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MASTER´S THESIS

DESIGN OF A QUADCOPTER TO WORK AT HIGH TEMPERATURES

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ABSTRACT

The project develops the design of a quadcopter to work within industrial plants which can be found even at 80 degrees Celsius. These plants should be checked as a way of detecting faults or cracks to prevent other serious incidents that may arise. Both the whole building as well as industrial machinery, which are inside the plant, should be inspected without the need to wait until the infrastructure is fully cooled down.

Both external mechanical defense to get close to surfaces, adapting to customer specifications, as well as mechanical and electronic components in the multicopter are designed. It shall support all the requested temperature at least 80 degrees.

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1.Introduction

A quadcopter, also called a quadrotor helicopter, is a multirotor helicopter that is lifted and propelled by four rotors. That is to say, it is a multirotor helicopter with four arms which has at its end a motor and propeller on it. Quadcopters are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of rotors (vertically oriented propellers).

Unlike most helicopters, quadcopters use two sets of identical fixed pitched propellers; two clockwise (CW) and two counter-clockwise (CCW); these characteristics achieve stability in its flotation. These use variation of RPM to control lift and torque. Control of vehicle motion is achieved by altering the rotation rate of one or more rotor discs, thereby changing its torque load and thrust/lift characteristics.

Early in the history of flight, quadcopter (referred to as 'quadrotor') configurations were seen as possible solutions to some of the persistent problems in vertical flight; torque-induced control issues (as well as efficiency issues originating from the tail rotor, which generates no useful lift) can be eliminated by counter-rotation and the relatively short blades are much easier to construct. A number of manned designs appeared in the 1920s and 1930s. These vehicles were among the first successful heavier-than-air vertical takeoff and landing (VTOL) vehicles. However, early prototypes suffered from poor performance, and latter prototypes required too much pilot work load, due to poor stability augmentation and limited control authority.

More recently quadcopter designs have become popular in unmanned aerial vehicle research. These vehicles use an electronic control system and electronic sensors to stabilize the aircraft. With their small size and agile maneuverability, these quadcopters can be flown indoors as well as outdoors.

There are several advantages to quadcopters over comparably-scaled helicopters. First, quadcopters do not require mechanical linkages to vary the rotor blade pitch angle as they spin. This simplifies the design and maintenance of the vehicle. Second, the use of four rotors allows each individual rotor to have a smaller diameter than the equivalent helicopter rotor, allowing them to possess less kinetic energy during flight. This reduces the damage caused should the rotors hit anything. For small-scale UAVs, this makes the vehicles safer for close interaction. Some small-scale quadcopters have frames that enclose the rotors, permitting flights through more challenging environments, with lower risk of damaging the vehicle or its surroundings.

Due to their ease of both construction and control, quadcopter aircraft are frequently used as amateur model aircraft projects.

1.1.Typical Design

The quadcopter is a popular concept for a drone, because of its properties. The major advantages for the quadcopter are its ability to hover, and take off vertically. This makes the quadcopter useful for many tasks and allows it to be operated in nearly any environments.

While a conventional helicopter design, which one main rotor and one tail rotor, have the same properties, the quadcopter is advantageous in several fields. The quadcopter have no moving parts except for the rotating motors and propeller that rotate about fixed axes, while the conventional helicopter have a complex hub to make it possible to start an translation movement. The quadcopter is also less prone to vibration and it is more robust when it comes to the placement of placement of center of gravity. It is also easier, due to the small size, to cover the rotors and thus making it safer to fly indoors. The typical design for a quadcopter has as stated earlier, no moving parts. The motors and theirs propellers are mounted onto the airframe; this configuration gives the quadcopter an interesting dynamic. Since the propellers are

fixed to the frame, the only way to induce a lateral motion is to tilt the entire airframe. To tilt the quadcopter, the moment about one axis have to alter. To change the moment, one or both motor have to either increase or lower its amount of thrust. If just one of the motors adjusts the thrust, there will be an unbalance in the rotational force about the yaw axis, therefore the motors would have to increase and lower the thrust with the same amount to keep the quadcopter still about the yaw axis. This is also the reason for why the motors turning the same direction is mounted opposite to each other, to be able to facility this operation. If the motors had been spinning opposite direction to each other, one could not regulate tilt, without inducing another tilt or yaw moment.

Unlike a conventional helicopter, the quadcopter does not have a tail rotor to help controlling the yaw motion. Instead the quadcopter rely on controlling the torque forces from the motors to control the yaw forces. Since the quadcopter is built with four motors where two are spinning clockwise and the other two spinning counterclockwise, the torque from the motors will cancel each other. This is only valid as long as each pair of motors has the same torque, if one of the motors gets a reduced torque the aircraft will start to spin in the air.

1.2.Uses

1.2.1. Research platform

Quadcopters are a useful tool for university researchers to test and evaluate new ideas in a number of different fields, including flight control theory, navigation, real time systems, and robotics. In recent years many universities have shown quadcopters performing increasingly complex aerial manoeuvres. Swarms of quadcopters can hover in mid-air, in formation, autonomously perform complex flying routines such as flips, darting through hula-hoops and organizing themselves to fly through windows as a group.

There are numerous advantages to using quadcopters as versatile test platforms. They are relatively cheap, available in a variety of sizes and their simple mechanical design means that they can be built and maintained by amateurs. Due to the multi-disciplinary nature of operating a quadcopter, academics from a number of fields need to work together in order to make significant improvements to the way quadcopters perform. Quadcopter projects are typically collaborations between computer science, electrical engineering and mechanical engineering specialists.

Because they are so manoeuvrable, quadcopters could be useful in all kinds of situations and environments. Quadcopters capable of autonomous flight could help remove the need for people to put themselves in any number of dangerous positions. This is a prime reason that research interest has been increasing over the years.

There are some world-class engineering research laboratories currently developing more advanced control techniques and applications for quadcopters. These include mainly MIT's Aerospace Controls Lab, ETH's Flying Machine Arena, and University of Pennsylvania's General Robotics, Automation, Sensing and Perception (GRASP) Lab.

1.2.2. Military and law enforcement

Quadcopter unmanned aerial vehicles are used for surveillance and reconnaissance by military and law enforcement agencies, as well as search and rescue missions in urban environments. One such example is the Aeryon Scout, created by Canadian company Aeryon Labs, which is a small UAV that can quietly hover in place and use a camera to observe people and objects on the ground. The company claims that the machine played a key role in a drug bust in Central America by providing visual surveillance of a drug trafficker's compound deep in the jungle (Aeryon won't reveal the country's name and other specifics).

1.2.3. Commercial use

The largest use of quadcopters has been in the field of aerial imagery. Quadcopter UAVs are suitable for this job because of their autonomous nature and huge cost savings.

As quadcopters are becoming less expensive media outlets and newspapers are using drones to capture photography of celebrities.

2.Goal

ALSTROM needs some specific requirements to exam the structure of some thermal plants. The example is represented by inspections of boiler furnace systems where an inspection of (50x50x100m) has to be covered. Using small sized inspection helicopters (quadcopter) to visually assess a boiler furnace has hence been regarded a viable option. Small aerial vehicles are considered for this operation (0.5 to 0.8 m platform diameter due to EHS concerns). Naturally, this has direct implications on the payloads such a vehicle may carry.

Unmanned aerial vehicles (UAVs) are particularly useful in applications where the operating site cannot be reached by ground vehicles or applications that require an aerial view of the whole scene. In the context of a larger project on three-dimensional semantic mapping of inaccessible areas and objects, the goal is the development of an unmanned aerial vehicle that is able to autonomously navigate in suburban areas and especially in the (close) vicinity of buildings, vegetation and other possibly dynamic objects. In particular, it is possible to focus on fast and reliable perception of (even small) obstacles in the vicinity of the UAV. It will be described the hardware design of our platform including the sensor setup and the applied methods for robustly detecting obstacles, as well as for planning the UAV's motion in order to reach goal poses while reliably avoiding collisions.

In this context, providing robotic inspection tools operable at elevated temperatures (60-80 degrees) to ALSTROM´s service customers would provide valuable advantages. Inspections might be realized at reduced plant outage time (one does not have to wait until the infrastructure is fully cooled down).

Size and weight constrains still have to be fulfilled, it would not be acceptable if a temperature tolerant hardware replica would have a considerably higher weight or size than its non-temperature tolerant counterpart.

The two main problems that will appear are the design of the defense to be able to contact the wall and examine the defects. Another one is the researching of different electronic devices that could endure the high temperature also.

3.Quadcopter Description

3.1.Dimensions

The design of quadcopter is based in the dimensions given by ALSTROM. The point has been to give the smallest dimension available but introducing all elements ordered. In the image below [Figure 3-1] is possible to observe the minimum dimensions of quadcopter design. These are below the minimum required by the customer.

The size of the cabin, which it will be explained later, will be perfect to hold all devices whose diameter and height are suitable. The cabin, unlike the frame that it is possible to buy in the market, will have to be made to order to contain all the required elements.

The arms have been designed to avoid the crash between propellers and the cabin. The arms are integrated in the frame.

It can also be seen in the picture below that there are two rods. These are what sustain the external defense of the quadcopter. They consist of two cylindrical rods with proper latching system for 2D and 3D defense.

The size of the engines and propellers correspond to those chosen from those available and valid on the market.

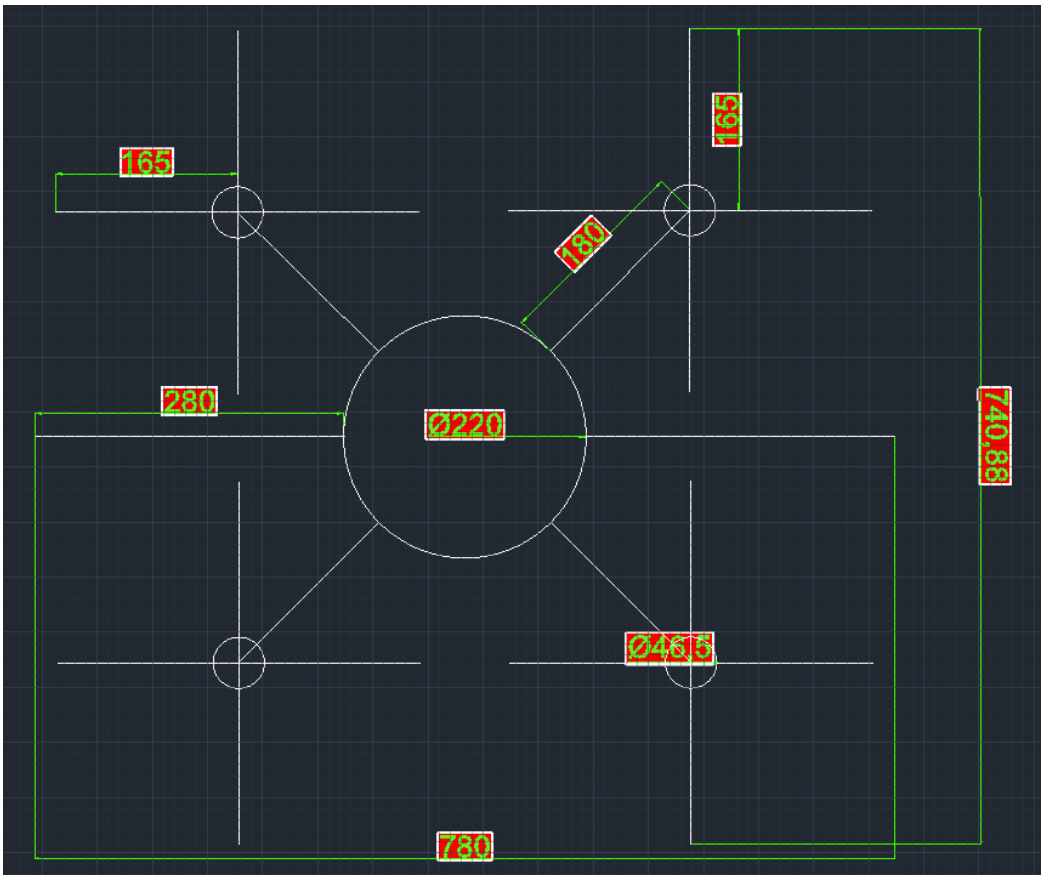


Figure 3-1: Simple design dimensions

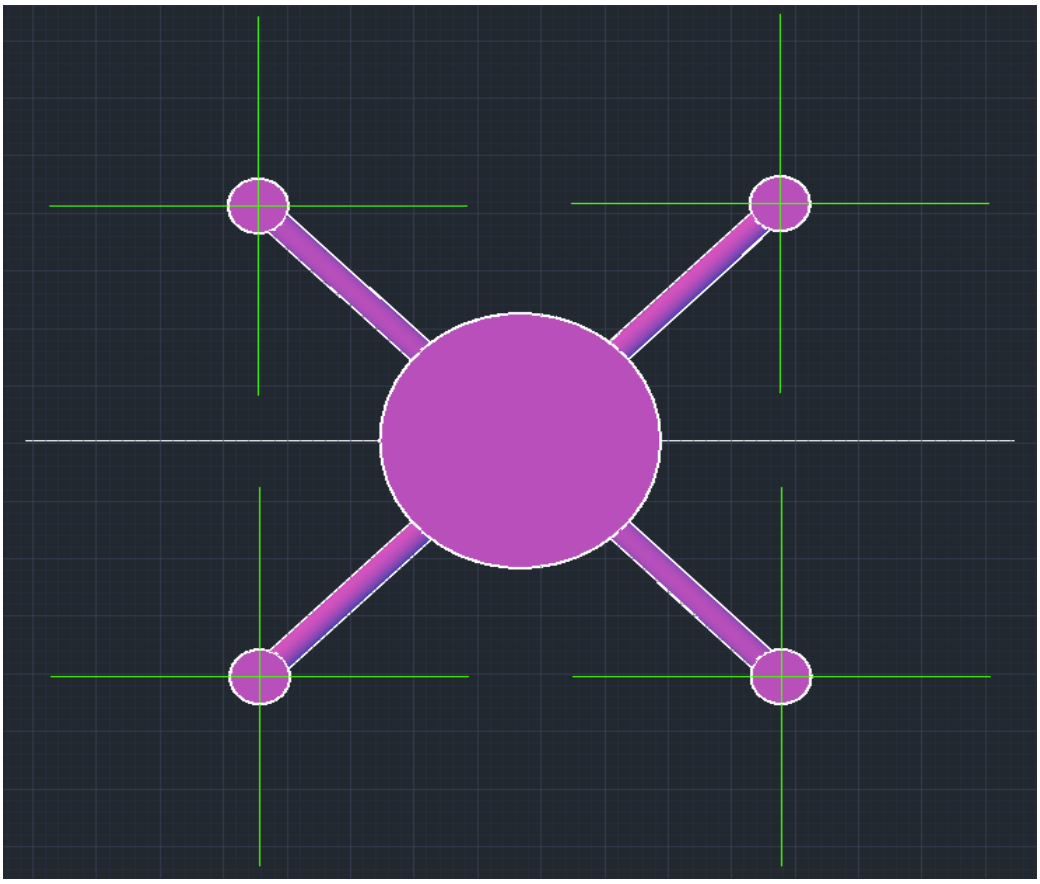


Figure 3-2: Basic design

3.2.Frame

The body of the quadcopter consists in four arms that the length is 290 mm each extension. On the top of these arms the motors and propellers are put.

