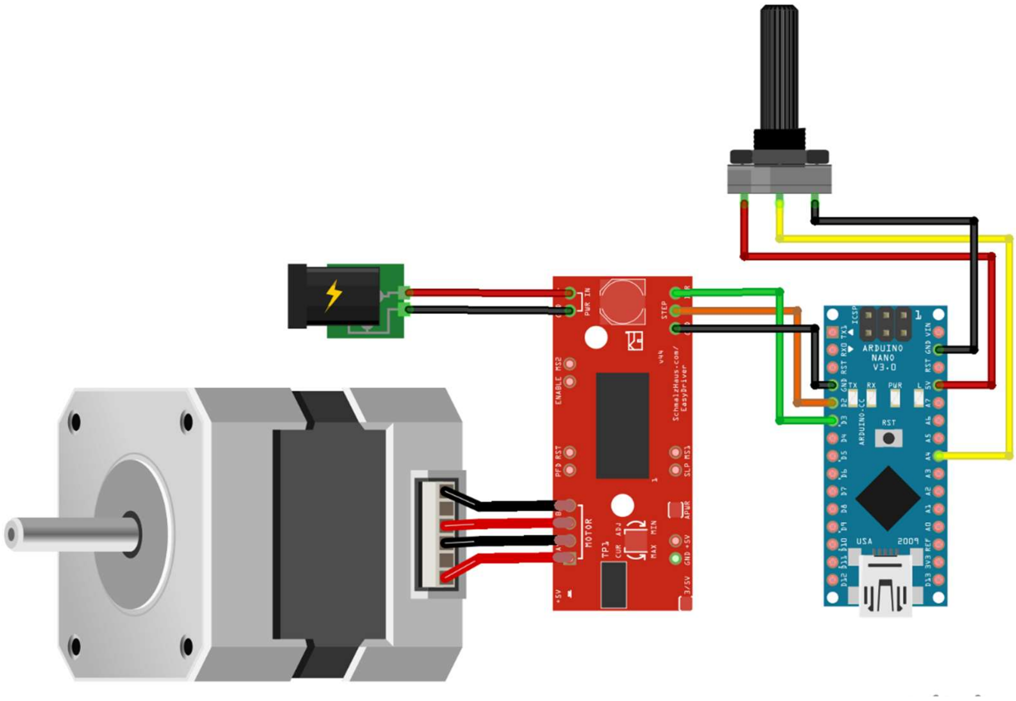

Figure 12. Electrical components of the system (BrainyBits 2016)

The wiring setup that is used for programming will be:

- The Stepper Motor will be wired to the Arduino through the Easy driver pins through pin GRD to pin GRD, 2 (D2) to pin STEP, 3 (D3) to pin DIR of the Easy Driver.
- The LCD will be wired to pin 4 (D4), 5 (D5), 6 (D6), 7 (D7), 8 (D8), 9 (D9) in the same ascending order of the LCD.

With this pin set up, the power supply will go through the Easy driver into the system. Since the power source will go through the Easy Driver to the Arduino, it is important to note that the GRD pin, which is the Ground connection of the Arduino, must be connected to the Easy Driver. The potentiometer will be connecting to any random Analog pin range from pin A0 to pin A7 to provide the Analog signal to the system. Figure 13 is the pin description of Arduino Nano.

