M-Fly AUVSI-SUAS Autonomous Unmanned Vehicle Hardware System

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Abstract

The M-Fly student project team is a multidisciplinary organization whose mission is to design, build, and compete aircraft. M-Fly builds several planes from scratch each year which are submitted to multiple competitions. One of these planes, the Michigan Autonomous (MAT) system, is an autonomous, unmanned system which is submitted to the Association for Unmanned Vehicle Systems International – Student Unmanned Aerial Systems (AUVSI-SUAS) competition. The yearly competition specification outlines several mission goals that M-Fly's MAT system must attempt. Among these for the 2020 competition were autonomous flight; object detection, localization, and classification (ODLC) with imaging; autonomous waypoint navigation; and autonomous detection and avoidance of other aircraft. In 2020, the competition also specified an additional mission goal involving a payload drop of an autonomous ground vehicle that had even more tasks itself. Though still a new competition and system for M-Fly, the third iteration of the MAT platform, the MAT-3, presented a novel design based on the lessons learned from the first two iterations. This report details the design of the system electronics architecture, evaluates the success of the system, and makes recommendations for further tests and development.

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Introduction

The Association for Unmanned Vehicle Systems International–Student Unmanned Aerial Systems (AUVSI-SUAS) competition is an annual event held for student project teams to submit and compete unmanned aircraft for prize money.[1] For SUAS 2020, held at the Naval Air Station (NAS) in Patuxent River, Maryland, the AUVSI released a competition mission specification to challenge teams to design a system which can complete several tasks. M-Fly is a student organization at the University of Michigan–Ann Arbor which enters the yearly SUAS competition and designs and builds aircraft to complete those mission tasks. This report will describe the competition goals and the aircraft that M-Fly designed and built to achieve them, the evaluation and testing of that aircraft, and the recommendations for further development to better achieve the competition goals.

Competition Mission Goals

Often the SUAS competitions attempt to solve a "real world" problem. The AUVSI often selects a problem for which no, or a limited number of, novel technology exists and derives key objectives from the desired technology. In this way, a solution which completes all objectives will essentially solve the "real world" problem. The stated problem of the SUAS 2020 competition is the following:

> Multiple package delivery companies have tasked Unmanned Aerial System (UAS) to deliver packages to customers. These UAS must avoid each other, avoid static obstacles like buildings, identify potential drop locations, drop the package to a safe location, and then move the package to the customer's location."[2]

From this context and for SUAS 2020, the AUVSI identified several restrictions. The unmanned aerial system was limited physically and mechanically in several ways. It was limited to fifty-five pounds while being capable of heavier-than-air flight. This encouraged the use of fixed-wing and rotary designs. Because M-Fly had much experience with fixed-wing aircraft, and the aircraft was required to fly more than six miles during competition, a fixed-wing style aircraft was selected and the body of the MAT-1 aircraft was designed based on other M-Fly airframes. There were other

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[1] https://www.auvsi-suas.org/competitions

[2] https://static1.squarespace.com/static/5d554e14aaa5e300011a4844/t/5e74c2e9b149a10a9c5daabf/1584710386075/auvsi_suas-2020-rules.pdf

constraints which limited the aircraft in other ways, but only those which were relevant to the design of the electronic hardware system will be discussed.

Along with aircraft restrictions, the AUVSI identified several key mission objectives from the competition problem. First and foremost was autonomous flight. The aircraft had to be capable of stabilizing and maneuvering itself automatically. At the time and location of the competition, a series of waypoints, consisting of latitude, longitude, and altitude points, were available. The UAS had to be able to fly through the airspace along the path while avoiding static and dynamic obstacles. The static obstacles were meant to emulate buildings and consisted of a latitude and longitude point along with a radius and maximum altitude. Though they did not exist physically at competition, flying within the obstacles involved a penalty of points. The dynamic obstacles were other UAS which flew in near proximity. A potential competition airspace is shown in the figure below.

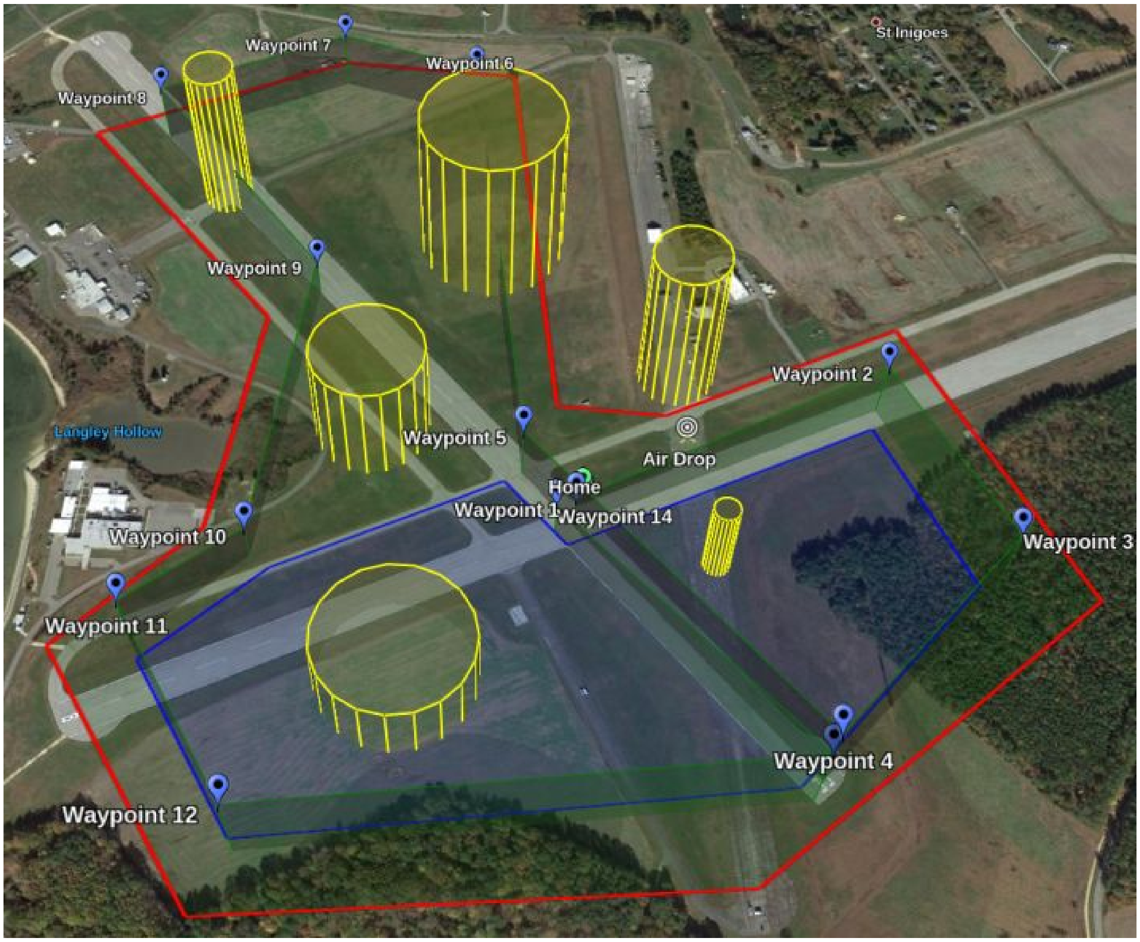

Figure 1: Sample Mission Map. The red polygon is the flight boundary. The blue polygon is the search grid. The yellow cylinders are the stationary obstacles. The green line is the waypoint path. There also exist points for air drop locations.

The UAS also had to be designed such that the team could perform a manual take over if necessary.

Another mission goal was object detection, localization, and classification (ODLC). This task required that while in flight, the UAS had to image the ground and search for objects of interest. There were static objects such as alphanumeric characters painted onto colored shapes as well as one dynamic object consisting of a person performing an interesting action. From the images of the ground, software had to determine if there was an object of interest, and if so, classify the object and relate its location.

The third task of interest was a payload drop of a secondary autonomous vehicle called an unmanned ground vehicle (UGV) holding an 8 oz water bottle. This drop was meant to emulate the drop of a package delivery robot. As such, the dropped system had to land in a specified drop location, and then drive along the ground to a delivery location to drop off the bottle. The system was strictly constrained by weight and had to be capable of driving upon landing. Because there were still points awarded for just the drop itself, the design of the UGV was not a priority for M-Fly at SUAS 2020.

Previous Work

The design of the MAT-3 was not a design from scratch per se. Rather because it was the third iteration of the MAT platform, lessons learned along the way perpetuated through iterations. Previous versions of the MAT platform spanning from 2017 to 2019–the MAT-1, MAT-2, and MAT-2.5 (shown in the figure below)–all ended in a crash and complete destruction of the system.

The beginning of the design was about exploration. In order to even understand what technology could help the system to achieve tasks, the MAT-1 began with one of the largest available off-the-shelf RC aircraft, crammed full of untested technology which seemed relevant to the mission objectives. From this, two important lessons were learned. First, the aircraft airframe had to be produced in-house. Although large for a commercially-available product, the airframe was significantly overweight and undersized when filled with components such as a flight controller, DSLR camera and off-the-shelf gimbal, and other components. The MAT-1 never left the ground. Second, component selection had to be more careful. The early flight controller and radios did not work well or at all, and the bulky components caused stress on the styrofoam airframe.

The MAT-2 offered significant improvements to the MAT-1. First, it was M-Fly's first ever carbon composite body aircraft. As a large aircraft, made with balsa wood wings and a powerful engine capable of generating much more lift, it offered much more room than the MAT-1. It also offered the first aerial test of MAT hardware. For the MAT-2, the camera and gimbal were excluded to eliminate weight and focus on more fundamental issues. However, after a few minutes of successful manually-controlled flight, the MAT-2 crashed and was destroyed. The cause of the crash was identified as a mechanical disintegration of the tail due to stress. Essentially, the MAT-2 was still too heavy, and because of where the weight was located in the body, this caused unstable flight and stress on the aircraft tail.

After a rebuild, the wings of the MAT-2.5 were also made from carbon composite, resulting in M-Fly's first fully composite plane. Antennas were replaced to give the plane more range, and after two successful manually-controlled flights, the hardware seemed to be working. However, during the third test flight, before the pilot was able to begin testing the first autonomous capabilities–a mode which automatically stabilized the aircraft while under manual control, the MAT-2.5 crashed due to loss of signal (LOS) from the transmitting controller. The cause of the LOS was determined not to be because of exceptional range, but rather that the angle of roll of the aircraft paired with the positioning of the new carbon wings blocked the line of sight from the transmitter on the ground to the antennae on the plane. This blocked line of sight caused the plane to fall into an unrecoverable nosedive.

Figure 2: (top left) MAT-1. (top right) MAT-2. (bottom) MAT-2.5. The most recent iteration, the MAT-3 uses the airframe design of the MAT-2.5 while improving the hardware.

Though it was the result of tragic history, the new MAT-3 uses the airframe design of the MAT-2.5 while making improvements to the communications hardware. The MAT-3 ultimately resulted in M-Fly's first ever autonomous flight.

System Design

Because the cause of the MAT-2.5 crash was caused by the hardware system, there was a necessity to review the system design and either improve the system to eliminate the anomaly or redesign the system from the ground up again. Since the system was largely still a permutation of the original MAT-1 system, and because the competition changed slightly since that system was designed, the MAT-3 team decided to opt for a system redesign.

Fundamental Flight Components

To fly even manually, the new MAT-3 needed two motors based on the design of the airframe. In its history, M-Fly has experimented with a number of different motor types. The MAT-3's propulsion subteam researched and tested a number of different motors and found two electric motors and complementary electronic speed controllers (ESC) to control them. The MAT-3 also needed servos to operate each of its control surfaces–two ailerons, two flaps, a rudder, and an elevator. The structures and aero subteams calculated the torque requirements based on fluid resistance and the correct servos were chosen based on servos that M-Fly has used in the past.

To power the electric motors, a battery was needed. To keep operating costs down, rechargeable secondary batteries were favorable compared to primary batteries. The Lithium Ion Polymer (Li-Po) was chosen for its low weight but large energy density, and because of the relatively high voltage requirement of the ESCs. A 6S 16 Ah Li-Po was selected to provide power for the motors. The battery was chosen to be 6S (nominally 25.2V) because of the 15V minimum voltage of the ESCs. The 16 Ah size was chosen with some uncertainty but with the understanding that the capacity could be increased if necessary following testing.

RC Transceiver and Antenna

The need for an RC transceiver and antenna to perform manually-controlled flight came from two sources. First, the competition required that the UAS be able to be manually overridden at any time during flight. Second, to test and calibrate the system, manual flight must be performed. To control the motor throttle and servos in manual flight, all ESCs and servos must be provided a PWM signal. The duty cycle of this signal encodes the throttle and servo throw. An RC transceiver with an antenna is able to wirelessly receive encoded communications transmitted from the ground and output all required PWM signals on wires to each servo and ESC. Because good RC transmitters can be extremely expensive, M-Fly uses the same RC transmitter for many of its planes. Because of this, the options for RC transmitters was limited to only those compatible with the Spektrum DX-9 transmitter, which broadcasts PPM signals on the 2.4 GHz frequency channel.

On the MAT-2.5 system, a LemonRX LM0039 receiver was used. However because of the LOS anomaly, it made more sense to abandon this receiver in favor of a more robust system. The Spektrum AR9320T and two Spektrum SPM9746's, shown in the figure below, were chosen as the LM0039's replacement for a few reasons. First, made by the same company as the DX-9 transmitter, these transceivers were highly compatible. Second, the AR9320T and SPM9746 were manufactured specifically for composite aircraft. With two remote receivers and extra-long antennae to avoid the carbon composite's RF interference, this receiver system was a much more robust solution. Further, by placing each of the four antennae on different parts of the fuselage, two, at the very least, was always visible via line of sight at all of the plane's rotations. Because only one is necessary for signal reception, this ensured that connectivity issues in the future were very unlikely.

Figure 3: Spektrum AR9320T and SPM9746 receiver

Flight Controller

For autonomous flight, a flight controller was needed. The flight controller of an aircraft replaces all jobs of human controller. It is responsible for adjusting the velocity of the aircraft as well as the position and orientation. From sensors like an airspeed sensor, GPS, accelerometer, and others, the flight controller is capable of learning how the aircraft responds to changes in throttle and servo control signals. From this, the controller tunes several proportional–integral–derivative (PID) controllers to accurately determine the necessary signals to obtain a desired position, orientation, and velocity. Many common flight controllers offer extra features such as multiple flight modes and even waypoint navigation.

The flight controller and sensors of the previous MAT iterations remained largely untested because most previous test flights were manually controlled directly from an RC receiver. However the flight controller chosen at the time of the MAT-1, the Pixhawk 4, was still a good controller and widely used in autonomous systems. Because of the hardware subteam's familiarity with its calibration procedure and sensor array, the software subteam's understanding of its waypoint navigation features and progress in tuning the controller, and improvements that were made to make the Pixhawk 4 safer since it was selected on the MAT-1, the Pixhawk 4 remained the selected flight controller for the MAT-3. Moreover, the Pixhawk 4 interfaced smoothly with the RC transceiver and offered a pass-through mode that would allow the received RC signal to control the throttle and servos without the controller's added input. Finally, the Pixhawk 4 not only output signals for controlling servos but also learned to automatically stabilize a camera gimbal. There was also no evidence to suggest that the Pixhawk 4 wouldn't work for the mission application.

Figure 4: Pixhawk 4 Flight Controller

The Pixhawk 4 comes with its own GPS and compass sensor as well as a power distribution board for controlling servos and throttle signals. A pitot tube air speed sensor was also selected to more accurately measure air speed and provide the controller with more accurate positional and velocity measurements. One benefit of a flight controller is that flight data can be recorded and transmitted to the ground in flight or saved for after flight. The competition required that this telemetry data be continually broadcasted to the ground so that the UAS could be monitored closely for any issue. Therefore, the selection of another transceiver was necessary.

The transceiver and antenna that was selected for this task was a Holybro Telemetry Radio V3 and L-Com HGV-903U, shown below, These components were chosen because they operate in one of the available frequency bands for amature use–900 MHz–as designated by the FCC.[3] The transceiver is also commonly used in hobbyist RC flight and works very well with the Pixhawk 4.

Figure 5: Holybro Telemetry Radio V3 and L-Com HGV-903U used to transmit flight data to the ground during competition.

To power the flight controller, radios, sensors, and servos, an independent battery was required. The decision was made to have two batteries onboard instead of one to keep the motor power system separate from the sensors. This was because the motors had the potential to draw an extremely high instantaneous current that could potentially cause the other components to be starved and turn off. To prevent this, the power provided to all other components apart from the motors was run off a separate battery. A 6S 3000 mAh LiPo was selected for this purpose. A 6S (nominally 25.2V) battery was chosen here because the maximum voltage to power the flight controller, and thus the

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[3] https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf

other components was 50.4V. It is difficult to find small batteries larger than 6S, so a six cell configuration was chosen. The 3000 mAh size was also chosen with some uncertainty but with the understanding that the capacity could be increased if necessary following testing.

Safety Override Switchboard

After the selection of both the RC transceiver and the flight controller there arose an issue. Both could control the plane by driving the throttle and servo signals. There was a requirement from the University of Michigan that when testing an autonomous vehicle with a flight controller, for safety purposes, the flight controller had to be able to be bypassed at any time during flight. If there were ever an issue with the flight controller, the aircraft could be recovered by this bypass. This led to the requirement for a custom built switchboard to determine which component drove the PWM signals to the throttle and servos. The board essentially performed a 5-channel MUX operation on the two signals based on another separate signal from the RC receiver.

All but one signal, designated the bypass switch signal, from the RC receiver were wired to both the flight controller and this switchboard. This included a signal for throttle, aileron servos, flap servos, elevator servo, and rudder servos. The corresponding signals from the flight controller were also wired to the switchboard. The duty cycle of the bypass signal could be manipulated at any time by a switch on the RC transmitter held by the pilot during flight. When the duty cycle of the bypass signal was small, the RC output was passed through to the ESCs and servos. When the bypass signal duty cycle crossed a threshold, the flight controller output was passed through to the ESCs and servos.

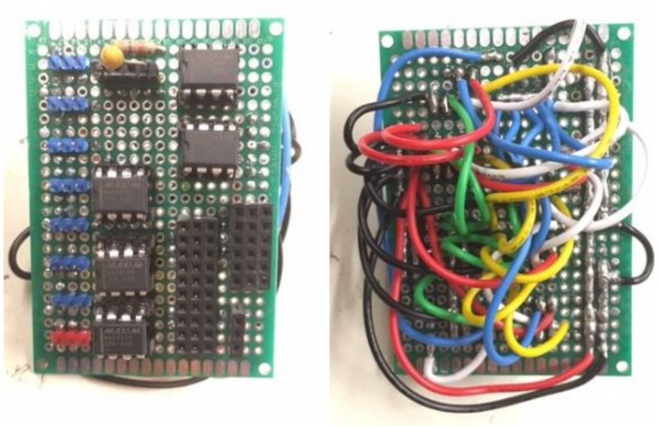


Figure 6: Both sides of the constructed override switch board

The override board consisted of five separate logic-controlled single-pole double-throw (SPDT) switches which each selected a single control signal. To power the switches, a universal battery-eliminator circuit (UBEC) stepped down the battery voltage to 5V. To determine the duty cycle of the bypass signal, an Arduino mini sampled the signal and output a logical on/off to control the switches. An image of the soldered board is shown above.

On-Board Computer

To perform the other competition tasks, an on-board computer was required. This computer was responsible for a number of tasks including aerial path-planning, image capture and ODLC, payload drop, and other communications to the ground. Because solutions to these tasks were largely developed by the software subteam which relied heavily on Linux, a RaspberryPi 3B+ was chosen as the flight computer. The choice of a RaspberryPi as a companion computer was beneficial in several ways. First, there were libraries that existed that made getting telemetry data from the flight controller as simple as two-wires. Secondly, a full Linux stack meant many computer vision algorithms and models could be used for ODLC. Finally, many team members had experience using it in the past.

Figure 7: RaspberryPi 3B+

To drop the payload, the only hardware that was required was a single servo which when activated, allowed a drop door to fall open and the UGV to be dropped out of the fuselage body. This was controlled by the RaspberryPi

To capture photos, the software team largely drove the camera selection. The software team required a high resolution, low cost camera that interfaced simply with the RaspberryPi. The Arducam with Sony IMX219, shown below, was selected because of its slim design, 8 megapixel resolution, and modular lens configuration. In addition, it was designed specifically for the Raspberry Pi and made use of the RaspberryPi's camera port. An LS2718 CS Mount lens was also selected because of its low FOV and long range focus. The gimbal which stabilized the camera was designed by the structures subteam, and its two servos for pitch and roll were automatically controlled by the flight controller.

Figure 8: Arducam with Sony IMX219 and LS2718 lens

To submit images of interest found with ODLC during competition, the images must be submitted to a cloud server on the ground. Because the capture and ODLC happens onboard the MAT-3, it was necessary to find hardware for a third communications link. This link would be responsible for transmitting images from the MAT-3 to the ground and waypoint, obstacle, and drop data from the ground server to the MAT-3 in the air.

Another available frequency was the WiFi band at 5.8 GHz. WiFi was chosen for this task because there were many options for transmitters and antennas operating at this frequency. Also, by extending a hosted WiFi network from the ground to the MAT-3 with essentially a signal extender, the RaspberryPi could be on the same local network as the ground station server. Therefore, for the software subteam, to talk to the ground from up in the air, communication was as simple as a broadcast over WiFi.

The Ubiquiti Bullet AC with an L-Com HG5806U-PRO antenna was selected to perform this connection. The Bullet AC is a WiFi module that can be configured over-the-air in a number of configurations. It also ran on 24V which is exactly what the battery voltage was. They are shown in the figure below.

Figure 9: Ubiquiti Bullet AC with an L-Com HG5806U-PRO

Wiring Harness

The wiring harness of the complete MAT-3 system was built by hand. Each cable connecting components was measured and rated for current draw through it to create a tidy, efficient harness. Many custom cables were made to optimize space, size, and power. A diagram of the MAT-3 system and harness is shown in the figure below.

