

# Horizontally stable quadrotor with modified drive capable of turning without tilting and rolling.

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Intermediate Project  
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## Abstract

The main idea of the project was to build a quadrotor which would be able to fly without tilting the drone platform. In order to do so, a special mechanism had to be designed, capable of changing the angle of DC motors positioning. A simplification was done which assumes that besides up and down, a drone would be able to fly only in four directions: forward, backward, left and right. In other words it would not be able to perform diagonal moves. The main assumption was that the control board was to be designed completely from scratch. The project was not finished because it is missing the last part which is implementing the controlling algorithm.



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## 1. Introduction

The idea for the project came from researching on tricopters and quadcopters topics. Tricopters are very different from the rest of the multi-rotor drones because of their another way of turning the drone. It is done by engine moving the propeller just like in the case of quadcopters but this engine is attached to servo which is tilting the motor. In a project described below such a mechanism will be implemented for all the propeller drivers. This solution, if applied correctly, will allow the quadcopter to turn and move freely in horizontal layer without changing angle of the frame and board .

## 2. Choosing the elements

One of the most important parts of building a drone is to know what its purpose will be. In case of this project a quadrotor will just have to fly using a modified drive so the components can be chosen in such a way that it will not have to lift some extra equipment but just the necessary things.

### a) Frame

First part that needs to be chosen is a frame because its dimensions are dictating other elements. In this project a 480 mm diameter, built from glass fiber, frame was selected.



Figure 1: Quadrotor frame

It is equipped with landing gear and a bonus power distribution board (PDB) build-in for neat and easy wiring. Size of this frame makes it ideal for 9 and 10 inch propellers and it also has an adjustable battery mount to achieve the perfect weight distribution. It weight only 405g and has holes for motors 16~19~25mm.

### b) Motors and regulators

Motors are the second pick in the projecting process. Normally their choice is vast but since the right frame was decided, there are some upper and lower limits of power the motors can possess. In this case it must be in range of 800-1000kV. KV unit tells how fast a given motor rotates for each additional volt that powers it. For instance 1350kV motor with 11.1V power supply will work with speed equals to  $11.1 \times 1350 = 14985$  RPM. For this project a MultiStar & Afro Combo Pack was picked because it has dedicated regulators included and it is inexpensive in comparison to other products available on the market. Each of the motor weight 22.8g (with wire, plug and heat shrink included). Normally regulators require a dedicated programmer to upload a device configuration, however Afro regulators are being programmed before they are packed and sent to the customer.



Figure 2: Motors combo pack

c) Propellers

Propellers pick is also dictated mainly by frame dimension. They cannot be too big so that they will not cause any damage to the drone and they cannot be too small to provide a proper lift force.

A very important parameter is a pitch of a propeller. If it is too big for a chosen set of motors it might result in their overheating during acceleration. For already mentioned above elements the best propellers are with 8 inch diameter and 4.5 inch pitch.

d) Battery

Correct battery pick is dictated by motors used in a project as well as an estimated time the drone would have to spend in air. The optimal choice in this project is a high capacity 4 cells 4000mAh Li-Po battery which will enable a quadrotor to fly for approximately 12 minutes. It gives a constant 14.8V power supply.

e) Power distribution board

This is not a vital element, however in order to easily and safely provide all the components (motors, control board) with a necessary power supply it is wise to equip a drone with one of these.

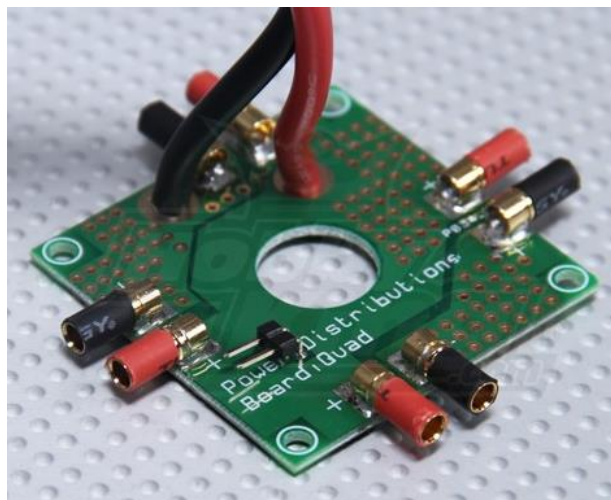


Figure 3: Power distribution board

f) Controller

In order to control a drone a special transmitter is necessary. Presently one of the best controllers available on the market is Turnigy 9x 9 Channel Transmitter with a receiver module attached.