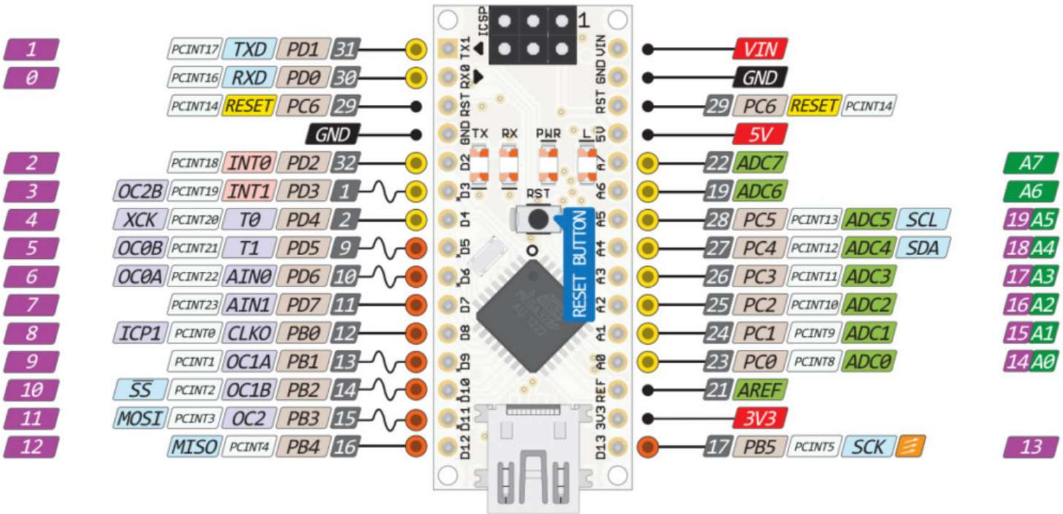


Figure 13. Default pin description for Arduino Nano (dejaworks.com 2016)

With the desired speed of the turntable is from 0-30 RPM, maximum speed of the stepper motor is determined by the gear ratio between two gears. Figure 14 is a demonstration of the gear system that is use by the turn table frame.

