

SPIRI ROBOTICS



Product Design Document

Adam Saule

April 6, 2020

Contents

1	Background	4
1.1	Introduction	4
1.2	Industry Background	4
2	Design Requirements	5
3	Component Information	6
3.1	Propulsion	6
3.1.1	Motor	6
3.1.2	Propeller	7
3.2	Chassis	7
3.2.1	Frame Design	8
3.2.2	Arms	8
3.2.3	Landing Feet	8
3.3	Electronics	9
3.3.1	Computer and Carrier Board	9
3.3.2	Flight Controller	9
3.3.3	Electronic Speed Controller	9
3.3.4	GNSS/Compass	9
3.3.5	Optical Components	9
3.3.6	Power	9
3.3.7	Power Management	10
3.3.8	Modular Payloads	10

4	Component Selection	11
4.1	Propulsion	11
4.1.1	Motor	11
4.1.2	Propeller	11
4.2	Chassis	12
4.2.1	Materials	12
4.2.2	Frame Design	13
4.2.3	Arms	13
4.2.4	Landing Feet	14
4.3	Electronics	14
4.3.1	Computer and Carrier Board	14
4.3.2	Flight Controller	15
4.3.3	Electronic Speed Controller	15
4.3.4	GNSS/Compass	15
4.3.5	Optical Components	15
4.3.6	Power	16
4.3.7	Power Management	16
4.3.8	Modular Payloads	16
4.4	Overall Construction	17
5	Research of Similar Products	18
6	Preliminary Design	19
7	Prototyping & Testing	20
8	Detailed Design	21
8.1	Design Overview	21
8.2	Electrical Design	21
8.2.1	Wiring Diagram	21
9	Verification & Testing	22

1.0 Background

The purpose of this document is to record the design process for the Spiri Mu II Autonomous drone. This includes design requirements and constraints, design decisions, testing and prototyping, verification, and a user manual. At the end of the document, drawings of the designs will be listed. Rendered images of the drone can be added later. All the files associated with the document should be in their own folder.

1.1 Introduction

Design of Spiri Mu 2

1.2 Industry Background

2.0 Design Requirements

There are several different quantities that need to be defined. These include:

- Thrust to weight ratio
- Mass
- Dimensions
- Power requirements
- Flight duration
- Noise levels
- Water proofing

Table 2.1: **Design Requirements**

Requirement Identifier	Description	Priority
A1	Shall have a battery life of 1 hour	High
B1	Shall have ...	Mid
C1	Shall have ...	Low

The requirements for each component (from the following sections) should be listed here Table 2.1. In the component selection section, an explanation for how each choice meets the requirement.

3.0 Component Information

This section details the definition, background information, and purpose for each component.

3.1 Propulsion

The motors and propellers work together to achieve a desired thrust. Many factors play into the amount of thrust, speed, and noise of the motor-propeller assembly.

3.1.1 Motor

Brushless DC motors (BLDC) are the common motors used for quadcopter drones. Motor selection depends on required thrust, thrust depends on the total weight of the frame size. Generally, the thrust to weight ratio (TWR) in Equation 3.1 is used to select a motor.

$$TWR = \frac{T}{W} \quad (3.1)$$

Where T is the thrust and W is weight, both in Newtons or pounds.

For the drone to be able to take off, a $TWR > 1$ is required. Once the drone flies at an inclination, the thrust is split into x and y components. This means that the y-component of the thrust can drop. So for a $TWR \geq 1.3$ would be required for a maximum inclination angle of 40. In general, a $TWR \geq 2.0$ should be used at a minimum, so with 4 motors, each motor must provide a thrust equal to the mass divided by 4. (Cite quadcopter paper)

The constant velocity of a motor (K_v) is defined as the number of RPMs a motor will turn when 1V is applied with no load.

3.1.2 Propeller

There are a couple of specifications that determine the performance of the propeller. Pitch, size, the number of blades; propeller material, and propeller weight [1]

The pitch of a propeller is defined as the distance the propeller would move in one revolution if it were moving through a soft solid. The higher the pitch, the faster the drone will fly. This is analogous to a screw; the pitch is measured the same way. The pitch must not be too flat or too steep as this will result in no lift being generated.

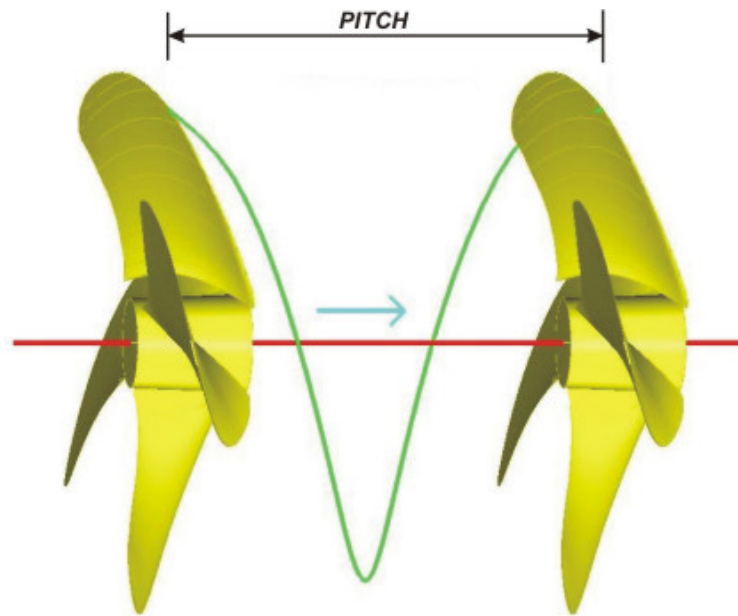


Figure 3.1: Propeller pitch

The length of the propeller from tip-to-tip is defined as the length. Longer propellers generate more thrust for the same speed but require more torque from the motor.

Number of blades - what effect does adding blades have?

Propeller material and weight - how does this affect performance? Noise? Would a smoother material be quieter? is noise caused by surface roughness or vibrations in the propeller along its length?

3.2 Chassis

The chassis includes the internal frame, the arms, and the landing feet.

Detail what characteristics each part of the chassis should have.

It might be helpful to develop a finite element model (FEM) of the top and bottom plates with the arms attached to determine optimal plate material and thickness.

NOTE: Make a table comparing manufacturing techniques; 3D printing, injection moulding.

Look for other manufacturing techniques for landing gears and other common parts.

3.2.1 Frame Design

The size of the drone will depend on several factors. The size of the propellers, battery pack, and electronics. The frame of the drone will be constructed of 3D printed nylon parts because this allows for modularity and easy replacement of parts in the event of a failure. The top and bottom plates will compress the arms to hold them in place, these plates will need to be stiff? (check) The arms need to be held in tight between the plates, we should consider adding some vibration damping between the plates to reduce transfer to the electrical components.

Why should there be a power and reset on the outside? Just quickly explain why.

3.2.2 Arms

Define what the arms are.

The arms must be long enough so that the frame does not hinder the function of the propulsion system. The arms must also be thin enough to ensure thrust is not reduced during operation. (not sure if this would make a big difference, could test in motor testing rig by placing different sized arms behind propeller and measure the drop in performance)

3.2.3 Landing Feet

Define what the landing feet are.

The feet could be placed in two different locations. Either beneath the motors at the end of the arms or near the body at the beginning of the arms. An analysis of the best location

should be conducted with consideration placed on durability of body on hard landings and the landing platform. (Compare the two placements, pros and cons)

3.3 Electronics

3.3.1 Computer and Carrier Board

Define what the computer and carrier board do.

What functions do they serve on the drone?

3.3.2 Flight Controller

Define what the flight controller does.

3.3.3 Electronic Speed Controller

The electronic speed controller (ESC) send pulse width modulation (PWM) signals to the motors to control the speed [\(source\)](#)

3.3.4 GNSS/Compass

Define what the GNSS/Compass does.

3.3.5 Optical Components

Define what role the optical components do; image recognition, finding landmarks, determining the distance to objects, etc.

The optical components are the cameras and the range finder.

3.3.6 Power

This includes the batteries and battery pack design.

Two types of lithium batteries are being considered, the lithium ion and lithium polymer batteries. Both have advantages and disadvantages compared to one another.

The major difference between lithium ion and lithium polymer batteries is the type of electrolyte used. LiPo batteries use a micro porous electrolyte as opposed to a liquid electrolyte and a porous separator. They also contain laminated sheets which eliminates the need for compression. Since the LiPo batteries don't need compression, they can be made into other shapes, such as a "pouch". They offer a slightly higher specific energy, but the manufacturing cost can be higher than traditional cylindrical batteries. Other than that, the two batteries are essentially the same. They both use the same cathode and anode material and have the same amount of electrolyte.

Lithium ion batteries vary depending on the type of material used as the cathode. (Elaborate on this, could influence which batteries will be used) reference

3.3.7 Power Management

The power management system consists of the power distribution board... Is there more?
What does the power distribution board do?

3.3.8 Modular Payloads

A feature of the Spiri is that it can accommodate different payloads mounted on its underside. (should include picture here) A **payload** is defined as an additional component added to the drone to serve a specific function.

4.0 Component Selection

This section details the process and reason for selecting each component

4.1 Propulsion

A testing rig should be designed to test the thrust of each motor-propeller assembly for two reasons:

1. Ensures the motors are functioning
2. Ensure the thrust from motor is within a certain tolerance

An example rig can be found [here](#), motor testing rig.

4.1.1 Motor

Include the desired motor specifications and possible products.

4.1.2 Propeller

There are a couple of specifications that determine the performance of the propeller. Pitch, size, the number of blades; propeller material, and propeller weight [1]

The pitch of a propeller is defined as the distance the propeller would move in one revolution if it were moving through a soft solid. The higher the pitch, the faster the drone will fly. This is analogous to a screw; the pitch is measured the same way. The pitch must not be too flat or too steep as this will result in no lift being generated.

The length of the propeller from tip-to-tip is the defined as the length. Longer propellers generate more thrust for the same speed but require more torque from the motor.

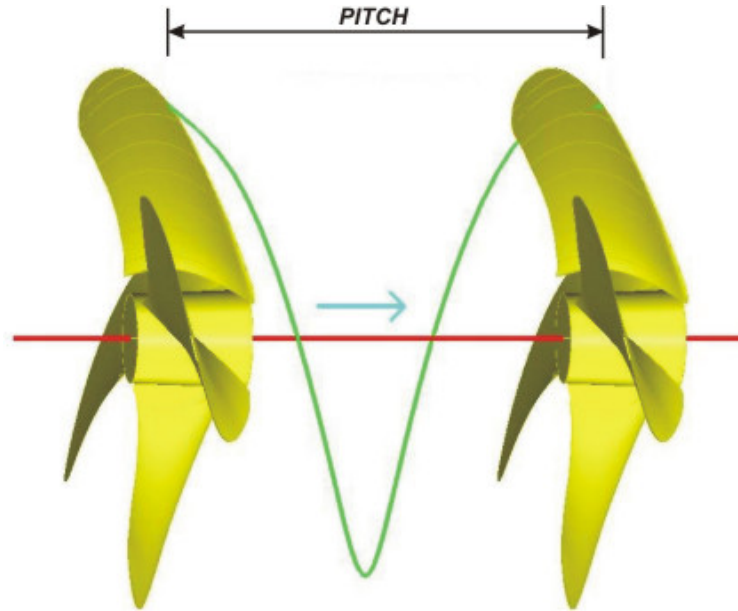


Figure 4.1: Propeller pitch

4.2 Chassis

The chassis includes the internal frame, the arms, and the landing feet. These will be made of various materials, most being 3D printed.

It might be helpful to develop a finite element model (FEM) of the top and bottom plates with the arms attached to determine optimal plate material and thickness.

NOTE: Make a table comparing manufacturing techniques; 3D printing, injection moulding.

Look for other manufacturing techniques for landing gears and other common parts.

4.2.1 Materials

Table 4.1 shows the possible material properties which could be used for the chassis components.

Other materials may be added and evaluated to determine if they are suitable for use in the drone.

¹This is an anisotropic material.

²These are average values.

Table 4.1: Material properties for chassis

Material	Density (g/cm ³)	Ultimate Strength (MPa)	Young's Modulus (MPa)
PA2200 Nylon – Laser Sintered	0.93	48.0	1700
PA1101 Nylon – Laser Sintered	0.99	48.0	1600
PA12 Nylon – Multijet Fusion	1.01	48.0	1800
Thermoplastic Polyurethane (TPU) ¹	1.12	5.5	65
Epoxy/Carbon Fiber Composite ²	1.4	878.0	94.6

a military version could be made with a carbon fibre and kevlar blend, hardened with resin through vacuum. Propeller guards could be made the same way.

Pros and cons of propeller guards?

4.2.2 Frame Design

The size of the drone will depend on several factors. The size of the propellers, battery pack, and electronics. The frame of the drone will be constructed of 3D printed nylon parts because this allows for modularity and easy replacement of parts in the event of a failure. The type of nylon from Table 4.1 will be selected based on cost. The top and bottom plates will compress the arms to hold them in place, these plates will need to be stiff? (check) and could be constructed from off the shelf carbon fiber sheets cut to the specified shape. The arms need to be held in tight between the plates, we should consider adding some vibration damping between the plates to reduce transfer to the electrical components. The manufacturer of these plates still needs to be determined.

Consideration should also be given to the placement of a power and reset button on the outside of the quadcopter.

List requirements for the frame design.

4.2.3 Arms

The arms should be constructed from carbon fiber tubes. The shape of the tubes will be selected based on the method selected to fix them to the frame, the strength of the tubes

under bending, and the cost. The possible shapes are as follows:

- Square – easier to fix to the frame and will not rotate, not as aesthetically pleasing
- Circular
- Elliptical
- Rectangular

The method for fixing the arms to the frame in order to prevent rotation is challenging.

Ideas need to be generated and documented.

List the requirements of the arms.

4.2.4 Landing Feet

The intent in designing the landing feet is that they will be modular and can accommodate a variety of use cases.

The feet could be placed in two different locations. Either beneath the motors at the end of the arms or near the body at the beginning of the arms. An analysis of the best location should be conducted with consideration placed on durability of body on hard landings and the landing platform.

List the different styles of feet.

List the requirements of the feet.

The landing feet should be

4.3 Electronics

4.3.1 Computer and Carrier Board

The Spiri Mu uses a Nvidia TX2 for the computer and an Elroy Carrier board, which acts as a motherboard for the computer.

The reason for using this computer is it has a graphics processing unit on board so the image recognition algorithms can be run on the unit.

ConnectTech will make the carrier board for the next generation Nvidia SOM. The new carrier board will incorporate camera input to remove the need for the camera interposers and ribbon cables. (source?)

Why was the connectech board selected?

4.3.2 Flight Controller

The current flight controller used on the Spiri Mu is the mRo AUAV Pixracer R15mRo AUAV Pixracer R15. The reason this was selected is ... (I assume this is due to the compatibility with the GPS or vice versa)

This package contains:

- Invensense ICM-20608-G 3-axis accelerometer/gyroscope
- Invensense MPU-9250 3-axis accelerometer/gyroscope/magnetometer
- MEAS MS5611 barometer
- Honeywell HMC5983 magnetometer temperature compensated

4.3.3 Electronic Speed Controller

For small drones, 4-in-1 ESC's are appropriate. For larger drones (what does larger mean in this case?), one ESC per motor would be required (why? I assume more power output)

Large drones (in our case) may have 8 motors, one up and one down on each of four arms.

4.3.4 GNSS/Compass

The GPS and compass used on the Spiri Mu is the mRo GPS u-Blox Neo-M8N.

For the next generation, the RTK GPS available from MRo, which greatly improves position accuracy. What are the differences from the current one? How much more accurate is it?

4.3.5 Optical Components

The optical components are the cameras and the range finder.

The camera units currently used on the Spiri Mu is two LI-M021C-MIPI . Another camera unit is being considered which is the the AR0144 [provide link](#)

An IR sensor could also be added to the array. what benefit does this provide

The reason for this is that we want direct CSI input for the built in cameras, not a USB interface. **what are the benefits to using CSI over USB?**

4.3.6 Power

The battery pack should incorporate a step-down converter and 5 cells. **why 5 cells? why not 6 cells?** The battery pack should have the following characteristics:

- Easily changed with a clip mechanism
- Connected to the drone using blade type connectors
- Fixed 15.5V
- Ability to supply 40A
- Spot welded connections between cells
- Balance charging

Hot-swapping batteries and moving batteries from one drone to the other should be possible.

4.3.7 Power Management

The power management system consists of the power distribution board.

4.3.8 Modular Payloads

The drone will be designed to carry a variety of different payload masses. These could include:

- FLIR Camera + gimbal
- Water testing equipment
- Normal camera + gimbal
- Agricultural multi-spectral sensor
- LIDAR

Need to know whether each needs a custom bottom shell

4.4 Overall Construction

Overview of properties for the entire drone.

Would be a good idea to make requirements for each subsection then requirements for the overall drone.

This section will include a wiring diagram to be added later.

5.0 Research of Similar Products

These section is for research on similar products and how they designed their drone.

6.0 Preliminary Design

Explain first design and why the decisions were made for the selected parts.

7.0 Prototyping & Testing

8.0 Detailed Design

8.1 Design Overview

8.2 Electrical Design

8.2.1 Wiring Diagram

9.0 Verification & Testing

10.0 Conclusion

References

- [1] DroneOmega. "Quadrocopter Propellers". 2020.[Online], *Available:*
<https://www.droneomega.com/quadcopter-propeller/>
- [2] Propeller Pages. "Propeller Pitch". 2020.[Online], *Available:*
http://www.propellerpages.com/?c=articles&f=2006-03-08_what_is_propeller_pitch
- [3] P. Formiga. "Material data sheet PA 2200". 2020. vol. 49, no. 0, pp. 1–2
- [4] "PA 1101 Product Texts EOS GmbH - Electro Optical Systems," 2018.
- [5] U.S. FDA, "HP 3D High Reusability PA 12," pp. 3–4.
- [6] "TPU Material Data Sheet," vol. 49, no. 0, p. 9492, 2016.
- [7] MatWeb, "Overview of materials for Epoxy / Carbon Fiber Composite MatWeb," pp. 1–2.
- [8] "BU-205: Types of Lithium-ion." [Online]. *Available:* . *Available:*
https://batteryuniversity.com/learn/article/types_of_lithium_ion