Figure 4: Turnigy controller

g) Control board

It is the most important element which brings together the rest of modules as a brain of a drone. It is possible to buy a ready and programmed control board however in this project it was constructed from scratch. To control everything a STM32F3 microcontroller was chosen due to its decent parameters, wide range of peripherals and fast operations (72 MHz). It also has a very useful property which will be needed in this project. STM32F3 has a PWM input reading mode in its timers (necessary to read data from Turnigy receiver channels). Since this module can be powered only by +3.3 V there had to be a voltage transformer added. It can transform a voltage 5 – 38 V into 5 V and can be charged with a current up to 6 A. There was also a stabilizer LF33CV used to acquire a stable 3.3 V power supply. Normally there had to be accelerometer, gyroscope and magnetometer installed on the board, but in this case, a special module containing all of these sensors was used. BNO055 can provide a quaternion describing a drone position and rotation in space using only UART interface. It is powered by 3,3 V (same as STM32F3). Next module is a 6-channel Pololu Micro Maestro USB controller which was used to steer the PWM signals of servos used to apply a modified drive. It is also controlled by UART interface, however it works powered by 5V, this is why a logic level converter was also necessary because in other case TX and RX signals of Maestro controller would not match with the signal logic of STM32F3 microcontroller.

h) Servos required for quadrotor motors tilting

It was essential for chosen servos to have as little weight as possible. Most of servomotors available on the market are approximately 65.0 g heavy which is not much for one module, however the project requires 4 such parts. Furthermore, each of these servos would have their own plastic tilting mechanism, so a resulting mass would have been much bigger. On the other hand ultra light servos with weight of only 3.0 g do not have enough torque to tilt motors with good precision. Taking those things into consideration, the final choice was Servo DGS S90 S05NF – medium. Despite quite a big torque 3.19 kg\*cm (0.31 Nm) caused mainly by metal gears, it weights only 20 g.

### 3. Project of control board

After assembling all necessary elements it was time to design a control board using Eagle 6.5.0 environment. Main parts of the schematic were:

- a) **Power module**, designed to be able to acquire power from quadrotor battery (14.8 V) and withstand a minimal current required to control servos. +5 V line can withstand even a 6 A continuous current load thanks to a voltage transformer used in project, while 3.3 V line just 1.5 A (it is LF33CV stabilizer limit) but it is used just for powering a microcontroller and BNO055 modules. Capacitors were added for high and low signal frequencies filtering, and LED1 was connected just to visibly indicate the current flow.

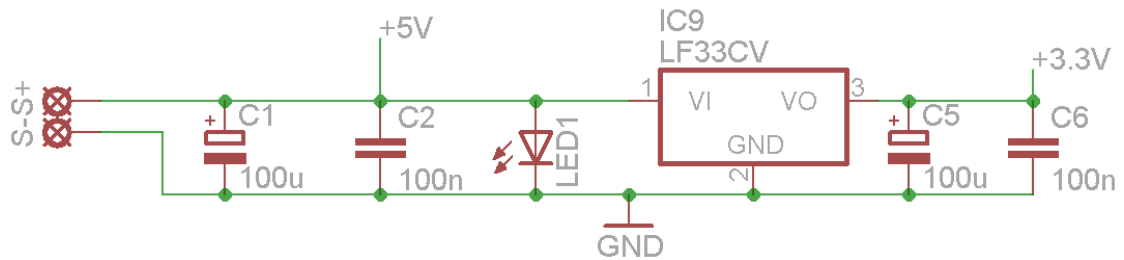


Figure 5: Power module

- b) **BNO055 module** connections were designed with the help of this module manual.

