Conceptual Design Review

Team # 6:

Autonomous Aerial Vehicle

EML 4551C – Senior Design – Fall 2012 Deliverable

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Introduction:

The United States Marines have been given a special assignment of humanitarian relief and security over a small island nation in the Caribbean. Team six has been given the task of providing an Autonomous Unmanned Aerial Vehicle that can support intelligence, surveillance and reconnaissance. The vehicle must search a designated area and look for items of interest as well as classify specific details of it within a given time. Such details include; color, shape, size and GPS location of each item. Aerial vehicles that are capable of completing such tasks have an opportunity to enter into a competition at the end of the 2012-2013 school year for a chance to win prizes and gain real life engineering experiences.

The 2011-2012 UAV team was given similar tasks but unfortunately was not able to complete their vehicle and make it into the competition while also going over budget. Their plan was to design and build an entire fixed wing aircraft from scratch while also implementing the needed software and hardware to fly autonomously and collect data. Such technology will be discussed in a later section of existing technology. The 2011-2012 UAV team ended up purchasing a plane to test the equipment they purchased for the competition. Most of the technology worked but requires adjustments to be able to qualify for this year’s competition. Team six plans on starting where last years team left off in order to be able to compete against other schools around the world.

Existing Technologies:

When analyzing the aircraft we can divide the technology used into two main sections, which would be the mechanical components and the electrical components. While looking at the electrical components of the aircraft, we can focus on three main subsections. The first section would cover all the existing types of autonomous vehicles. The next would focus on existing camera and optics software and the last subsection would cover existing autopilot software.

Currently, there exist three main types of autonomous vehicles. The most popular would be the fixed wing aircraft. A key benefit of this design is that there is a lot of existing research for autonomous fixed wing aircrafts, which helps immensely when picking the autopilot software. Moreover, the most important benefit of this design for this particular project is that last year's senior design team chose this particular model, shown below in figure 1. This helps lower the cost of materials and gives us a solid foundation of background information that we would be able to build on. The main cons are mobility (compared to a quadrotor and/or helicopter) and, for our specific case, the task of designing and building the plane has already been done, which would make the project feel like more of a continuation rather than starting completely new. However, this is not to say that the designs of the aircraft could not still be altered if we choose to do so.

Figure 1- Senior Telemaster used for last year's design project (1)

The second type of autonomous vehicle researched for this competition is the quadrotor pictured below in figure 2. Quadrotors are relatively new and provide a notion of innovation and creativeness. Also the quadrotor has great mobility and would likely be able to navigate a search area and reroute to a new search area easier than a fixed wing aircraft or possibly even a helicopter. A key disadvantage of the quadrotor is reliability. Not only are there four separate motors that have to operate simultaneously, but the vehicle must travel at high altitudes where the vehicle will, almost undoubtedly, endure strong gusts of wind that may alter the flight path of the vehicle. Possibly the main disadvantage of the quadrotor is that it uses a lot of power consumption. The competition flight should last approximately twenty to forty minutes, but may last as long as an hour. This could lead to problems supplying ample power to the vehicle for the duration of the competition.

Figure 2- Aerial picture of a Quadrotor (2)

The final autonomous vehicle design researched for this competition is the helicopter shown below in figure 3. Realistically, this is the least likely of the concept designs to be chosen for this project. The only real pro of this design is that it is not a very popularly chosen model, which would provide for more self-satisfaction of constructing something more unique than an actual technical advantage. The helicopter may also be more agile than the fixed wing aircraft, but still less capable than the quadrotor. Also, due to the less research done for this model, finding an autopilot system to operate the helicopter would be a lot harder and more constricting than, say, the fixed wing aircraft.

Figure 3- Aerial picture of an R/C helicopter (3)

The next subsection would be the camera and optics software. These software devices are typically used for acquisition of certain targets or for surveillance purposes. Within this subsection lies the option to either use a still-image camera to capture, send, and process the images or to implement a real-time video display. As always, both options have their pros and cons. The advantages of using a still-image camera are that the still-image camera requires less data transmission than a constant data feed, as well as requiring less transmission power to transmit the images. The disadvantages of the still-image camera are obvious. Without a constant feed the camera will need to take several photos to cover the search area. Also, more than one camera may be required in order to obtain the picture rate needed to sufficiently capture and record the given search area. A gimbal system may also be required to alter the viewing angle of the camera. With all of these aspects taken into account, it seems not unlikely that a given area may be missed that may or may not contain a desired target. Using a video camera would enable a constant footage feed, which would drastically decrease the chances of missing a target. However, the video camera will require more power than the still-image camera, must be transmitted at a higher frequency, and the video camera must have real time image stabilization, as well as maintaining a good, clean signal for operation.

Figure 4- Sony FCB Block Camera (4) Figure 5- Sony KX-181 (4)

As with the type of aircraft, a specific camera system was chosen and used in last year's project. The video camera chose was the IX11A Sony FCB Block Camera, shown above in figure 4. The specifications of the video camera are given in the chart shown below in figure 6.

The camera that placed runner up in last year's decision matrix was the Sony KX-181 shown in figure 5. This analog camera is very popular among RC aircrafts, but will not be chosen for this project not only because we already are in possession of the Sony FCB Block Camera, but also due to the disadvantages previously mentioned regarding still-image cameras. The main advantages of this camera are its 520 TV line, and that it only weighs 26g.

The desirable features of the FCB camera is that it is capable of high-performance Digital Signal Processing, it has high-speed Serial Interface (max.38.4 Kb/s) with TTL Signal-Level Control (VISCA protocol), and it has a relatively low power consumption (1.5/1.6 W when motors are inactive) (8). The 40x optical zoom will undoubtedly enable the camera to determine the targets from an altitude of 500 feet. The video camera also has a customizable On-Screen Display, that could be used to display information such as heading, airspeed, altitude, and GPS coordinates.

	FCB-IX47C	FCB-IX47CP	FCB-IX45C	FCB-IX45CP	FCB-IX11A	FCB-IX11AP
Image device	1/4 type Super HAD CCD				1/4-type Exview HAD CCD	
Effective picture elements	Approx. 380,000 pixels	Approx. 440,000 pixels	Approx. 380,000 pixels	Approx. 440,000 pixels	Approx. 380,000 pixels	Approx. 440,000 pixels
Lens	18x zoom, f = 4.1 mm (wide) to 73.8 mm (tele), F1.4 to F3.0				10x zoom, f = 4.2 mm (wide) to 42 mm (tele), F1.8 to F2.9	
Digital zoom	4x (72x with optical zoom)				4x (40x with optical zoom)	
Viewing angle (H)	48 ° (wide end) to 2.8° (tele end)				46° (wide end) to 5.0° (tele end)	
Minimum working distance	10 mm (wide end), 800 mm (tele end)				10 mm (wide end), 1000 mm (tele end)	
Sync. system	Internal					
Minimum illumination	1.0 lx (50 IRE)			1.5 lx (50IRE)		
S/N ratio	More than 50 dB					
Electronic shutter	1/1 to 1/10,000 s, 22 steps		1/60 to 1/10,000 s, 16 steps	1/50 to 1/10,000 s, 16 steps	1/1 s to 1/10,000 s, 22 steps	
White Balance	Auto, ATW, Indoor, Outdoor, One-Push, Manual					
Gain	Auto / Manual (-3 to 28 dB, 2 dB steps)					
AE control	Auto, Manual, Priority mode, Bright, EV compensation, Back-light compensation					
EV compensation	-10.5 to +10.5 dB (1.5 dB steps)					
Back-light compensation	On/Off					
Flicker cancel	Auto	–	Auto	–	Auto	–
Focusing system	Auto (sensitivity: Normal, Low), One-Push AF, Manual, Infinity, Interval AF, Zoom Trigger AF					
Picture effect	Neg. Art, Black & White, Mirror Image, E-Flip				Neg. Art, Black & White, Mirror Image	
Camera operation switch	Zoom tele, Zoom wide					
Video output	VBS: 1.0 Vp-p (Sync. Negative) Y/C Output					
Camera control interface	VISCA (TTL/RS-232C signal level) Baud Rate 9.6 Kb/s, 19.2 Kb/s, 38.4 Kb/s Stop bit 1/2 selectable					
Storage temperature	-20 °C to 60 °C (-4 °F to 140 °F)					
Operating temperature	0 °C to 50 °C (32 °F to 122 °F)					
Power consumption	6 to 12 V DC / 1.5 W (inactive motors), 2.0 W (active motors)				6 to 12 V DC / 1.6 W (inactive motors), 2.1 W (active motors)	
Mass	170 g (6.0 oz)				95 g (3.4 oz)	
Dimensions (W x H x D)	48.2 x 56.6 x 92.3 mm (1 15/16 x 2 ¼ x 3 ¾ inches)				39.3 x 44.8 x 65 mm (1 9/16 x 1 13/16 x 2 5/8 inches)	

Figure 6- Data chart for the Sony FCB Block Camera (4)

The last subsection is the autopilot system. An autopilot is a MEMS system used to guide the UAV without assistance from human operators, consisting of both hardware and its supporting software (7). The first aircraft autopilot was developed by Sperry Corporation in 1912 (7). There are two types of autopilots to be considered. The first is an off-the-shelf closed source autopilot or open source. We will be using an open source autopilot, which allows for flexibility in both the hardware and the software. The open source autopilot can be easily modified to carry out specific requirements.

A popular off-the-shelf autopilot system is the Piccolo LT autopilot shown below in figure 7. The dimensions of the Piccolo LT autopilot are 13 x 5.9 x 1.9 (mm), it weighs 45 g, it has a power consumption of 4 W, and it has an operating temperature of -40 to +80^{o}C. Its functions include waypoint navigation, auto-takeoff and landing, altitude hold, air speed hold, and multi-UAV support. The main disadvantage of the Piccolo LS autopilot is that it is not open source. This makes the source code difficult to modify which, in turn, makes it difficult to implement a search area.

Figure 7- Piccolo LT Autopilot (26)

Once again, we have an existing autopilot from last year's project. However, this autopilot was not the selected autopilot. The selected autopilot was not available at the time last year's team attempted to purchase the autopilot system, therefore the runner up was purchased. The autopilot purchased was the Adrupilot Mega shown below in figure 8. The dimensions are 40 x 69 (mm) and it weighs 45g. The main advantages of this autopilot is that it has a built in kill switch if the UAV needs to be flown manually and the software interface runs windows, which makes it very portable. The negatives are that it lacks extra ports for the camera system gimbal and there is no source code given with the software, which would, again, make it difficult to modify the search area.

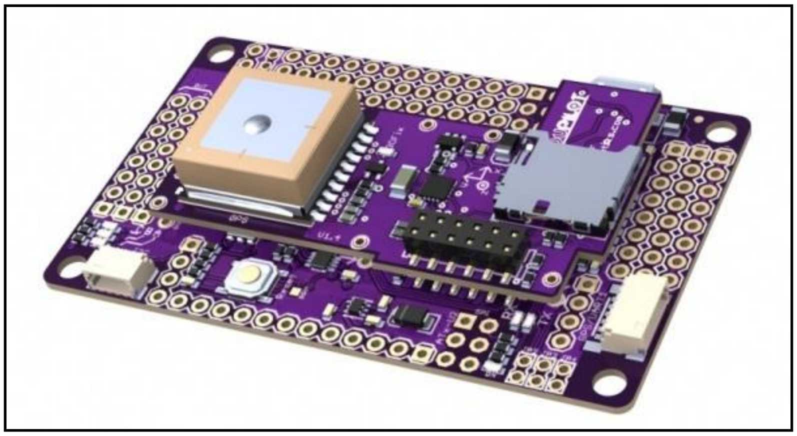

Figure 8- Ardupilot Mega Autopilot (6)

The autopilot system chosen last year, but not purchased, was the Paparazzi Tiny v2.11 autopilot system. The dimensions of the Paparazzi Tiny are 70.8 x 40 (mm) and it weighs 24g. This autopilot also has a kill switch, as well as other safety considerations, and has the extra ports for the camera system gimbal. The source code is downloadable and it works with most sensors. The software can achieve waypoint tracking, auto-takeoff and landing, and altitude hold. The con of this board is that the interface software runs only on Linux platforms, which limits its portability. The autopilot also does not have a good speed hold.

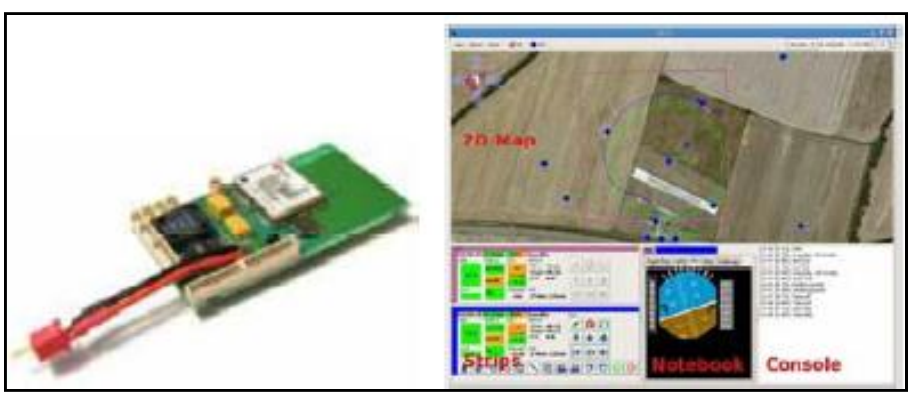

Figure 9- Paparazzi Tiny v2.11 autopilot system (26)

Concept 1: Quadrotor

The quadrotor concept is classified as a rotorcraft as opposed to fixed-wing aircrafts because their lift is generated by a set of narrow-chord airfoils. As opposed to the helicopter, these airfoils are symmetrically pitched blades which can be adjusted collectively but not individually based upon the blade's position in the rotor disc, as with the helicopter. Motion is achieved by alternating the pitch and rotation rate of the rotor discs, changing its torque load and thrust lift characteristics. The idea to utilize the quad-rotor in this competition was based upon the agility and ease of takeoff and landing that these vehicles are capable of. Figure 10 shows an example of a quadrotor and camera system. It was initially thought that the image processing guidelines for this competition would be achieved easier with the quadrotor concept due to its in-flight stability.

Figure 10- Quadrotor Example(14).

There are numerous advantages to the quadrotor as opposed to the helicopter and the fixed wing aircrafts. First, they do not require mechanical linkages to vary the rotor blade pitch angle in which they spin. This is not the case for the helicopter (10). Second, the use of four rotors allows each individual rotor to have a smaller diameter than the equivalent helicopter rotor. This allows for less kinetic energy per blade during flight and thus reducing damage should the rotors make contact with anything. This also makes the vehicle safer for close interaction. Due to their ease of both construction and control, quadrotor aircrafts are frequently used as amateur model aircraft projects and in competitions (11). However, it was recognized that up until last year's AUVSI competition, there had not been any quadrotor entries.

When comparing the quadrotor to the fixed wing aircraft and helicopter, the most important consideration to compare was the flight controls and the battery capability. For flight, each rotor produces a thrust and a torque about the center of rotation as well as drag force in the opposing flight direction. If all rotors are spinning at the same angular velocity, with rotors one and three rotating clockwise and rotors two and four counterclockwise, the net aerodynamic torque, and hence the angular acceleration about the yaw axis is exactly zero. The yaw axis lies in the centerline and is perpendicular to the copter and yaw motion is defined as a side to side movement of an aircraft (12).The difference in rotation of the four rotors allows the quadrotor to produce a more stable yaw motion then the helicopter. When compared to the fixed-wing aircraft, the quadrotor can achieve a greater yaw due to its rotors whereas the fixed wing, under the same aerodynamic conditions, would be put into a tail spin. Figure 11 below shows the axial representation of the quadrotor's yaw about the $Z_{B\ axis}$. For the quadrotor to be flown autonomously it will then be necessary to produce a programming code that would be unique to each rotor with each rotor needing a unique motor voltage, therefore making the overall programming aspect of this project more complex.

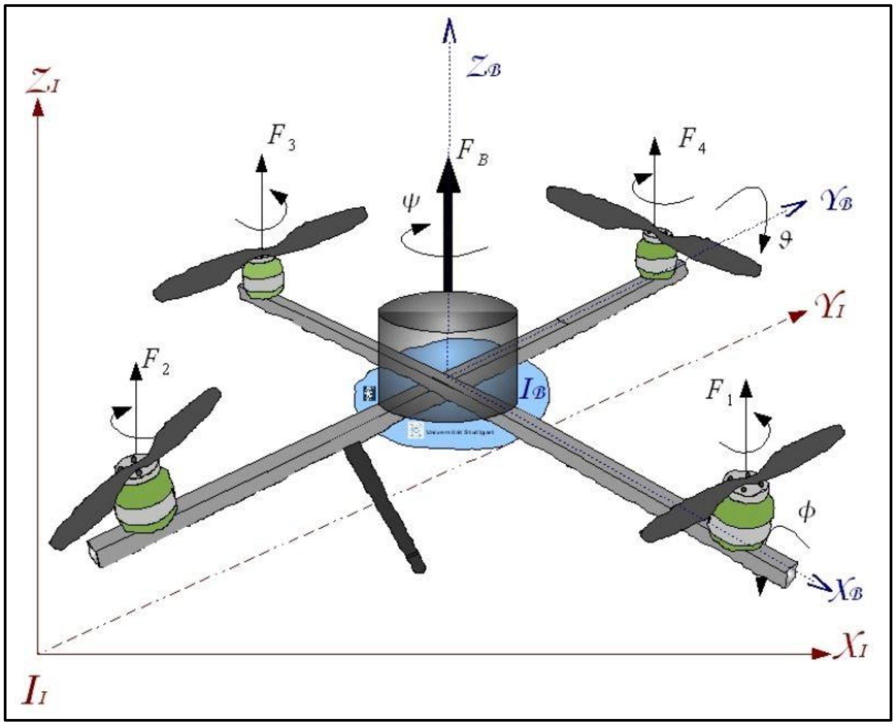

Figure 11- Graphical representation for the yaw of a quadrotor (13).

Lastly the power performance for the quadrotor is much greater than that of a fixed wing aircraft. The American Institute of Aeronautics and Astronautics has run tests on their Velasoraptor experimental quadrotor and has found that with each rotor utilizing lithium polymer 4100 mAh batteries, normal flight conditions would discharge the batteries in under 6 minutes (15). Unfortunately, the AUVSI competition requires a flight time of approximately 20 to as much as 60 minutes to complete the mission. The power supply to the fixed wing plane from last year's project has been proven to provide ample flight time in order for the mission to be completed.

Concept 2: Fixed Wing Aircraft

This traditional concept is where aviation began. It has kept its place in aviation because of its primary virtue: simplicity. The fuselage provides a strong base on which each component or appendage of the airframe may be attached, as well as houses a significant portion of the weight of the aircraft in the case of single-engine aircraft. This feature gives a great deal of stability to the airframe and allows for a higher tolerance of variation in environmental circumstances.

The conventional airplane design also allows for a great deal of customization and options. There is an array of parameters that affect the flight characteristics; many of them are static on the airframe which gives an ease to fabrication. These parameters can be highly manipulated to best serve the needs of the customer and a machine may be produced to fit exactly what is needed. Some examples are the area of the wing surface which varies the amount of drag and lift, the aspect ratio of the wing which changes the lift-to-drag ratio, and the use of anhedral, dihedral or polyhedral wing design which affect the stability and turning characteristics (18). Figure 12 below shows examples of wing design profiles as seen from the front and a basic wing as seen from above. The surface area of a wing is calculated by multiplying the span by the chord, and the aspect ratio is the square of the span divided by the chord (18).

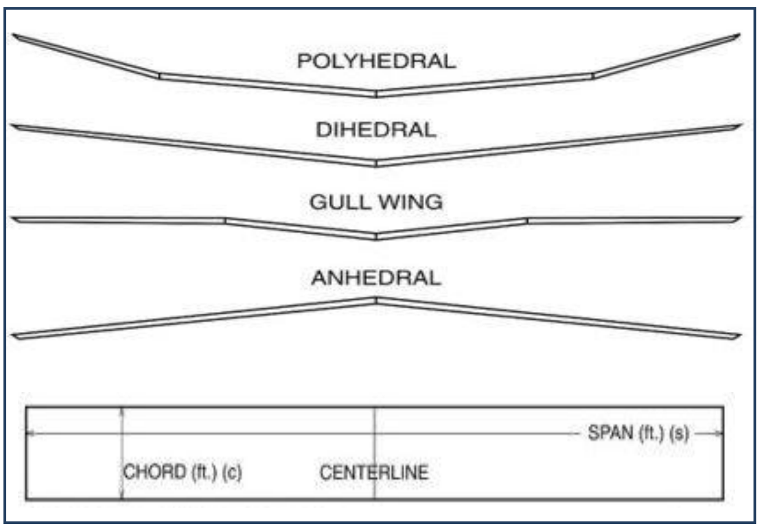

Figure 12- Wing profile designs and front and top view (18)

Continuing with last year's fixed wing aircraft is one of the options available to this year's team. As seen below in Figure 13, the airplane available to us is a Senior Telemaster made by Hobby-Lobby. The Telemaster is recognized for its stability and large lift-to-drag ratio, both of which play a major role in the successful completion of our mission. The stability comes into play when maneuvering the plane either manually or in autopilot, as well as getting a clean and clear image from our onboard camera. The large lift-to-drag ratio is created by the 1,330 sq. inches of wing area that the Telemaster provides (16). The greater lift leads to extra payload capabilities such as the camera, GPS, and additional batteries, without compromising flight.

Building on last year's project and keeping the airplane will save us time since we will not have to build a completely new aircraft from the ground up, in addition to saving us money since purchasing the components for the aircraft will not have to come out of our budget (Approx. $500 savings!). Along with saving us time and money, remote control airplanes are simpler to fly than their rotary wing counterparts, which will benefit us in the testing phase of the project.

The draw backs to going with the Senior Telemaster are that for takeoff/landing we would require a runway, whereas a helicopter or a quadrotor does not. