Microcontrollers that...fly:
how to make a drone

Catching up with promising drone technologies, this workshop will let you switch from buying a drone to building and customizing one on your own. With the use of standard Fab Lab equipment and materials, quickly and at a low cost. Starting from making the flight controller and ending with software configuration, you will go through all the necessary steps to create an understanding for future designs and construction of drones of your own specifications. This workshop will use the satshakit and satshacopter Fab Academy outcomes as technical references to build the drone.

General structure of the workshop

Total length: 3 days.

Participants 12 or 16, divided in groups of 2 people each, building 6 or 8 drones.

Day 1 - Structure and PCB - 4h
Day 2 - Flight controller - 4h
Day 3 - Be ready to fly - 6h

Day 1 - Structure and PCB

Materials

- 30cm x 30cm 8mm plywood
- 15cm x 15cm 4mm plywood
- 5cm x 7cm FR2/FR4 copper sheet
- PLA 100g, in two colours if possible
- 8 x 12mm M3 bolts
- 8 x 10mm M3 bolts
- cyanoacrylate glue
- 2 x CW LD-Power MT2206- 1900kv motors from D250-2 kit (link)
- 2 x CCW LD-Power MT2206- 1900kv motors from D250-2 kit (link)

Machines

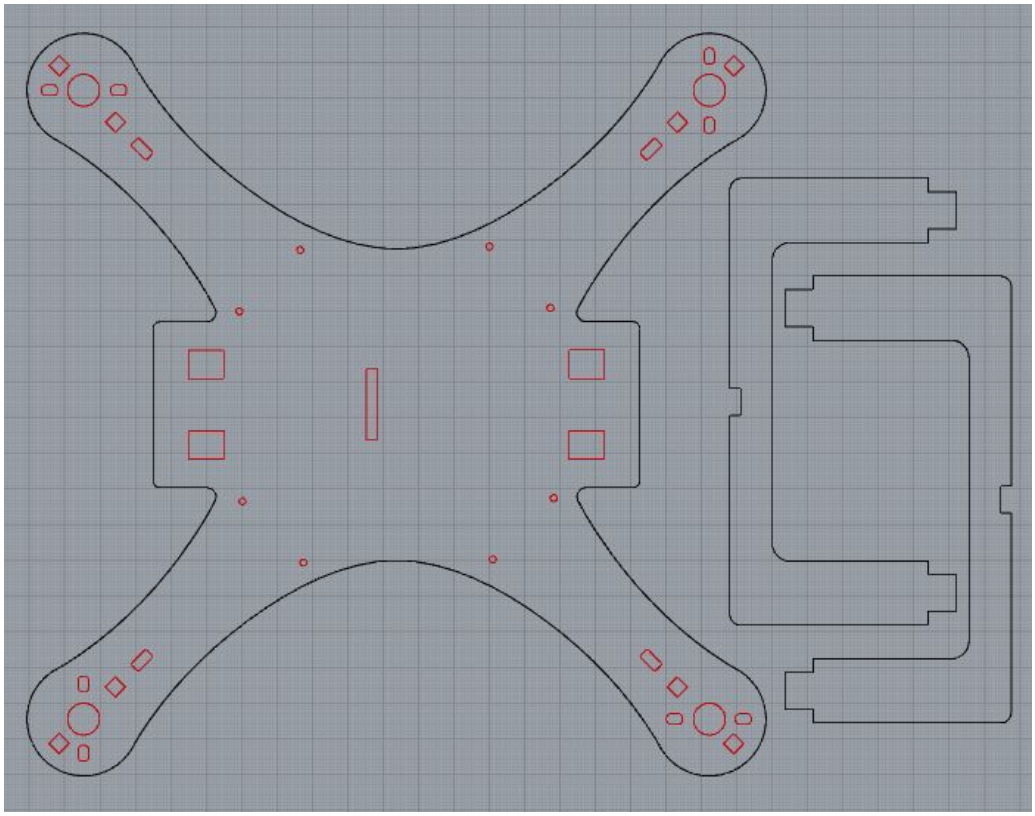
- CO2 laser cutter
- 3D printer
- small CNC

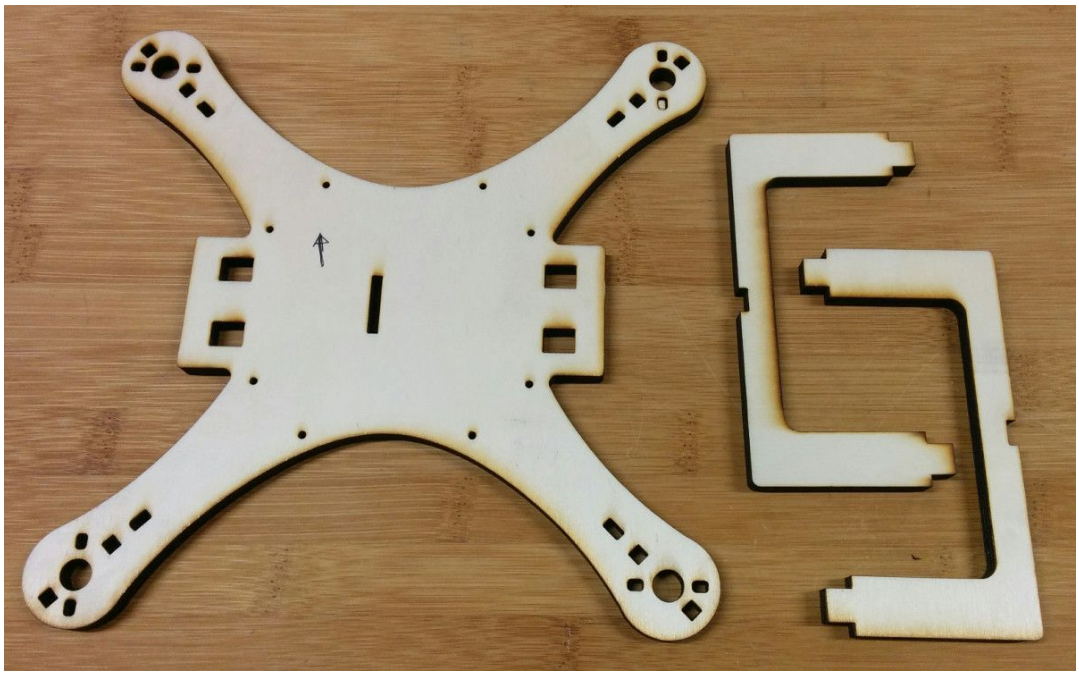
Files

- main frame dxf 3dm
- upper frame dxf 3dm
- foots stl 3dm
- flight controller internal traces png
- flight controller holes png
- flight controller external cut png

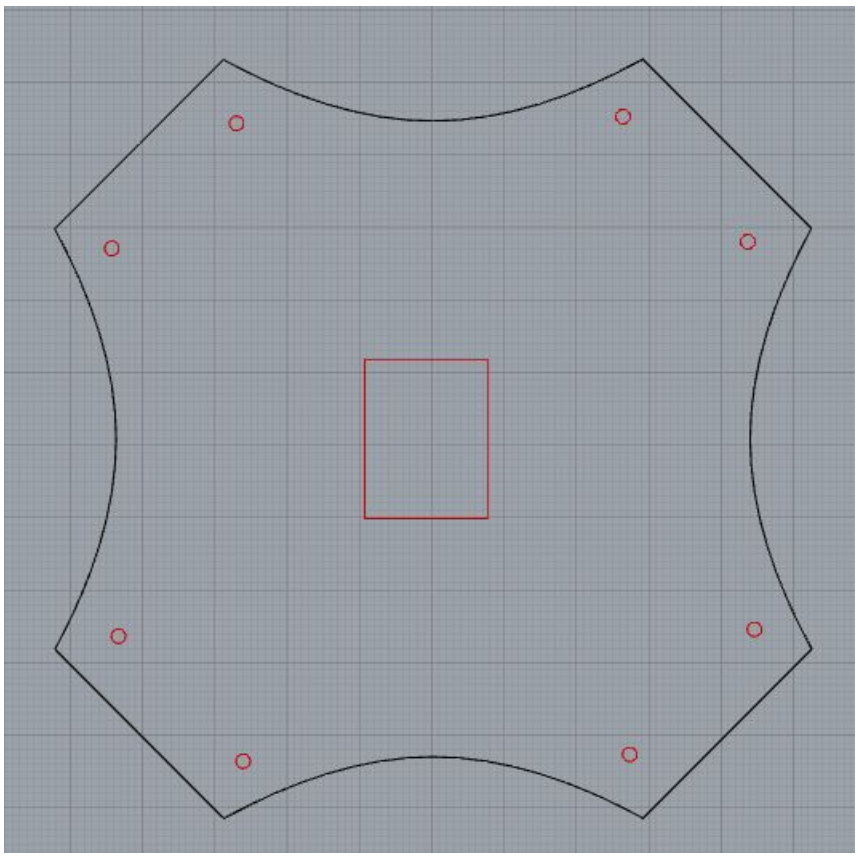
Making the frame and the foots

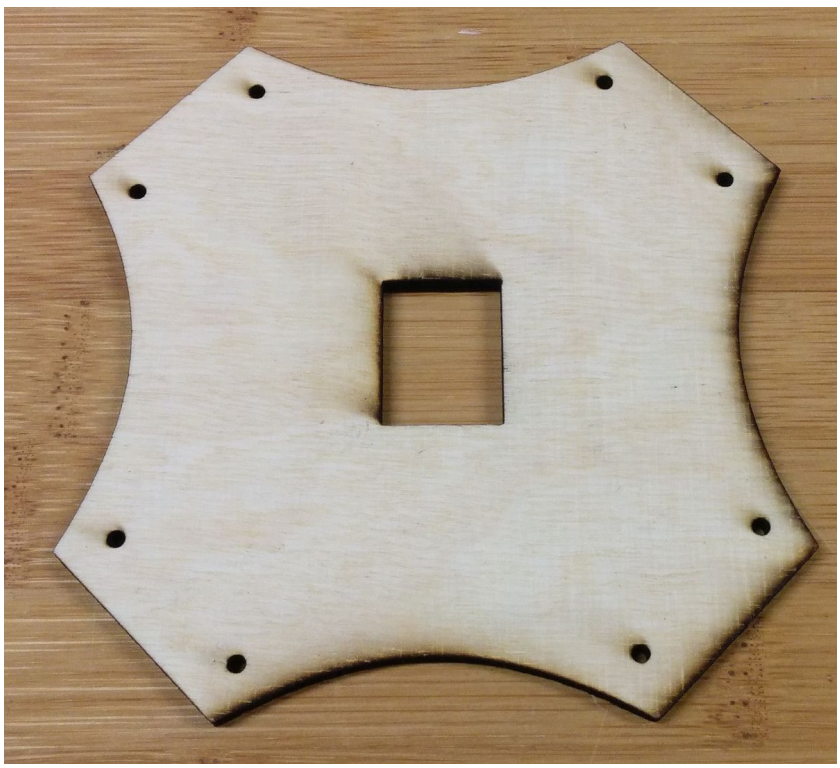
The main frame and the supports are made of 8mm plywood. You can easily cut these using a C02 laser cutter, please make sure that you cut the internal holes first and then do the external cut, by using different layers and/or colours in the laser cutter settings.



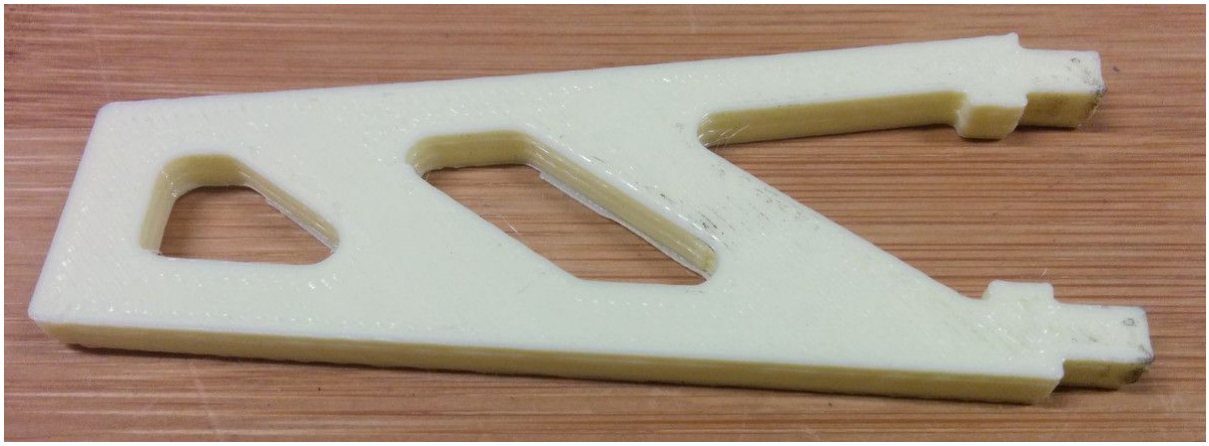


The upper frame is made using 4mm plywood, also this is a pretty easy cut you do can by using the laser cutter.



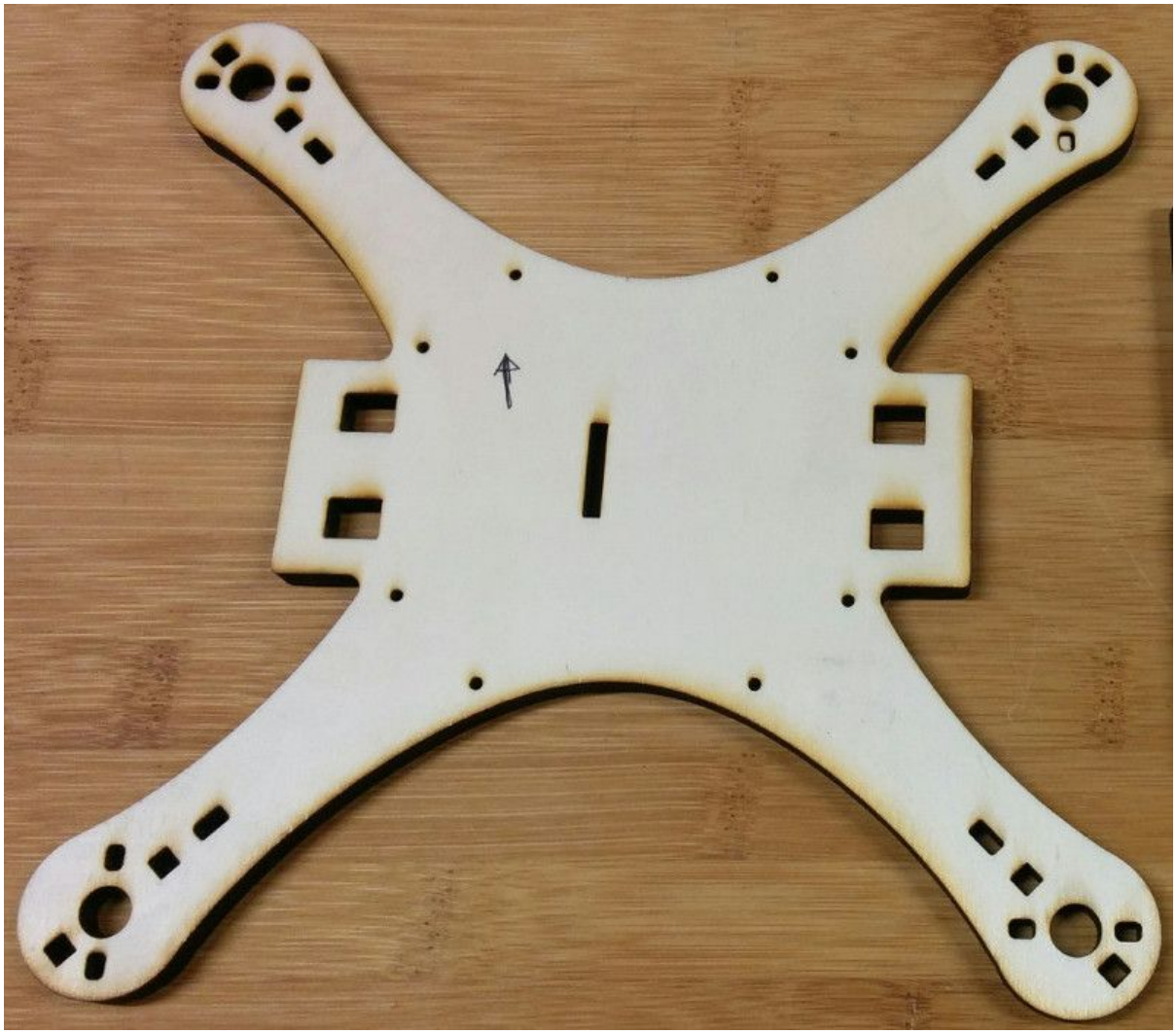


Foots are pretty simple 3D printed objects, is recommended to use PLA, 25% infill and a shell thickness of 1.2mm. Please make 4 of them and be sure to remove the brim if any.

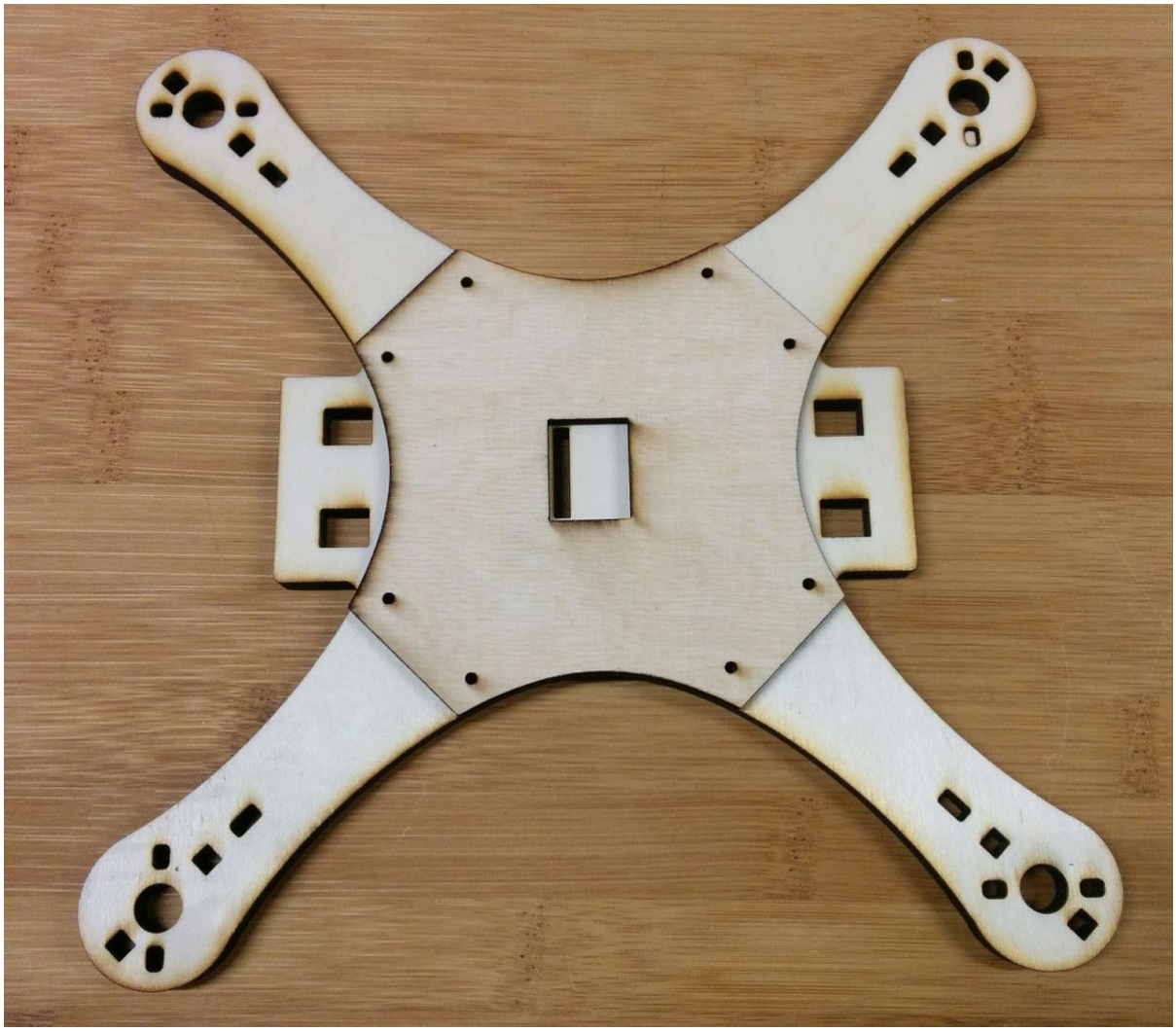


Frame assembly

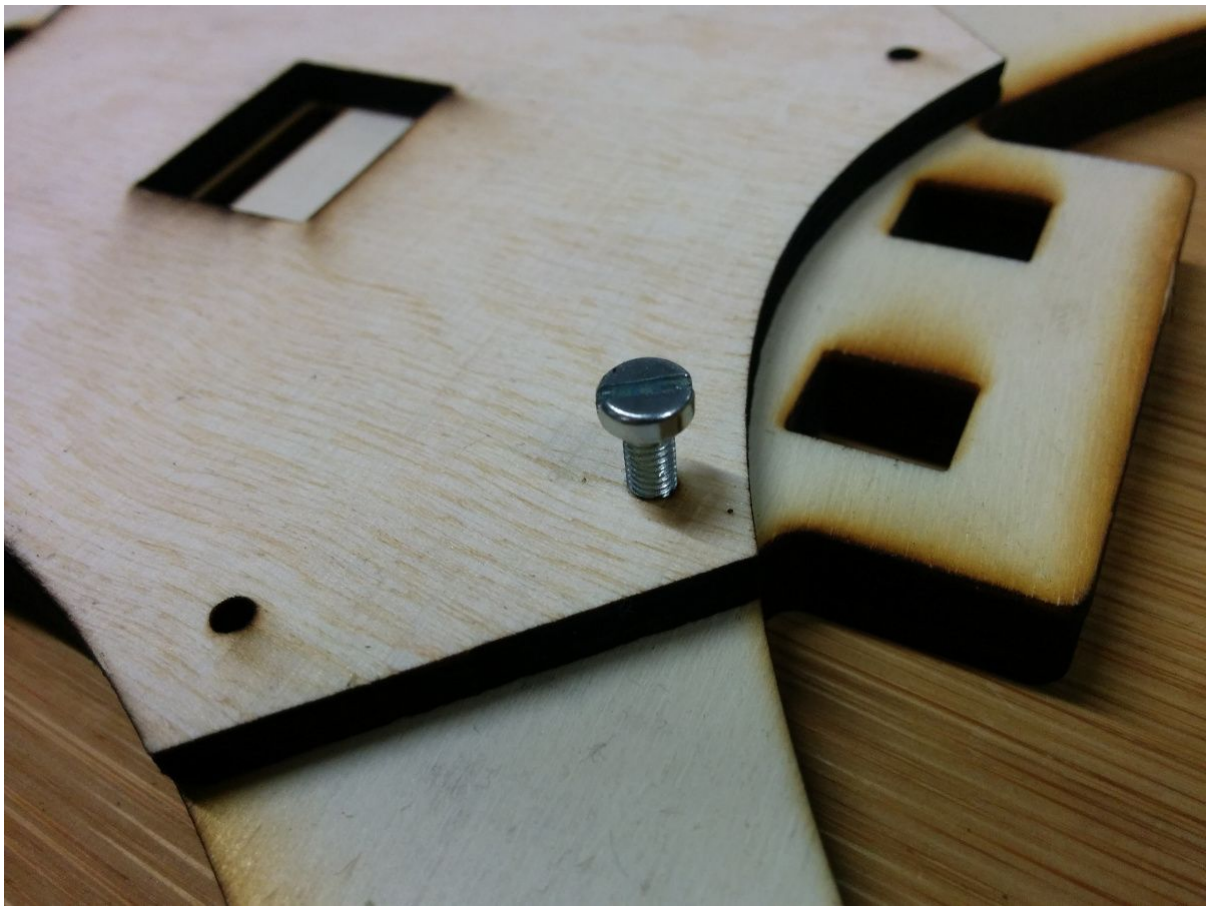
First, detect which **side of the main frame must be up**, you can do this by looking at the following picture and taking as reference point the rectangular hole that is in the center-left of the frame and the holes for the screws of the motors at the end of the arms.