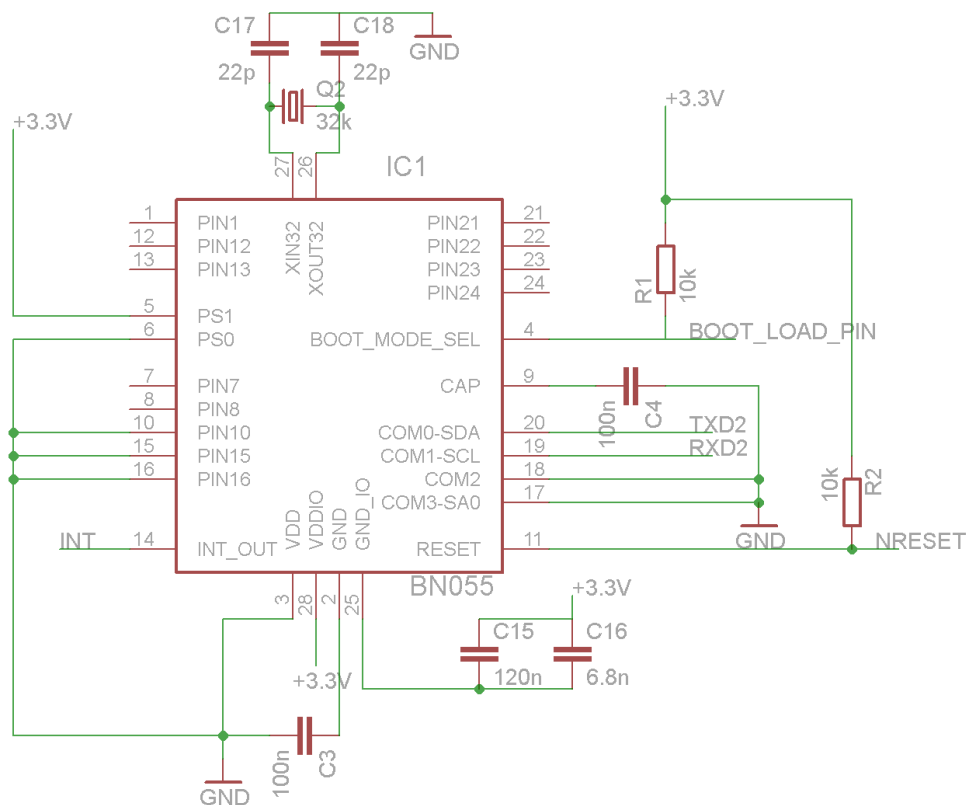


Figure 6: BNO055 connections

As it can be seen on the picture 6 there was a setup chosen of communicating via UART interface (there was also SPI possible) and for enhancing module operations there was an external 32 kHz crystal added.

### c) External modules sockets

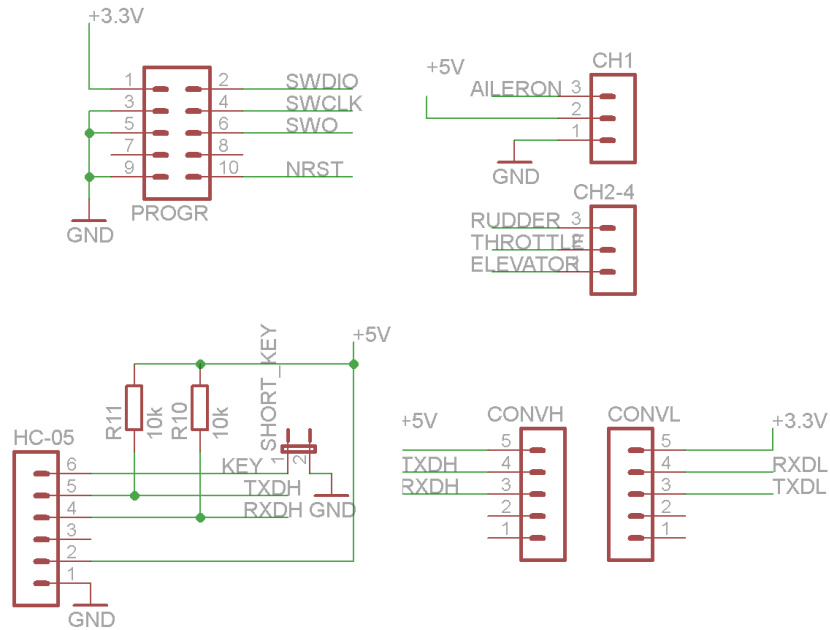


Figure 7: extra pins

To make programming of the microcontroller possible there had to be a programmer socket added. Control board will use a radio receiver this is why some signal inputs (CH1 and CH2-4) were added. In order to use Maestro servo controller additional pins had to be inserted and CONVH CONVL for signal converter in order for microcontroller to be able to communicate with Maestro module using different signal logic levels.

### d) Microcontroller connection setup.

The last module which is a brain of the control board is STM32F3. Figure 8 features a standard connections (described in STM32F3 manual). There was also an external 16 MHz crystal added.

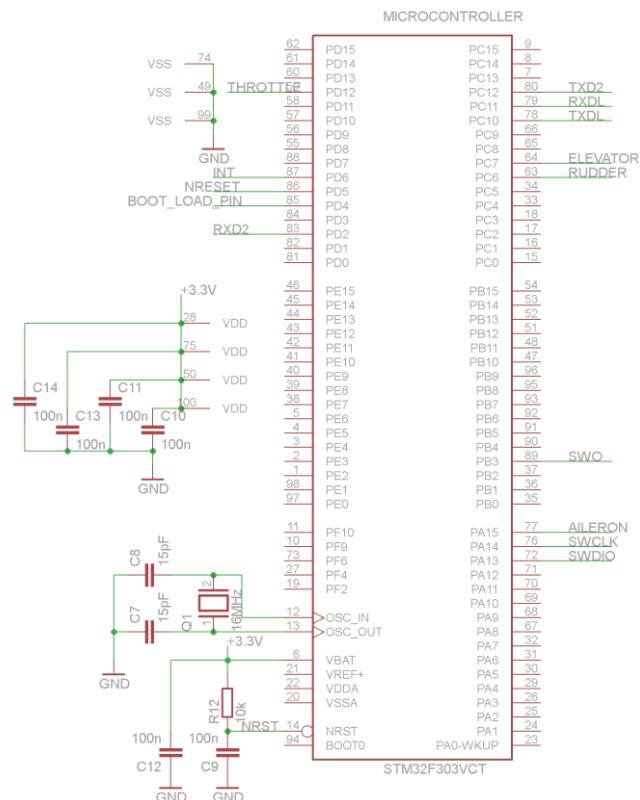
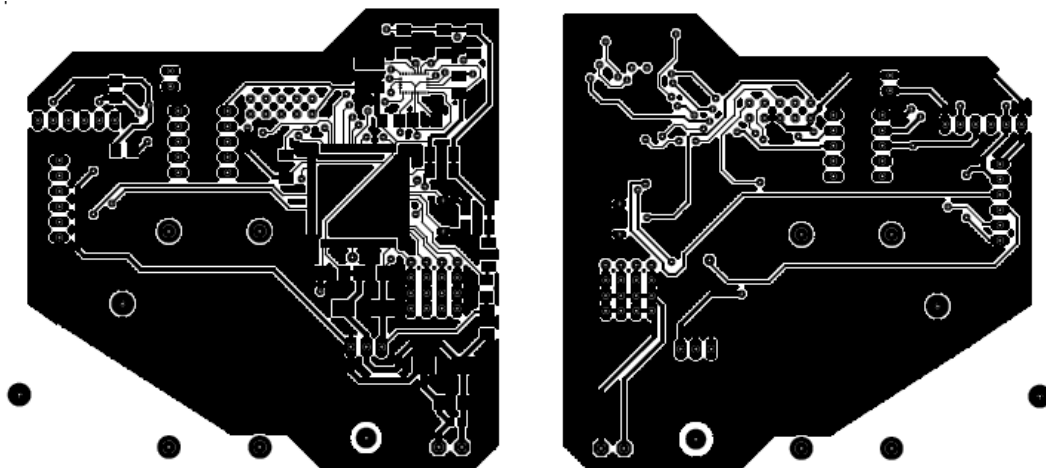


Figure 8: Microcontroller connections

After designing a schematic there had to be a PCB created (also with the use of Eagle software). The effect is presented on the pictures 9-10 which shows PCB top (inverted for the purpose of soldering) and bottom layers and also the elements setup on the board.