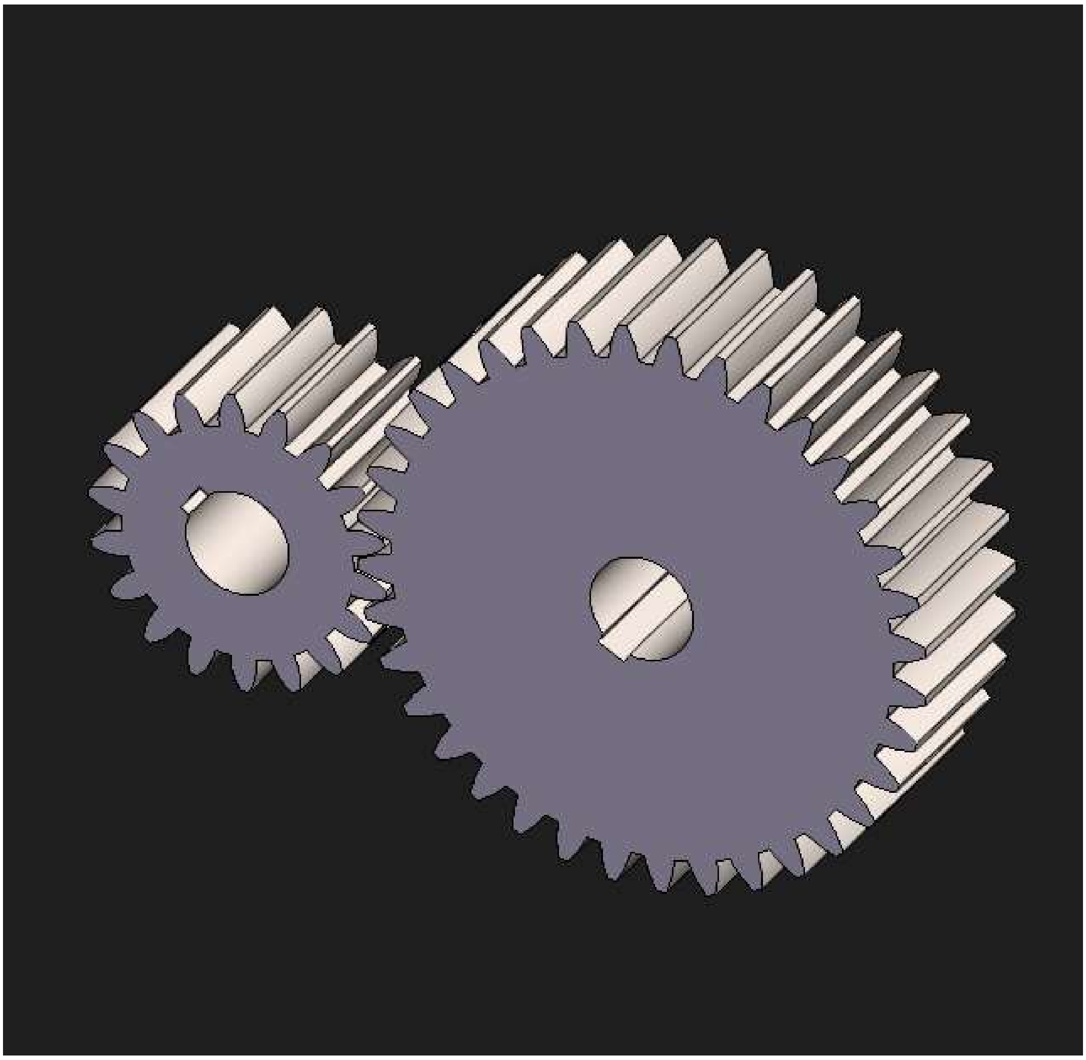

Figure 14. Demonstration of the gear system

The speed ratio $i$ between the stepper motor and the turntable will determine by a formula (1), in which, $Zsm$ is the number of teeth of the gear attached to the stepper motor, while $Zt$ is the number of teeth of the turntable.

$$i = \frac{Zt}{Zsm} \qquad (1)$$

The speed of the stepper motor $vsm$ is equal to the gear ratio $i$ multiply with the speed of the turntable $vt$.

$$vt * i = vsm \quad (2)$$

The pinion of the motor has 15 teeth and the transmission gear of the turning table has 376 teeth. The required speed of the turntable is 0-30 RPM, in order to match the recommended speed, the maximum speed of the motor should be:

$$30 * \frac{376}{15} \approx 752\ RPM \qquad (3)$$

The recommended speed of the turn table is 4.62 RPM (Artec3D), so the recommended speed of the motor should be:

$$4.62 * \frac{376}{15} \approx 116\ RPM \qquad (4)$$

### 4.4 Programming

The programming is also a factor to determine the choice for components. With Arduino Nano, the programming can be done on an operating system, with a USB type B port to transfer the program to the system.

Figure 15 is the finished program for the stepper motor control. The program was written with Arduino IDE application, a free program provided by the Arduino company for developing program on Arduino Microcontroller Board. The finished program has been verified by the application itself to detect all grammar errors. There are some note over some important line for easy adjustment in the future because the program has not been tested yet.

```
/*
/*
Revised Arduino Example code by dreamcircuit arduino team
Added 1602 LCD to print Motor RPM
*/
#include <Stepper.h>
#include <LiquidCrystal.h>


const int stepsPerRevolution = 3200;

// AccelStepper Setup
Stepper SDStepper(stepsPerRevolution, 2, 3); //
LiquidCrystal lcd(4, 5, 6, 7, 8, 9);

int stepCount = 0;  // number of steps the motor has taken

void setup() {
  lcd.begin(16, 2); // define lcd matrix
  lcd.setCursor(0, 0); // define below message's start point
  lcd.print("Turntable");
  lcd.setCursor(0, 1);
  lcd.print("Speed: ");
}

void loop() {
  // read the sensor value:
  int sensorReading = analogRead(A0);
  // map it to a range from 0 to 752 rpm:
  int motorSpeed = map(sensorReading, 0, 1023, 0, 752);
  // set the motor speed:
  if (motorSpeed > 0) {
    SDStepper.setSpeed(motorSpeed);
    // step 3200 of a revolution:
    SDStepper.step(stepsPerRevolution);
  }
  lcd.setCursor(7, 2);
  // print motor rpm to lcd
  lcd.print(motorSpeed/25 );
}
```

Figure 15. The program for the Arduino Nano

The program will allow the user to control the minimum and maximum speed of the motor with a potentiometer. The minimum speed of the stepper motor will be 0 rpm, at the starting point of the potentiometer. The maximum speed of the stepper motor will be at 600 rpm, at the ending point of the potentiometer. It is important to notice the program use 2 support libraries, which is the <LiquidCrystal.h> and the <Stepper.h>.

The <LiquidCrystal.h> library is a default library comes with the Arduino IDE application; this library support system that consist of LCD attached to Arduino Microcontroller board. When programming, the developer can type in #include <LiquidCrystal.h> and the application can recognize the library without additional step.

The <Stepper.h> library was made for stepper motor controlling system. The library is also installed within Arduino IDE, developer can add the library by type in #include <Stepper.h> and Arduino IDE can automatically recognize the library.

The value that will be displayed on the LCD will be the speed of the turntable. The speed of the turntable will be defined by the speed of the gear ratio of the gear system:

$$\frac{752}{30} \approx 25 \qquad (5)$$

The gear ratio between the motor speed and the turntable is about 25. The speed that is displayed with the LCD will be the speed of the motor divided by 25.

For smooth movement, 1/8 step setup is applied, the stepper motor will have the resolution of 3200 steps/rev.

The first row of the LCD will print: “Turntable”. The second row of the LCD will print: ”Speed:”. In the second row, started from column 7, the speed will be printed in RPM.

### 4.5 3D modelling design

The aim of the design for this system is to fit all the component of the electronic system into the existing frame of the project. The system also needs a compact appearance with minimum exposed interior components.

The display and the potentiometer will be put on the same side of the frame for easy adjustment and observation by the user. Figure 16 shows the 3D model of the turntable after the modification.

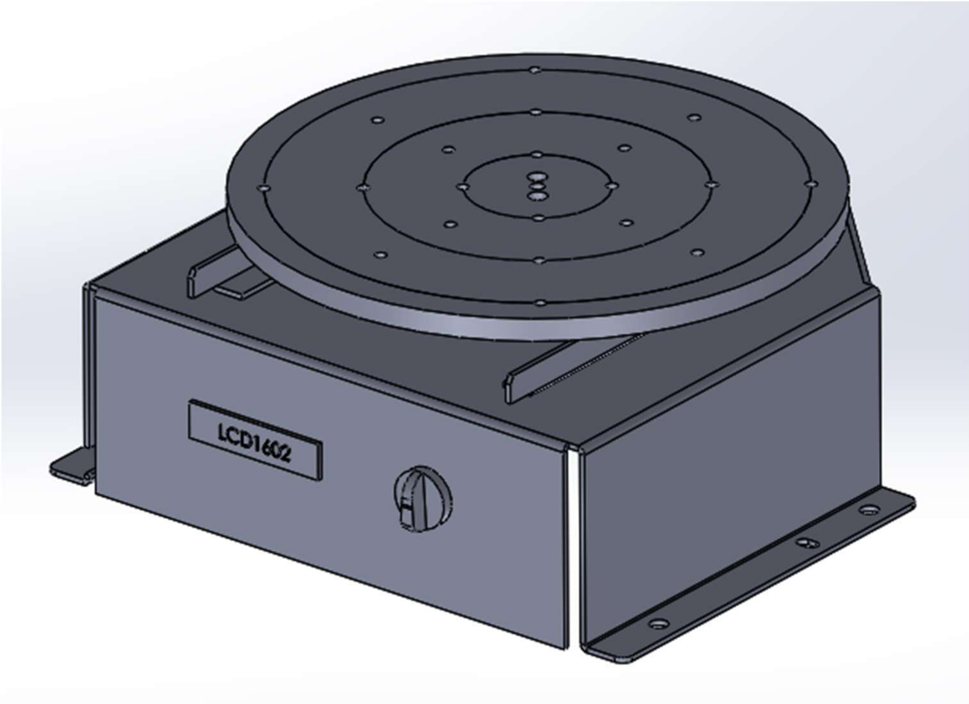


Figure 16. View of the design with the display of the LCD display and the potentiometer switch

The control board and the driver are put under the turntable. The gap around the outer box might affect the overall appearance of the whole system since user can see the components and their wires from outside. In that case, sealing the gap by welding or silicon filling to hide the interior of the system might be needed.

A square hole for the power supply port is needed. However, the power usage of this system is very small that it can run by battery. In that case, the cut will not be necessary. Figure 16 will show the position of the components under the turntable.

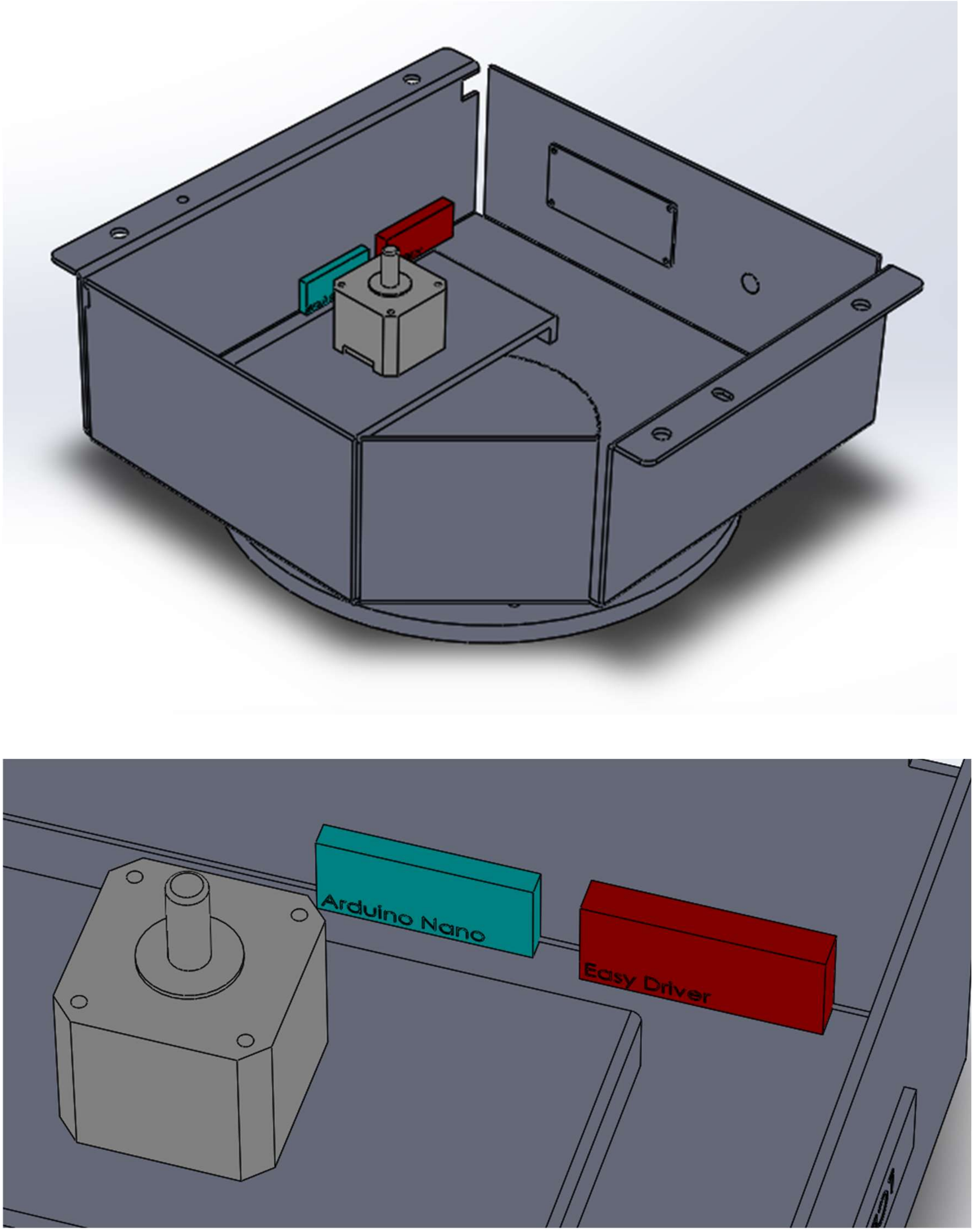


Figure 16. View of the design with the display of the set up for the electrical system and the power supply space.

# 5 Conclusion

The aim of the thesis is to design an electrical system for an existing turntable frame to make it suitable to be used as a turntable for a handheld 3d scanner. The finished product should be functional, reliable and easy to assemble and allow further development within an acceptable price range.

In order to design the electrical system, research about similar project has been made. After gathering information about the general idea of how to control the stepper motor in different ways, the most suitable methods were determined based on many factors: the existing components, the existing knowledge of IT and dimensions of the metal frame. The optimal rotation speed for the turntable has not been publicly researched for this type of product, so it was determined by taking standard speed from similar products that are sold on the market.

During the thesis, the components required to meet design specification were chose. These components were designed to fit the existing turntable. During the thesis, the assembly was not conducted hence it was not possible to perform any test runs.

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