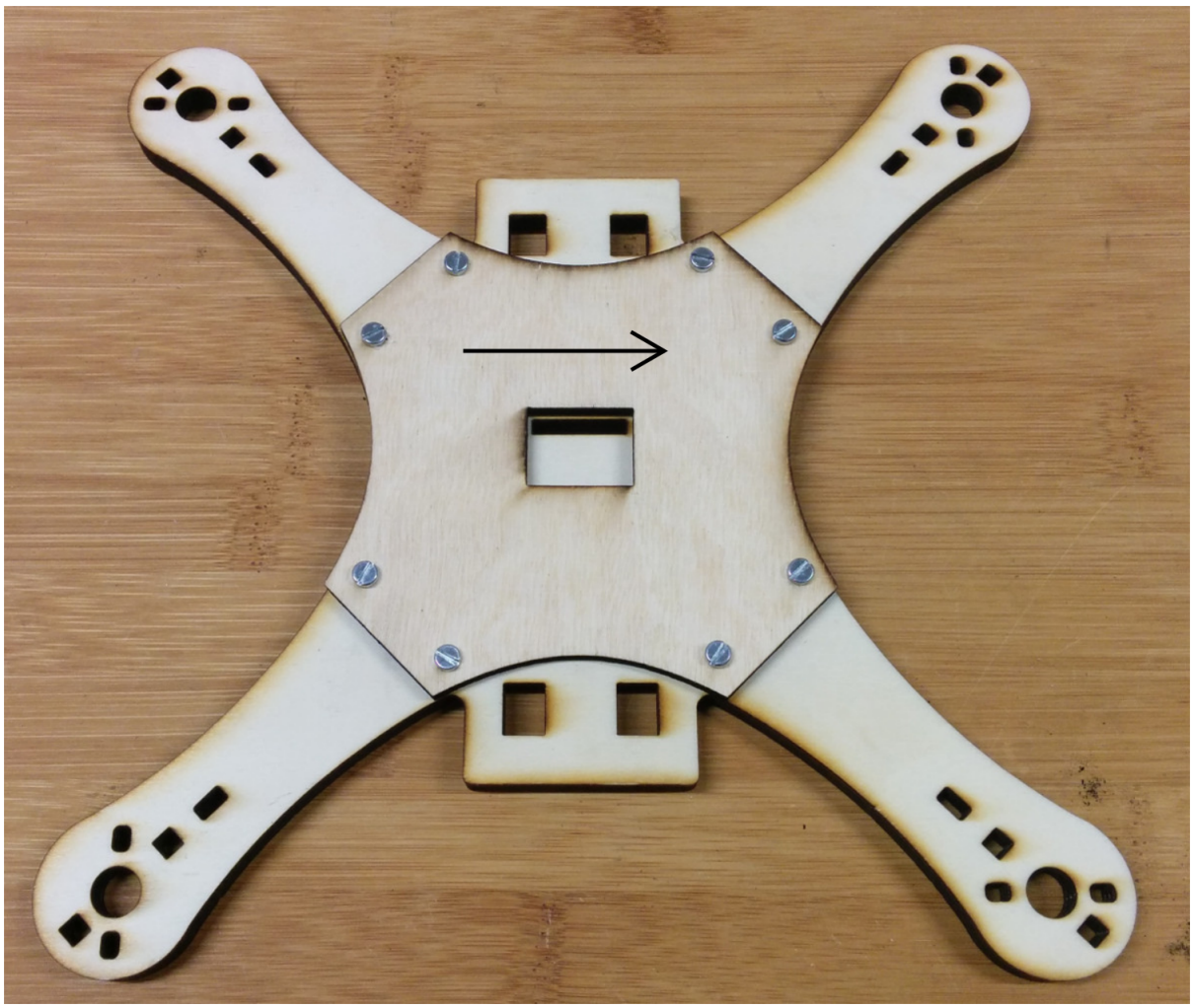
Then put the upper frame on the main frame to obtain the **location for the IMU** (the rectangle at the center) as following:



Now fix the upper frame using 8 x 12mm M3 bolts screwing them directly into the wood. It does not require to use nuts.

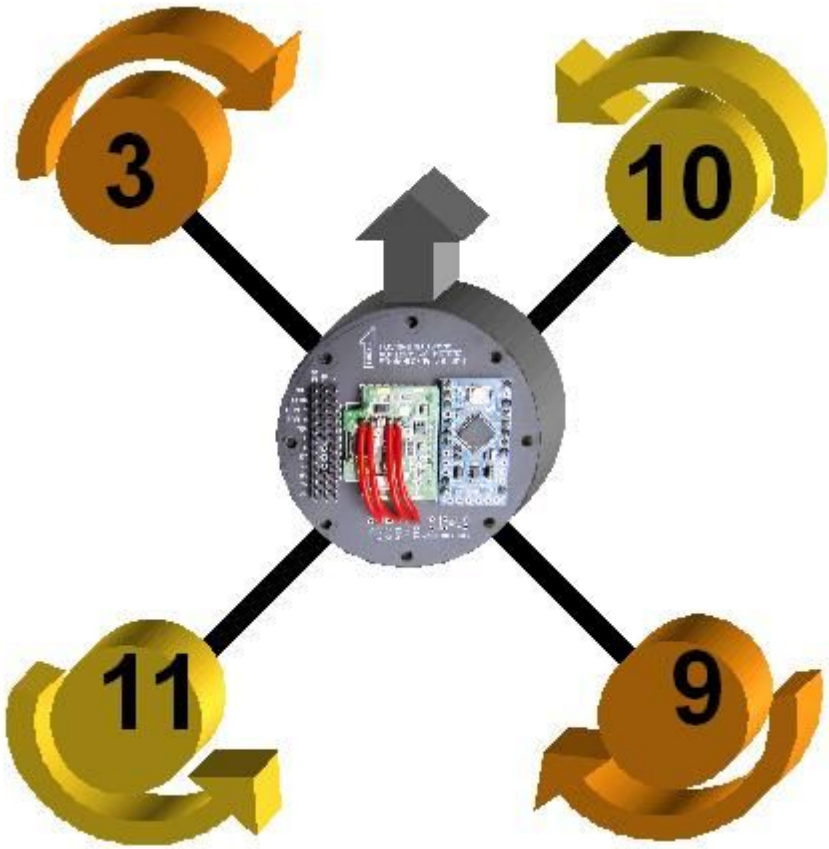


At the end you must have the frame assembled as the following picture. Take as a reference the position of the center rectangle with the fessure. Draw an arrow to mark the direction, as it will be really useful for the next steps:

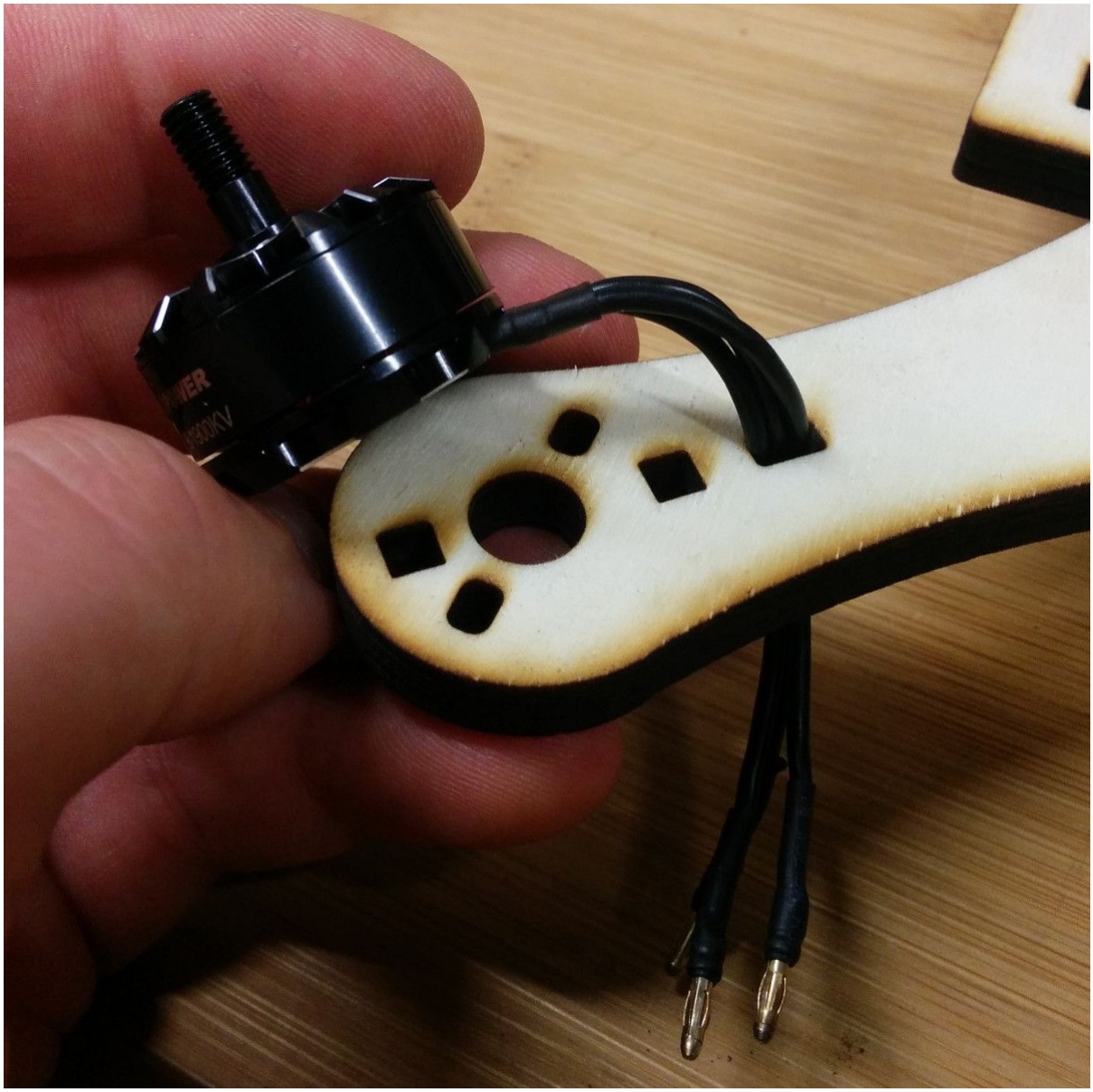


Before attaching the motors to the arms you have to make sure you know if the motor is **clockwise(CW)** or **counterclockwise(CCW)**, to place it in the right position. You can check if a motor is **CW** or **CCW** by trying to screw the caps into the motor axis, and check in which direction they can rotate. The direction of the motor is the opposite direction in which the motors will screw on the motor axis.

You can look at this picture to see right position of the motors depending if they are **CW or CCW**. Remember that the direction of the propeller rotation must be go in the opposite direction of screwing the cap, so that will always tighten the propeller on the motor.



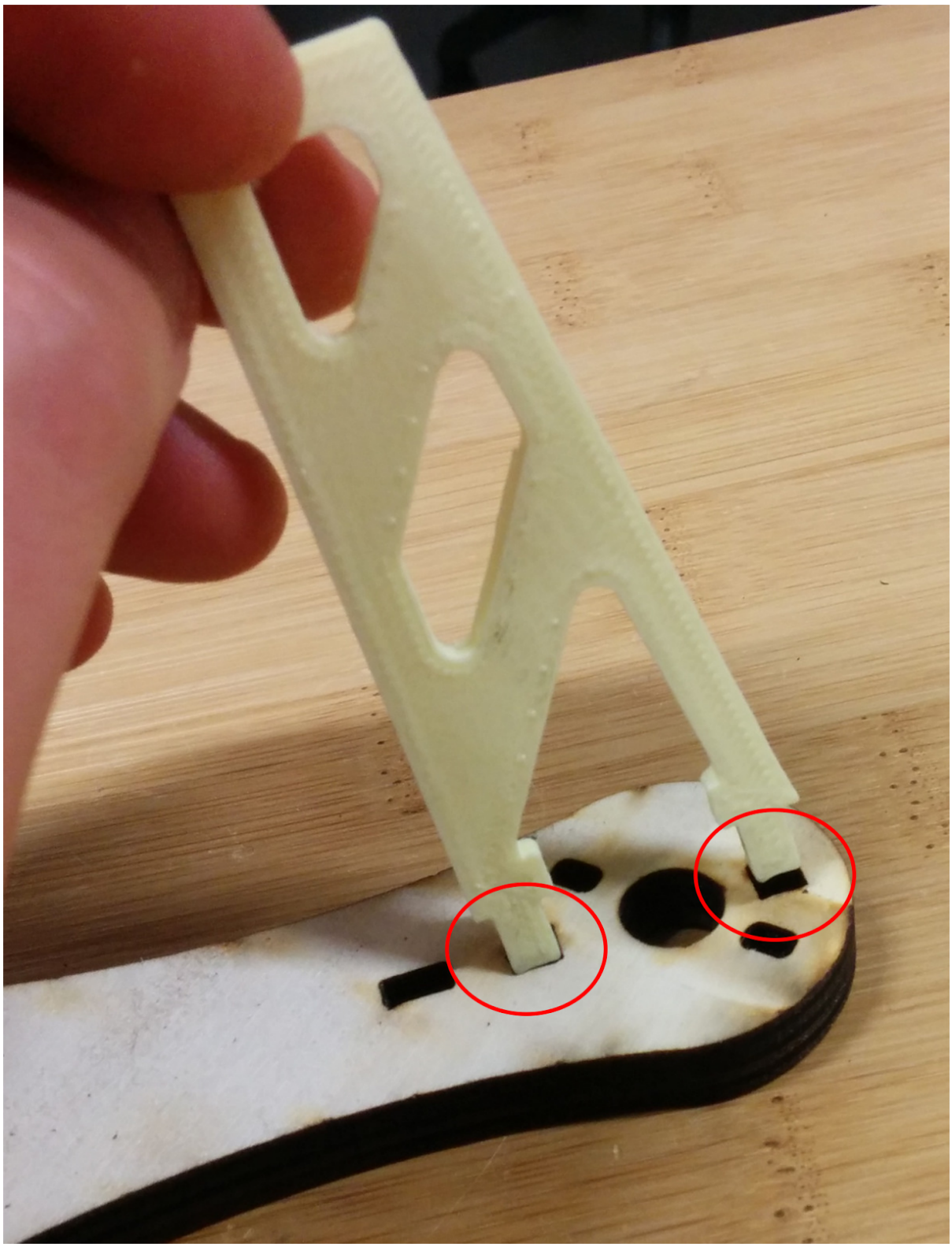
Now is the turn to attach the motors. First be sure to **pass the motor cable into the predisposed arm hole**.

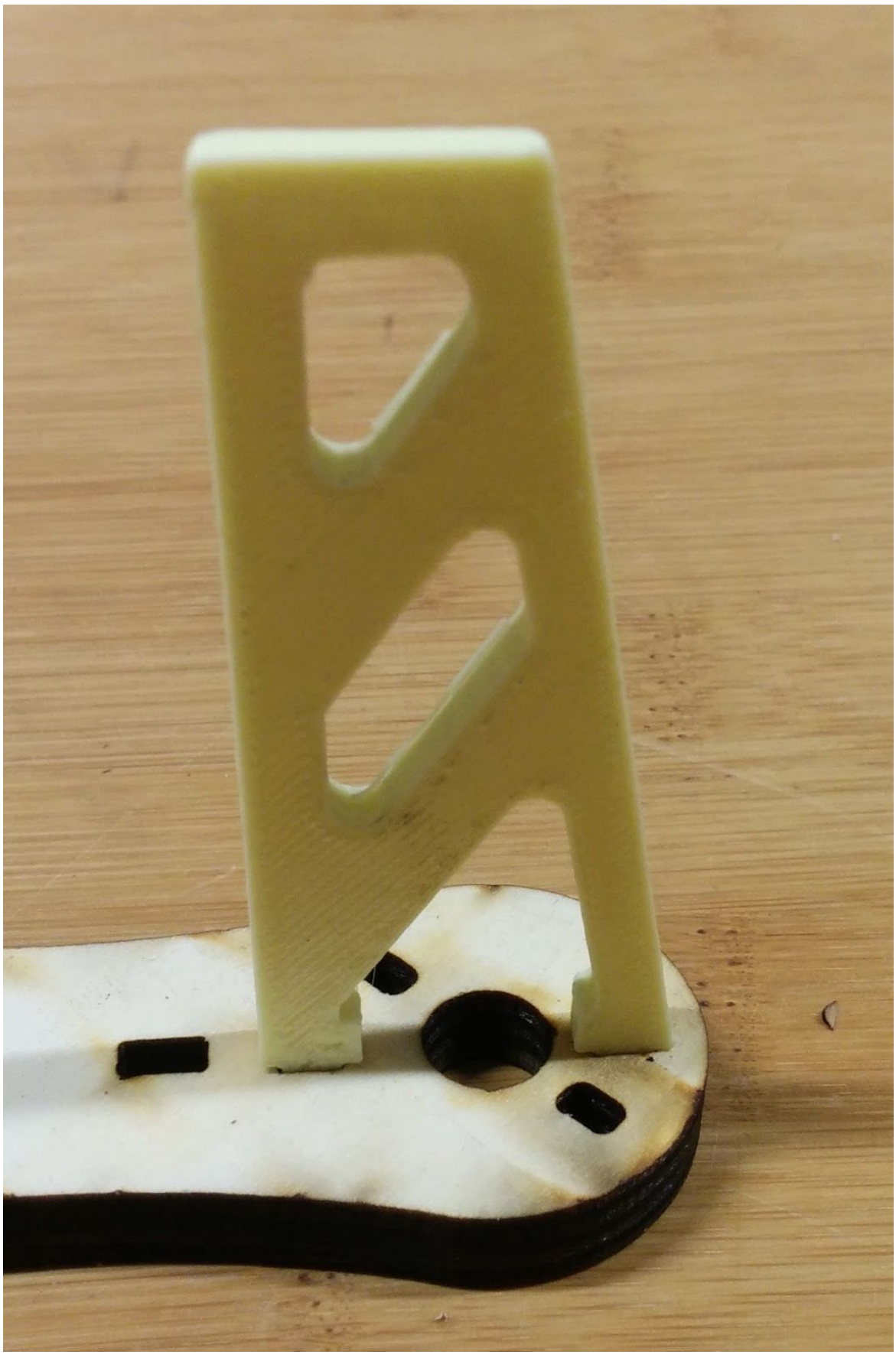


To attach the motors, you need to use 2 x M3 10mm bolt for each. Fix them from downside of the arm:

Please adjust the position of the motor more or less at the center before tighten the bolts:

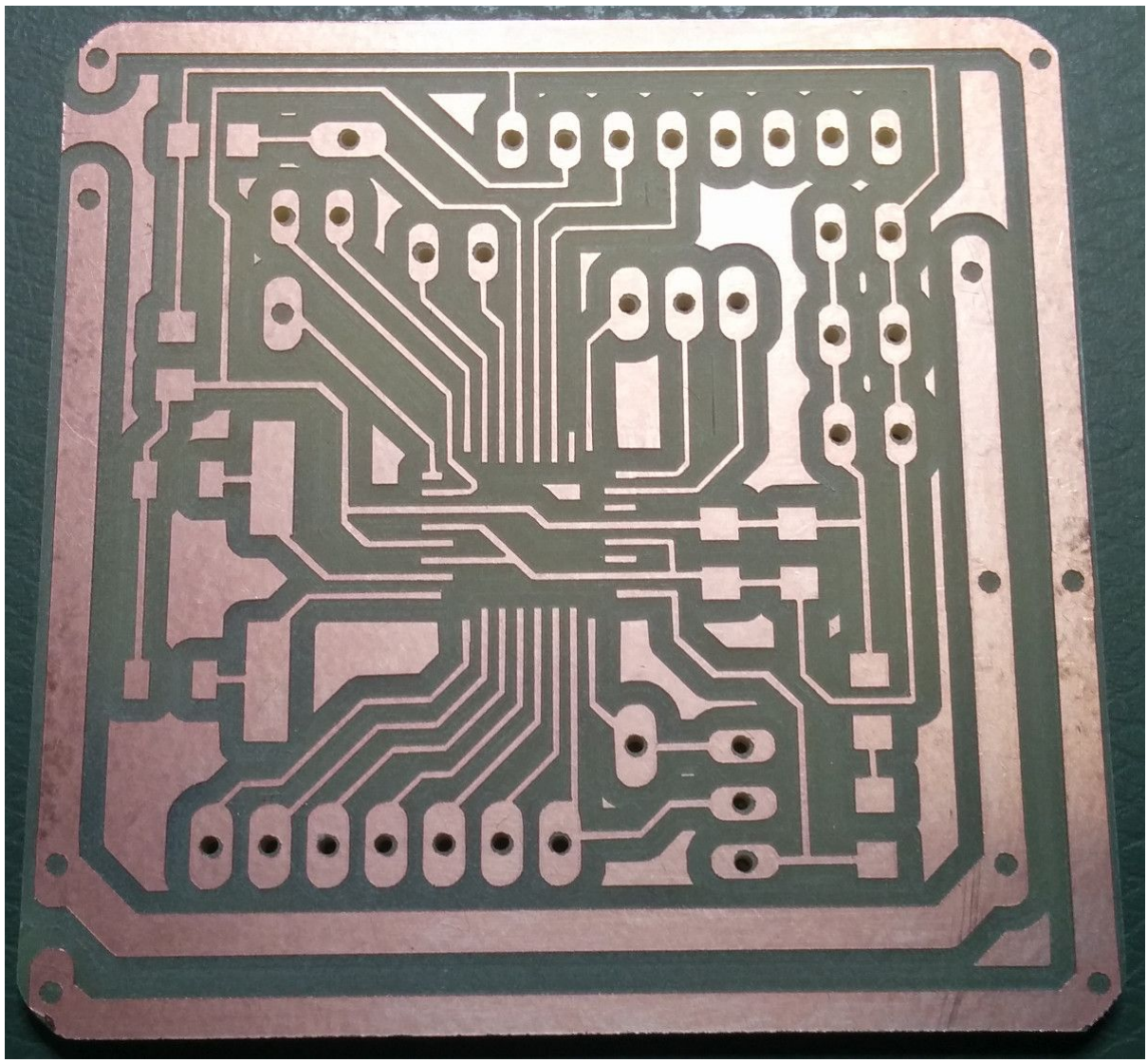
Put a little bit of glue on the top ends of the 3D printed foot (highlighted by the red circles), and attach them how is shown in the following two pictures. Best is to use a cyanoacrylate glue, even better is the one specific for wood and other porous materials.





Making satshakit flight controller PCB

To make the **satshakit flight controller** is needed to use a little cnc machine. You can make the board using different copper sheets, like **FR2 or FR4** (FR4 preferable as is more resistant). If you can, use a **0.2mm milling bit or smaller** to be able to easily make the traces of the processor. Otherwise the can rely on a 0.1”/0.254mm milling bit. Also, put some offsets between the traces to avoid bridges during soldering, for example 8 offsets and 55% overlapping in Fab Modules. Make sure to clean the board after the milling process, to ensure that no little pieces of copper are going around making unwanted contacts. The final result should be like the following image.



Day 2 - Flight Controller

Materials

- satshakit flight controller components, check the BOM here
- soldering wire
- Arduino UNO and its usb cable
- 6 Male-Female jumper wires

Machines

- soldering station

Files

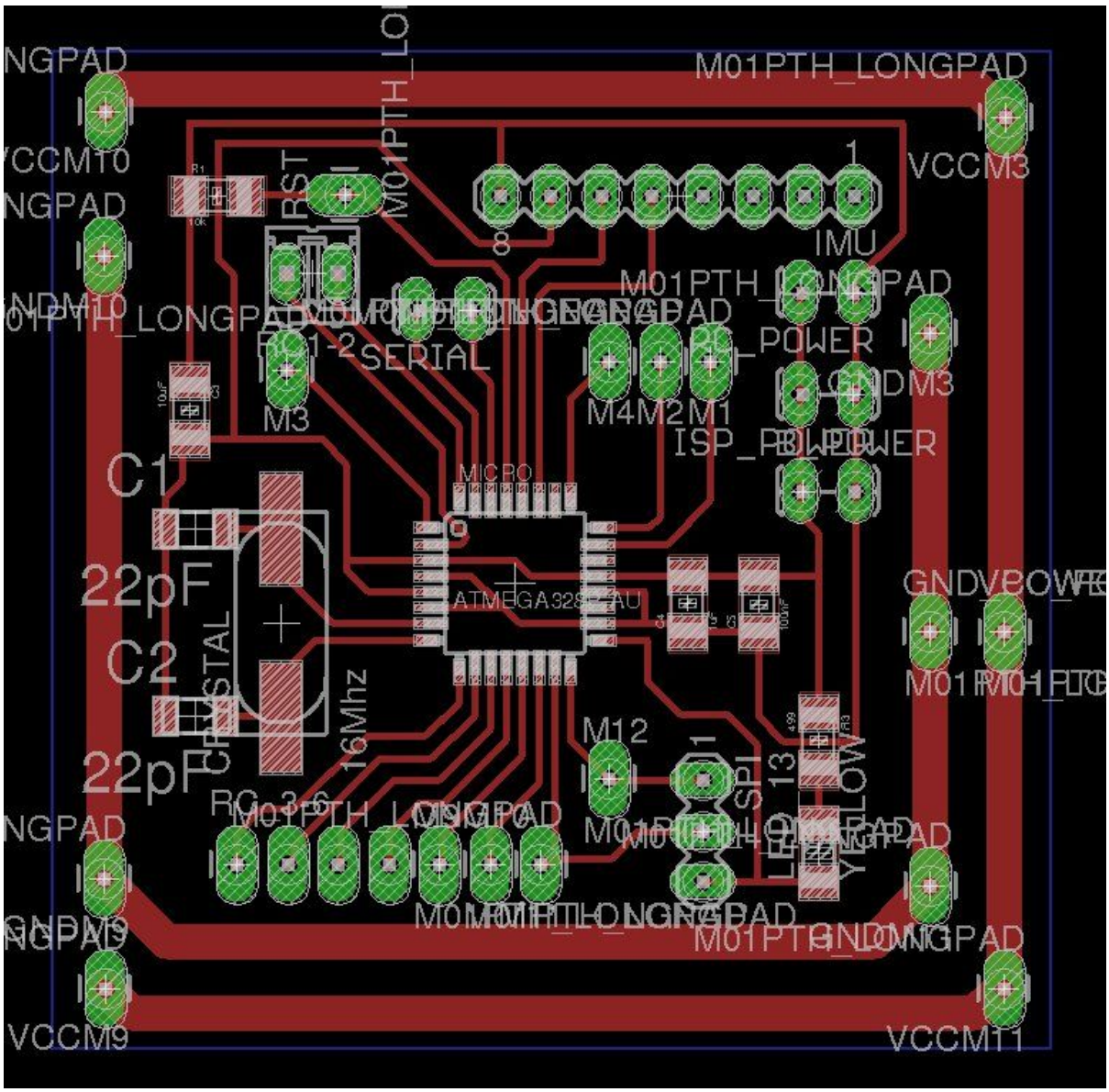
- satshakit flight controller schematic
- satshakit flight controller board

Software

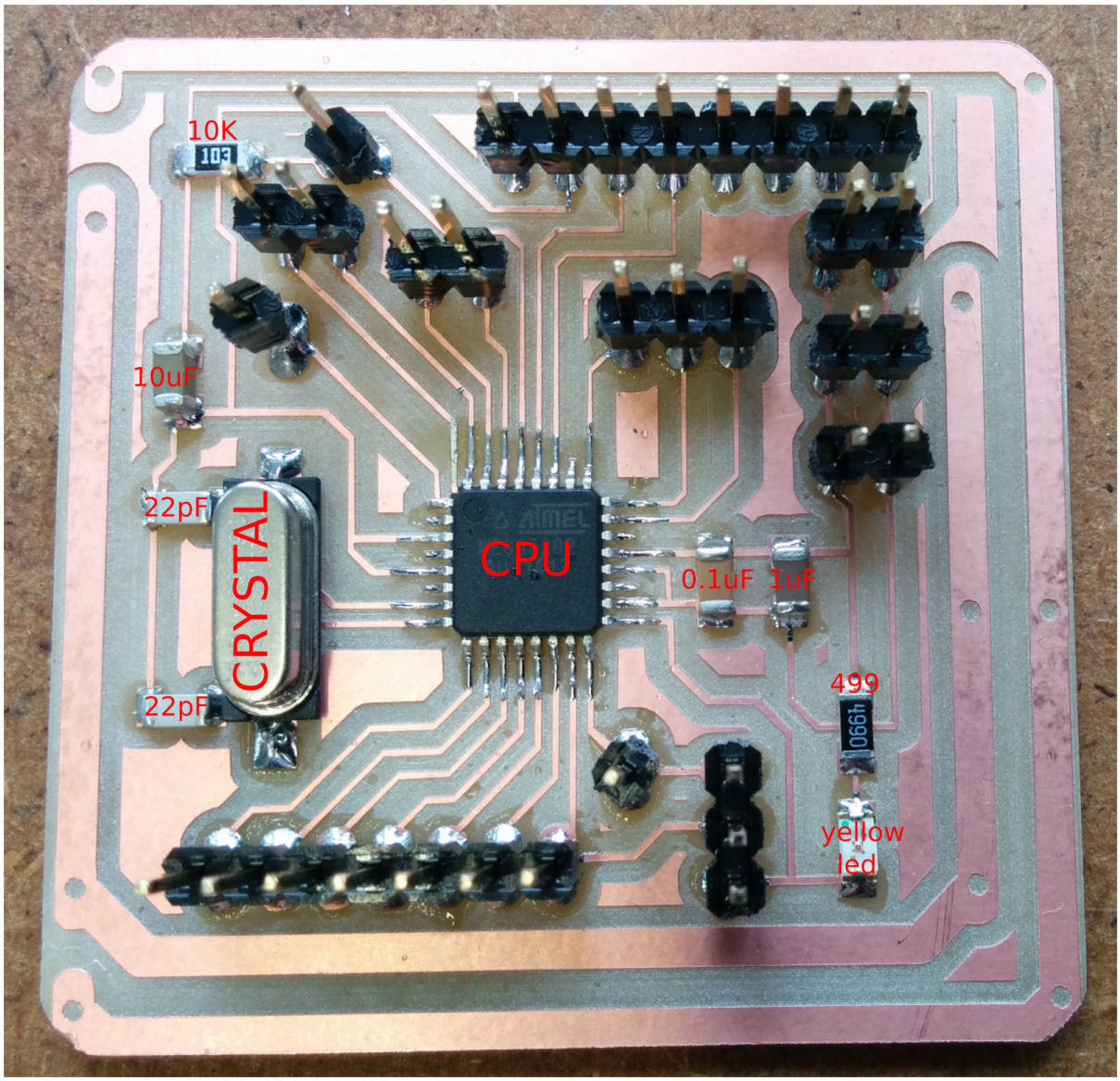
- Arduino IDE last version (link)

Soldering the components

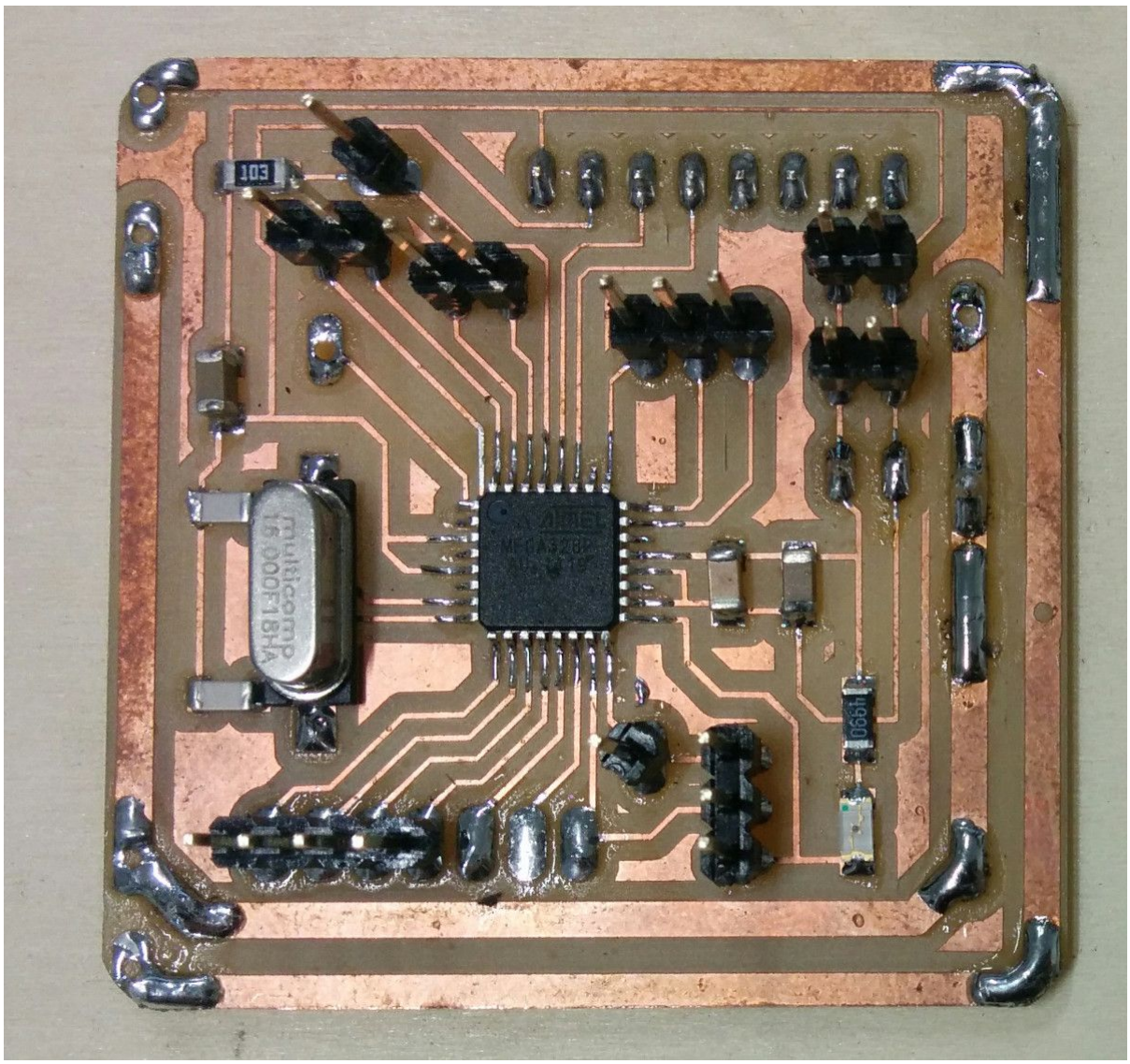
To solder the components please use a **thin soldering wire (0.3mm-0.5mm)**, most important to easy solder the ATMega328p pins. Use use a temperature of **max 290 degree** to avoid damage the chip and **make solid solderings** as this board will fly with the drone and you don't want that something will disconnect during flight as this will result in crashing the drone. Also, **don't stay too much time with the soldering iron** touching the components to avoid damage them. You can look at the following pictures to see where solder the component.



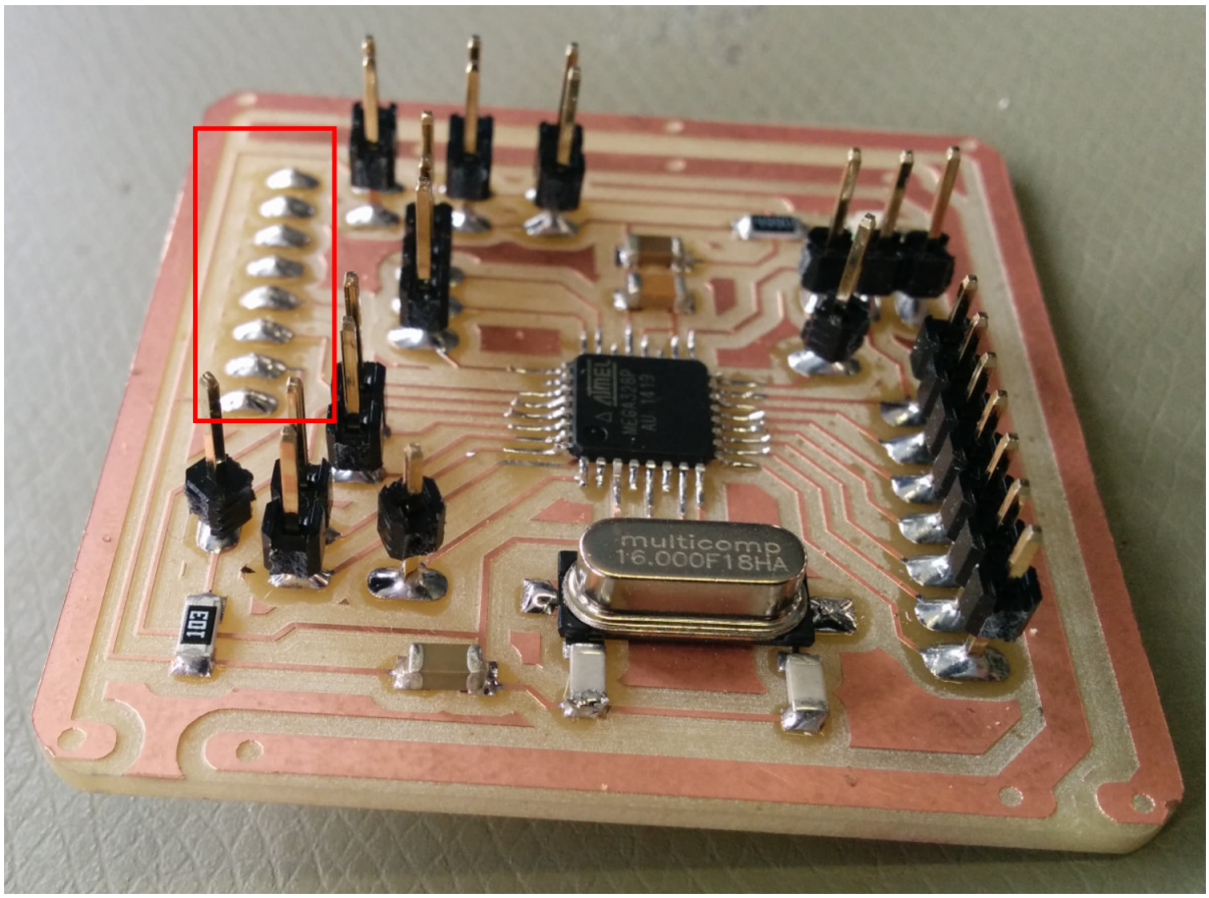
Here you can also have a look to the soldered board to see which components are where. Please do not solder any pin header in this stage.



The following picture is showing the pin headers required to be soldered:

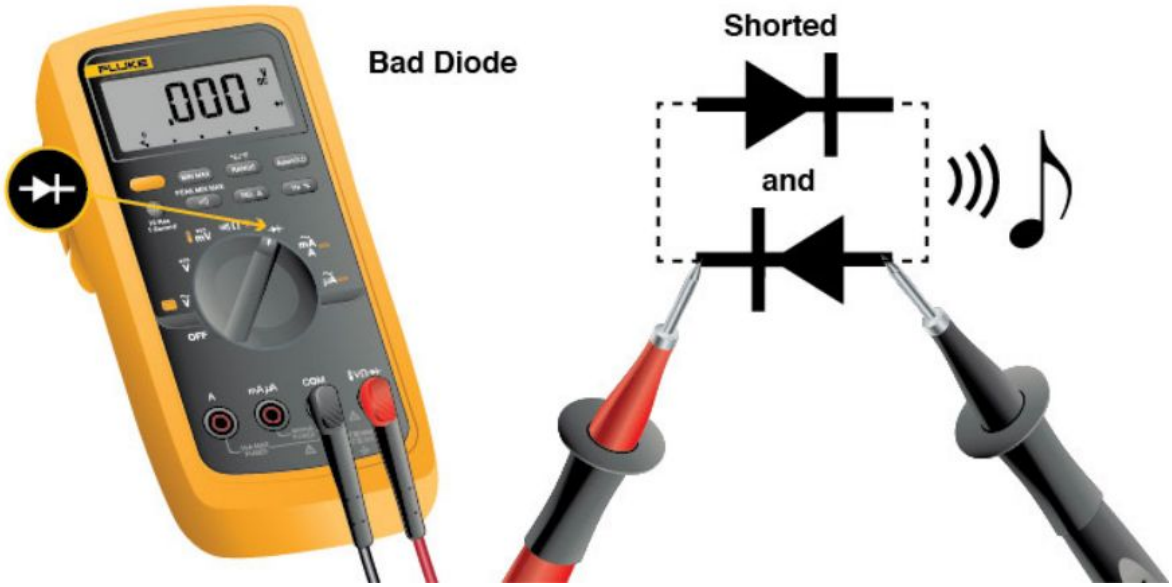


Please solder the IMU connector to be on the downside of the board instead of being up, inserting them from below instead from the upside:

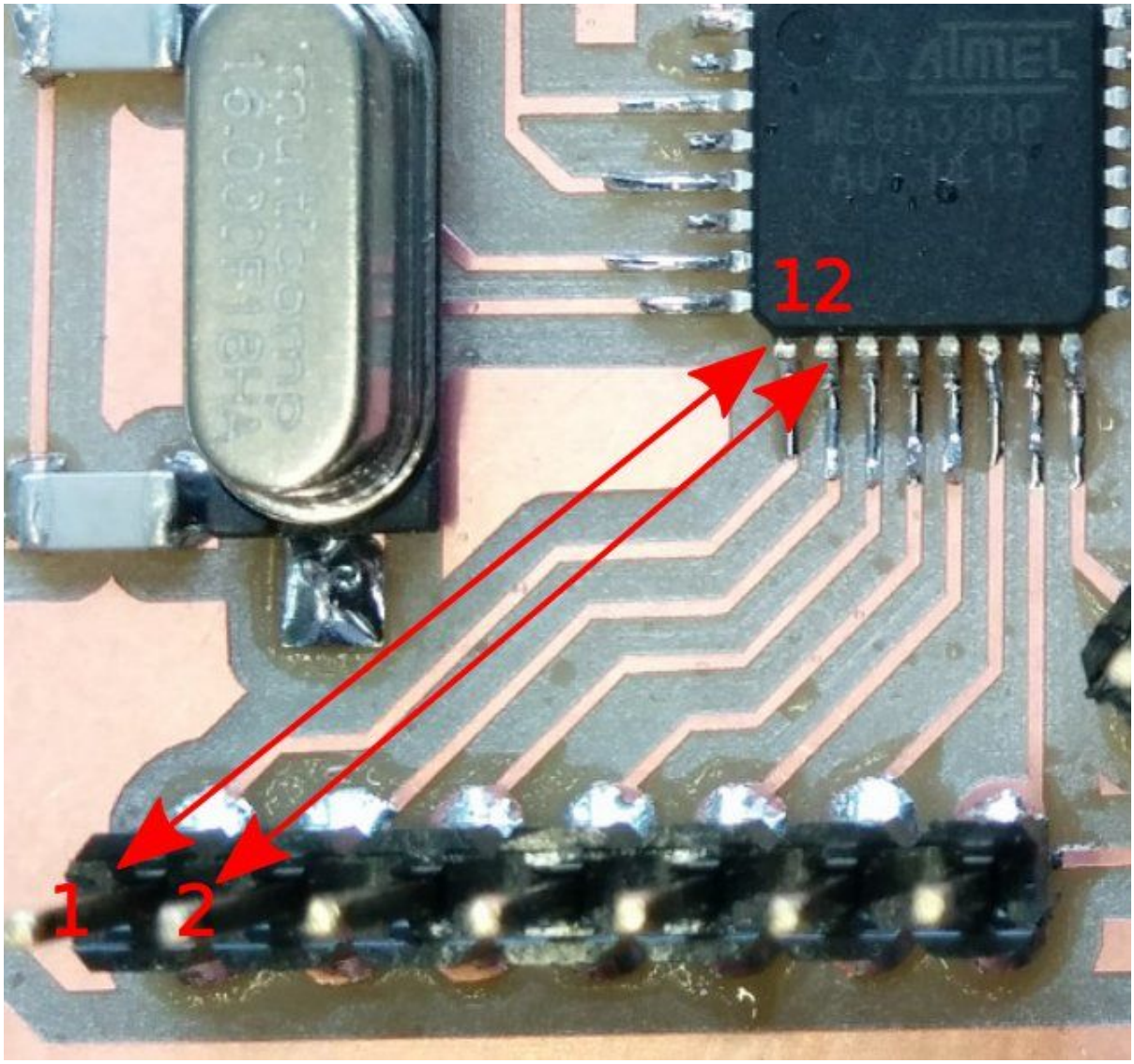


Testing the board

Testing the board is really important task, that will make you sure of its working status before going to fly. To test the board we can use the **diode function with beeps** of a multimeter, checking from the tip of each pin header, to the soldering of each of the component.



Most important to test are connections between the processor and the other components, such as the pin headers.



If something is not making **any beep, please solder it again**, eventually adding some more soldering wire to the solderings and then test it again. Repeat this process until everything is properly connected.

Programming

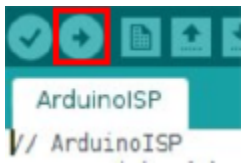
Once you have finished soldering the flight controller you can program it using an Arduino.

To do this you need:

- Arduino Uno board
- USB cable
- 6 Male-Female jumper cables
- a computer with the last version of Arduino IDE installed

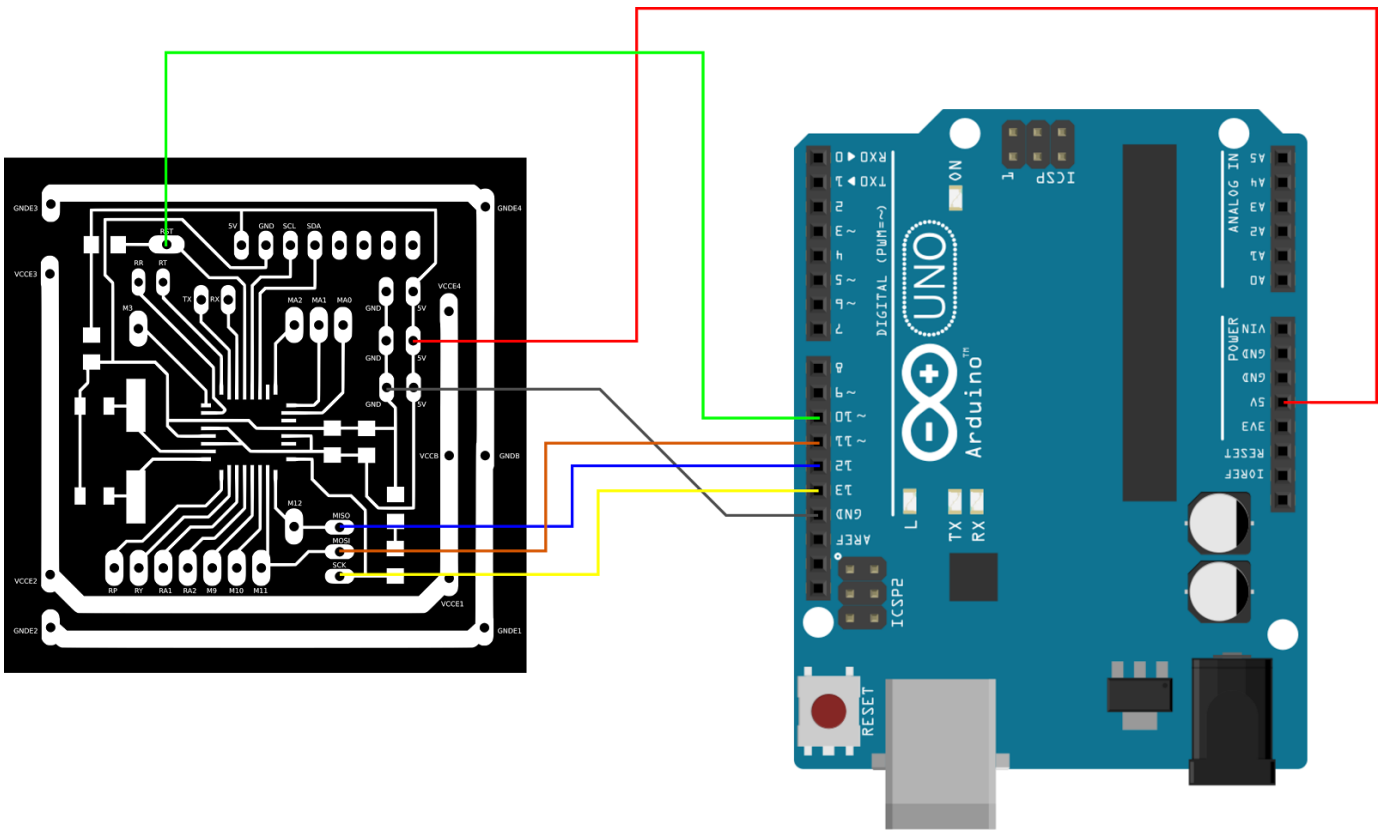
Do the following steps to program you flight controller:

1. make sure that nothing is connected to the Arduino (cables, shields and so forth)
2. connect the Arduino to the PC using the USB cable
3. open the Arduino IDE
4. upload to the Arduino the Arduino as ISP sketch clicking on **File -> Examples -> 11.ArduinoISP -> ArduinoISP** and then click onto the upload arrow of the IDE

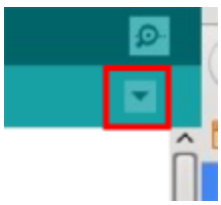


5. disconnect the Arduino USB cable from the PC

6. connect the Arduino with the satshakit flight controller using 6 jumper wires as follows:



7. connect again the Arduino to the PC using the USB cable
8. download the latest version of the MultiWii from here link, and extract the zip archive content in a folder
9. open the **MultiWii.ino** sketch found in the MultiWii folder doing **File->Open**
10. click on the files dropdown menu on the right (the triangle pointing down on top right), and look for and open the **config.h** file



11. inside the config.h file scroll down and do the following:
    a. decomment **#define QUADX** line to enable the quad X flight configuration

```
//#define TRI
//#define QUADP
#define QUADX
//#define Y4
//#define Y6
```

b. set min throttle to 1040 changing this line from
   i. #define MINTHROTTLE 1150, to
   ii. **#define MINTHROTTLE 1040**

```
//#define MINTHROTTLE 1050 // for brushe
#define MINTHROTTLE 1040 // (*) (**)
```

c. decomment **#define GY_521** line to enable the GY-521 IMU

```
//#define GY_88 // Chinese 10 DOF with MPU6050 HMC5883L BMP085, LLC
#define GY_521          // Chinese 6  DOF with  MPU6050, LLC
//#define INNOVWORKS_10DOF // with ITG3200, BMA180, HMC5883, BMP085 a
```

12. select **Tools-> Programmer: -> Arduino as ISP**
13. upload the MultiWii code by doing **Sketch-> Upload Using Programmer**

If the everything is fine, the IDE should say that the upload is done. If not, check again the connections and repeat the previous steps. If it is not working anyway, please check again the board using the multimeter.

Day 3 - Be ready to fly!

Materials

- plastic strips
- FTDI cable
- wires of assorted colours
- LD-Power ESCs and propellers from the 250-2 kit (link)
- soldering wire
- GY-521 MPU 6050 IMU breakout board
- a row of 8 female pin header connectors
- 6 Female-Female jumper wires
- 1 Male-Male jumper wire
- 2 Female-Male jumper wires
- 4 x M3 washers
- 4 x M3 10mm wood screws
- XT60 female connector
- 2 x 2.5-3mm thick copper wires
- 1000mAh 3S LiPo battery (link)
- Hobby King 4ch Tx & Rx (link)
- paper scotch tape
- double side mounting scotch tape

Machines

- soldering station

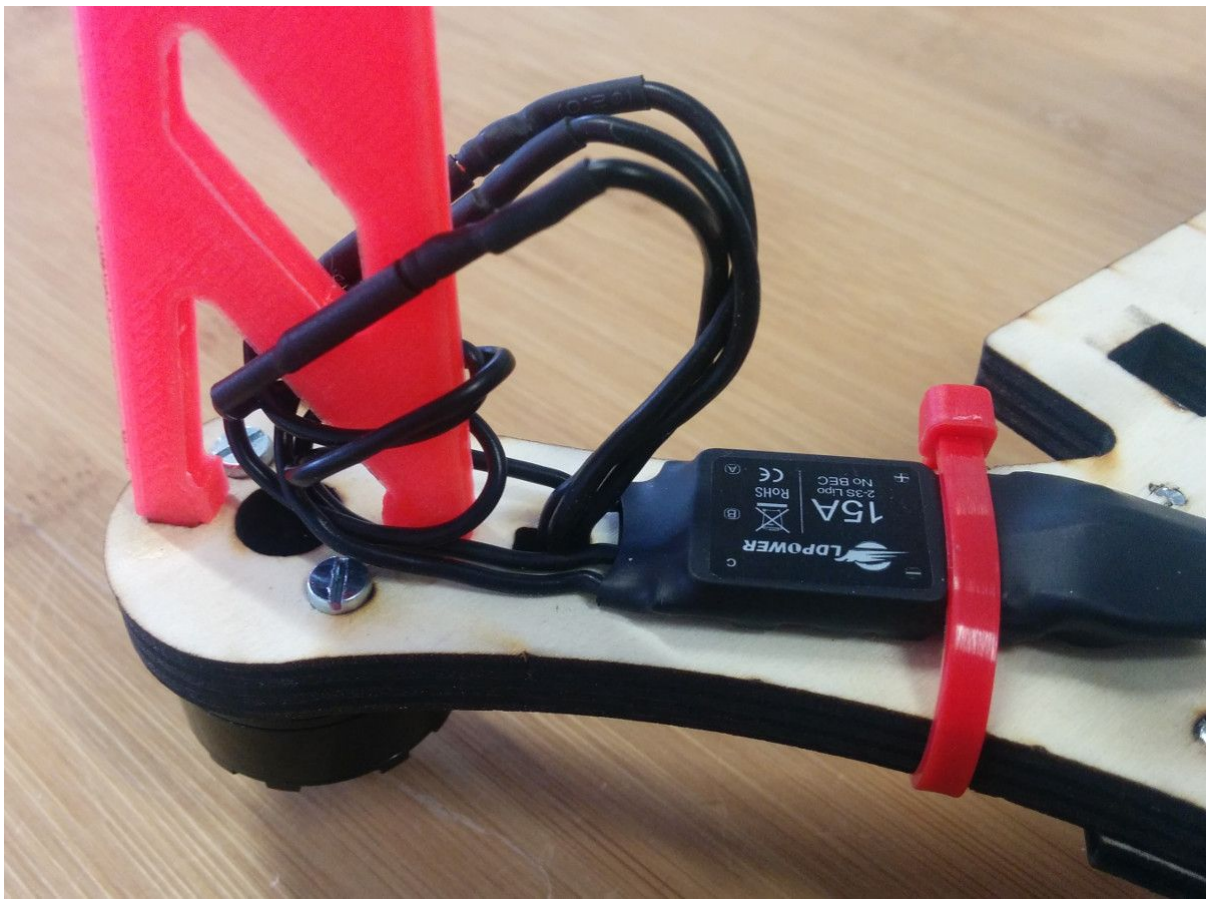
Software

- Arduino IDE last version (link)

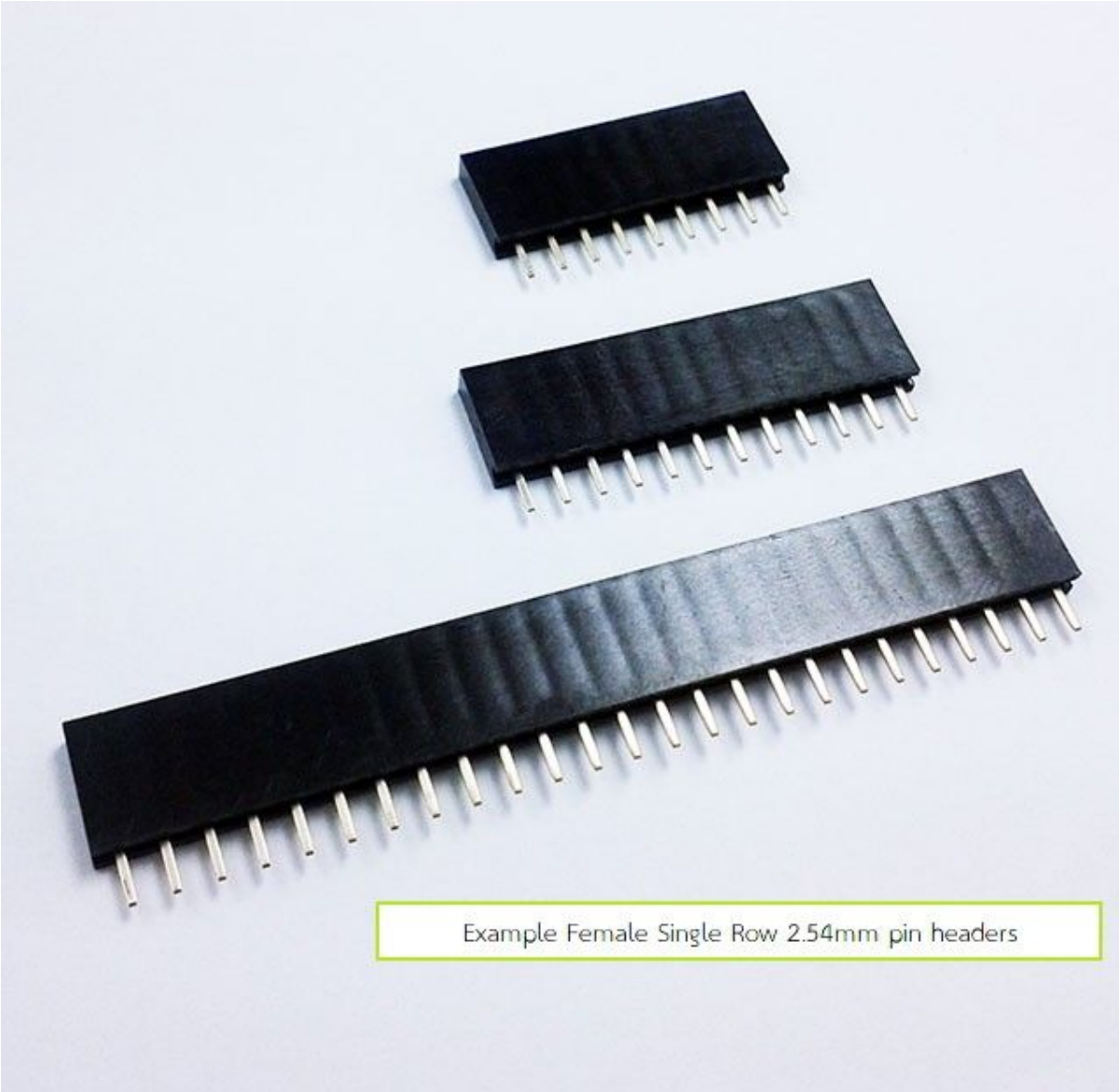
Mount the electronics

Fix all the 4 ESCs under the arms by firmly blocking them using plastic strips as shown in the following picture.

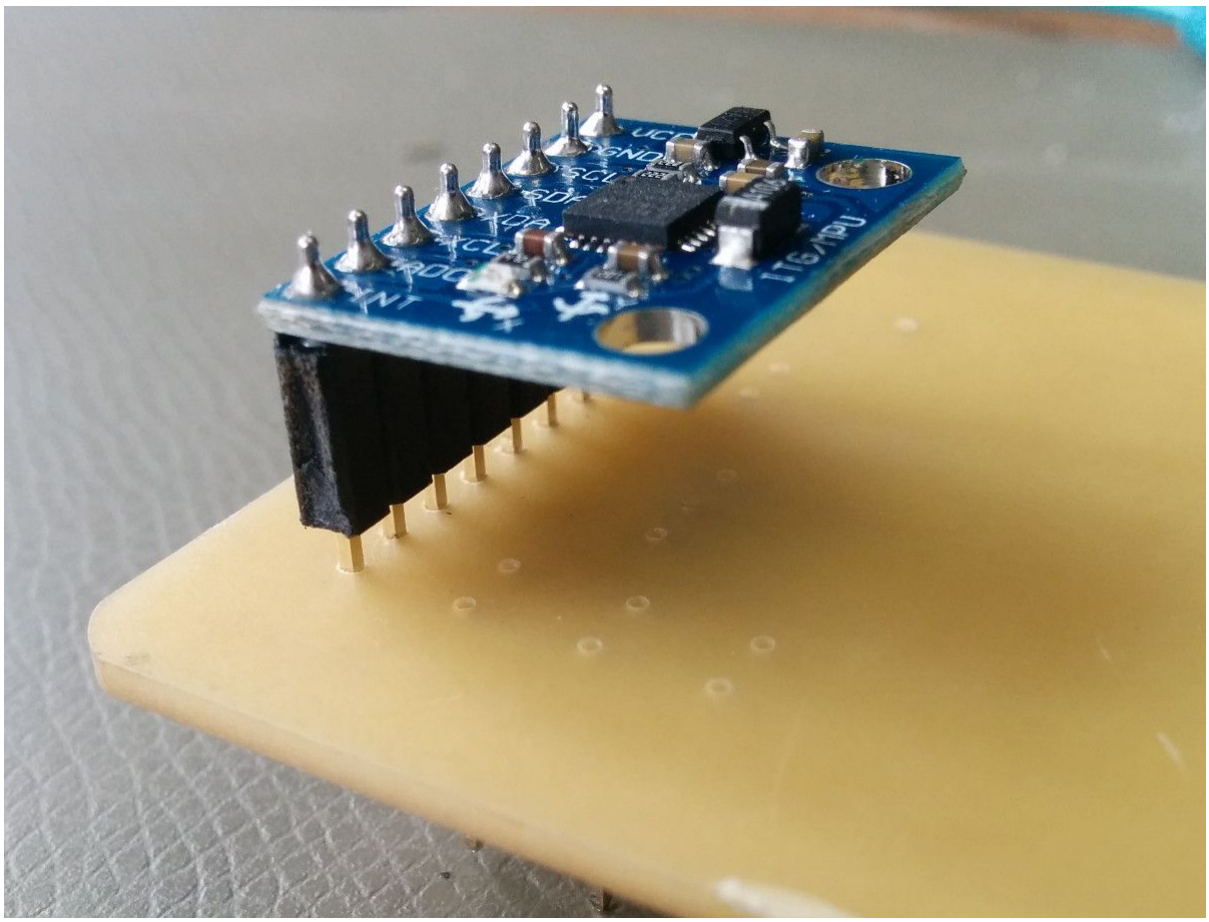
Then connect the ESCs wires with the motor wires using the predisposed connectors. It does not matter the order of the three wires right now, so just connect them in any order. You can also pass the wires inside the foot holes to have a more compact design.



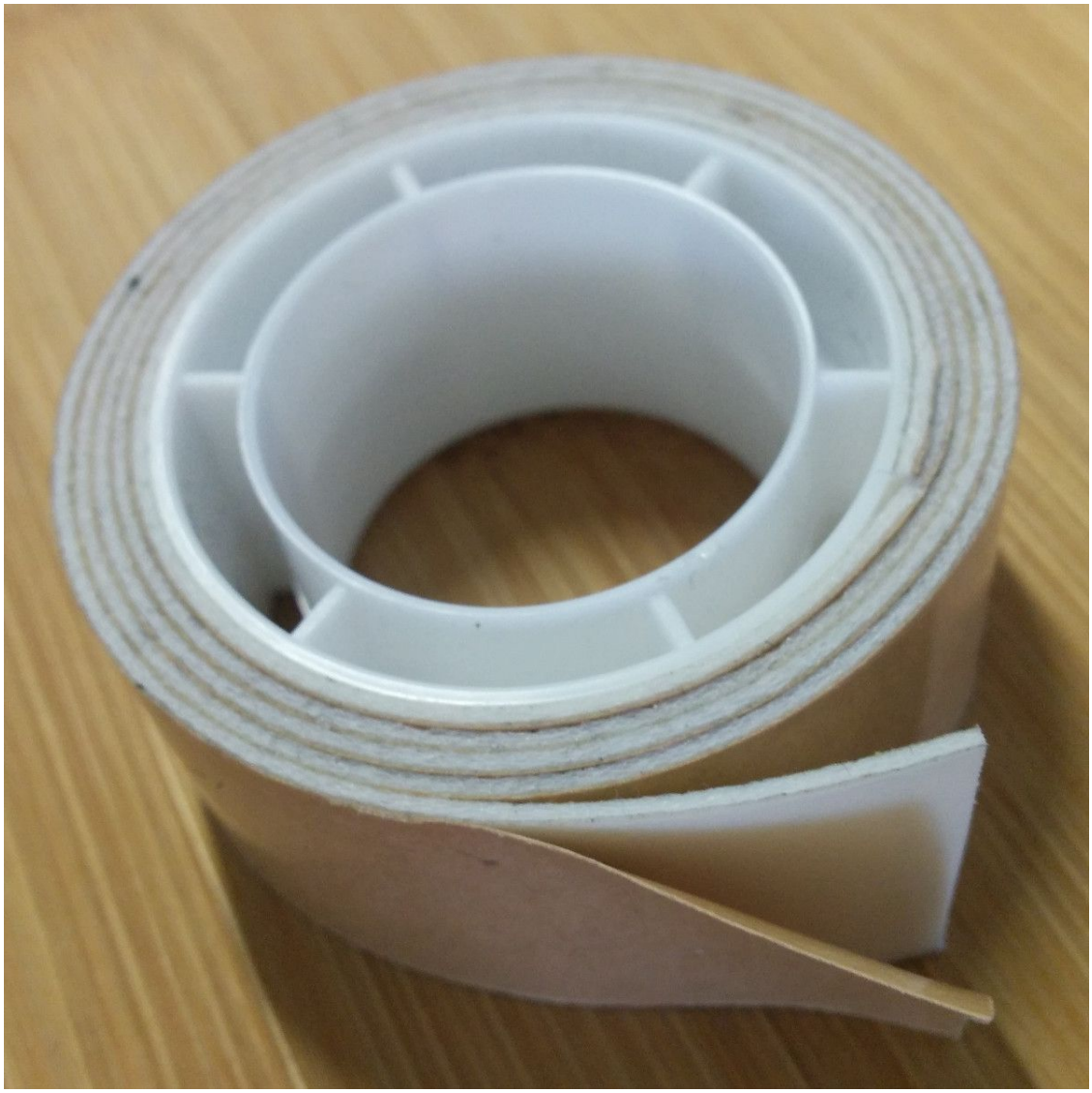
Now is time to mount the board. You have to solder a row of female connectors below the **GY-521** IMU. Please solder only the following IMU connections: VCC, GND, SCL, SDA, XDA, XCL.



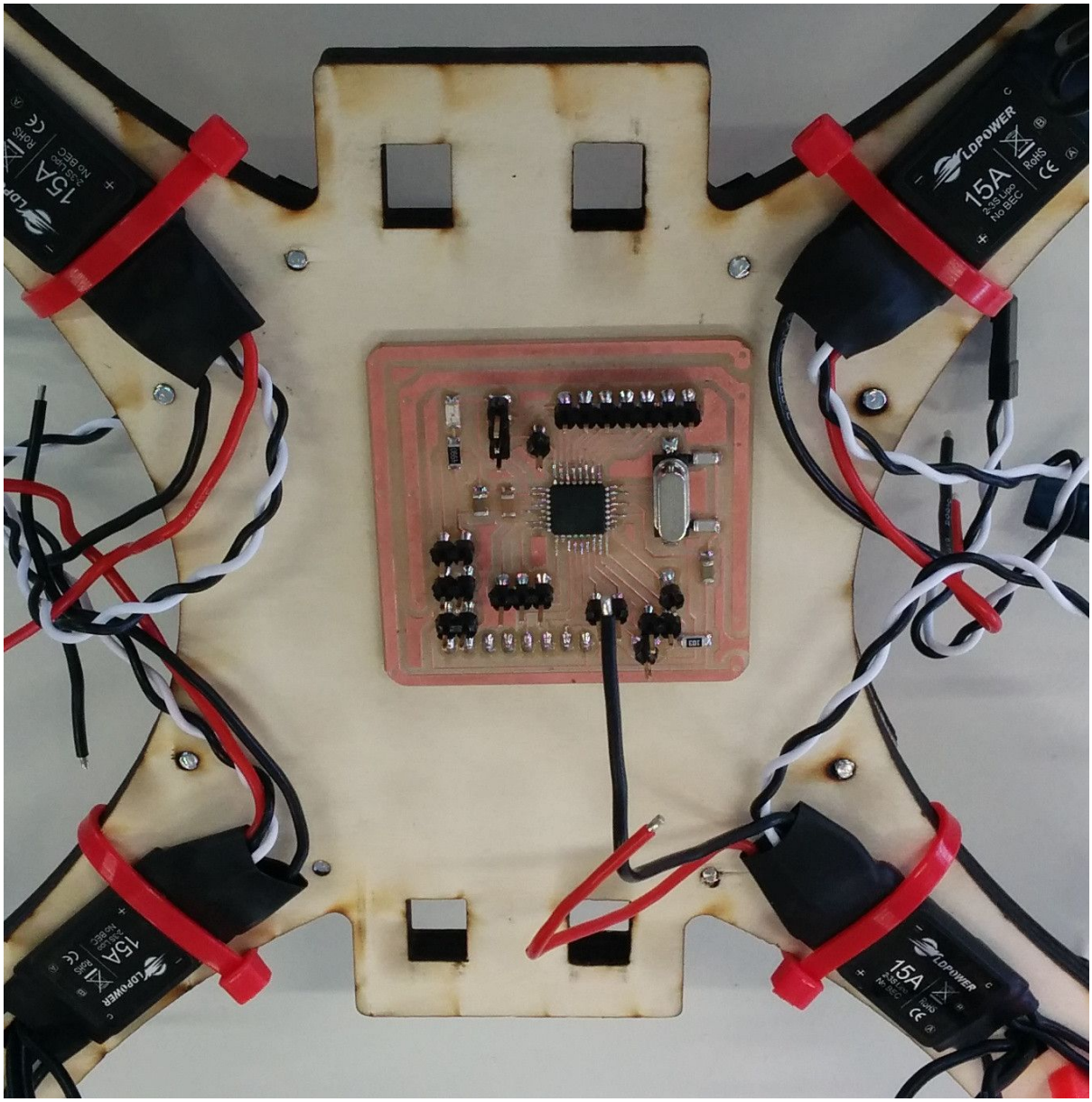
Then attach the female connectors of the IMU on the male connectors on the downside of the board. This is likely how it will be connected, but without the frame (that will be between the board and the IMU). Eventually cut a little bit of the male pin headers coming from the board, to fit the 10mm total thickness of the wood.