a) b)  
Figure 9: PCB layers: a) top, b) bottom

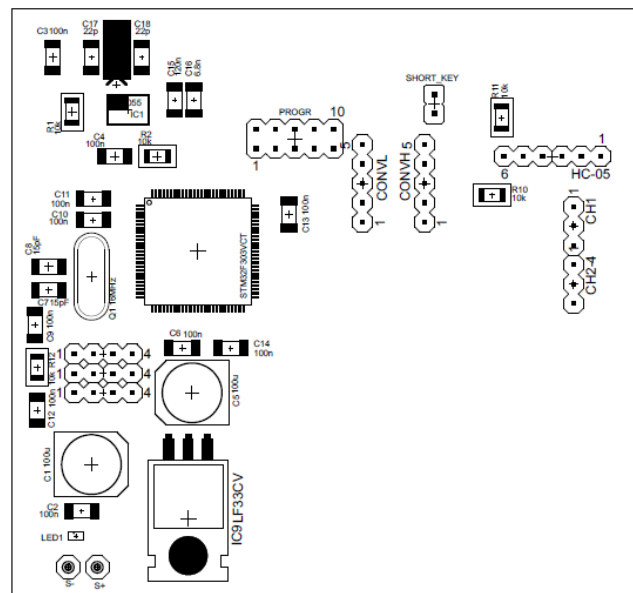


Figure 10: Elements location on the board

#### 4. Project of tilting mechanism

Crucial part of the project was to design a mechanism capable of tilting DC motors which would be powered by servomotors. In order to do so an Autodesk Inventor Professional 2016 was used. A model was based on already existing mechanisms which are working on tricopter devices. It was also assumed that a created design will be printed on a 3D printer with the use of a stiff ABS material. Final model design is presented on the picture 11. It consists of a mounting and servo platform. Mounting was used to attach the whole mechanism to a drone frame and servo platform was created to be able to connect with a DC motor itself using standard 3 mm screws and to the mounting by a pin from one side and to servomotor from the other side.

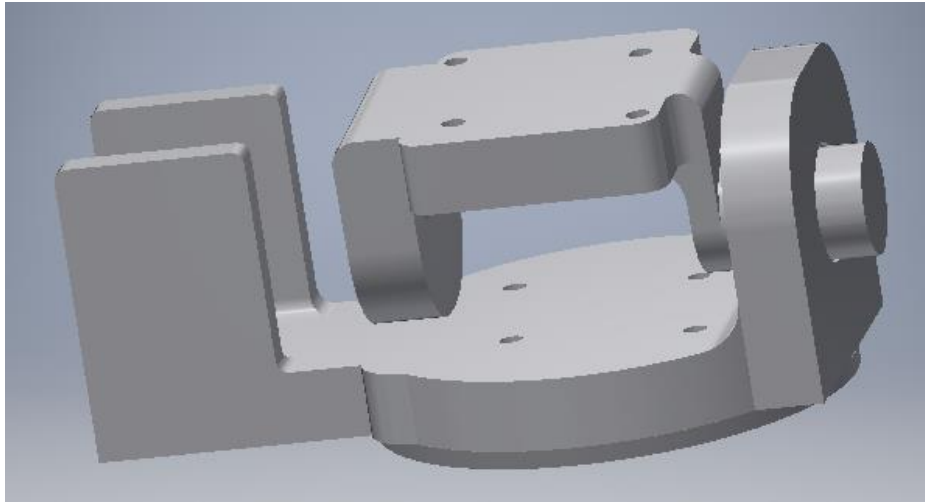


Figure 11: servo mount mechanism

## 5. Control board configuration

When the control board is soldered the last thing left to do is to program it. STM microcontroller family possess a really good programming environment which is called “System Workbench for STM32”. Generally it is an Eclipse application however it contains some accessories that make programming STM microcontrollers much easier. What is more it is supported by another program “STM32CubeMX” which task is to simply create a microcontroller pin and peripherals configuration, based on user needs, without necessity of changing every single register. Main window of this program is presented on the figure 12 with all peripherals already configured for the purpose of this project.