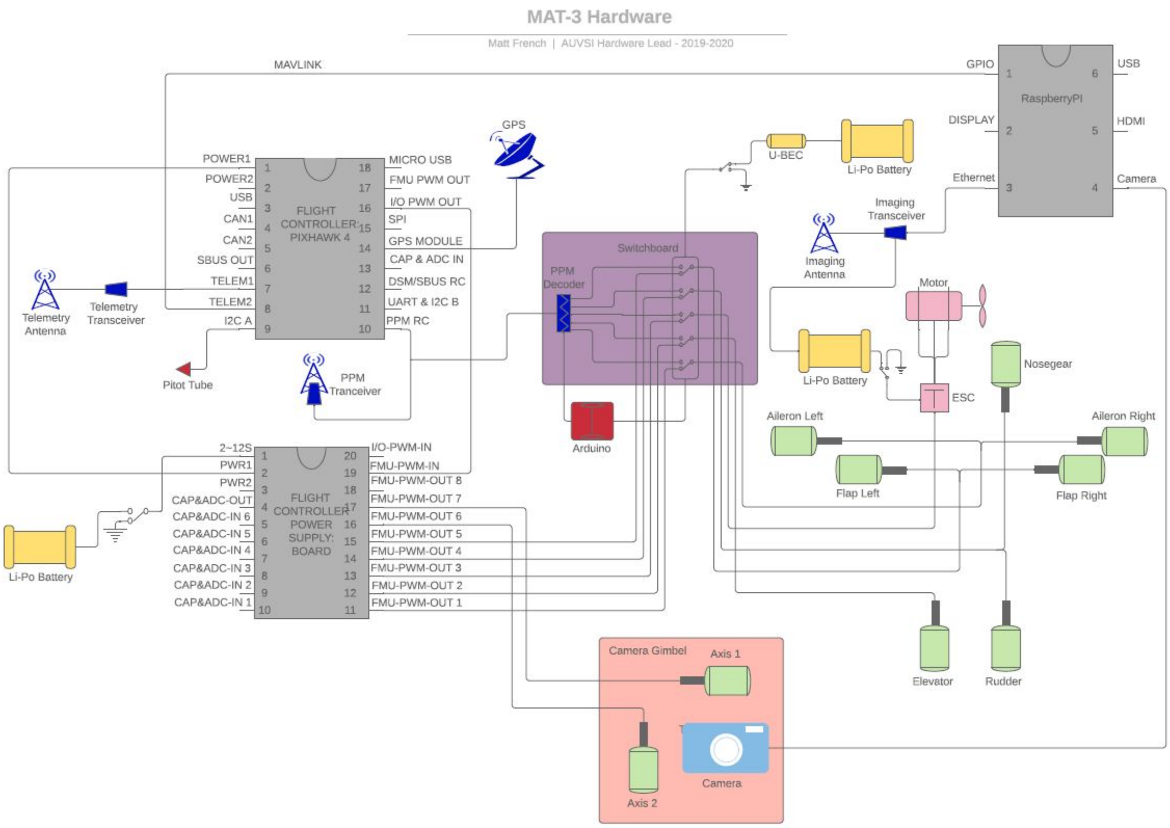


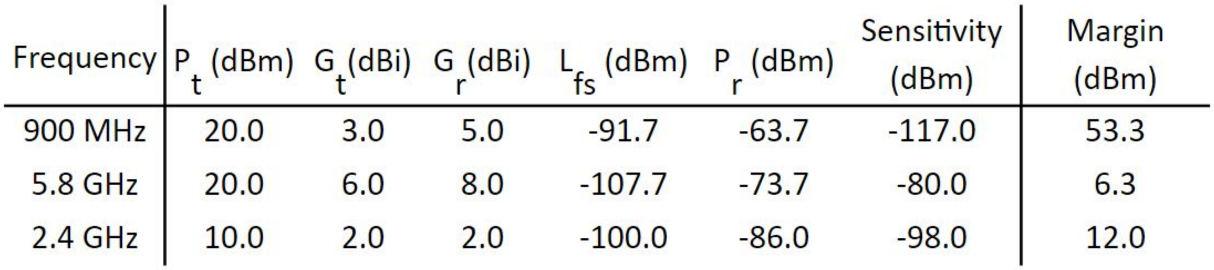
Figure 10: Complete Wiring Diagram for the MAT-3 system

System Testing

An important part of any new design is significant testing. To evaluate the design, several ground tests were performed such as communications range testing, sensor calibration, and power usage tests. Following ground tests, the design was tested in multiple flights starting with manually-controlled flight, transitioning to manually-controlled but autonomously stabilized flight, and culminating in autonomous flight. These tests and their results are discussed in this section.

Communications Range Testing

Since the competition flight area is constructed in such a way that the furthest aerial distance from the ground station could be upwards of 0.62 miles, the ability to maintain long-range communications is essential. At the time of selection early in the year, relatively little was known about the true range of the communications hardware. A crude estimate of the potential margin was calculated as shown below.



Frequency	P_t (dBm)	G_t (dBi)	G_r (dBi)	L_{fs} (dBm)	P_r (dBm)	Sensitivity (dBm)	Margin (dBm)
900 MHz	20.0	3.0	5.0	-91.7	-63.7	-117.0	53.3
5.8 GHz	20.0	6.0	8.0	-107.7	-73.7	-80.0	6.3
2.4 GHz	10.0	2.0	2.0	-100.0	-86.0	-98.0	12.0

Figure 11: Communication link range margin

The power received by the receiving antenna is given by the formula:

(1) $$P_r = P_t + G_t + G_r - L_{fs}$$

Where P_r is the transmitter power in dBm, G_t is the gain of the transmitting antenna in dBi, G_r is the gain of the receiving antenna in dBi, and L_{fs} is the loss of power in free space over the maximum competition range. The received power was calculated and compared to the receiver power P_r. As shown in the figure, there is positive margin for each communications link which suggests that the communications hardware for all links is sufficient for competition.

To test this expectation, a real range test was performed for the telemetry link on 900 MHz and the RC link on 2.4 GHz. On a flat open road. The MAT-3 system was connected to the transmitting receiver and telemetry ground station. Then, the MAT-3 was walked down the road until the connection was disrupted. The results of this test are shown below.

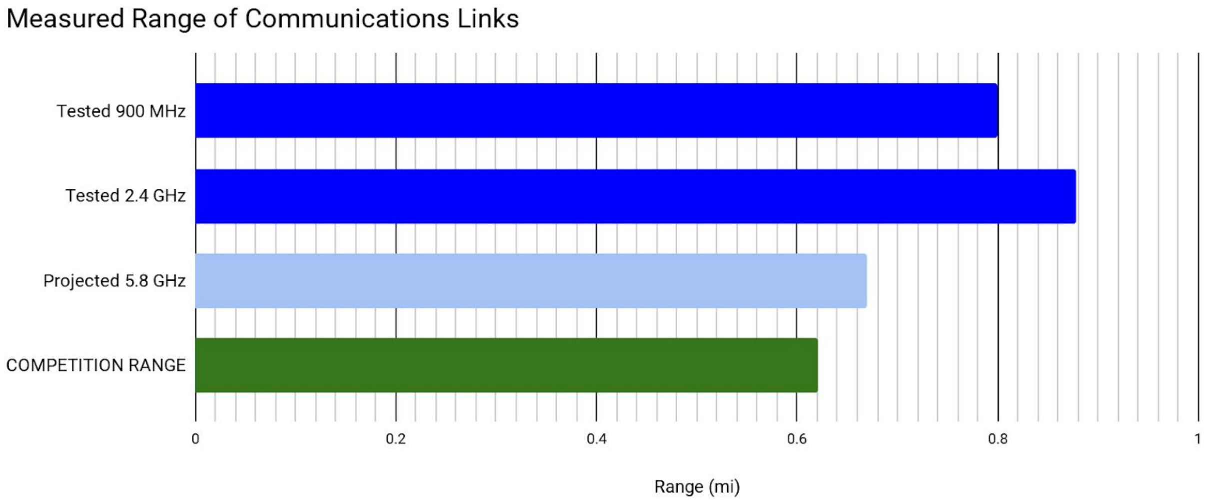


Figure 12: Communication link range test results. All tested links surpass maximum competition range. The untested link, not critical for flight, was also projected to exceed competition range.

The software subteam did not have an available method to test the WiFi link on 5.8 GHz so this hardware was not included in the test.

Power Draw Testing

Battery capacity had always been a concern because there was thirty minutes allotted for flight at competition. It was extremely difficult to measure the power draw from all batteries accurately. There were a number of issues which prevented the data collection from being complete or even accurate, but nonetheless attempting to evaluate the total draw of the system gives a rough estimate of usage.

To test the current draw from the battery powering the two motors, a custom connector cable was soldered that allowed a battery monitor to be placed in series with the battery. This allowed the hardware team to take rough instantaneous current measurements. Specifically, the maximum current that the motors drew from the battery was around 80A at full throttle, and the average was around 30A at half power. According to the propulsion and aero subteams, the MAT-3 was expected to fly at under half-throttle since the motors provided adequate thrust at that draw. The capacity of the battery was 16AH, so ignoring nonlinearities for the Li-Po battery, the battery was expected to last at least 30 min, and likely closer to 50 min.

The battery powering the other hardware components was measured on the ground. However, without a load on the control surfaces due to air resistance, the draw from the servos was likely significantly less than real conditions. Therefore, the numbers obtained from this test were not useful.

Flight Tests

After completing the communications and battery checks required for flight, the MAT-3 was flown in several test flights. The MAT-3 is shown in flight below. The first flight consisted of a very short, close range flight to validate the airframe. A secondary flight tested the range of the communications and other mechanical adjustments made after the first flight.

The third and fourth flights began to test greater system functionality. Specifically, in order to tune the flight controller, a special manual flight was performed involving many intense maneuvers to give the flight controller a broader range of experience to learn how to adjust the aircraft. Following this flight, the fourth test flight was a manually-controlled flight with autonomous stabilization. The pilot controlled the general position, orientation, and velocity of the aircraft, while the flight controller made changes to the orientation smooth. Also, in this flight, the camera was tested, and images were sent from the ground.

After each flight, the battery status was measured to ensure that the capacity was sufficient. Even after, the fourth flight which took over fifteen minutes, both batteries had significant power leftover. This confirmed that the selected capacity was sufficient.

Finally, the MAT-3 aircraft completed M-Fly’s first two autonomous flights. First, a circle test was performed. When the flight controller was set into this mode, when autonomous mode was activated, the flight controller held the aircraft at a desired roll angle and throttle. This mode is often used in the case of LOS because at a constant roll angle, the aircraft flies in a circle. The MAT-3 successfully completed this maneuver. Second, a waypoint test was performed. This involved setting a desired latitude, longitude, and altitude as a waypoint. When the flight controller was set into autonomous mode after being flown manually, the aircraft immediately rolled and turned toward the waypoint. The MAT-3 successfully flew directly through the waypoint before returning to manually-controlled flight.

Figure 13: The MAT-3 during a successful test flight.

Conclusion

System Success

There are many ways to measure success for a complex system such at the MAT-3. In one way, this project was not successful. Due to complications from the spread of COVID-19, the AUVSI-SUAS 2020 competition was cancelled, and students were sent home from school. This resulted in the termination of development of the system and the elimination of any opportunity to test the system in competition circumstances.

In another way, since the aircraft is a result of iterative design, any improvement from previous iterations at all could be called success. The MAT-3 improved upon previous versions in a number of ways. It was the first system for which the communication link ranges were verified with ground range tests and flight. It also completed record breaking flights for M-Fly. It was also a system designed from scratch which took advantage of lessons learned from earlier versions. The structural design and component integration was much more polished and thought out, and the harness and placement of components was made more efficient.

In a third way, this project was extremely successful on an individual level. M-Fly is a student organization, and as such it provides a great opportunity to work in a multidisciplinary setting and to learn about the design process itself. Because of the structure of the team into sub-teams, the interaction and collaboration with engineers and non-engineers is very similar to that of a corporate experience. Learning to navigate the requirements, suggestions, and work from other groups within an organization is a very important skill to have as an engineer. Since this iteration was designed from the ground up, it also was a great experience to participate fully in the design process, which begins with a problem, progresses through research, design, test, and iteration. All stages of design were present barring potentially some end stages due to the project being terminated short.

Recommendations for Future Work

Because of the early end to the MAT-3's development, the design process was not completed. In particular, there are several areas for which the MAT-3 hardware can be improved. Because there was a focus on autonomous flight over all else, design for other mission requirements was lacking. A summary of work left undone is below.

After autonomous flight is fully validated with a fully autonomous flight involving autonomous takeoff, navigation along a waypoint path, and autonomous landing, a priority should be made for an obstacle avoidance solution. Some research into radar, stereo vision, lidar, and ultrasonic detection methods was done, but much more must be done to come up with a good solution.

Another missing hardware is the development of the payload UGV system. Several members within M-Fly have started the process of designing this hardware, but not much significant progress has been made. This is an area with many potential missing points at competition.

Finally, an effort should be made to switch to a custom in-house flight controller. Barring the sensors, an in-house controller would be very beneficial to M-Fly moving forward because it also could undergo iterative design year-after-year. Much of the testing of the current flight controller involves research into a very complex controller, and much of the functionality of the Pixhawk 4 will never be used. In addition, the support for this controller from the manufacturer and other users is seriously lacking now. With each year, the need to move on from it increases.