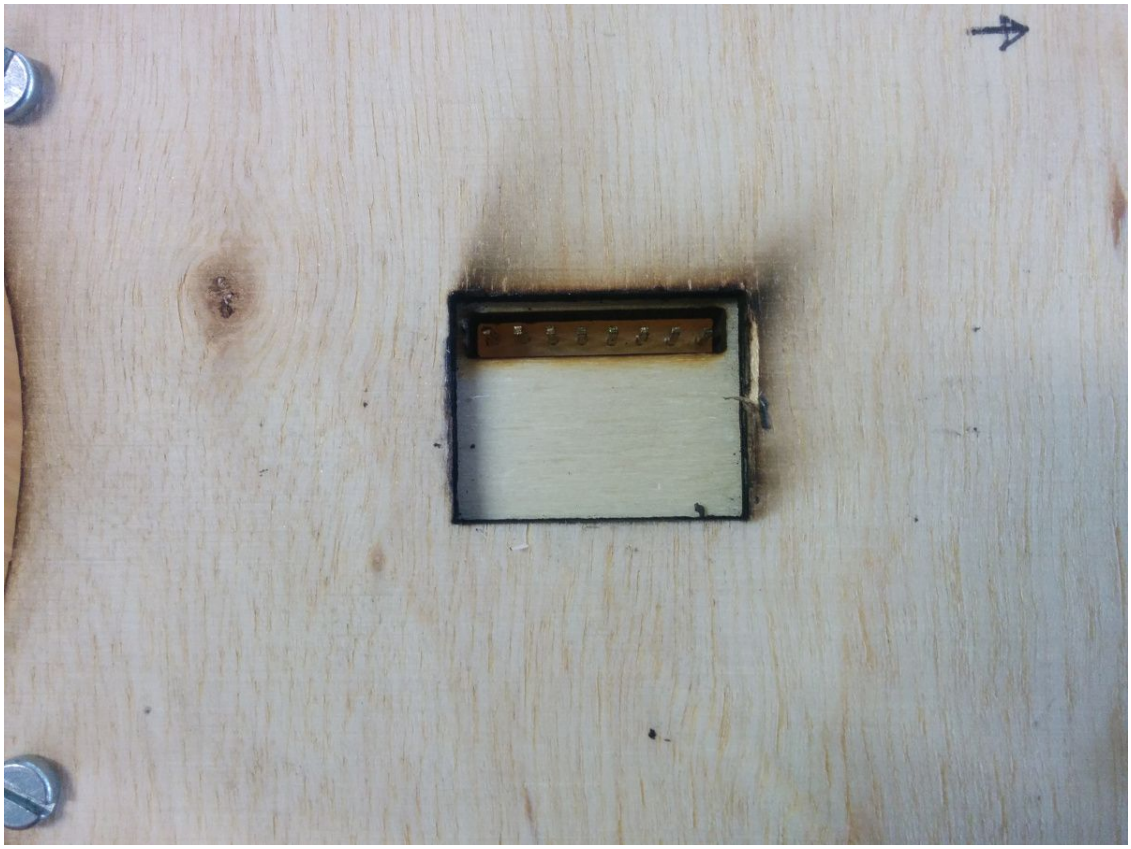
Put some **double side mounting scotch tape** on the back of the board and fix it to the underside of the main frame.



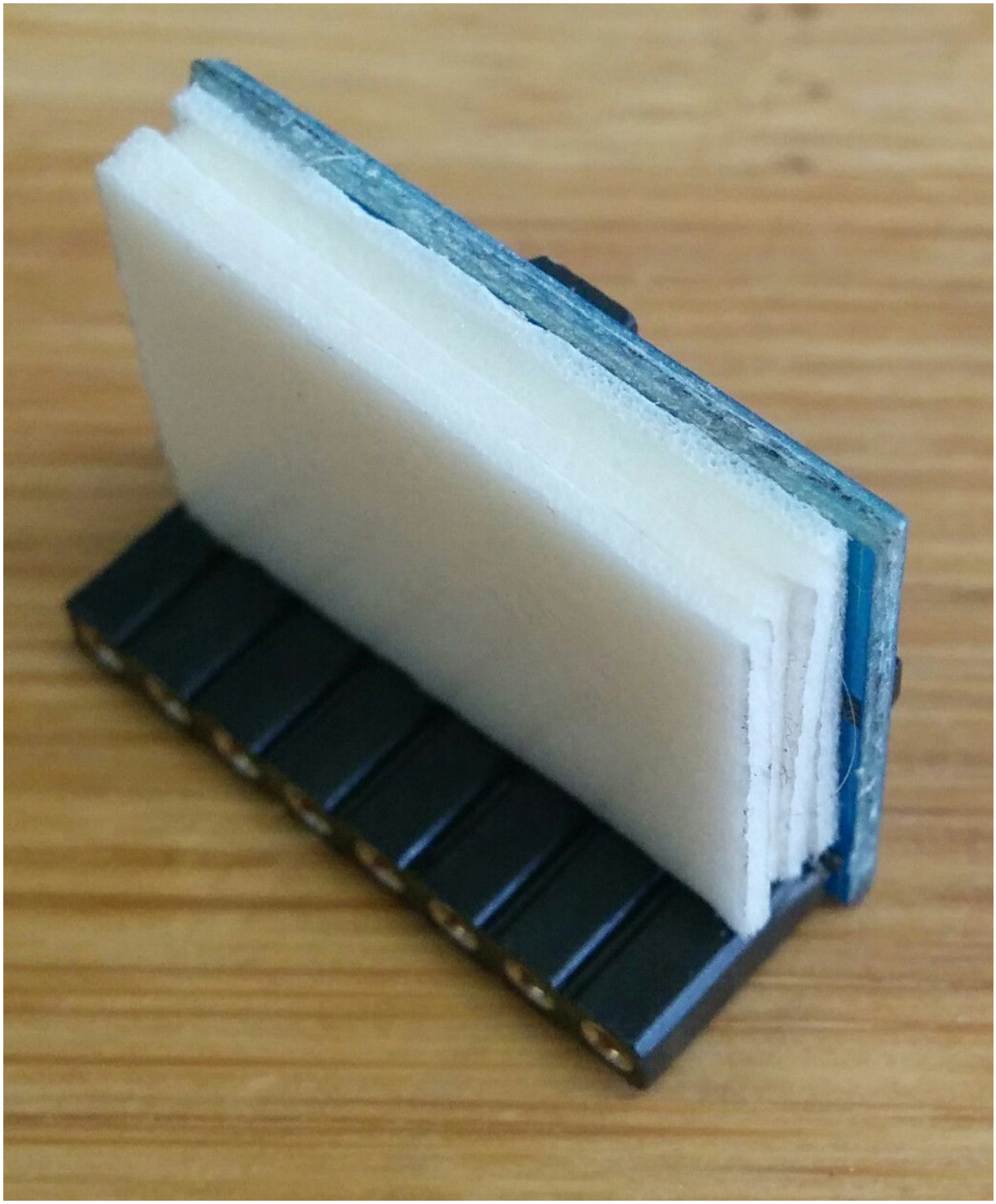
Doing so you should have the setup shown in the following picture.



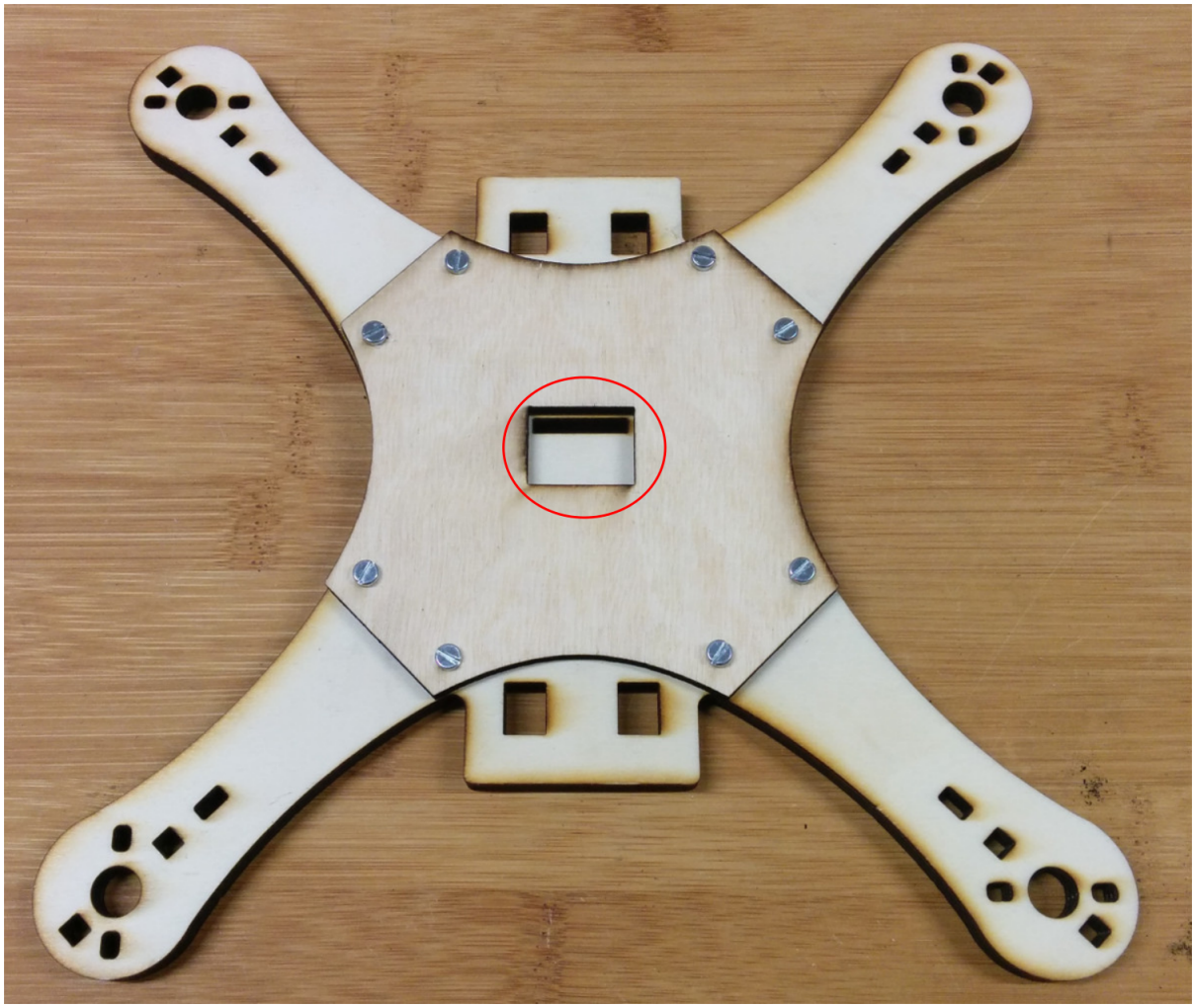
Now you should see on the top side the male connectors for the IMU coming from below the board.



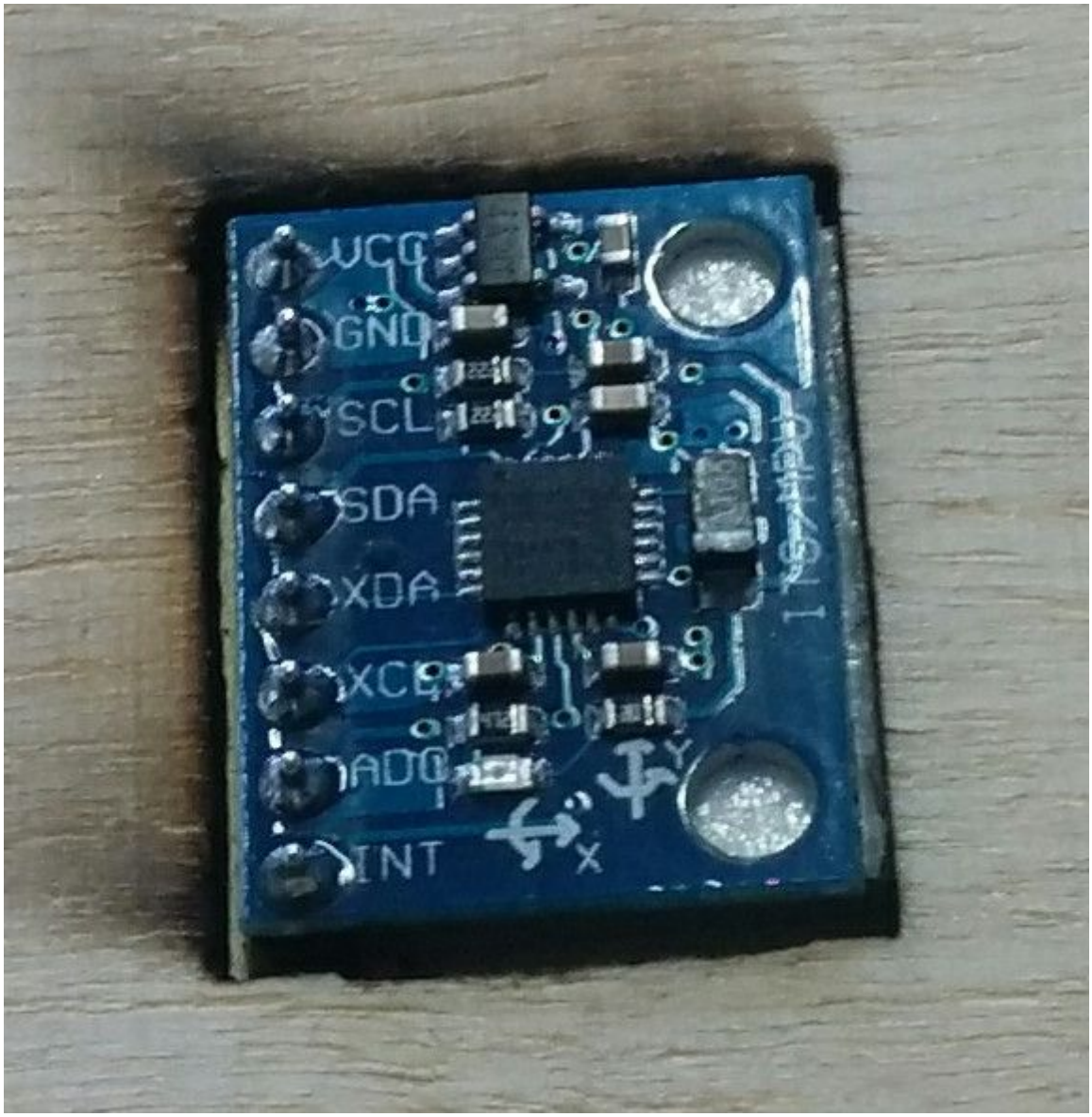
Now put **4 layers** of double side thick scotch tape under the IMU:



And plug the IMU inside the predisposed rectangular area (red circle).



Be sure that the IMU is in a **flat position (parallel to the wood surface) and that doesn't touch the wood** (adjust it with your fingers if needed).



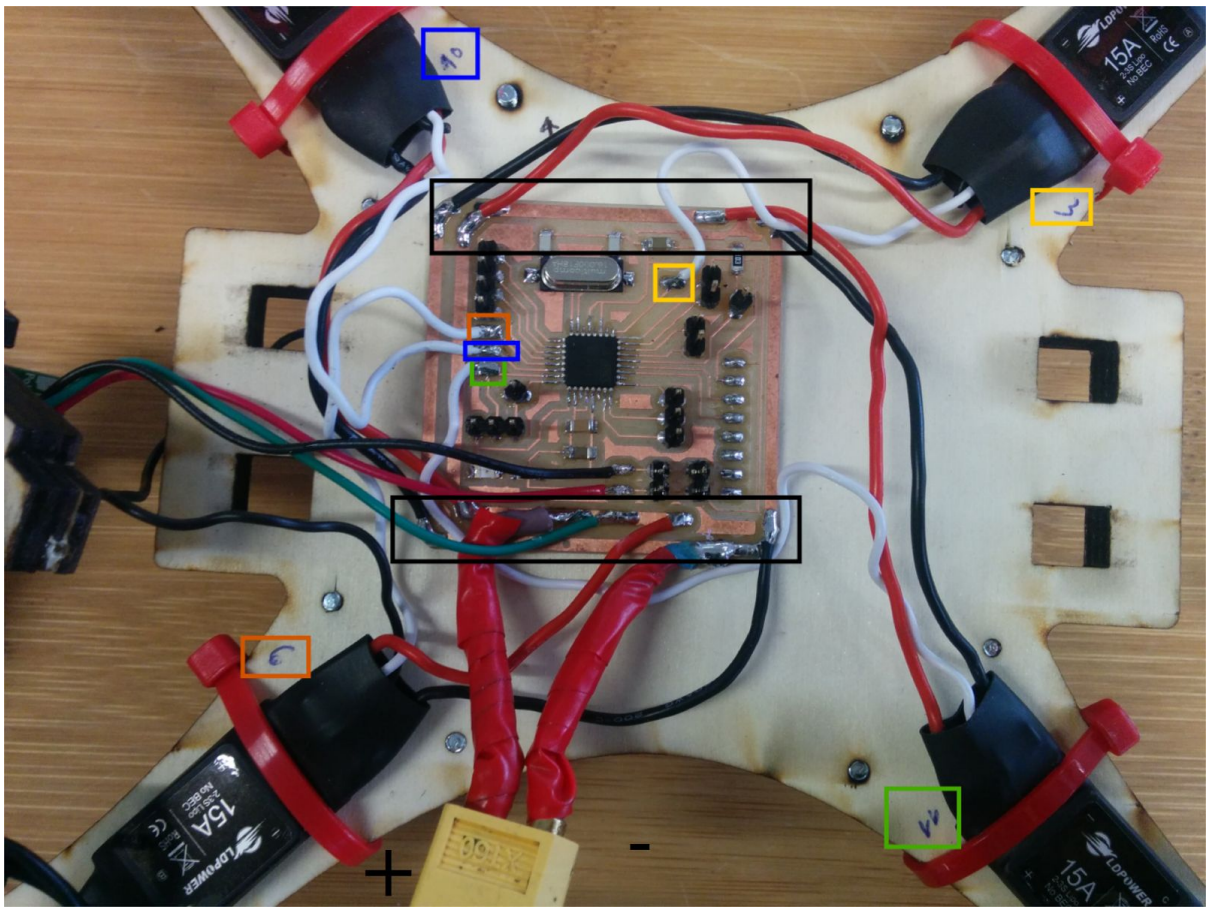
Connect the electronics

First we need to make the power cable that will connect the board to the battery. To to this solder the XT60 male connector the thick wires. Use an huge amount of soldering wire as these wires will transport an high current.

Now is time to solder some wires that you don't want to be disconnected during flight. You have to solder to the board the following things:

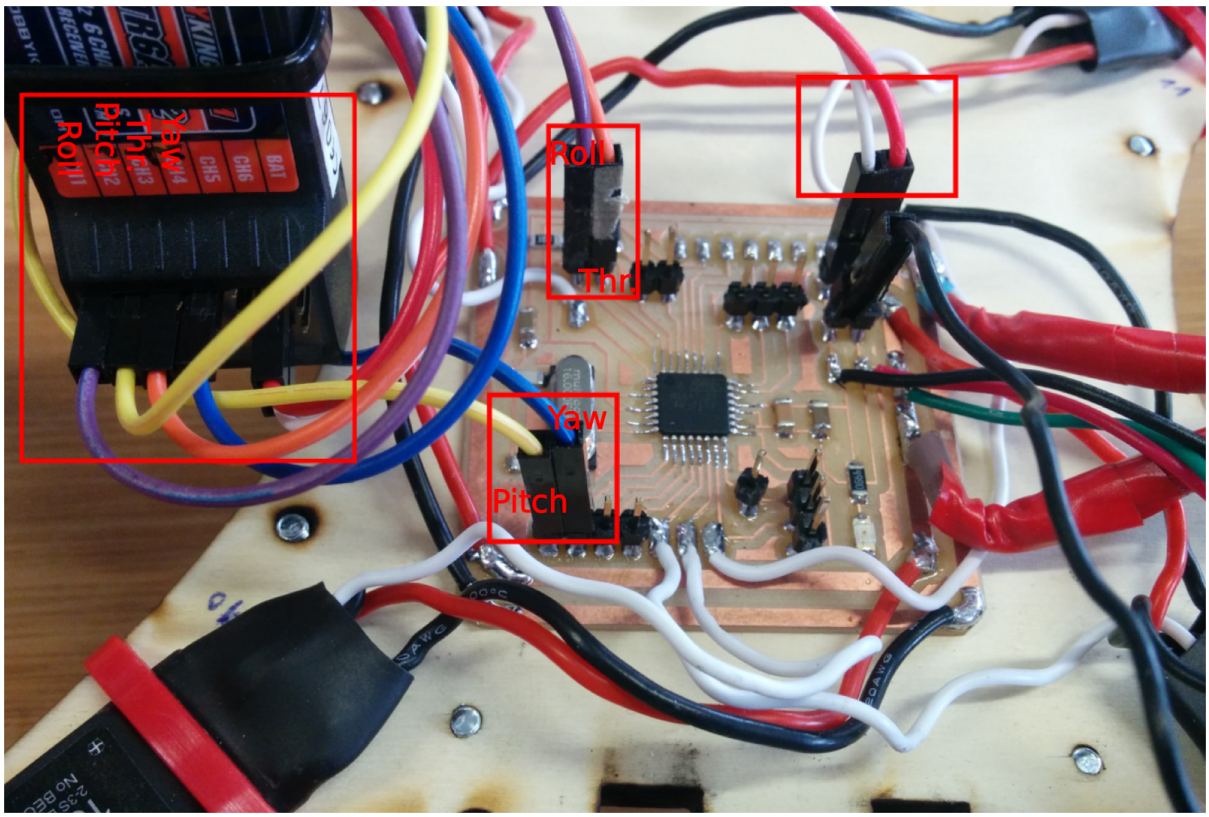
- the white signal cables of all the ESCs, you have 4 of them, surrounded by yellow, blue, green and orange in the picture; check the correspondence with the correct motor
- the ESCs power connectors, you have 4 red VCCs and 4 black GNDs, surrounded by black in the picture
- the XT60 power connector for the battery, the thick red wires, surrounded by black in the picture

Also make sure that the solderings are strong and solid, most important on the outer/power traces of the power board (the thick ones near the border). The following image shows how and where to connect all, and also identifies the position of the motors:

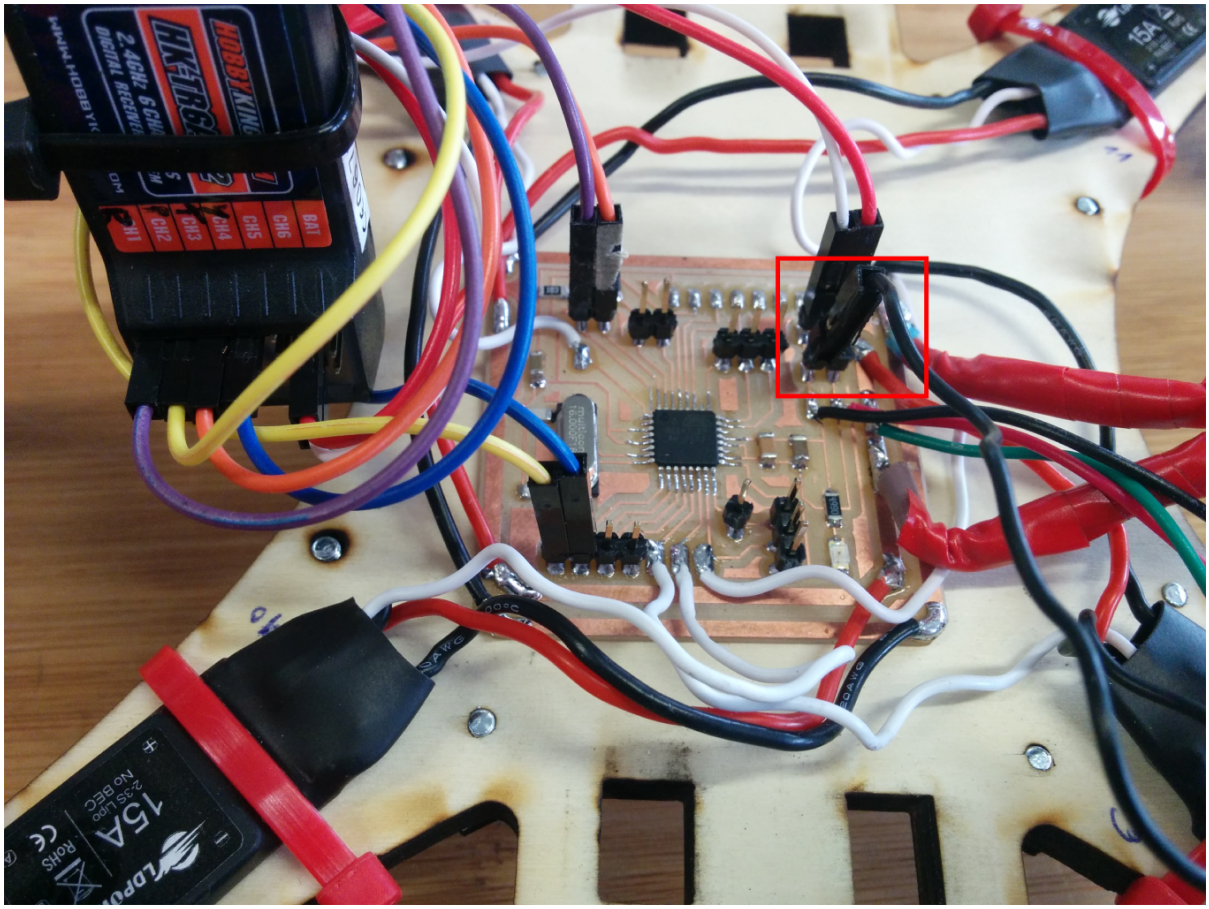


Next step is to connect the remote controller. You can connect this using 6 standard Arduino Female-Female jumpers connectors. Look at the following image to understand how to connect it to the board. 4 wires are for the signals, 2 wires are to give power to the receiver.

- pink wire is **ROLL**
- yellow wire is **PITCH**
- orange wire is **THROTTLE**
- blue wire is **YAW**
- white wire is **GND**
- red wire is **5V**

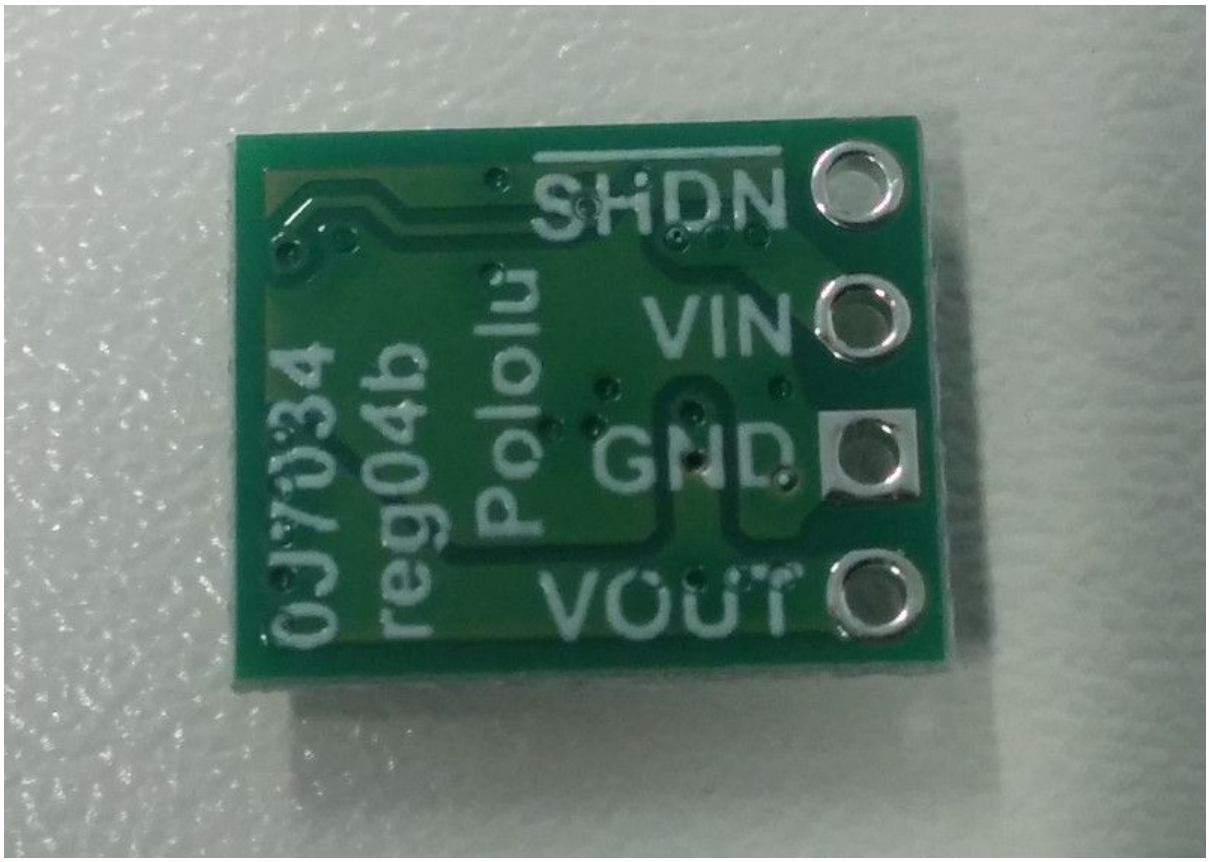


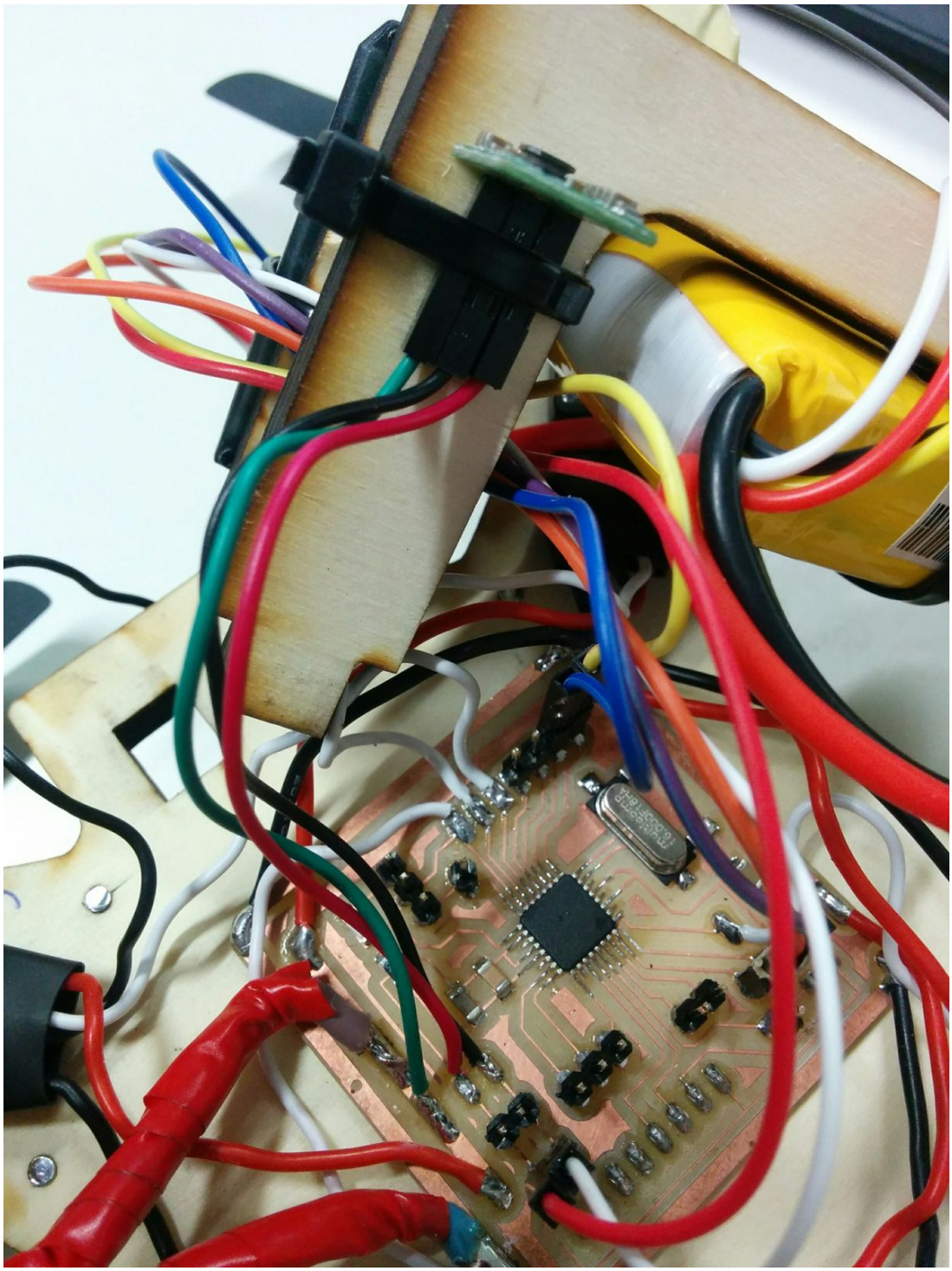
Connect to ground of one of the ESCs black wire, to a free ground of the board (near the ground of the remote controller):



The last component to connect, this time again by soldering, is the pololu voltage regulator. Please solder both ends of the wires in the voltage regulator and in board.

- black wire is **GND**
- red wire is **VOUT 5V**
- green wire is **VIN**, in this case 11.1V due to the 3S battery
- leave unconnected the SHDN pin of the voltage regulator

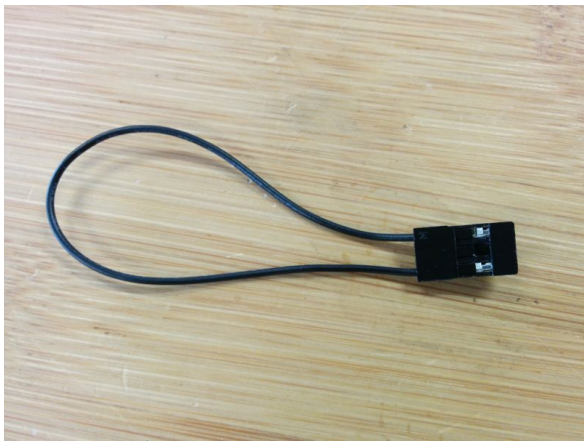


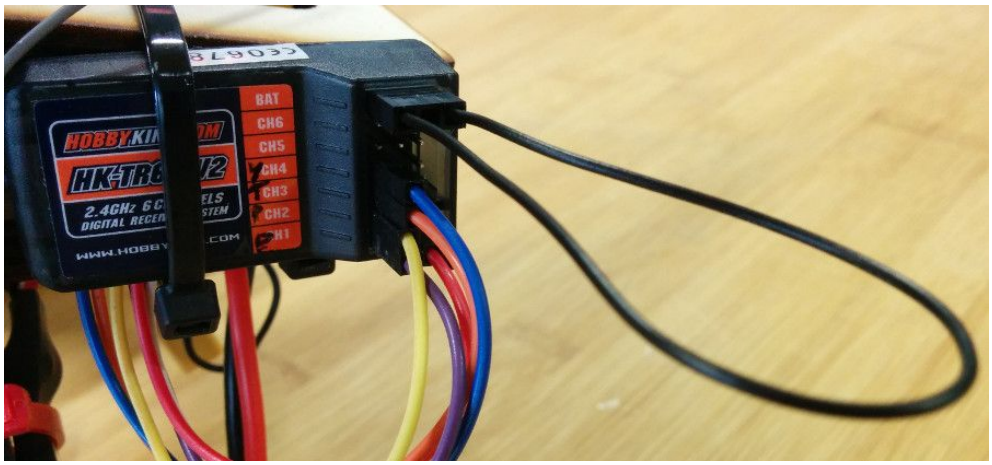


Bind the remote controller and the receiver

Before using you radio with the drone, you need to bind the transmitter to the receiver. This will permanently set a radio link between them, until you decide to change this again.
To do this follow these steps:

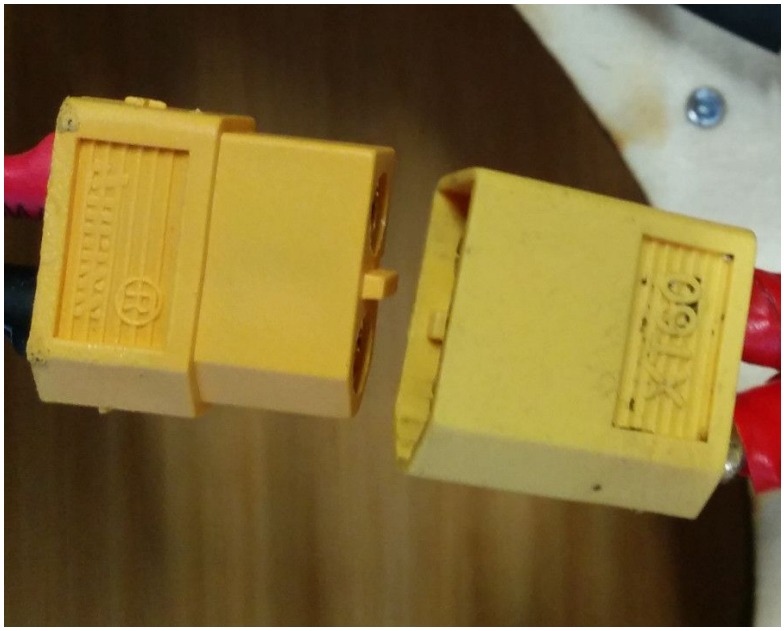
1. insert the bind plug to the receiver bat slot (you will find the bind plug inside the HobbyKing Tx & Rx package)





2. insert 8 fresh alkaline batteries into the rear compartment of the transmitter, oriented as shown

3. connect the Zippy 1000mAh 3s battery to the drone



4. check if the LED is blinking inside the receiver

5. keep pressed the bind button of the transmitter

6. now, **while you keeping pressing the bind button** turn on the transmitter (you should see the LED on the front panel glow green)

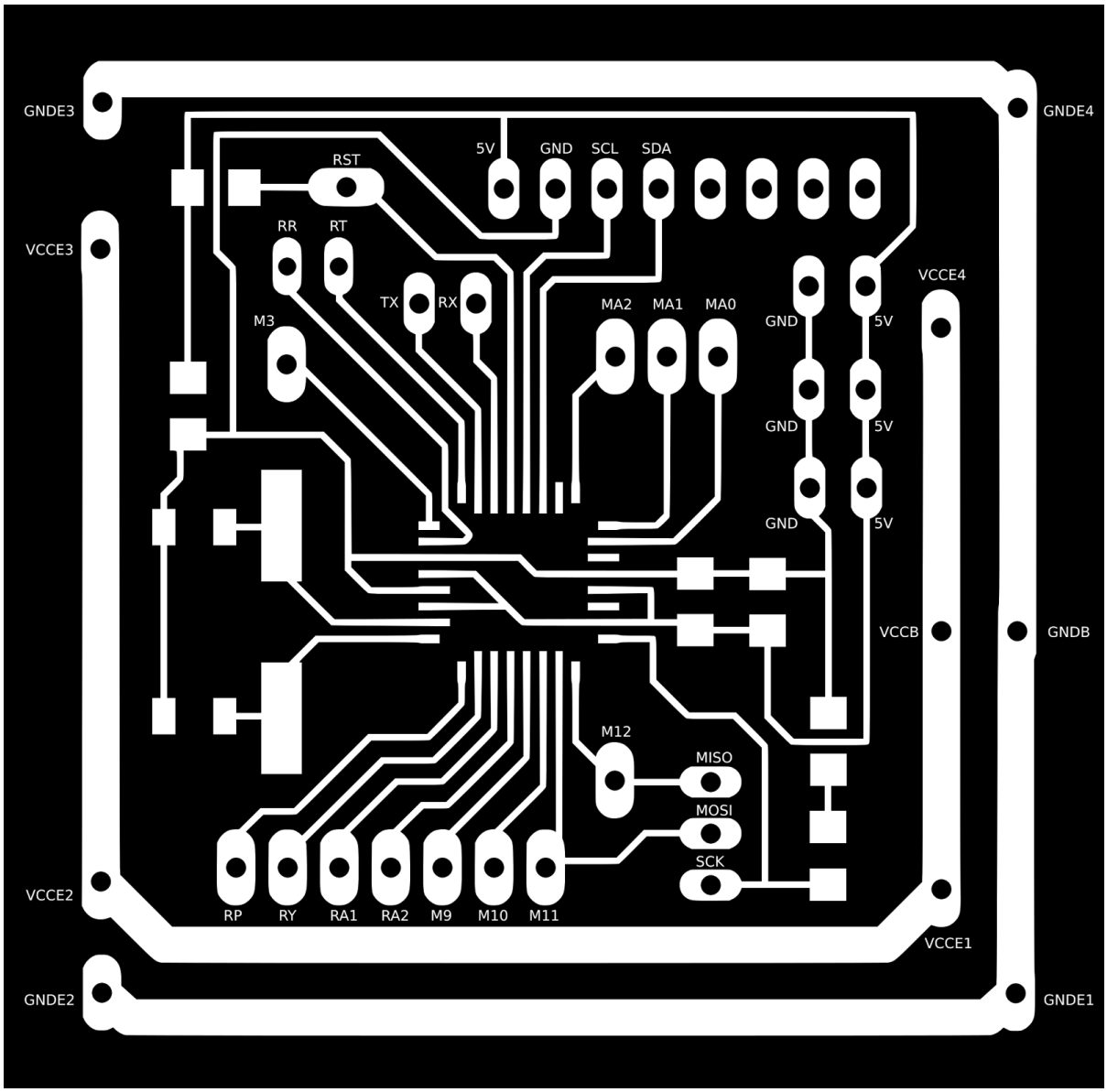
7. check the receiver LED, if now is no more blinking but it is switched on this means that the transmitter and receiver are now binded
8. release the bind button
9. disconnect the drone battery
10. power off the transmitter
11. **remove the bind plug** from the receiver

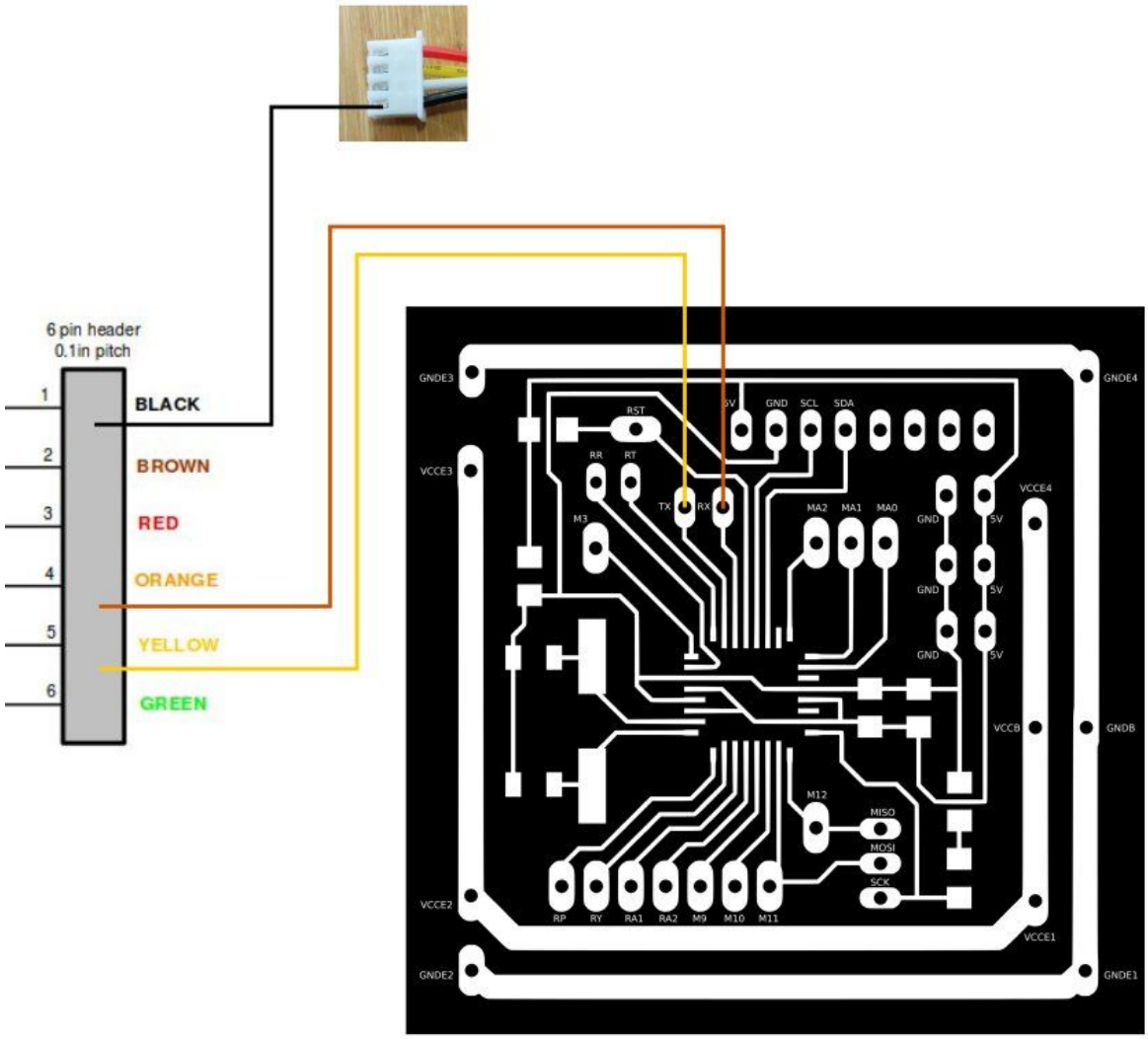
Configure MultiWii and finish the assembly

Now is time to configure some Multiwii parameters before going to flight.
First connect the FTDI cable as following. You need 2 Male-Female and 1 Male-Male jumper wires.

- yellow wire of FTDI must be connected to the **TX** of the board, use 1 Male-Female jumper wire
- orange wire must be connected to the **RX** of the board, use 1 Male-Female jumper wire
- black wire must be connected to the **GND** of the balance plug of the battery, use 1 Male-Male cable

Look here to see where connect the FTDI cable onto the board:



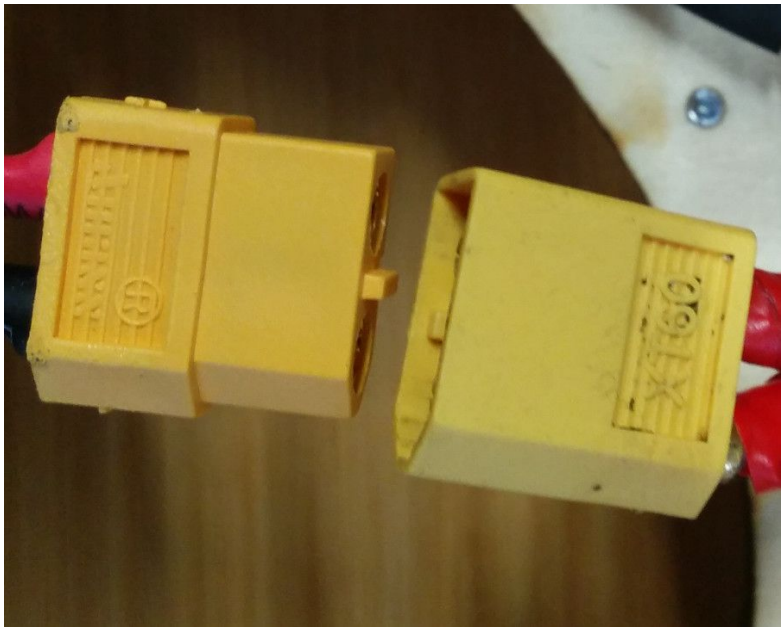

6 pin header
0.1in pitch
1
2
3
4
5
6
BLACK
BROWN
RED
ORANGE
YELLOW
GREEN
GNDE3
GNDE4
VCCE3
VCCE4
VCCB
GNDB
VCCE2
VCCE1
GNDE2
GNDE1
RST
RR
RT
TX
RX
M3
MA2
MA1
MA0
GND
SCL
SDA
5V
M12
MISO
MOSI
SCK
RP
RY
RA1
RA2
M9
M10
M11

After everything is connected, execute the following steps to enable the communication between the flight controller board and the PC:

1. connect the USB FTDI cable into one USB port of the PC
2. put the throttle at the minimum

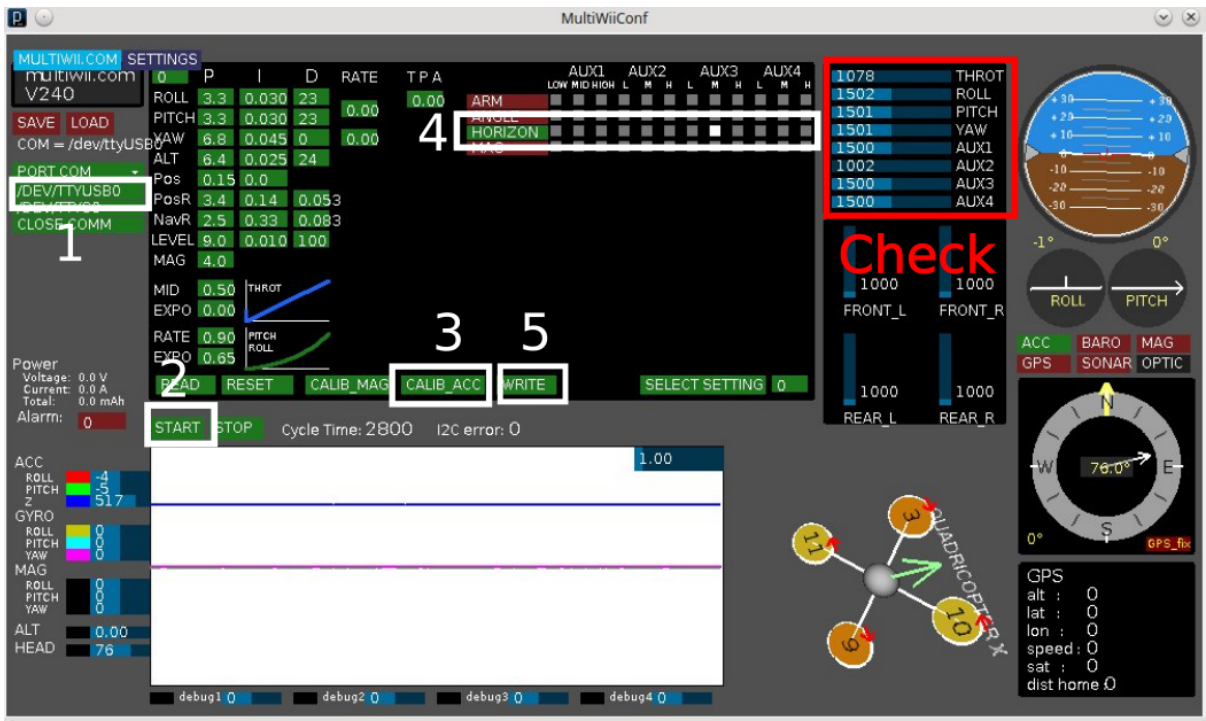
3. switch on your transmitter

4. connect the battery to the board power XT60 connector



Now you can open the MultiWii GUI you can find inside the MultiWii folder of before, if you are running Linux please run this using **sudo** (sudo ./MultiWiiConf) to obtain the permission to use the serial ports. Once the GUI is open, do the following (follow the white marks on the image):

1. select by clicking on the right **serial port button** and wait for everything to become green
2. click on the **START** button
3. put the drone in a surface you think is really flat and hit the **CALIB_ACC** button
4. click on **mid of AUX3** to always enable the **HORIZON MODE**
5. press the **WRITE** button

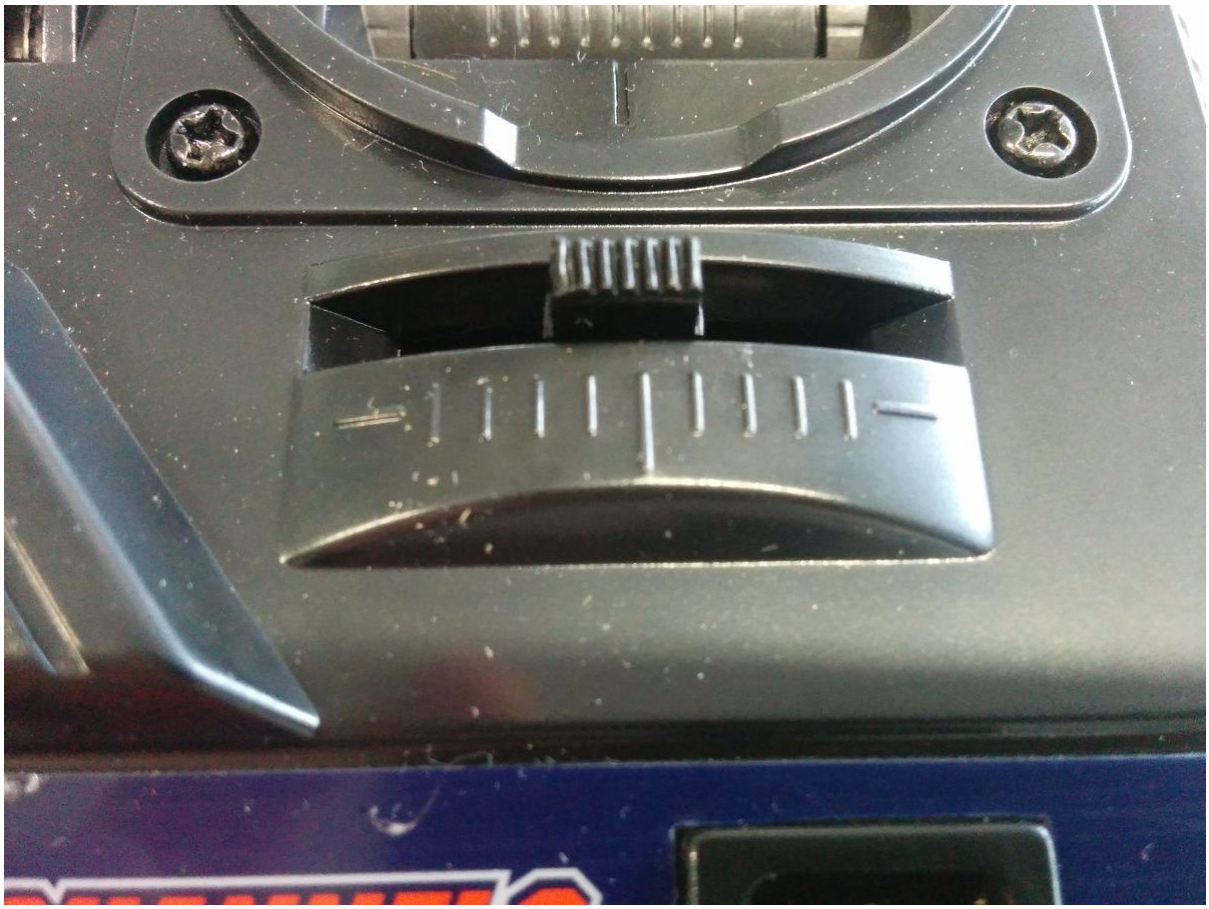


Be careful on the signal from the transmitter you have to **Check** (the red rectangle into the picture). Look at the following image and move the sticks to check if they are binded in the right way on the interface:

Eventually you can reverse the channel on the remote to achieve the right movements of the signals on the interface:

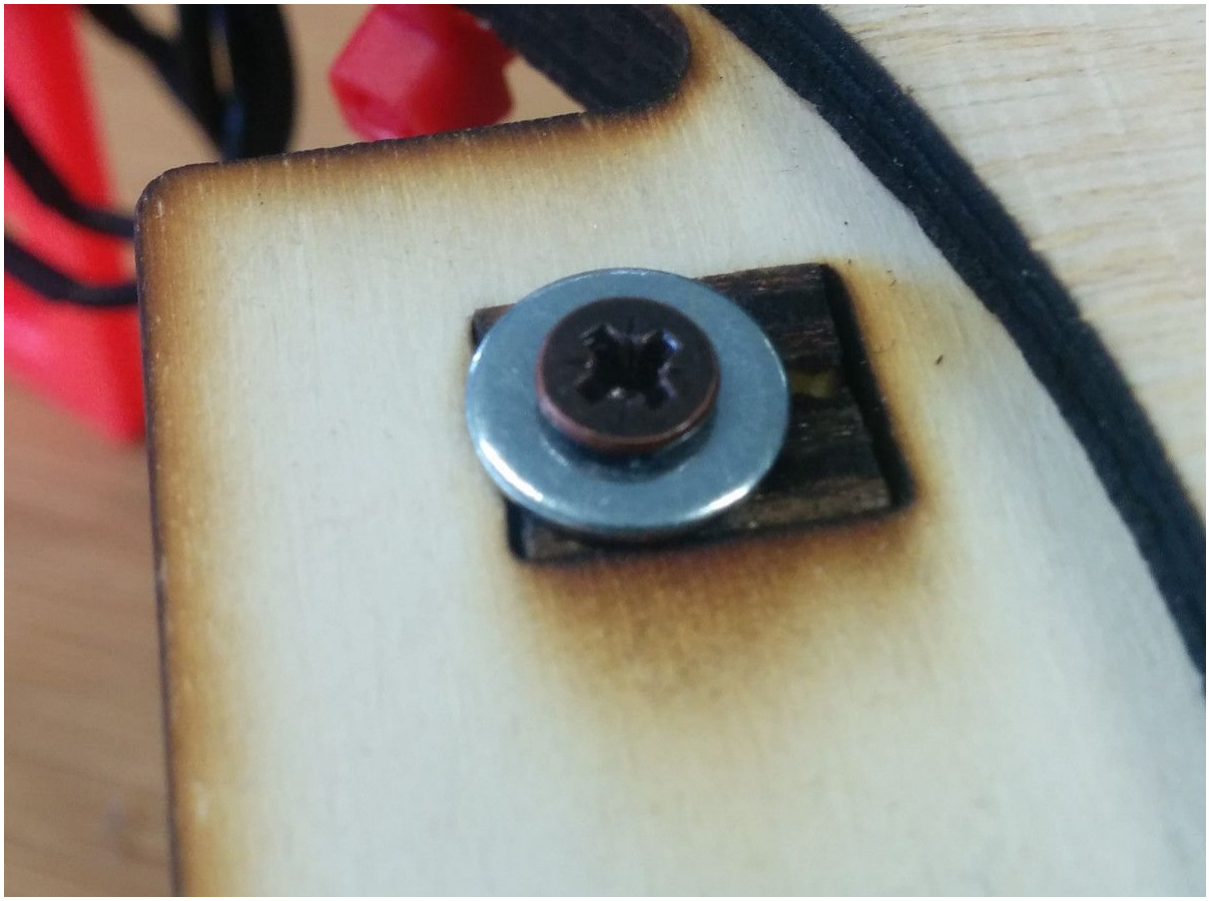
Now adjust the values of the PWM signals (the blue bars on top right representing the remote controller sticks and surrounded by the red rectangle) using trimmers (see the next picture) on the remote. The values should be like:

- **1500** Pitch, Roll, Yaw
- **1080** Throttle

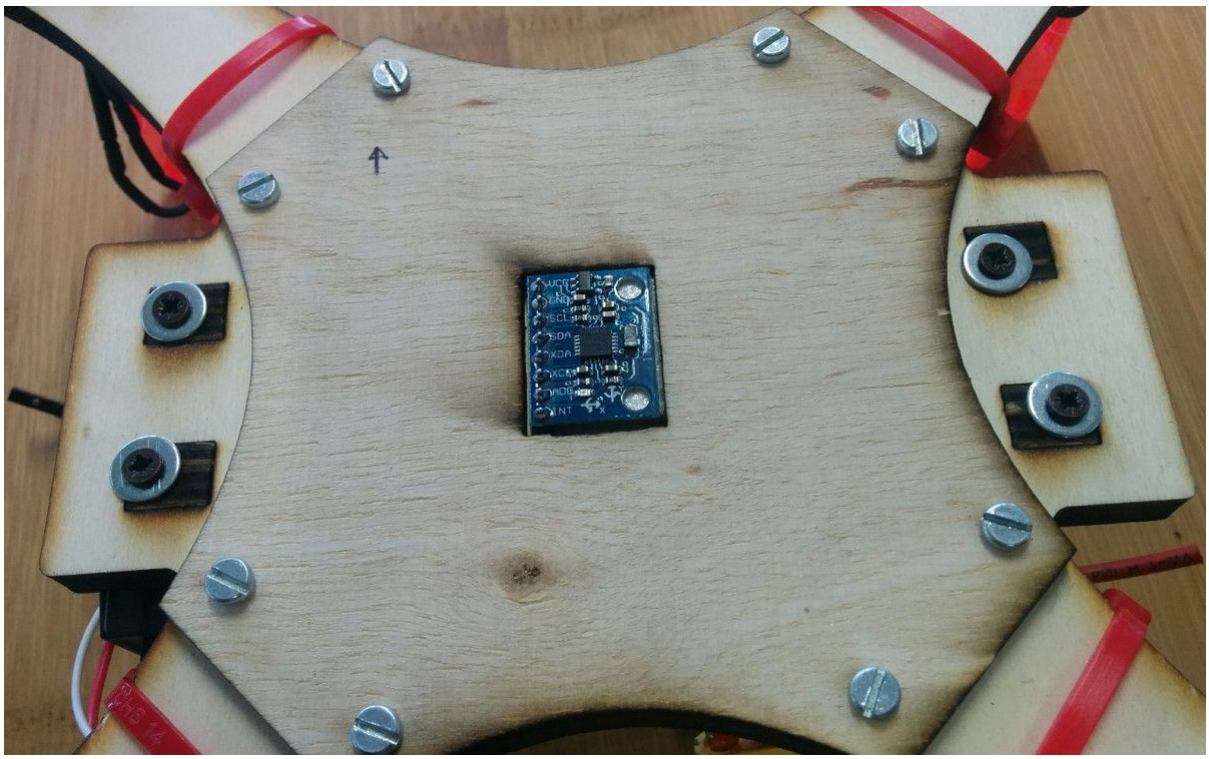


If everything sounds to be ok, now you can attach the supports using the following screws and washers:

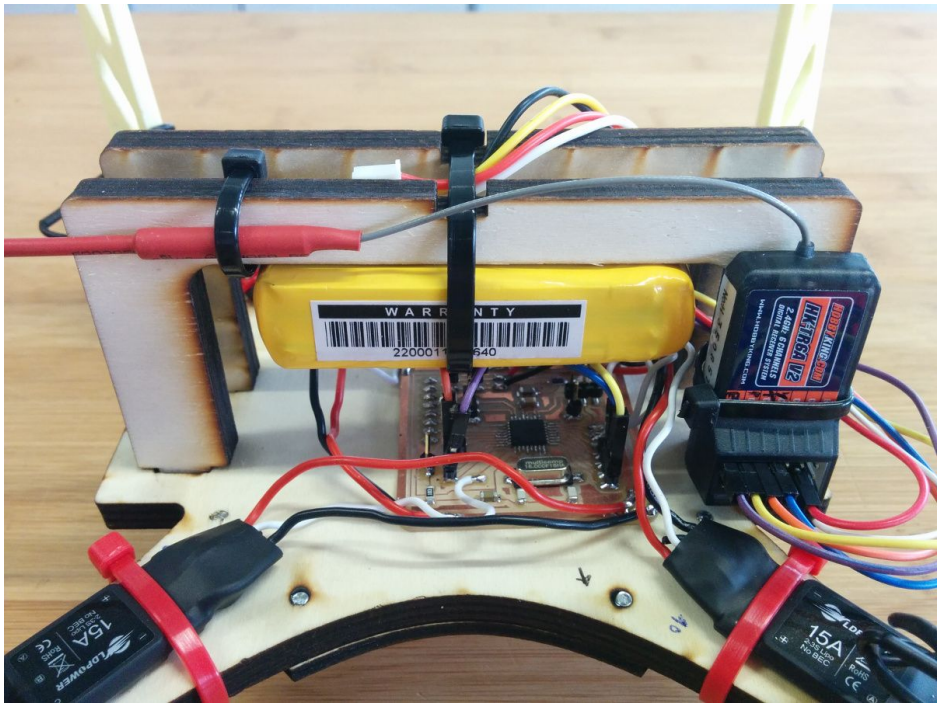
Use the washer to fix the supports with the surface of the main frame:

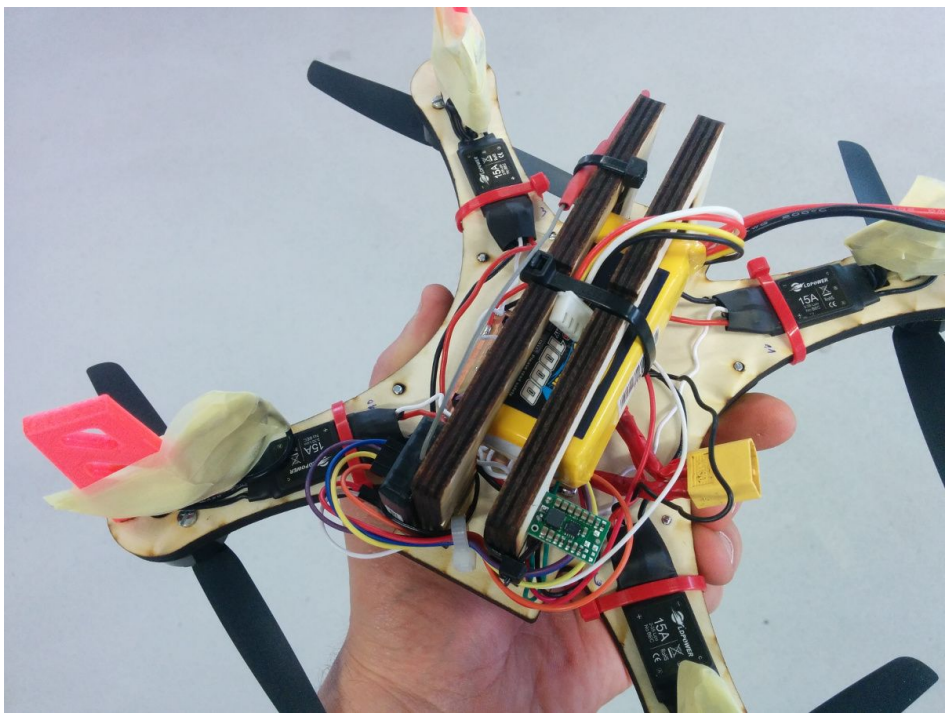


Now you should be similar to this picture on the top side of the main frame:

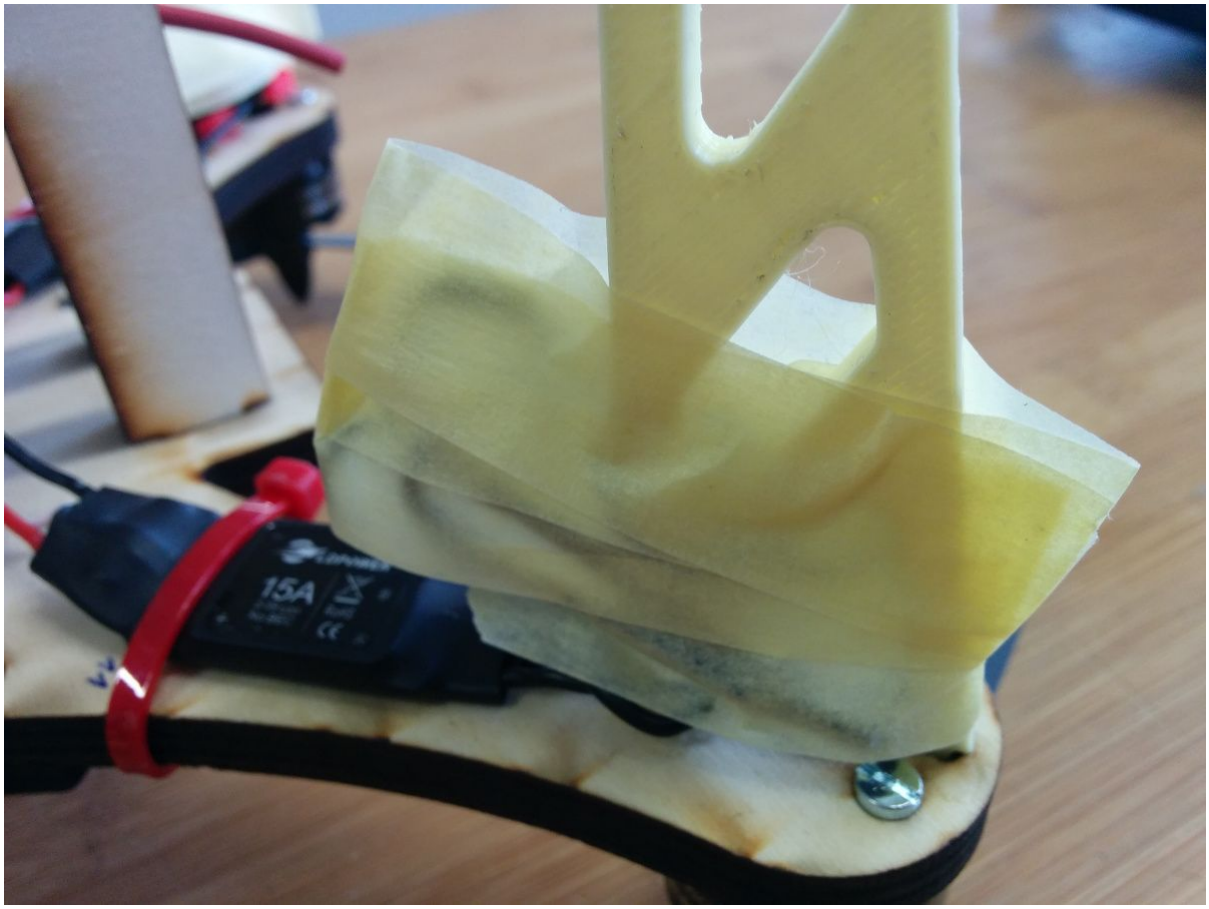


Now is time to fix the receiver, the voltage regulator and the battery to the supports:





Before going to fly you can close everything with paper scotch tape to avoid the wires making unwanted vibrations.



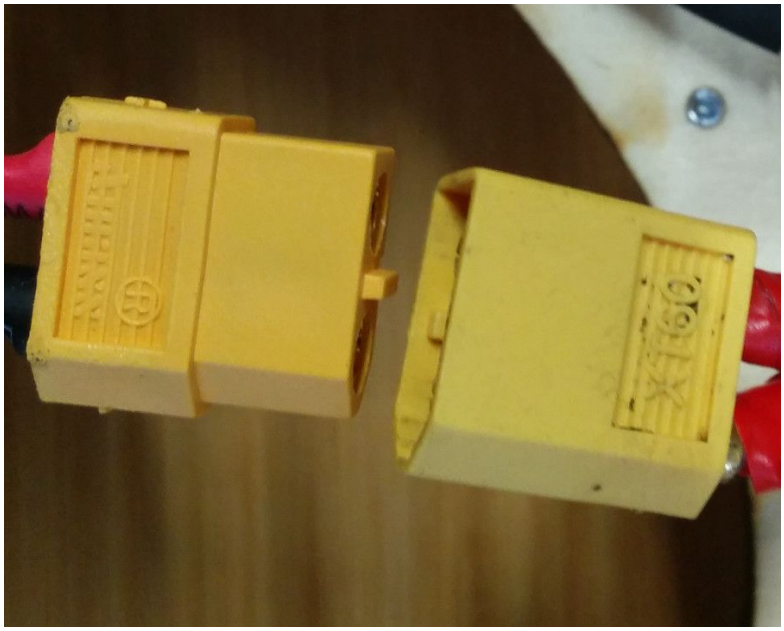
Mount the propellers and do a test flight

Before do a test flight you have to check the rotation direction of the motors. If it is not correct just change the connection of one of its wire with the ESC and check again after. Hold the motor with your hand and gently go up with the throttle to easy check the rotation direction of each motor. After some tries you should have the desired rotation directions. Before doing this follow the standard procedure to arm the drone. To arm the drone means you that you have enabled the motors and you are ready to fly. Disarm instead means that you will disable the motors and then you are ready to disconnect the battery from the drone with your hands. You have to follow the same procedure always when you want to use the drone:

1. set the throttle at minimum on the transmitter

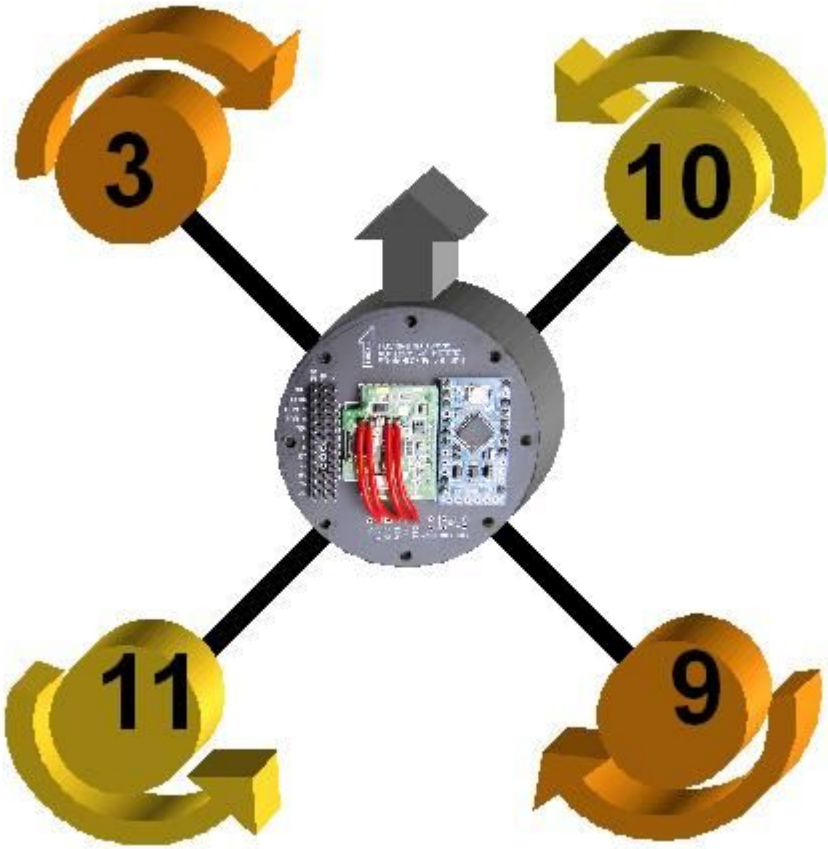
2. switch on the transmitter

3. connect the battery to the drone

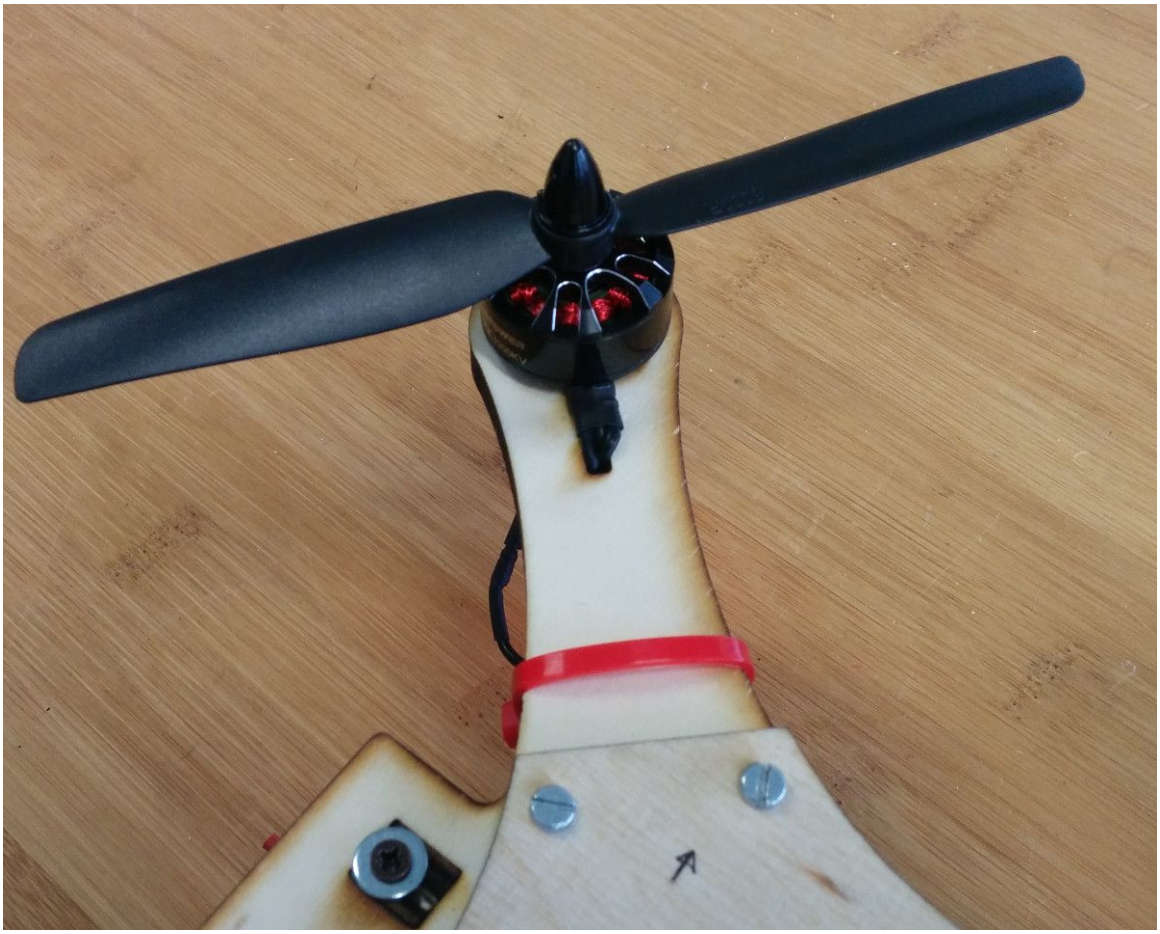


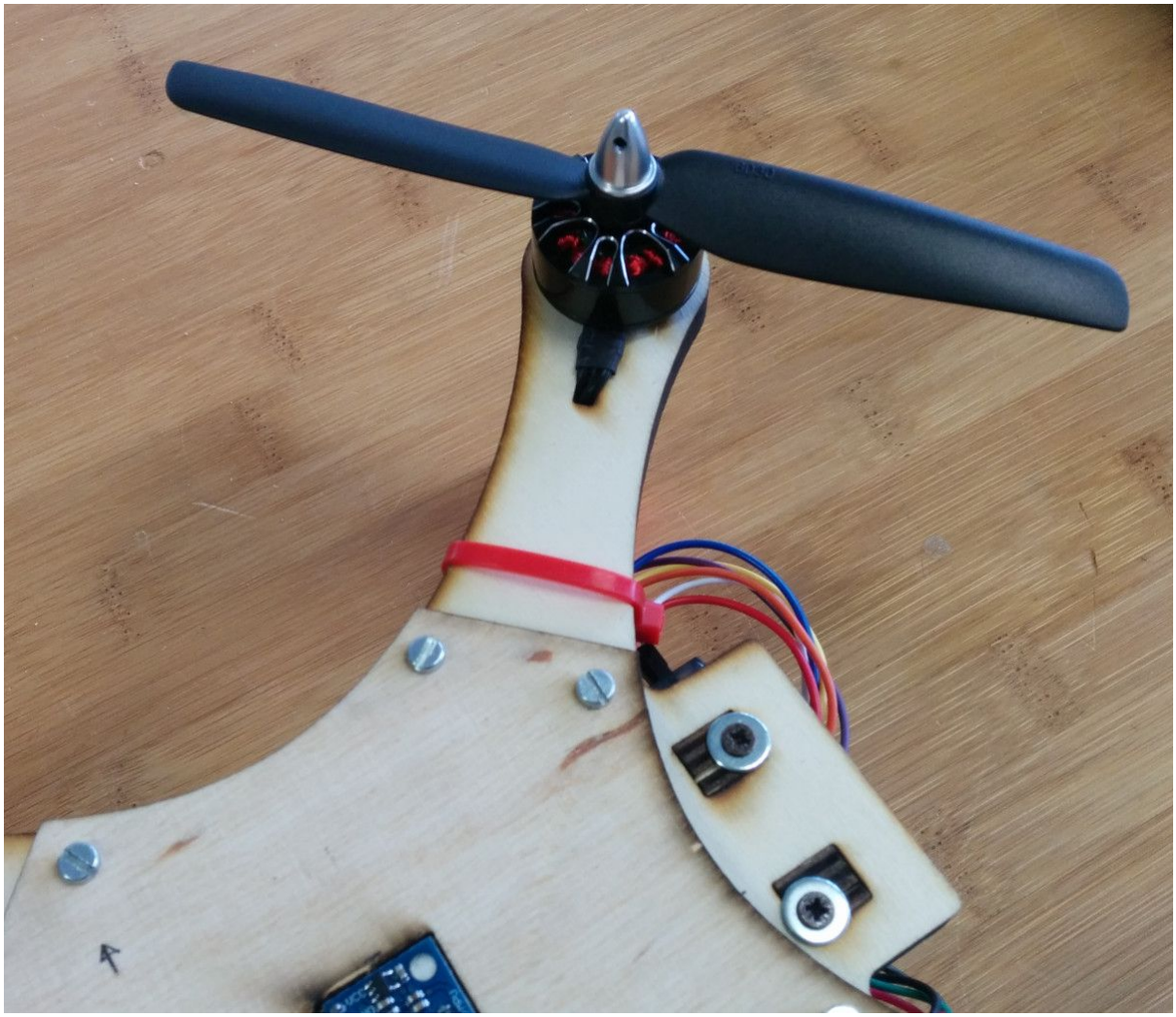
4. arm the drone by moving the left stick in bottom right position

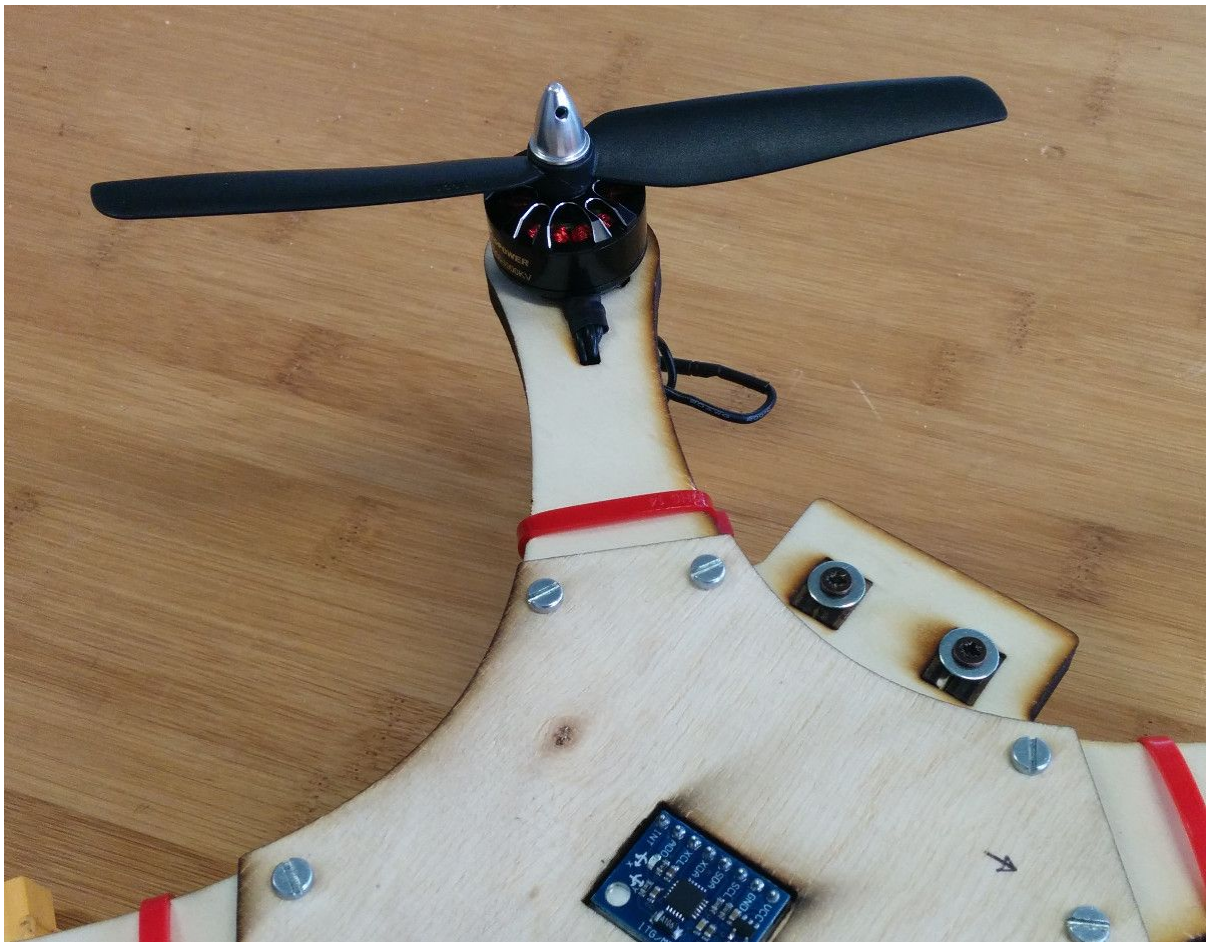
Now you can gently go up with the throttle you should see motors spinning. If not go back and check the previous instructions. The following image shows the right rotation direction of each motor you have to look for.

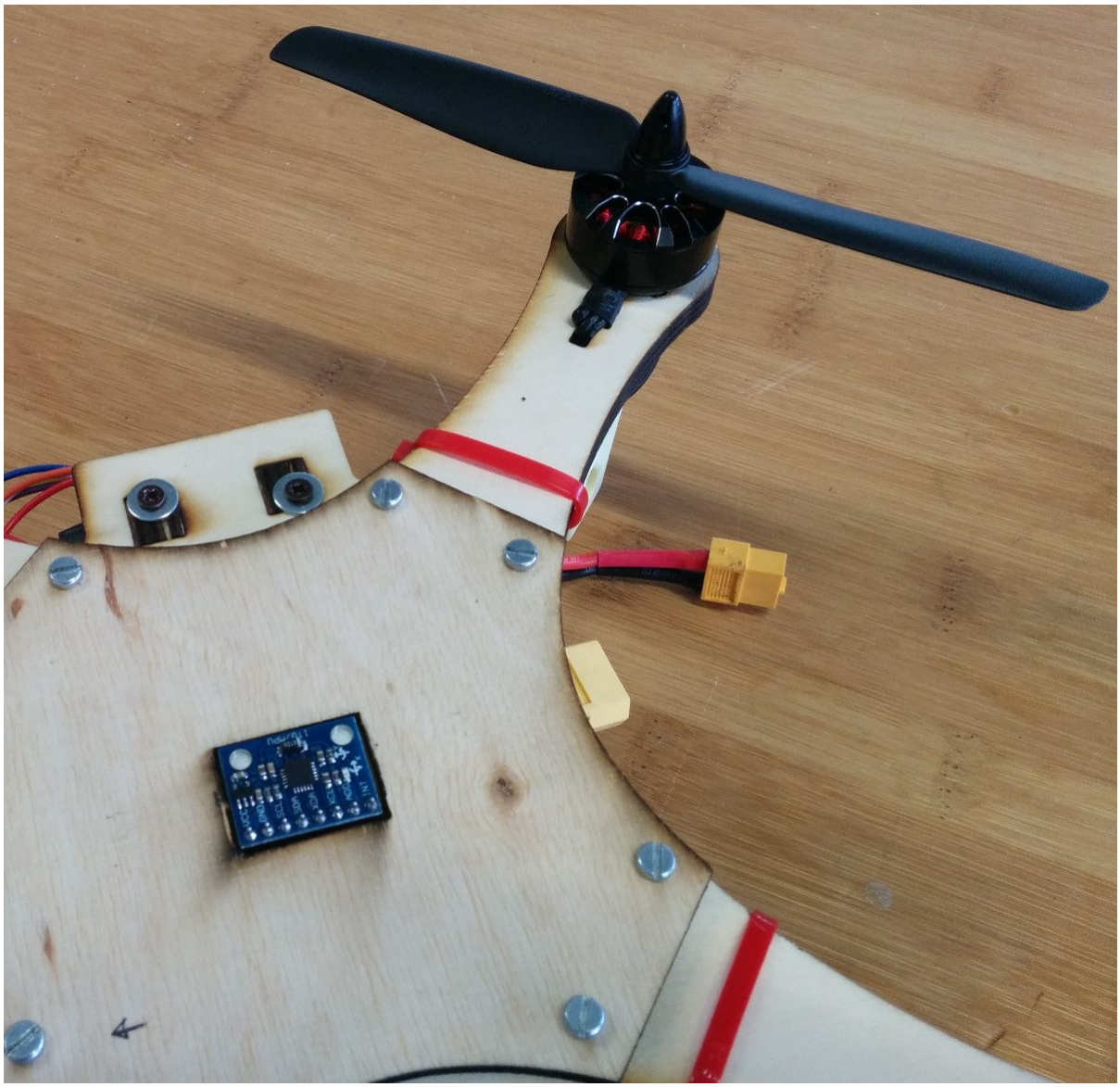


Once the rotations directions are ok, is time to mount the propellers. Remember that every propeller has to push the air down according with the rotation direction. Here are pictures about the right propeller in each position (use the arrow on the frame to orient yourself).



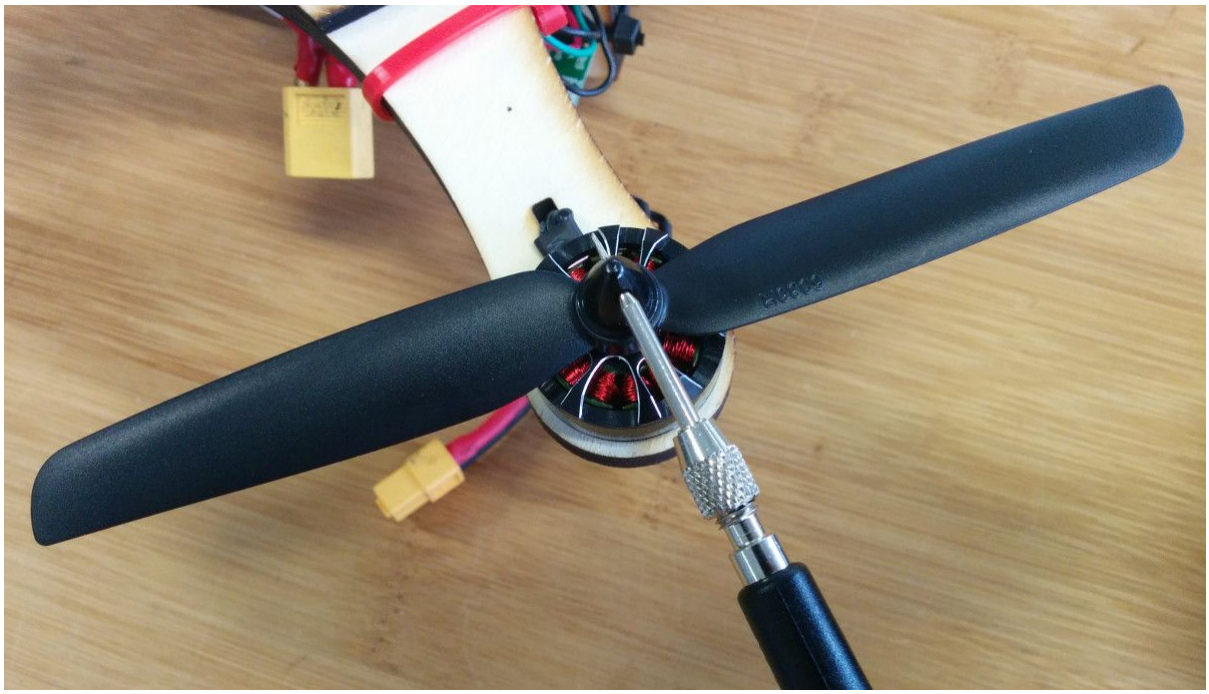




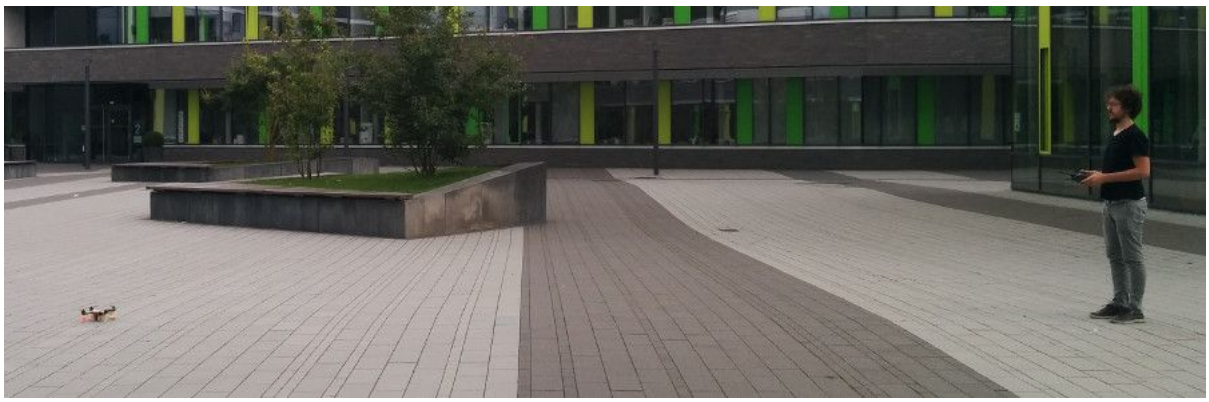


At the and the propellers should be like this:

Now put the propellers caps, and tighten them a little bit using a thin screwdriver:



You are almost ready to fly. Place the drone in **area without any risk of hitting someone**, stay away at least 5 meters from the drone and place yourself on the back of the drone, checking the front of the drone by looking at the arrow you drew on the frame.

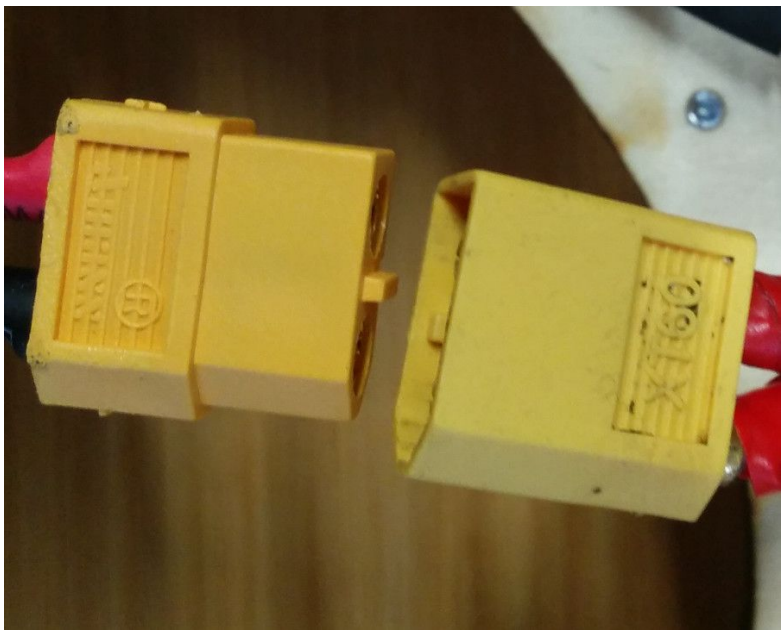


Now follow the same procedure of before to arm the drone:

1. set the throttle at minimum on the transmitter

2. switch on the transmitter

3. connect the battery to the drone



4. arm the drone moving the left stick in bottom right position

Remember that to when you finish you have to disarm the drone by staying with the left stick in the bottom left for more than 5 seconds.

Now try to spin a little the propellers and, if everything seems to be ok…..increase the throttle and have good flights!

References

- Daniele Ingrassia:
  - ingrassiada@gmail.com
  - http://www.fabacademy.org/archives/2015/eu/students/ingrassia.daniele/index.html
- FabLab Kamp-Lintfort
  - http://fablab.hochschule-rhein-waal.de/index.php/de/
- satshacopter on github:
  - https://github.com/satshacopter/satshacopter-250X
- satshakit flight controller on github:
  - https://github.com/satshakit/satshakit-flight-controller
- youtube videos:
  - satshacopter performance tests:
    - https://www.youtube.com/watch?v=MrtPuotW08c
  - satshakit fc upload MultiWii:
    - https://www.youtube.com/watch?v=ZrNh0s9pX4o
- MultiWii:
  - http://www.multiwii.com/
- Arduino IDE:
  - https://www.arduino.cc/en/Main/Software