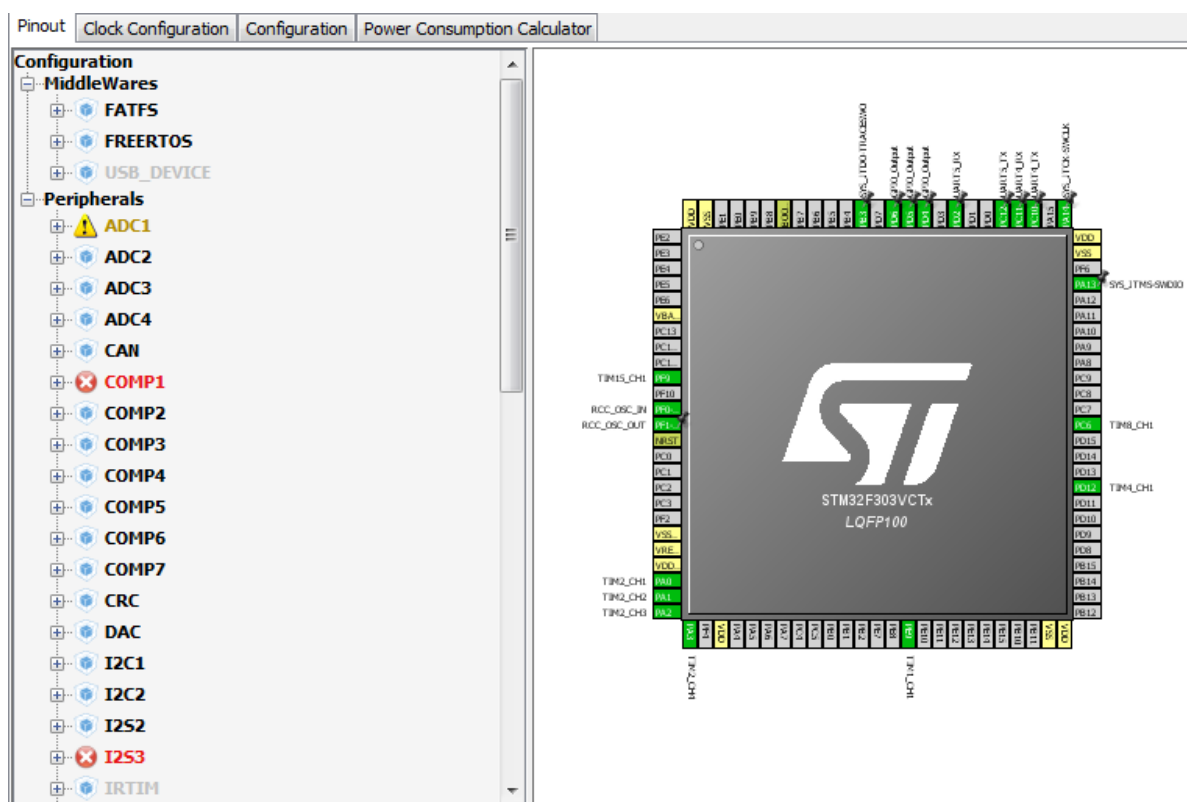


Figure 12: STM32CubeMX project main window

On the right side there is a graphical representation of a microcontroller (STM32F303VC) which contains interactive pins. By simply clicking on any of them, user can define a purpose of each connection. Green color of a pin marks that it is successfully configured, orange one tells that there is an inconsistency in pin



application. On the left side of picture 12 a list of peripherals is available, where user can define source of clocking, timers modes or communication interfaces. In this project there were two UART interfaces defined (used to communicate with BNO055 and MaestroPololu modules) , four timers set for PWM input mode (to read signals from a drone controller receiver), four timers channels as PWM output (used to control DC motors rotation speed) and a few GPIO pins (necessary to correctly program BNO055). After choosing necessary peripherals, next step was to exactly select parameters of each of them which takes place in "Configuration" tab. There a user can define for example timers counters settings, interrupt sources and everything else that normally would have been done by changing registers values. Last thing to do is to build a project and export it. Then it is possible to open created project in Eclipse and start working on the main code of control board.

## 6. Summary

Almost all of the project goals were accomplished successfully however the most crucial one, which is developing a control algorithm, is still to be done. Very important thing in project like this is to make a thorough research on the topic to know how to divide available time in order to accomplish every task which was set on the beginning. To ensure that all of the drone parts are picked correctly a special calculator can be used which computes average time flight, power consumption, lift power or even heating process of a drone based on modules chosen. Link to such a calculator is given in the reference section. After a drone was built and all servo mountings fastened to a drone frame, it appeared that ABS material was a little too weak to be used in a pin construction because in one case of all four modules the part broke. This is why it is advised to use a small screw or a stake instead of a pin made from ABS. Next thing concerns a control board. In the above project it was etched using termotransfer technique. It was almost impossible to properly solder BNO055 module without any short circuit. This is why, in the end, the whole board etching was ordered to be done professionally by a certain company. It made soldering of previously mentioned module possible because of its printed boarders on the board and soldermask protecting all the circuits. Unfortunately, this made enough delays in project schedule, that the last part of developing control algorithm was not done. However all the peripherals were successfully programmed together with BNO055 communication and MaestroPololu control of servomotors. While System Workbench for STM32 and STM32CubeMX are free to download, Eagle and Autodesk Inventor Professional were available from the Autodesk internet site, thanks to a student licence.

## 7. References

<https://www.youtube.com/watch?v=0E-K5vMZ89E>

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