Carbon fiber will be the material chosen. It is an extremely strong and light fiber-reinforced polymer which contains carbon fibers. The binding polymer will be a thermoset resin (epoxy), but other thermoset or thermoplastic polymers, such as polyester, vinyl ester or nylon are sometimes used.

Carbon Fiber Reinforced Polymer (CFRP)				
Composition: 70% carbon fibers in epoxy matrix				
Property	Value in metric unit		Value in US unit	
Density	$1.6 * 10^3$	kg/m^3	101	lb/ft^3
Tensile modulus (LW)	181	GPa	26300	ksi
Tensile modulus (CW)	10.3	GPa	1500	ksi
Tensile strength (LW)	1500	MPa	215000	psi
Tensile strength (CW)	40	MPa	5800	psi
Thermal expansion (20 °C, LW)	$0.02*10^{-6}$	$°C^{-1}$	$0.01*10^{-6}$	in/(in* °F)
Thermal expansion (20 °C, CW)	$22.5*10^{-6}$	$°C^{-1}$	$12.5*10^{-6}$	in/(in* °F)

Figure 3-3: Table carbon fiber (70%) reinforced polymer

Also it will be enough tough to resist the charge of the cabin. The weight of the cabin could give a big bending moment, including the possibility of break the structure with any lightness material.

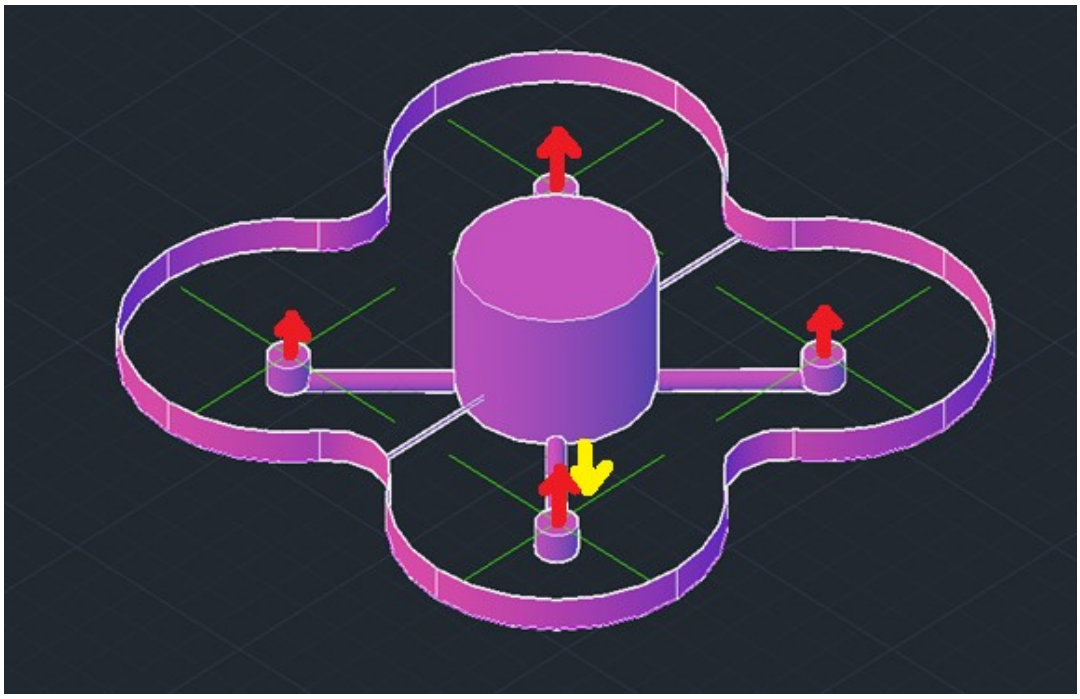


Figure 3-4: Bending moment in the quadcopter

It is bought a structure manufactured called FC X580 580MM folding quadcopter frame carbon and fiber landing gear.

Figure 3-5: FC X580 580MM folding quadcopter frame carbon and fiber landing gear.

The structure will be 580 mm long from the end of an arm to the end of the adjacent arm. Material is 1.5 mm thickness of fiber-processed by CNC. Each arm will

have the base for brushless motors and four holes for the screws. Also in the middle of the structure is the base for the cabin.

The landing skid gear is included whose main advantage is the height and it is enough to install, under the cabin, the gimbal with the camera chosen. It will have four legs linked two by two with horizontal bars. It is interesting to keep the stability of the quadcopter during the landing and also it improves the stiffness of the structure. These elements will resist harder landings and will avoid deformations of the legs also. Each pair of legs will be also linked in the belly of the quadcopter.

Some landing skid gears are retractable, so the position in the landing and flight are different to permit more agility. However, in this case, the static landing skid gear will protect the gimbal system and the camera of possible collision during missions. One of the goals of the project is to protect all devices so that using this system will be an important defense of quadcopter.

3.3.Cabin

The cabin is a cylinder where the main electronic devices are. The dimensions are: diameter 220 mm and high 150 mm. In the cabin, the most important controlling and telemetric devices can be found.

It will be used the carbon fiber as material also. This cabin must be designed and customized as shown in the pictures below.

The dimensions are exclusive of the project and it is not only a cylinder cage. It will have a hole in the top of 40 mm in diameter for the selected fan. The larger outer diameter of the fan is 44.45 mm and the fan´s core diameter is 39.67 mm, so it is important to stick the fan to the cabin using a resistant silicone.

It is estimated that the thickness of the cage will be the same as the frame's thickness. But the cage will have two parts: the base fixed to the frame with all the important devices inside and the top cover will have only the fan. Both parts will fit with thread. This system will be perfect to replace the batteries easily and to fix immediately any problem that could appear.

It will avoid the damage for important devices inside and it will be enough light and resistant for the flights. Here some useful properties:

The thermal isolation will be an important point because of the high temperature of the environment. The thermal protection of the devices is the most difficult problem to face. The isolation of outside high temperature will be ready with this material and internal heat of devices will be expelled using the fan.

Corrosion resistance will make the quadcopter suitable for wet environments like steam plants. The material will avoid the corrosion of the cabin and the devices inside, so it will grant the correct performance.

Another property is the fireproof so that the fire will not be a problem outside because the plants will be switched-off in the inspections. But it is interesting to use a fireproof material to endure possible fires inside the structure because some electronic devices could fail during the work.

3.4.Defense

The outer defense is based on existing designs. All can be found in the multirotor helicopter market. Although it may be the case and not to find one with the right dimensions, so it would order it or just fix one of the existing ones.

The first 3D design cage is the most useful in terms of being able to cover all surfaces and protect himself from these smoothly. Besides this cage can pivot and roll on walls or surfaces adjusting the speed to the requested needs.

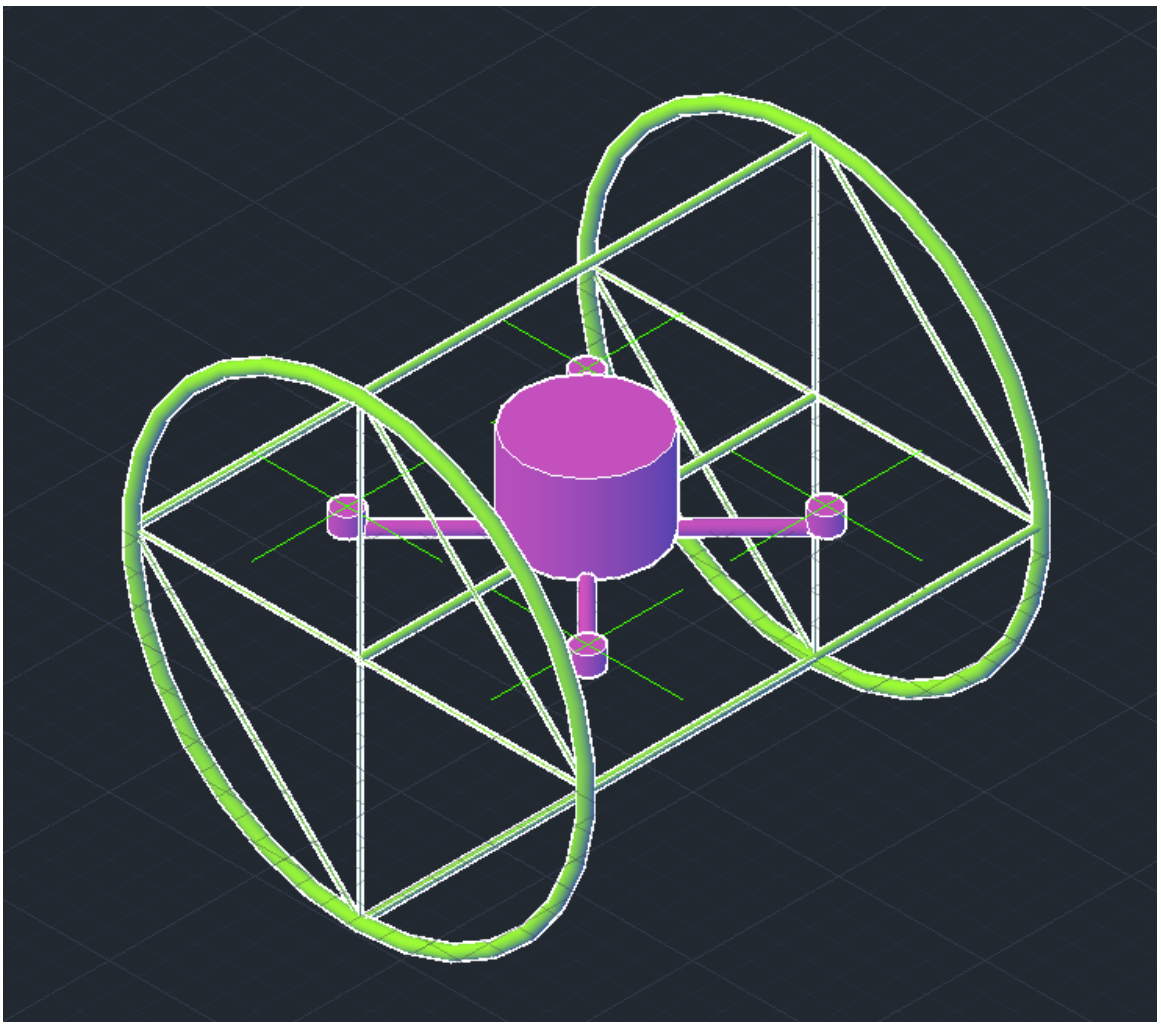


Figure 3-6: Jail design 1

This design must be put on CNC software just to reproduce the perfect pattern of piece to produce. Once it is used the CNC and pattern is obtained, it is time to apply the different sheets of carbon fiber just to have the required thickness.

Some companies, like iLLSTREET COMPOSITES, are specialized in manufacturing designs of different prototypes. They fabricate a pattern to follow the composite design based in design or drawing of client.

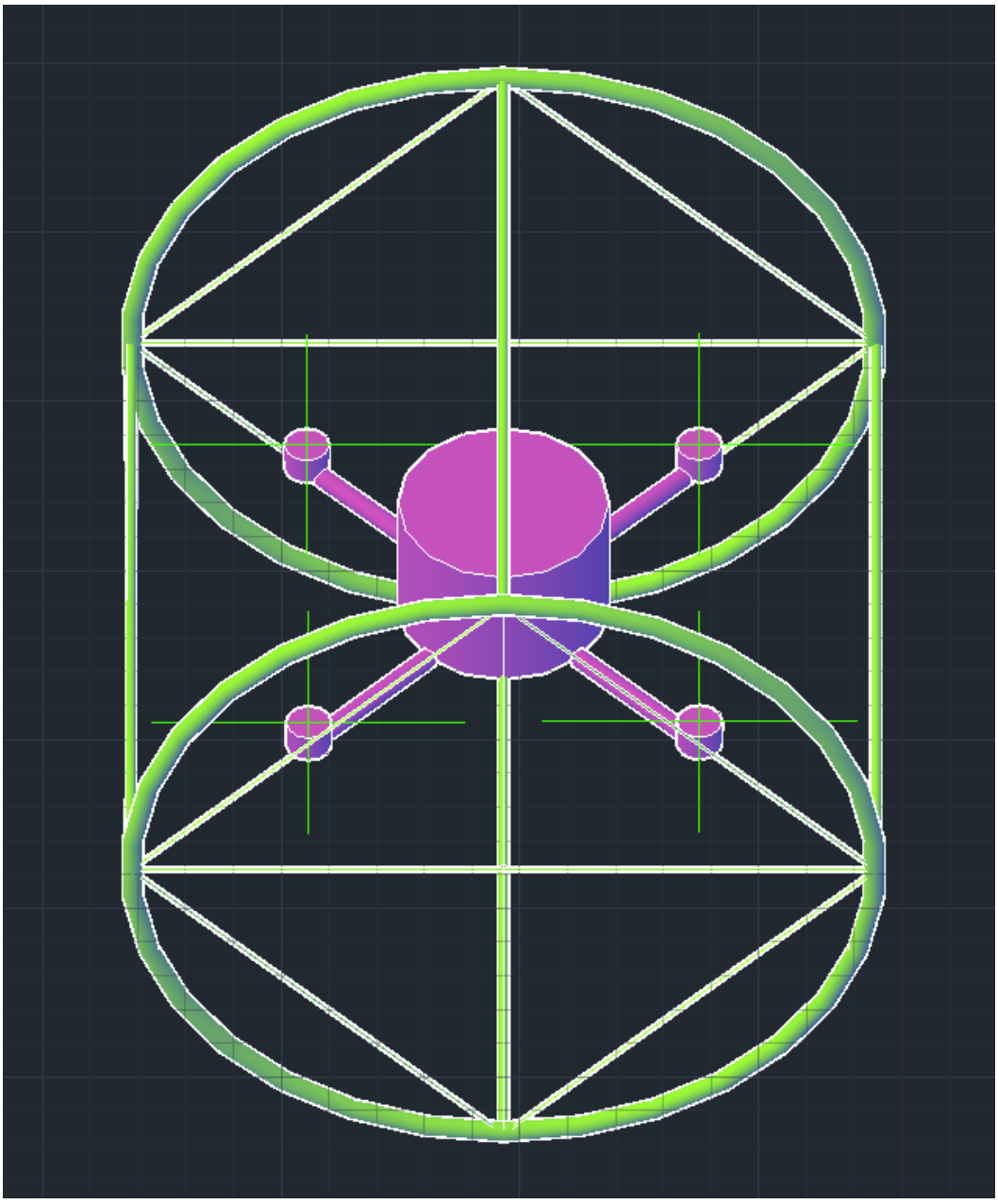


Figure 3-7: Jail design 2

The external protection, type wheels, allows such movements flush with surfaces, but could be more insecure in that it has only protection on the sides.

It means that not all the axes or directions are covered or protected. The propellers will be more exposed to any possible collision.

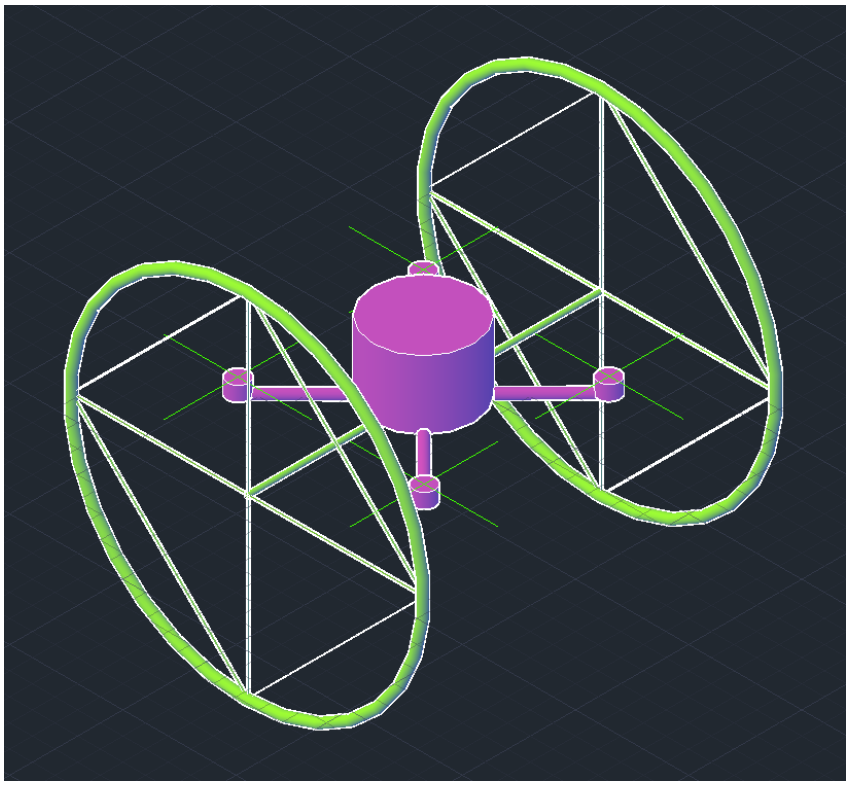


Figure 3-8: Wheels design 1

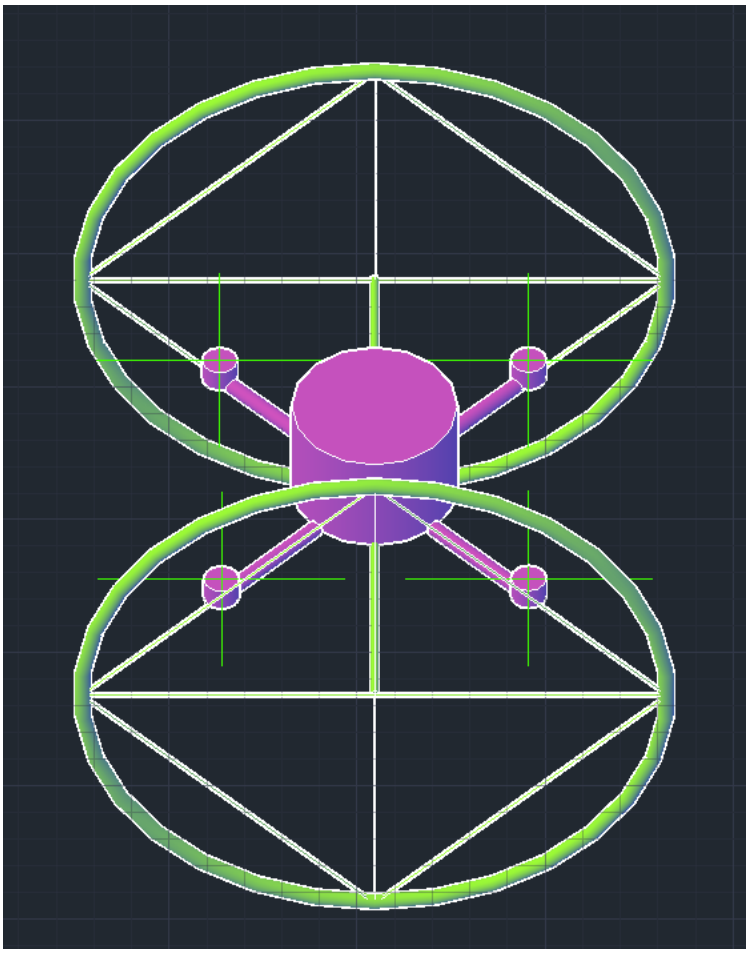


Figure 3-9: Wheels design 2

The quadcopter dimensions would increase compared to a 2D defense, being these maximal dimensions of 780x780 mm which length corresponds to diameter. The picture below show how will be this design.

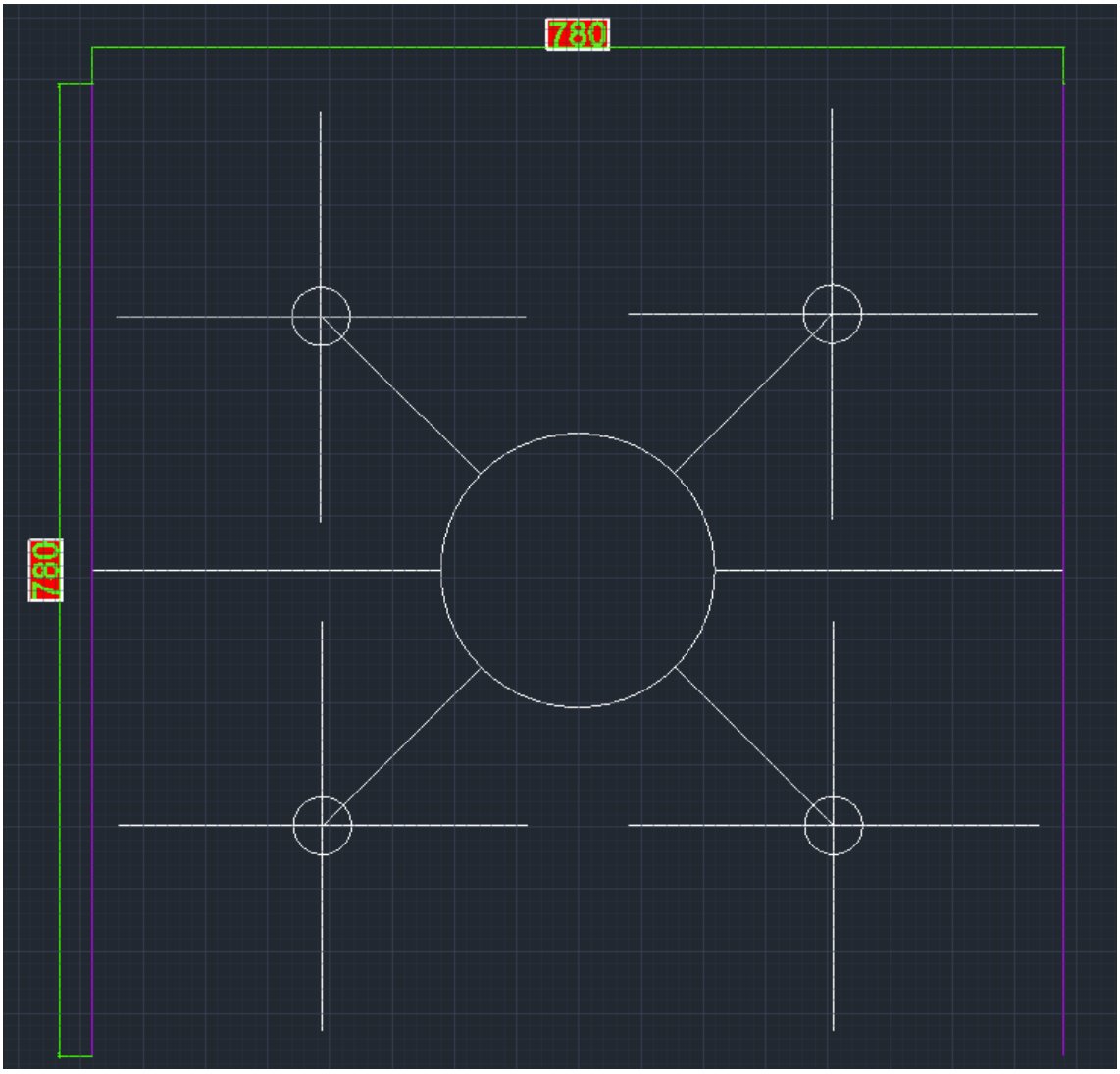


Figure 3-10: Dimensions for 3D designs

Finally, 2D defense is chosen to minimize the surface getting more agility. So it is important that the space between propellers and defense will not be too much, just a few millimeters.

Although the ability to change the defense, when is needed, will be always available. It is a simple method of exchanging defense. 3D defense will give the protection in all axes and the opportunity to examine the walls easily also.

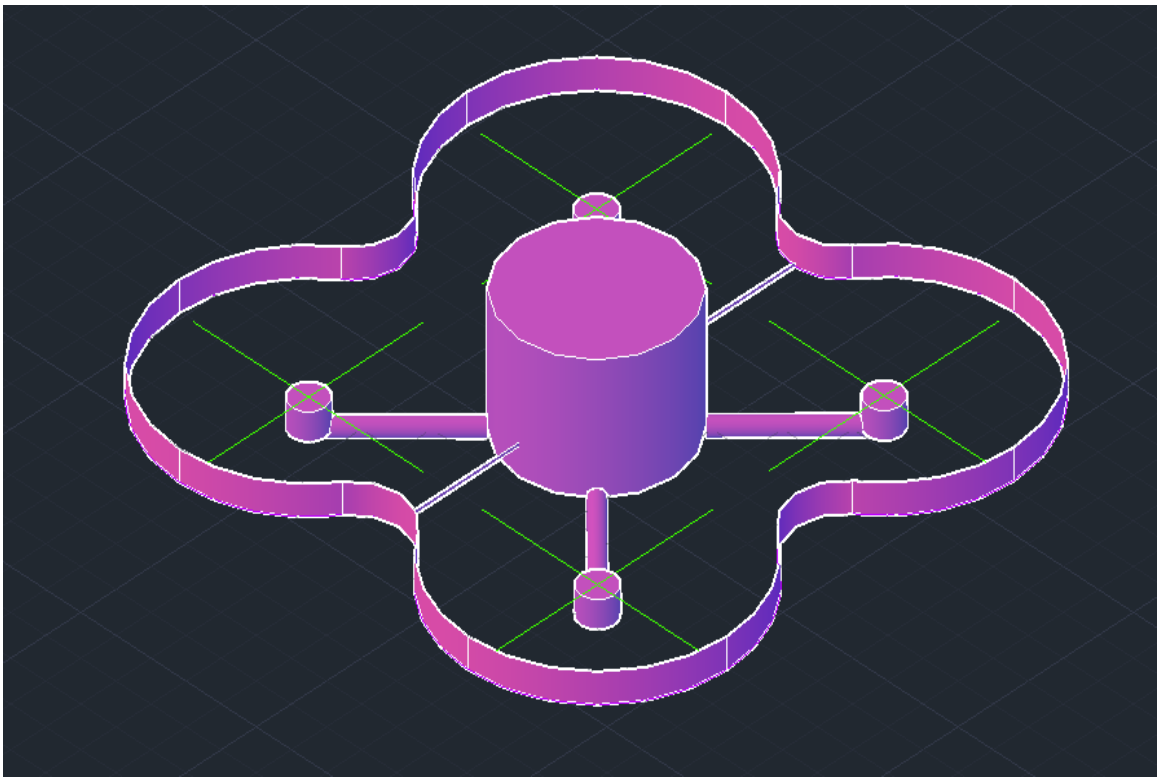


Figure 3-11: Rose 1

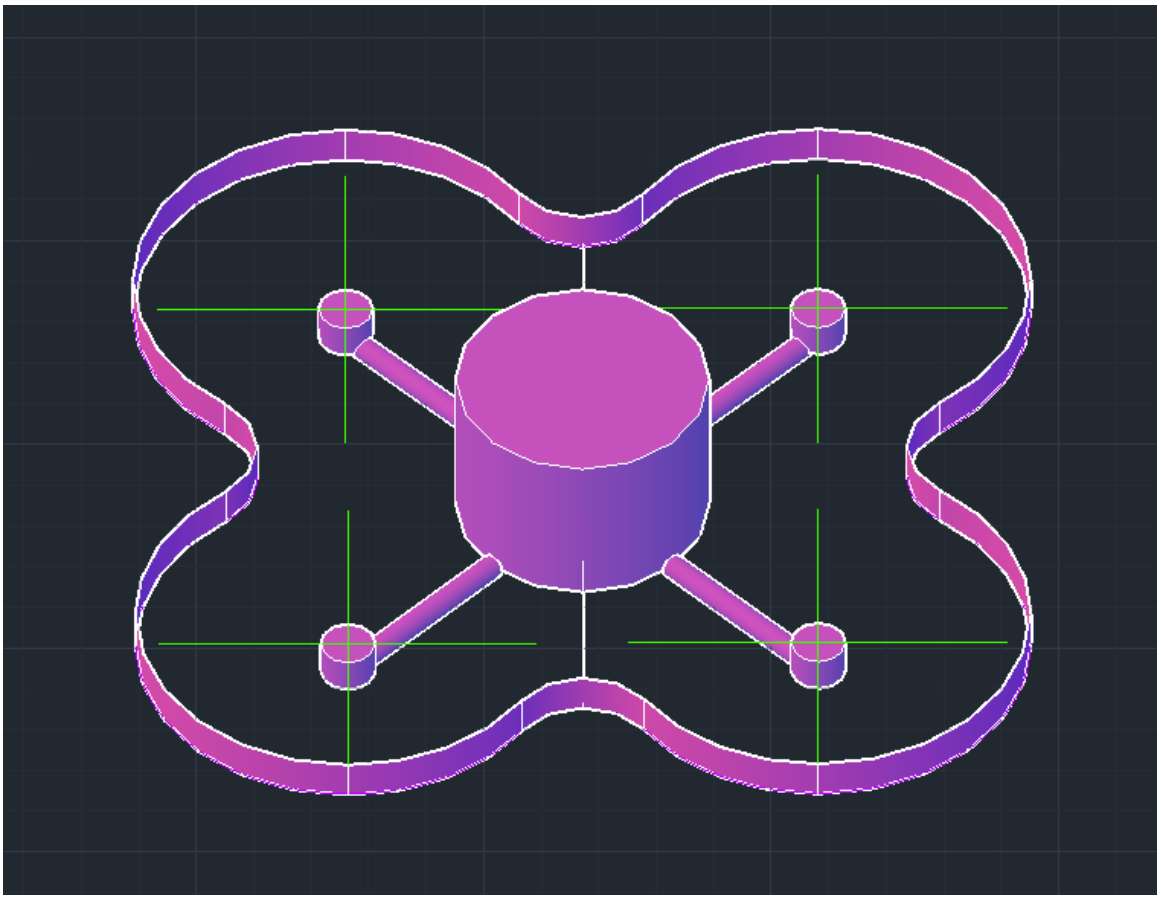


Figure 3-12: Rose 2

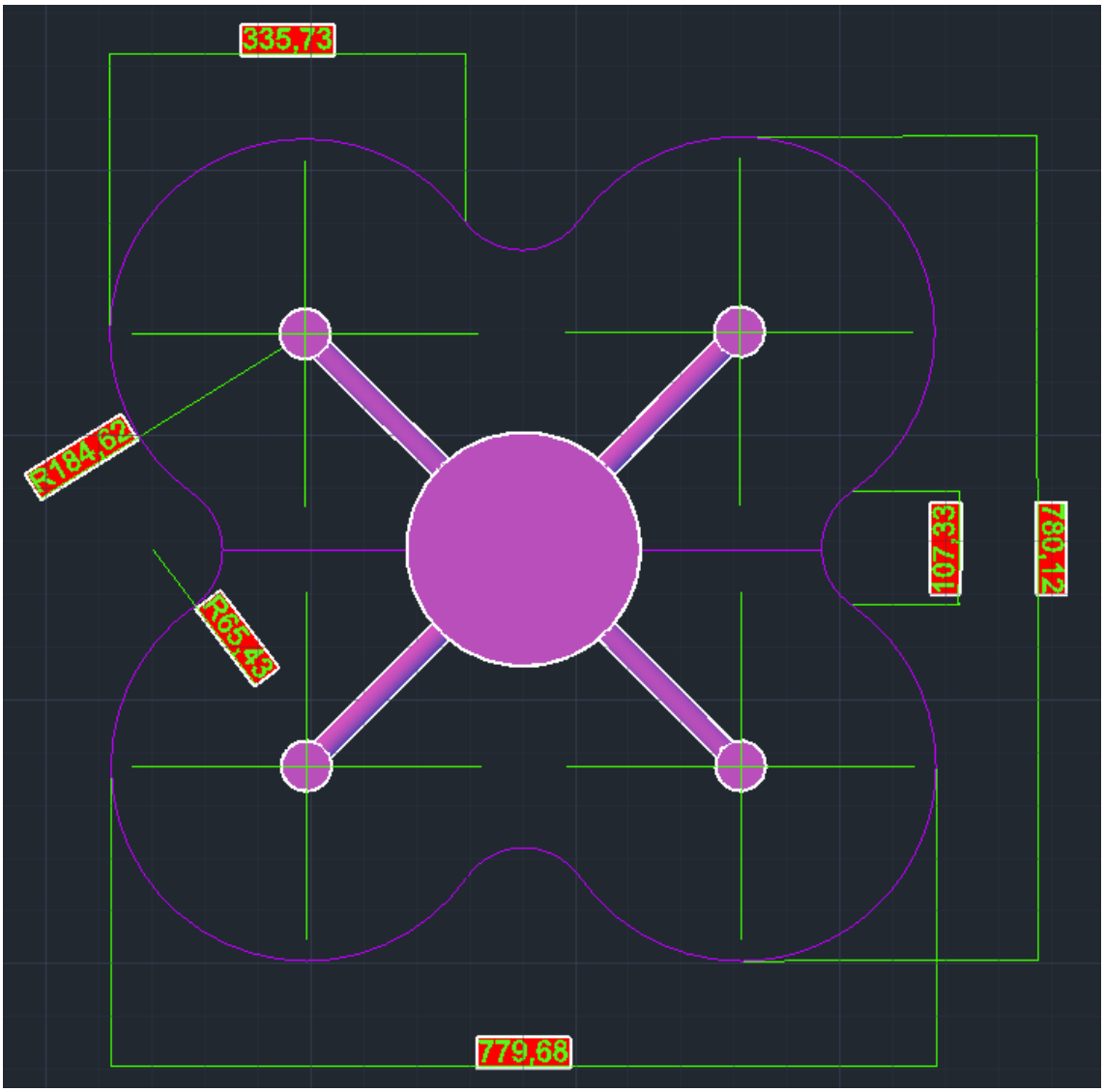


Figure 3-13: Rose 3 dimensions

The shape of the defense will be kind of flower which is optimized, giving the opportunity to examine better the corners.

With this system the surface of the defense is minimized and can be reached by air for most locations. So it is possible to avoid more obstacles or turn better the corners and nooks.

The basic lateral defensive system would be another possible but less recommended about money and protection. It should be modified coupling systems

for a special order for this system. Besides, some protection is lost, being that the propellers are protected only, not the entire side.

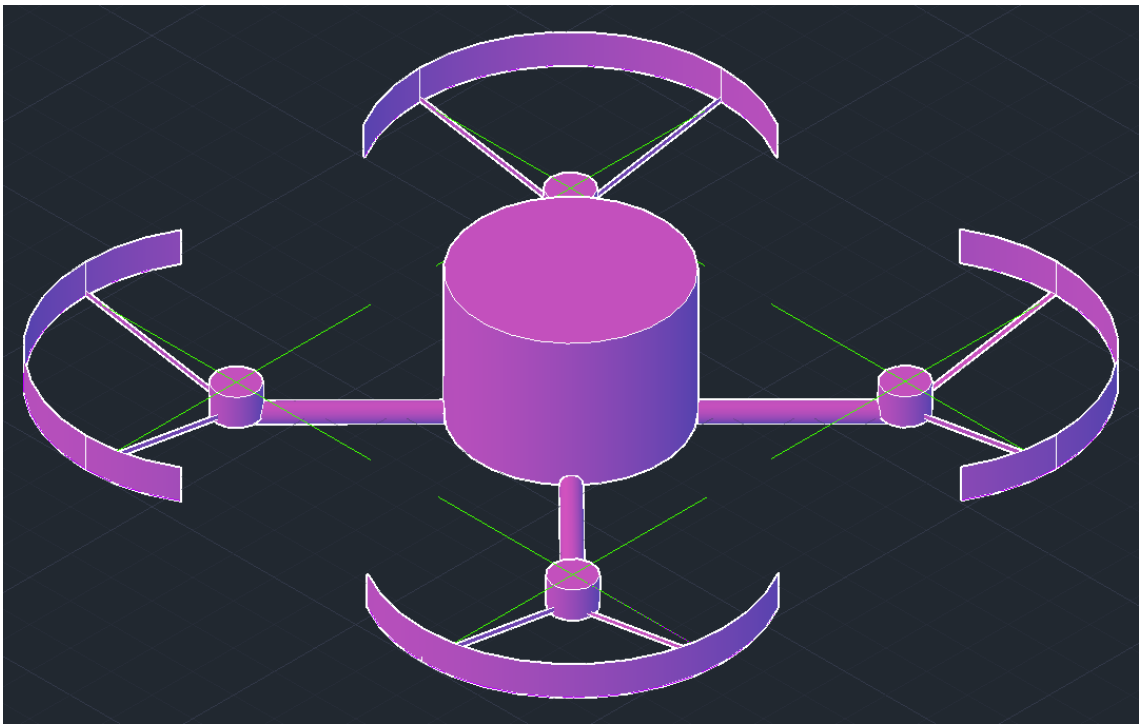


Figure 3-14: Basic lateral defense 1

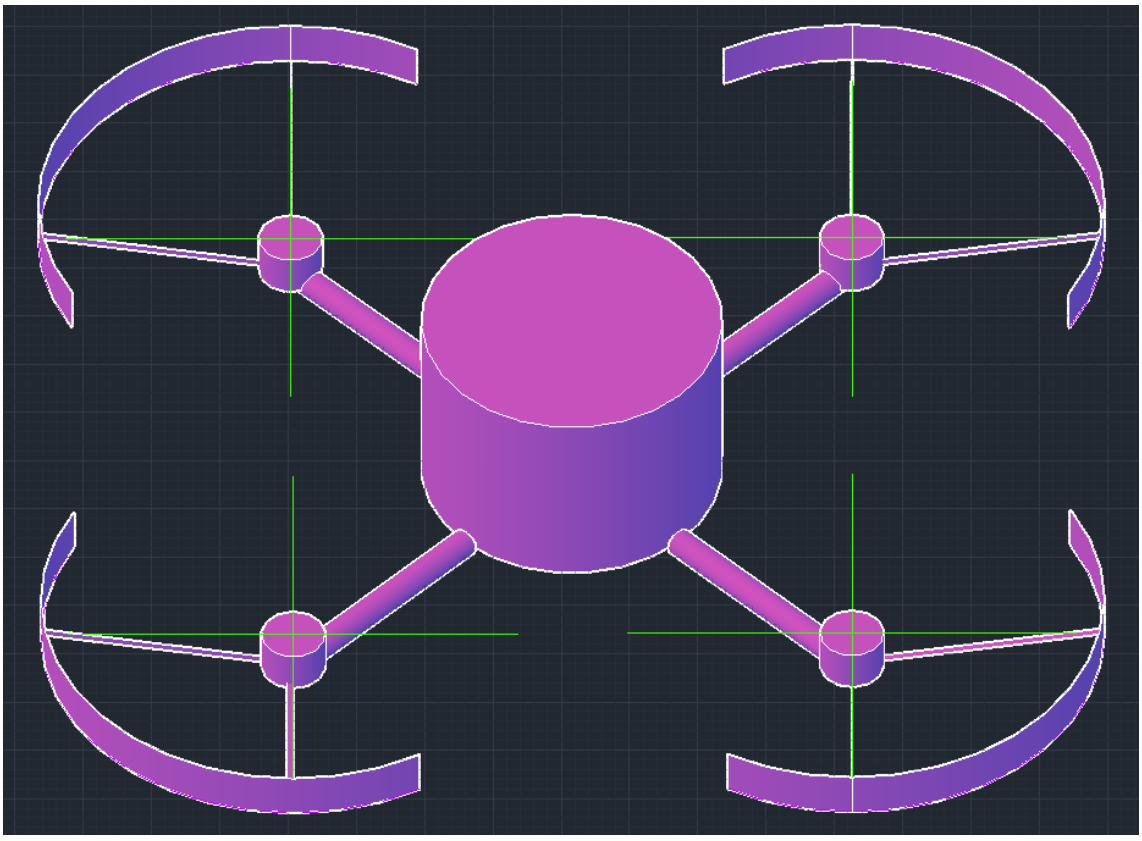


Figure 3-15: Basic lateral defense 2

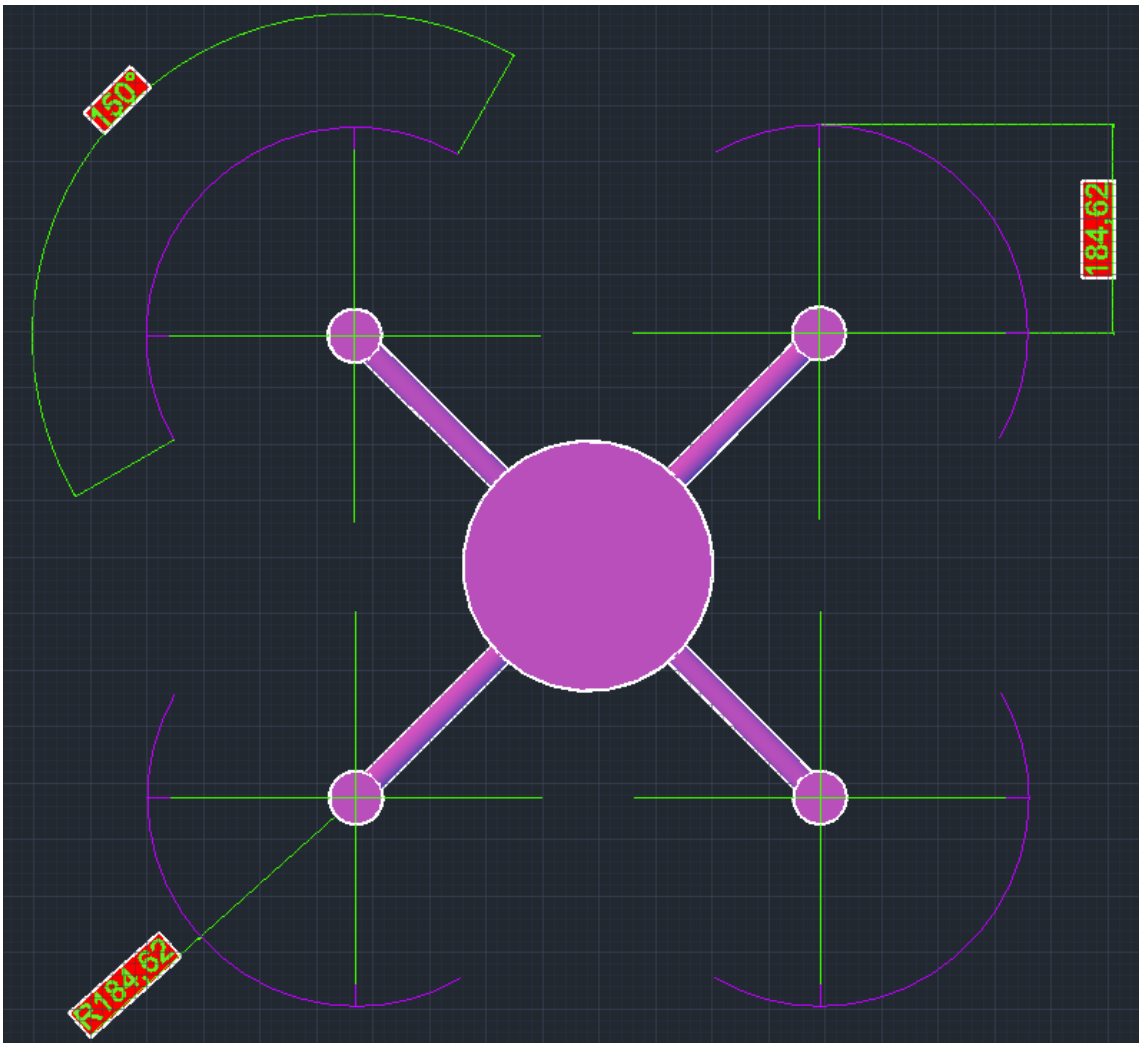


Figure 3-16: Basic lateral defense dimensions

3.5.Gimbal

A gimbal is a pivoted support that allows the rotation of an object about a single axis. A set of three gimbals, one mounted on the other with orthogonal pivot axes, may be used to allow an object mounted on the innermost gimbal to remain independent of the rotation of its support.

Storm Pro-3 Universal Gimbal is a system with 3 axes of movement, which is really useful to examine all angles of the structure, being not necessary to move the

quadcopter for it. Also it is good to be focused in one object and avoid others movements like vibrations or jerk from UAV.

Figure 3-17: Storm Pro-3 Universal Gimbal

This exclusive gimbal is so special because it is not made for a specific camera; it is universal, which means you can mount different cameras. If the camera weight is between 350 grams to 600 grams range, the gimbal will work. The B6640 Imperx (camera used in the quadcopter) is situated in this range so it will fit perfectly.

The design of the gimbal is simple but clever, all arms can be adjusted with a screw driver to meet different gravity centers of the camera (gimbal requires perfect center of gravity for all axis to work properly). It is possible to change the parameter for each axis (like increasing gyro sensitivity or decrease power, etc.) using a computer until the gimbal is perfectly stable.

Figure 3-18: Changing center of gravity in the gimbal

Also the mounting to the drone's belly will be really important to obtain perfectly stable video. Even the slightest movement will amplify in the video.

3.6.Camera

The work of examining of the furnace will be with the camera B6640, which is an advanced high-speed progressive scan, fully programmable CCD camera designed for

imaging applications that require high quality images with powerful features and flexibility.

The 29-Mpixel ICL-BB640 Bobcat is a four-tap camera with an extended operating temperature range from -40°C to +85°C and a mean time before failure of >660.000 hours at 40°C. The 60 x 60 x 53 mm camera provides an image resolution of 6576 x 4384 and delivers up to 4.7 frames per second with a 43.3 mm optical format. These characteristics will fit perfectly in our exhaustive tests in the surfaces, furthermore if it is considered the light weight and size.

Figure 3-19: B6640 Imperx Camera

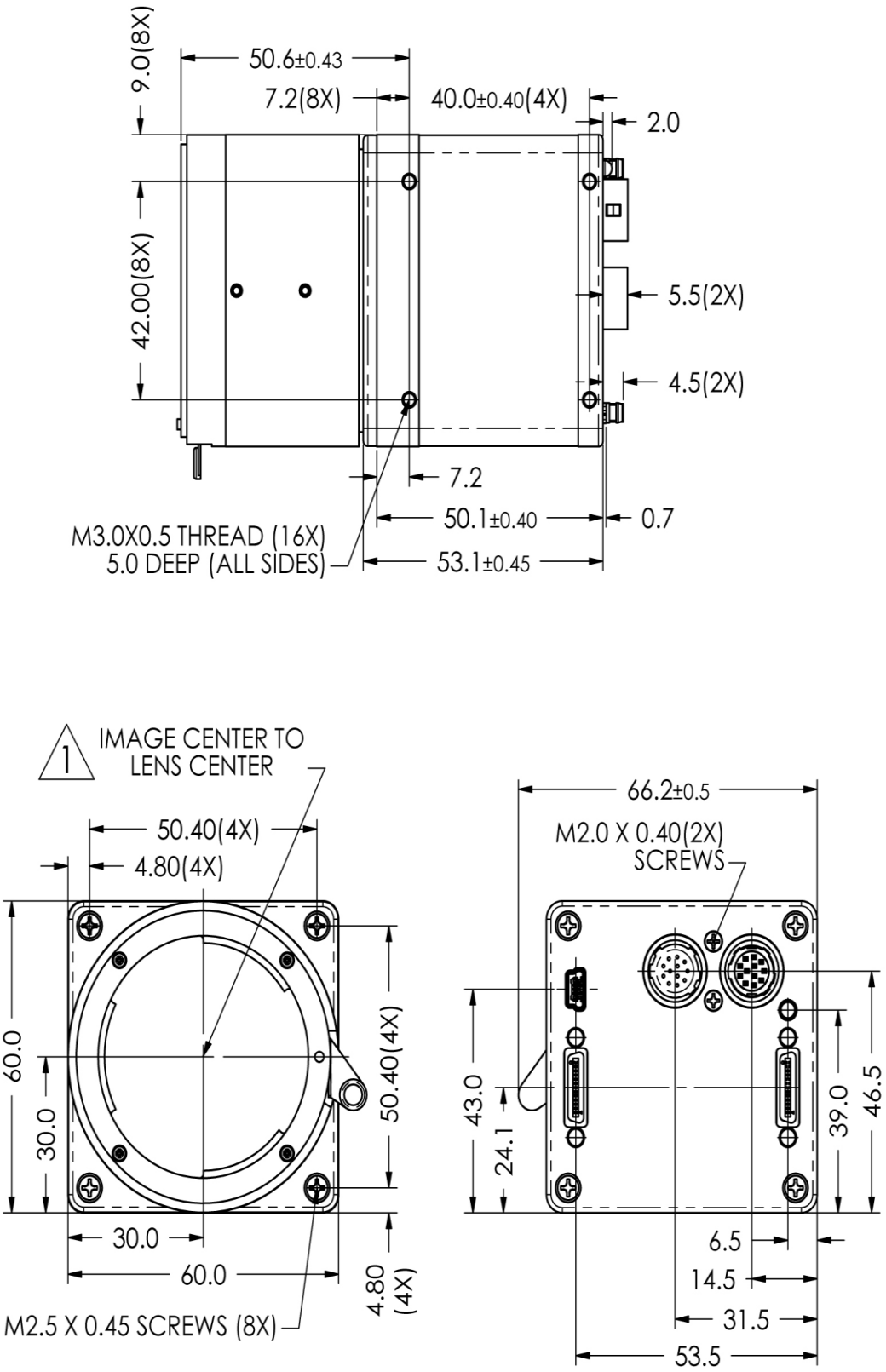


Figure 3-20: B6640 Imperx camera dimensions

3.7.Flight Control Board

The AeroQuad 32 is powered by a 168MHz 32 bit ARM processor, to give fast and solid flight performance. This flight board has been upgraded to use the new HMC5983-TR for locked in heading hold and uses the trusted MPU6000 in SPI mode for ultra fast senor sampling for rock solid stability. It has been redesigned for ease of connection with the multicopter frame, yet exposes all the pins of the initial version for the own customization as desired. This is a pre-soldered board, there is no need for further assembly and it will come pre-loaded with flight software for a Quad X configuration.

Board Features:

- 8 PWM receiver inputs
- 8 PWM ESC/motor outputs
- 4 PWM servo outputs
- 3 USARTs
- 1 SPI
- 1 I2C
- 6 ADC (12bit)
- 1 mini USB device port for PC connection
- 1 µSDCard slot
- 1 I2C shared with onboard components
- 4 LED driver switching raw power input to connectors
- 2 5V outputs from on board 5V regulator
- 2 3.3V outputs from on board 3.3V regulator
- 1 DAC (12bit)
- SWD debug port
- all PWM lines are controlled by hardware timer for low jitter

Power:

- Typically driven by the motor's electronics speed controllers (ESC) +5V output, so no more extra connections from your power harness is required. The additional ESC power outputs power the optional camera stabilization servos and ultrasonic sensor.
- Board can be powered from USB, 5V output will have ~4.7V in this case, which should work with most receivers

Dimensions:

- PCB size 50x50mm, 4 mounting holes with 45 mm distance

Figure 3-21: AeroQuad 32 Flight Control Board 1

Figure 3-22: AeroQuad 32 Flight Control Board 2

3.8.Autonomous Flight Control Unit

The VECTOR is UAV Navigation's high-end Autonomous Flight Control Unit. It is ideal for demanding applications where advanced features and performance are required. VECTOR is capable of controlling fixed wing multirotor platforms over a wide range of flight control tasks:

- Auto take-off
- Auto flight plan execution (waypoints)
- Fly-to
- Hover/hold
- Auto Return-To-Base (RTB) in case of communications failure
- Auto landing

- Manual override
- Camera (payload) stabilization, pointing and control
- Onboard 3D Digital Elevation Model (DEM) for accurate flight control and camera pointing
- Multiple datalink management
- Transponder integration
- Precision inertial navigation in GPS-denied environments

In addition, VECTOR features the following advanced functions as standard:

- Multiple datalink management
- Transponder integration
- Flare and parachute activation for target drones
- Precision inertial navigation in GPS-denied environments

Autopilot Software Upgrade Modules:

- DGPS and Laser Altimeter (enables integration of the external hardware required for precision landings).
- Sea-skimming capability (together with an external radar altimeter, enables high speed target drone flights at altitudes as low as 7 meters ASL. Ideal for training against anti-ship missile threats.

VECTOR is a robust and dependable unit, with built-in physical and logical redundancy; this allows it to survive all individual sensor failures while maintaining accurate estimates of attitude and position. For this reason VECTOR has rapidly become the AFCU of choice for high value RPAS and Optionally Piloted Vehicle (OPV) applications.

VECTOR can host UAV Navigation's mission and flight control software or that of the customer, making it a superb avionics development platform. Its processor core is compatible with commercially available certified avionics operating systems.

Figure 3-23: VECTOR Autonomous Flight Control Unit

The VECTOR Installation Kit includes the main items required to install the unit in the aircraft:

- 37P and 25P system connectors
- GPS passive antenna
- SMA coax cable
- SMA to SMA bulkhead connector

Figure 3-24: VECTOR Installation Kit

Dimensions

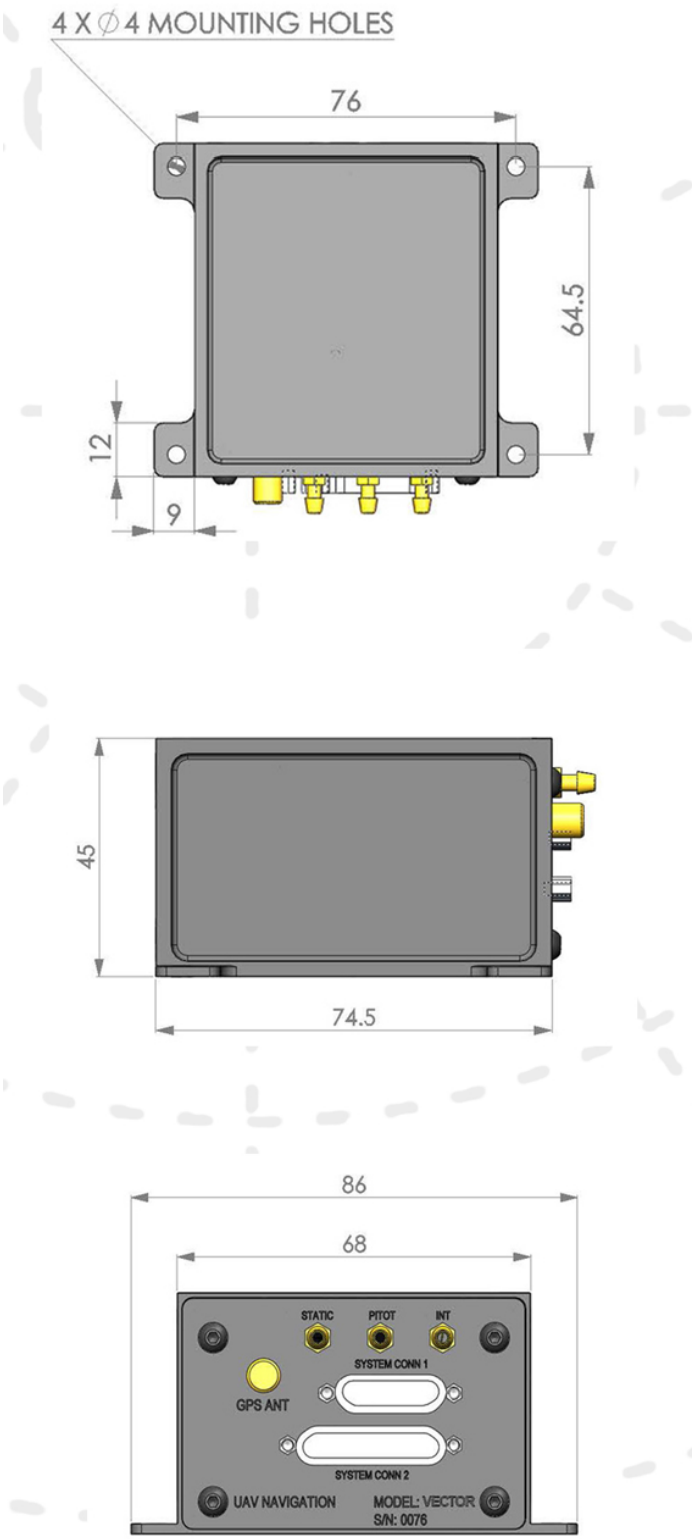


Figure 3-25: VECTOR unit dimensions (mm)

3.9.Transmitter & Receiver

The best choice to control the quadcopter is the receiver and transmitter kit, DEVO 12, with a camera DV04 which is included in the pack. This is the easiest way to fly with view.

Figure 3-26: DEVO F12 Transmitter & Receiver

Figure 3-27: Receiver battery

Given the characteristics of the elements included in the kit, it is possible to check that is well suited to the requirements.

So finally the quadcopter will have two cameras, DV04 for navigation with DEVO12 transmitter and B6640 Imperx camera to analyze the thermal plant.

3.10. Fan

The adaptation of the quadcopter to high temperatures has been the hardest task. The problem is the outside temperature because all the devices exchange heat with the environment (inside the cabin). The thermal isolation is not the only solution. It will be necessary any device to exchange the internal heat in our cabin with the environment to keep the internal temperature safe.

The best solution is to add a fan in the cabin. Ametek´s Fan has higher-pressure building capabilities than tube-axial fans. It utilizes the same style inverted motor that allows for very high-speed operation due to the small diameters. The pressure capability of this fan is the result of both the use of stationary guide vanes located upstream or downstream of the impeller and the high speeds.

It is compact, high-speed fan whose airflow is parallel to the motor shaft. The impeller and guide waves are of airfoil construction for maximum aerodynamic efficiency and minimum acoustical noise.

This fan is designed for use where size and weight must be held to an absolute minimum, where reliability is critical and where high heat loads must be dissipated with cooling air.

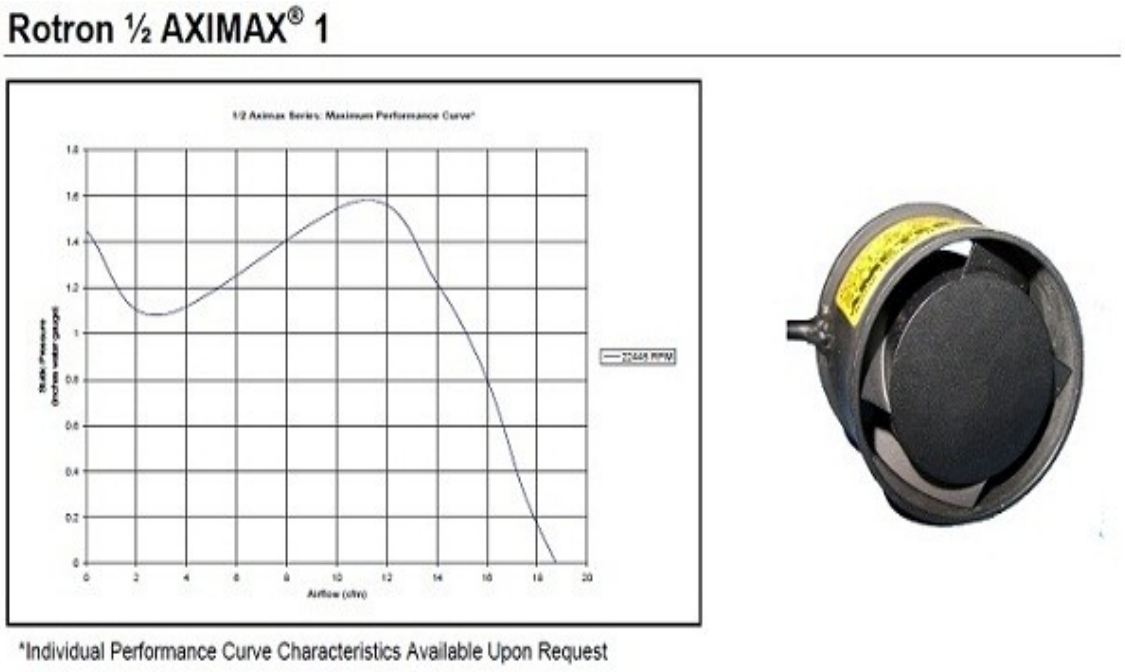


Figure 3-28: Ametek´s fan – characteristic curve

Figure 3-29: Ametek´s fan

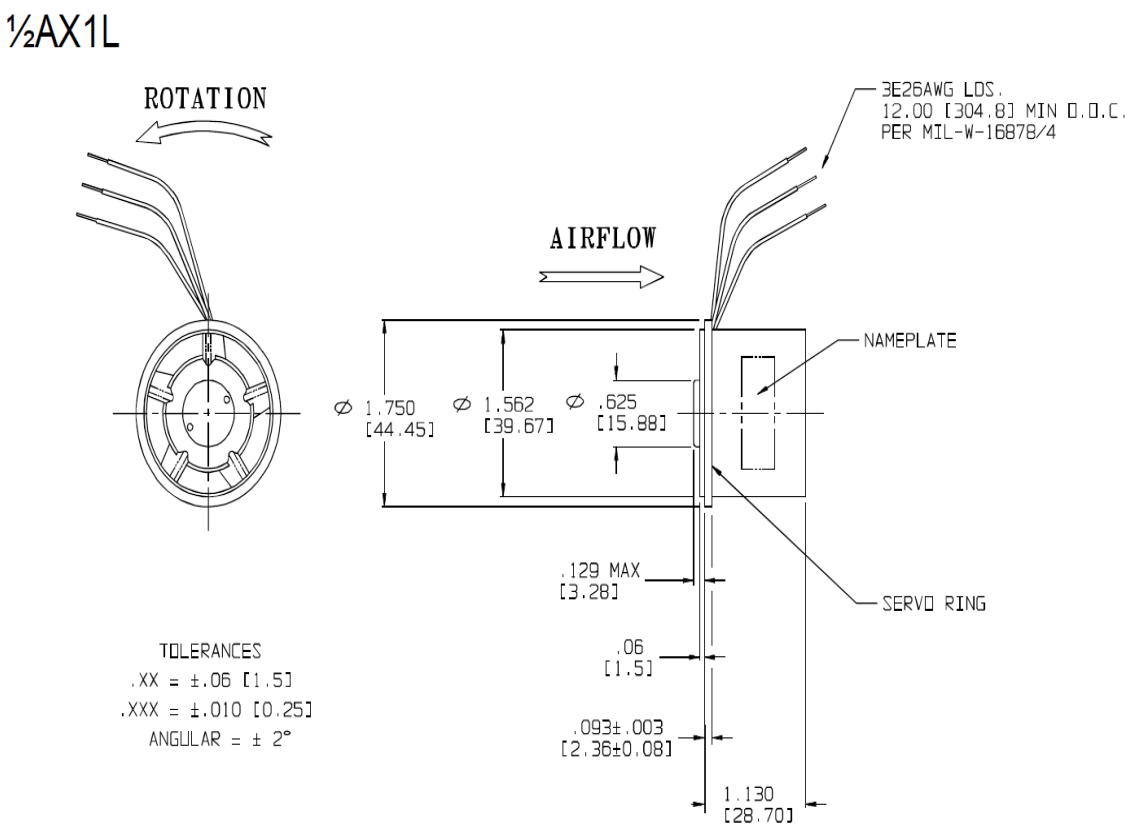


Figure 3-30: Ametek´s fan dimensions

3.11. Motor

The new KDE Direct 4014XF-380 Multi-Rotor Brushless Motor, which is an extremely efficient and powerful motor for numerous multi-rotor and sUAS heavy-lift applications, was designed to bring high-quality and vibration-free motors to the market. The motors are designed with performance and durability in-mind, with features unseen in the current market: high-grade, 240°C high-temperature solid-core copper windings for failure-free operation in extreme-climates, 0.2 mm silicon-steel stator laminations and Kevlar tie-wraps for high-efficiency performance. The motor is triple-bearing supported, ABEC-7 bearings for maintenance-free and worry-free flying for hundreds of hours also.

Figure 3-31: KDE Direct 4014XF-380 Multi-Rotor Brushless Motor

Motor includes 200°C, 15 AWG, 760mm silicone-wire leads and ϕ3.5mm 24k Bullet Connectors (pre-soldered to the motor leads and ESC female bullets included).

Figure 3-32: Motor Kit

3.12. ESC

Controlling of the motors is done by KDE Direct XF UAS Multi-Rotor Electronic Speed Controller (ESC) which is optimized for multi-rotor applications. They utilize a proprietary algorithm for up to 600Hz refresh rate control and high-speed response to the flight system commands. Dynamic PWM and Motor Advance Timing algorithms are used for optimal flight performance. The series is specifically designed and optimized for the KDE Direct XF Multi-Rotor Brushless Motor Series. For maximum stability and performance of the flight controller, the system is tuned to react almost instantaneously to the flight commands and XF Brushless Motor response capability.

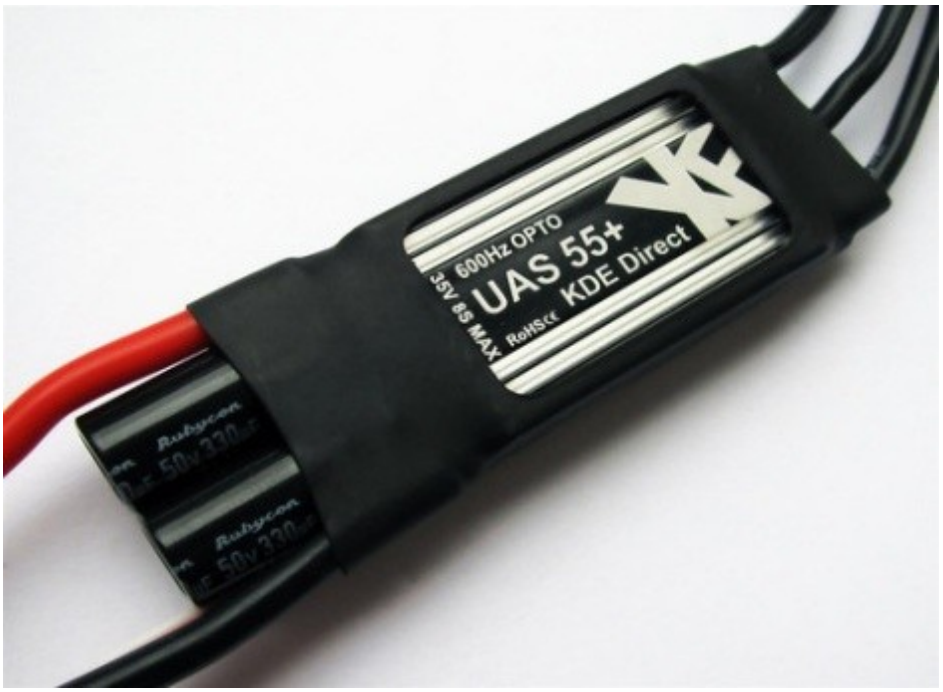


Figure 3-33: KDE Direct XF UAS Multi-Rotor Electronic Speed Controller (ESC)

ESCs include 200°C, 13 AWG silicone-wire power leads and 15 AWG silicone-wire motor leads with dual ϕ4.0mm and ϕ3.5mm 24K matching Bullet Connectors.

Figure 3-34: AWG silicone-wire power leads and AWG silicone-wire motor leads

3.13. Propellers

T-MOTOR will provide the carbon-fiber propellers. The size chosen is 13 x 4.4 inches.

The lightness will provide a higher loaded ability and longer flight times, which is very interesting to avoid coming back to base station several times to charge batteries. With cork wood sandwich construction is possible to get this lightweight with high-strength.

The 100% balanced is granted by the company, so the working stability will be perfect to examine the structures.

Features:

- Lightweight.
- High-strength.
- Prolong hover time.
- Increased loaded capacity.
- Less inertia.
- Reliable controllability.
- Safe flight necessity.

These propellers can be mounted in the selected motors. It will be necessary to use the size adapters which will be installed in each motor.

The blade length (13 inches) is adequate to fly the quadcopter and it is the perfect size for the designed quadcopter.

Figure 3-35: T-Motor 13x4.4 inches propellers

3.14. WIFI Transmitter

So as to obtain a reliable communication link with the base station with a high bandwidth (e.g., for communicating high resolution imagery), it is used the SkyZone 5.8Ghz 200mw FPV Wireless AV Tx & Rx Set.

This system is good for up to 500m flying with the supplied antenna. An optional directional antenna can extend range to 1km+. This unit includes built-in microphone. The receiver unit has additional AV outputs for video recording while using FPV goggles.

Figure 3-36: SkyZone 5.8Ghz 200mw FPV Wireless AV Tx & Rx Set

3.15. Wireless points

In order to retrieve higher level mission plans and exchange information with advanced components on a base station computer it will be used a WiFi link.

The XTend Modem packs a ton of RF punch into a small, low-power, easy-to-use, and reliable module. Outdoors, with line-of-sight, this module can communicate at up to 40 miles; indoors it can still do up to 3000ft. The module transfers a standard asynchronous serial data stream, operates within the ISM 900MHz frequency band and sustains up to 115.2kbps data throughput. The module comes with an attached RPSMA antenna connector.

The XTend module utilizes FHSS (Frequency Hopping Spread Spectrum) agility to avoid interference by hopping to a new frequency on every packet transmission or re-transmission. Its transmit power is software adjustable from 1mW to 1W—the maximum output power allowable by governments that use 900MHz as a license-free band.

No configuration is necessary for out-of-the-box RF communication. The XTend module's default configuration supports a wide range of data system applications. Advanced configurations can be implemented using simple AT or binary commands.

Figure 3-37: XTend 900 1W RPSMA Zigbee

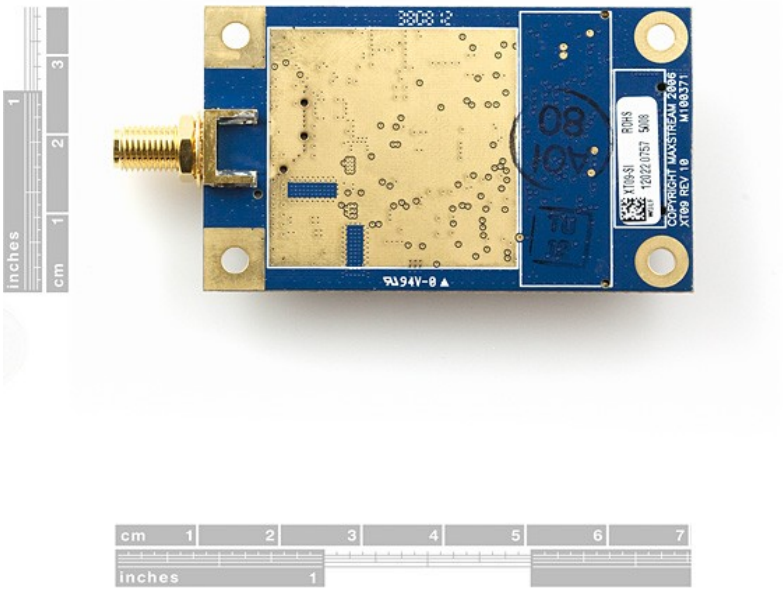


Figure 3-38: XTend 900 1W RPSMA Zigbee Dimensions

This is a simple breakout board for Digi's XTend 900 Modem. This board breaks out all eleven of the pins used by the modem to a 0.1" pitch header.

Figure 3-39: DigiXTend Modem Breakout

3.16. GPS Receiver

The D2523T-6 is a complete GPS smart antenna engine board, which includes a built-in Sarantel's GeoHelix high-gain, low-noise amplifier active antenna and GPS receiver circuits, designed for hand- held or portable device that are going to integrate GPS function. The engine board is powered by the high performance 50-channel u-blox 6 technology; these modules provide excellent performance at an economical price. Besides, it can provide with superior sensitivity and performance even in urban canyon and dense foliage environment. The miniature size makes it the best choice to be integrated into portable devices, such as portable navigation devices.

The D2523T-6 allows weak signal tracking and positioning in severe environments such as urban canyons and under deep foliage.

The GPS module D2523T-6 brings high performance of the u-blox 6 positioning engine to the industry standard. These versatile, stand-alone receivers combine an extensive array of features with flexible connectivity options. Their ease of integration results in fast times-to-market for a wide range of automotive, consumer and industrial applications with strict size and cost requirements.

Figure 3-40:D2523T Helical GPS Receiver

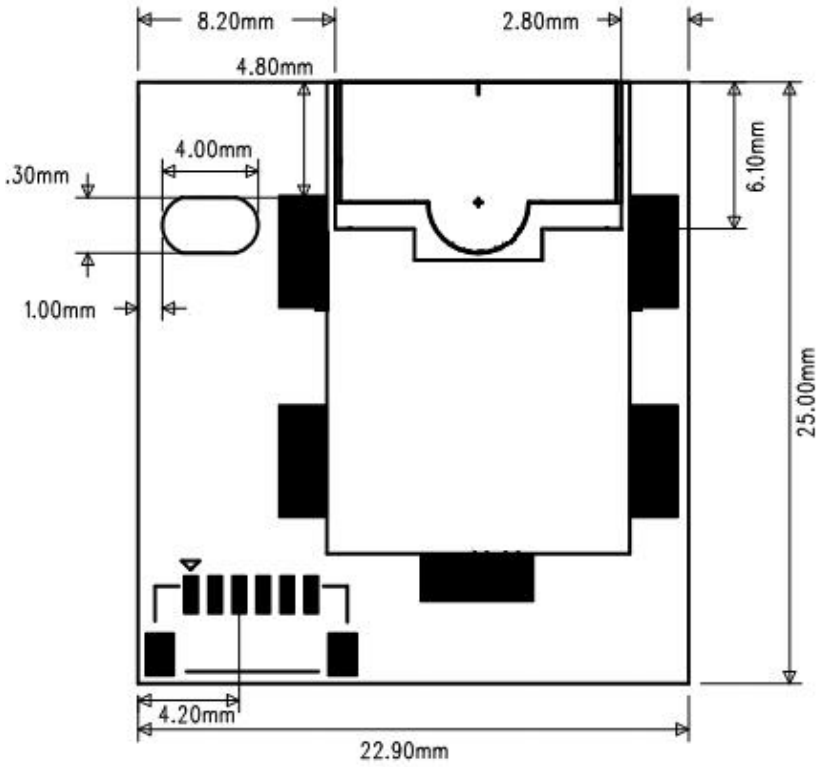


Figure 3-41: GPS board dimension

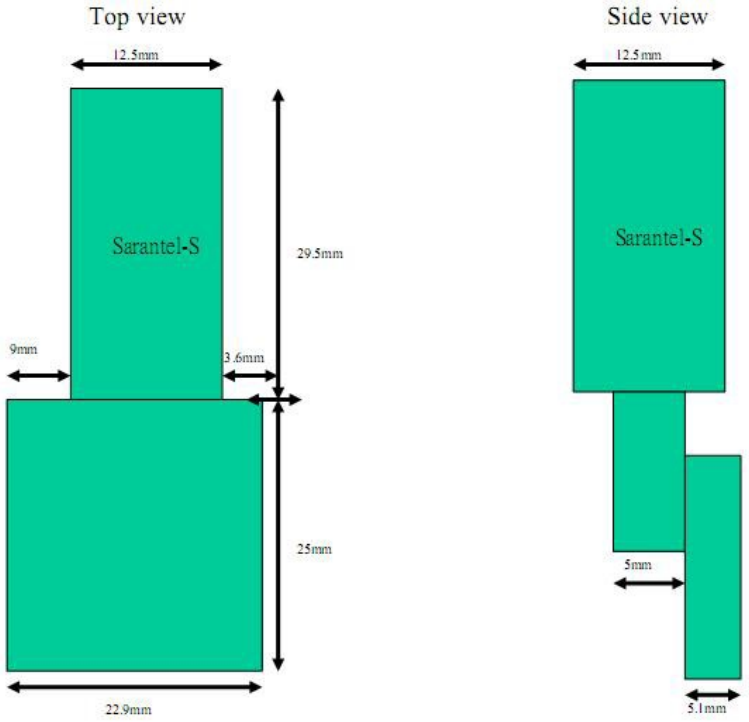


Figure 3-42: Main board with active antenna dimension

3.17. Ultrasonic Sensor

This UAV will be equipped with eight ultrasonic sensors PZT which are lead zirconium titanate (PZT) based ultrasonic sensors for continuous operation between -30°C and 160°C, covering the near space around it. Ultrasonic sensors are particularly well suited for detecting close obstacles.

In the setup the sensors are used as a fallback for dynamic obstacles suddenly appearing in the UAV's vicinity. Furthermore, their measurement principle with the wide sonar cone allows for perceiving obstacles that are hard to detect otherwise.

As well as excellent functionality at high operational temperatures, the sensors can tolerate wider non-operational temperature ranges and regular thermal cycling during service.

The ultrasonic sensors are mounted in a ring around the UAV in a star-like pattern with one pair of sensors at each of the four riggers of the frame. The range measurements are sequentially read using an AVR ATmega2560.

It will filter out erroneous measurements by examining a sequence of measurements for each of the ultrasonic sensors and only take a measurement into account for collision avoidance when it appears stable over several readings. In all the experiments, incorrect measurements were sparse and not persisting over multiple range readings.

The sensor setup is aimed at perceiving as much of the UAV's surroundings as possible in order to obtain almost omnidirectional obstacle perception.

The material finally selected will often be chosen to fulfill multiple criteria with known heritage in comparable applications. For example, an aerospace-qualified material rated for continuous high temperature operation up to 250°C may be selected

for one application, while another material, operating at very similar temperatures in a sonar application, may be selected for its high resistance to pressure. Complimentary sensors, actuators or elements can also be incorporated at customer request to provide increased device capability and system integration.

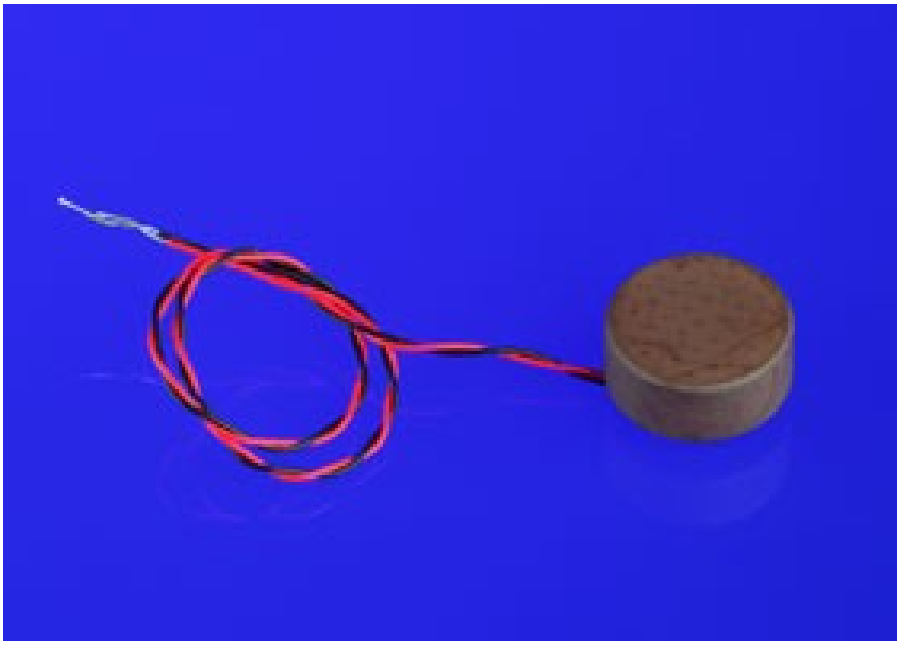


Figure 3-43: PZT Sensor

3.18. Ultrasonic Controller

Crumb2560 V1.1 is a versatile and very compact (61x30mm size) microcontroller module with the ATmega2560 microcontroller, CP2102 USB UART converter, RS232 and RS485 transceiver. All microcontroller signals are available on pin headers.

The module is shipped without preassembled pin headers since everybody has different preferences or requirements.

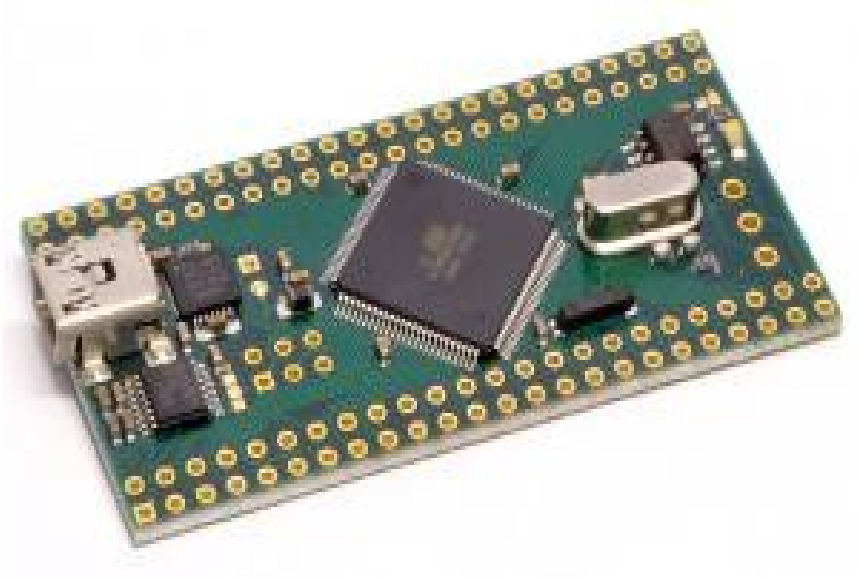


Figure 3-44: Crumb2560 V1.1 - Atmel AVR ATmega2560 microcontroller

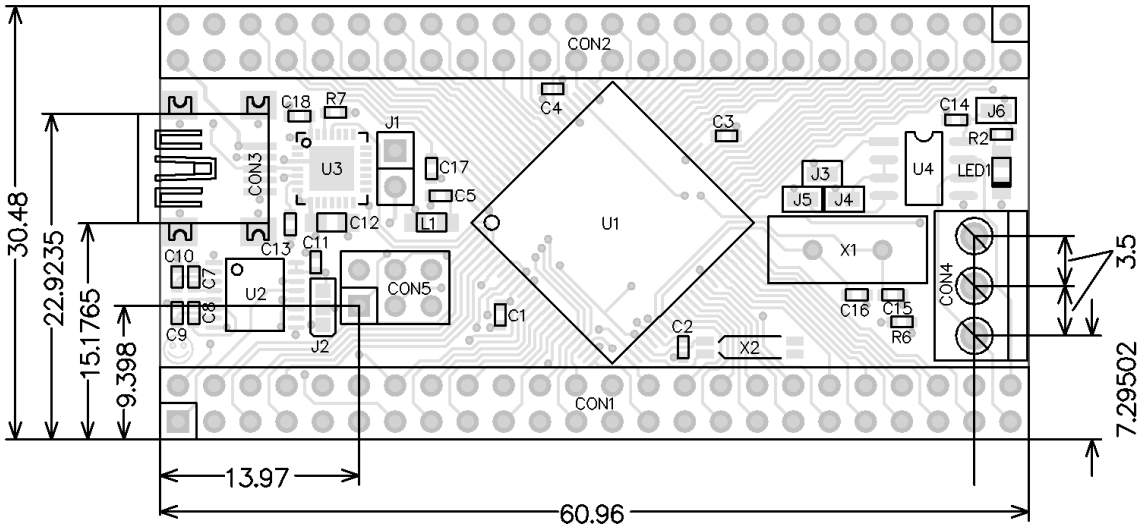


Figure 3-45: Microcontroller Dimensions

3.19. High Temperature Sensor

Thermocouples are very sensitive, requiring a good amplifier with a cold compensation reference. The Grove temperature sensor uses a K type thermocouple temperature detection with a thermostat to detect the ambient temperature as

temperature compensation. The detectable range of this sensor is between -50 and 600ºC and the accuracy is ±(2.0% + 2ºC).

Figure 3-46: Grove - High Temperature Sensor

3.20. Temperature & Humidity Sensor

This is a multifunctional sensor that gives you temperature and relative humidity information at the same time. It utilizes a TH02 sensor that can meet measurement needs of general purposes. It provides reliable readings when environment humidity condition inbetween 0-80% RH and temperature condition inbetween 0-70°C, covering needs in most home and daily applications that don't contain extreme conditions.

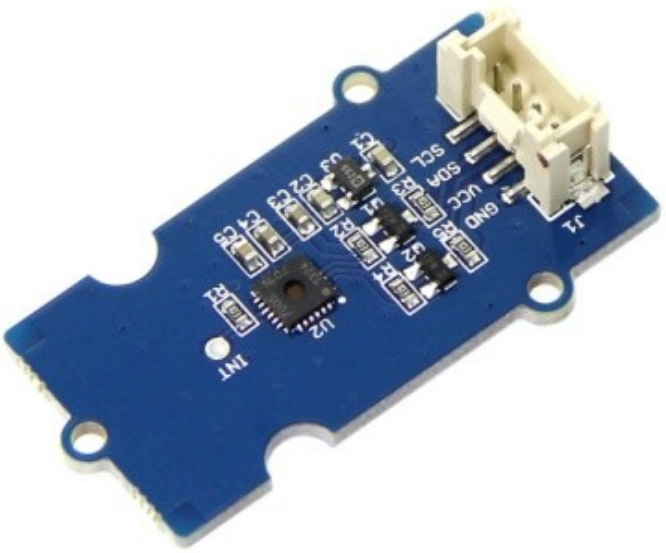


Figure 3-47: Grove - Temperature&Humidity Sensor

3.21. Optional items

3.21.1. Luminance Sensor

This luminance Sensor provides the linear transform lumen intensity for the output voltage levels. And APDS-9002 spectrum and human eye is extremely close to. It is very suitable for application in the field of human intelligence.

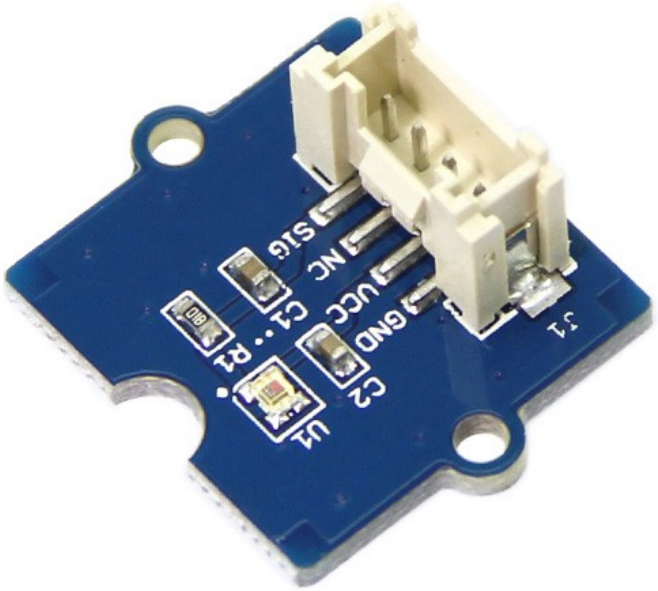


Figure 3-48: Grove - Luminance sensor

3.21.2. Barometer (High-Accuracy)

This Grove - Barometer (High-Accuracy) sensor features a HP206C high-accuracy chip to detect barometric pressure, altimeter and temperature. It can widely measure pressure ranging from 300mbar~1200mbar, with a super high accuracy of 0.01mbar (0.1m) in ultra-high resolution mode. The chip only accepts 1.8V to 3.6V input voltage. However, with outer circuit added, this module becomes compatible with 3.3V and 5V. Therefore, it can be used on Arduino/Seeeduino or Seeeduino Stalker without modification. It is designed to be connected directly to a micro-controller via the I2C bus.

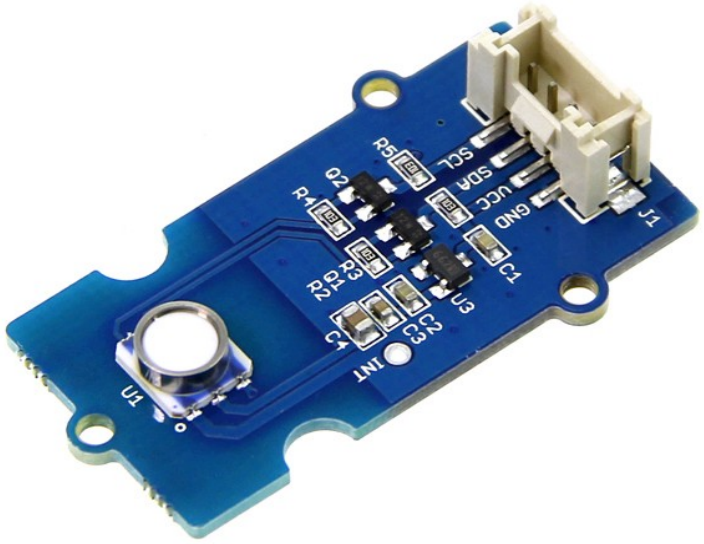


Figure 3-49: Grove - Barometer (High-Accuracy)

3.21.3. Adjustable DC/DC Power Converter

This is a DC/DC step-down voltage regulator that converts input voltage between 4.5V and 16V into a smaller voltage between 1V and 12V, capable of driving a 1.5A load with excellent line and load regulation.

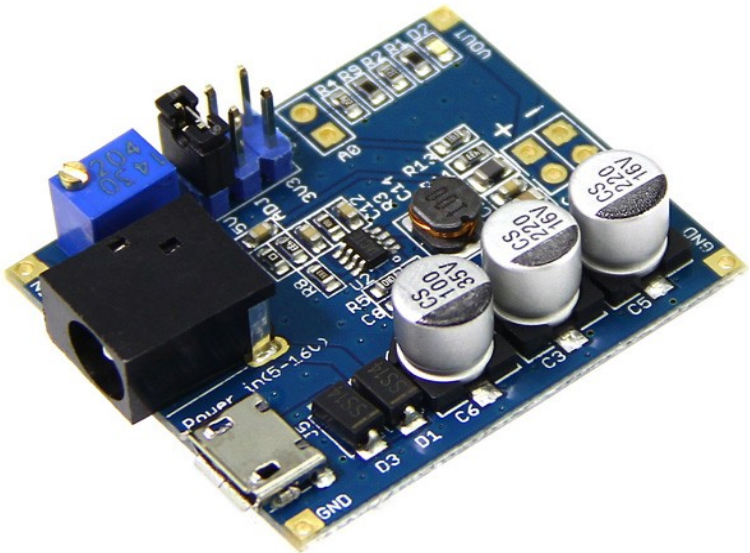


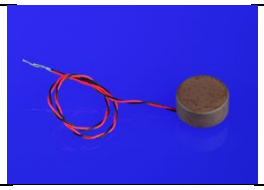
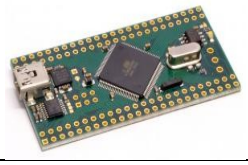
Figure 3-50: Adjustable DC/DC Power Converter

4.Table best devices for quadcopter

The prices are in dollars and euro, depending on the provider, manufacturer or seller.

Nº	Use	Image	Provider	Price
1	Camera		http://imperx.com/	6.475$
2	Flight Control Board		http://www.aeroquadstore.com/	149,95$
3	VECTOR Autonomous Flight Control Unit		http://uavnavigation.org/	4.500 €
4	VECTOR Installation Kit		http://uavnavigation.org/	476€
5	Transmitter & Receiver		http://www.walkeraonline.com/	627.99$
6	Receiver Battery		http://www.walkeraonline.com/	15$

7	Fan		http://www.rotron.com/	249,95$
8	Motor		http://www.kdedirect.com	118,95$
9	ESC		http://www.kdedirect.com	87,95$
10	Frame and landing skids		http://www.amazon.com/	76,02$
11	Gimbal		http://www.helipal.com/	599$
12	Propellers		http://www.rctigermotor.com/	52,90€ peer
13	WIFI Transmitter		https://www.hobbyking.com/	48,39€
14	Wireless points		https://www.sparkfun.com/	194,95$

15	GPS Receiver		http://www.aeroquadstore.com/	79,95$
16	Ultrasonic Sensor		http://www.morganadvancedmaterials.com/	25,95 €
17	Ultrasonic Controller		http://www.chip45.com/	44,95€
18	High Temperature Sensor		http://www.seeedstudio.com/	8,90$
19	Temperature & Humidity Sensor		http://www.seeedstudio.com/	11,50$

Considering the price of the devices and the above material, it is possible to approximate an initial cost, although there were parts that need to be customized and tailored and whose cost will increase the final amount.

But looking at the electronics devices and items available in the market, which can be purchased directly, can be prepared an initial budget.

Adding all costs presented in the table above, the total amount will be 5201.09 € + $ 8.695,11 (1 € = $ 1.058 - Currency exchange of 12.04.2015) which equals the final sum to 13.419,53 €.

5.Devices list

In this section it will be possible to find links to go directly to the product datasheets discussed above. Other substitute elements of the previous are found also as well as complementary to the design of quadcopter.

5.1.Flight control board

http://www.aeroquadstore.com/AeroQuad_32_Flight_Control_Board_Version_2_p/aq32-001.htm

http://www.nitroplanes.com/82p-a001078.html

http://www.goodluckbuy.com/eagle-n6-multicopter-controller-board-aero-copter-quadcopter-multicoptor.html

5.2.Camera

http://imperx.com/ccd-cameras/B6640/

http://www.walkera.com/en/showgoods.php?id=1765

http://www.walkeraonline.com/fr/walkera-parts-91648482/walkera-fpv-first-person-view-593492403/walkera-hm-tx-5805-5-8ghz-video-camera-with-transmitter-fr.html

http://www.walkeraonline.com/fr/walkera-parts-91648482/walkera-fpv-first-person-view-593492403/walkera-ilook-fpv-hd-camera-1344872261.html

http://www.jmcanty.com/_private/CustDetailedInfo/Products/

http://www.jmcanty.com/_private/CustDetailedInfo/Products/TA7355-1.pdf

5.3.Ultrasonic sensor

http://www.morganadvancedmaterials.com/new-ultrasonic-pzt-sensors-allow-continuous-operation-between-30degc-and-160degc

https://www.futurlec.com/Ultrasonic_Sensors.shtml

http://www.chip45.com/products/crumb2560-1.1_avr_atmega_module_board_atmega2560_usb_rs232_rs485.php?en

5.4.Control flight unit

http://uavnavigation.org/products/uav-autopilot-vector

http://uavnavigation.org/products/uav-autopilot-proton

http://www.lowpricerc.com/product_info.php/feiyu-tech-flight-stabilization-system-pro-p-1551

5.5.IMU/IMS

http://uavnavigation.org/products/polar-imu-ahrs-ins-sensor-system

http://uavnavigation.org/products/atom-imu-ahrs-ins-sensor-system

http://www.aeroquadstore.com/IMU_Digital_Combo_Board_6DOF_p/sen-10121.htm

5.6.Attitude heading reference system

http://www.memsic.com/inertial-systems/

http://www.alava-ing.es/ingenieros/productos/avionica-y-ensayos-en-vuelo-uavrpa/componentes-y-soluciones-para-vehiculos-aereos-no-tripulados-uavrpa/unidades-inerciales/documentos/

5.7.Connection

5.7.1. ZIGBEE

https://www.sparkfun.com/products/9411

http://www.sparkfun.com/datasheets/Wireless/Zigbee/xtend-datasheet.pdf

http://www.digi.com/pdf/ds_xbeemultipointmodules.pdf

http://www.digi.com/products/wireless-wired-embedded-solutions/zigbee-rf-modules/point-multipoint-rfmodules/xbee-series1-module#models

http://www.aeroquadstore.com/XBee_Shield_v1_2_p/wrl-11000.htm

5.7.2. Receivers & transmitters

http://www.walkeraonline.com/es/walkera-parts-196676862/walkera-common-parts-308597598/walkera-devo-f12e-5-inches-lcd-5-8g-fpv-transmitter-es.html

http://www.getfpv.com/5-8ghz-32ch-a-v-500mw-transmitter-ts58500.html

5.7.3. WIFI

https://www.hobbyking.com/hobbyking/store/__15295__SkyZone_5_8Ghz_200mw_FPV_Wireless_AV_Tx_Rx_Set.html

5.7.4. GPS

http://www.aeroquadstore.com/50_Channel_D2523T_Helical_GPS_Receiver_p/gps-09566.htm

http://www.xheli.com/05p-gps-38400-apm.html

5.8.Motor

http://www.kdedirect.com/KDE4014XF380.html

http://copter.ardupilot.com/wiki/advanced-multicopter-design/

5.9.Frame and landing skid

http://www.amazon.com/580MM-Folding-Quadcopter-Carbon-Landing/dp/B00LIUUAQU

5.10. Gimbal

http://www.helipal.com/storm-pro-3-universal-3-axis-gimbal.html

5.11. Propellers

http://www.rctigermotor.com/html/2013/prop_0904/31.html

5.12. Luminance sensor

http://www.seeedstudio.com/depot/Grove-Luminance-Sensor-p-1941.html?cPath=25

5.13. Barometer

http://www.seeedstudio.com/depot/Grove-Barometer-HighAccuracy-p-1865.html?cPath=25

5.14. Temperature sensor

http://www.seeedstudio.com/depot/Grove-Temperature-Sensor-p-774.html

http://www.seeedstudio.com/depot/Grove-High-Temperature-Sensor-p-1810.html?cPath=25

5.15. Temperature & humidity sensor

http://www.seeedstudio.com/depot/Grove-TemperatureHumidity-Sensor-HighAccuracy-Mini-p-1921.html

5.16. Power converter

http://www.seeedstudio.com/depot/Adjustable-DCDC-Power-Converter-1V-12V15A-p-1996.html?cPath=1_4

http://blog.oscarliang.net/3a-voltage-regulator-mobius-quadcopter-rc-model/

5.17. FAN

http://www.rotron.com/fans/small-vaneaxial/half-ax1.aspx

5.18. Magnetometer

http://www.aeroquadstore.com/Triple_Axis_Magnetometer_Breakout_HMC5883L_p/sen-10530.htm

5.19. ESC (Electronic Speed Controller)

http://www.kdedirect.com/collections/xf-multi-rotor-electronics/products/kdexf-uas55

6.Conclusion

For one thing, defense´s alternatives with wheels, jail and 2D defenses, similar to square shape, have been studying to protect the propellers. In this case, agility is the most interesting tag to examine smaller surfaces. Therefore, the 2D defense system will be the first to be installed and used to examine the thermal plants.

If the customer wanted, it would be possible to reinstall the defense and change it for the jail or wheel design. This does not preclude the right landing and in turn increase the protection. Besides, it would not be necessary to warn any technical service to perform this task.

Deepening and studying the development of the project can reach this conclusion as to the mechanics of the quadcopter.

For another thing, electronic research was focus to find the different elements given by ALSTROM, but always with operating temperature valid for the range of temperatures. This research was the most difficult task because these devices are really delicate and do not work at high temperatures. Finally the required devices are found and described above.

Camera is a requirement really important in the design of the quadcopter because it will be used for all inspections. The problem to face was the temperature to resist, however, the quality of the image is important; in this case so the camera chosen will fit perfectly. A gimbal system will be used to have more comfortable vision during the controls. This system is not a requirement of ALSTRON but it is interesting in small spaces such a thermal plant.

The flight control board has good features like the easy fixation to the quadcopter frame and the easy programming of it with all the inputs and outputs available in the system.

The autonomous flight control unit is required to execute advanced performance and control different tasks available like auto take-off, fly-to or auto landing for example. Built-in physical and logical redundancy allows it to survive all individual sensor failures while maintaining accurate estimates of attitude and position.

Transmitter and receiver will be included in DEVO F12 which includes a camera for the guidance of flights also. They are needed for transmission of different data, telemetry, sensors and texting Imperx camera signal.

Once all electronic devices of the cabin were found with right requirements, it was needed a way to refrigerate the cabin where these will be situated. So a fan was the best option to expel the heat of these devices. The fan chosen is small but with enough power to keep the devices in the correct range of temperatures.

The selected motors are efficient and powerful enough to lift the full quadcopter and do the work without vibration. To control these motors few electronic drivers are installed, instantly reacting to the flight control while maintaining stability and smooth movements.

Onboard cables to connect all devices are designed to resist more than 150ºC so there will be no problem in finding the necessary in the market. This is the reason that cables have not been developed and analyzed in the project.

Multirotor mainly consists of carbon fiber, so the material as a whole give a lot of flight hours without maintenance.

The different pictures which have appeared in the project have been drawn by AutoCAD.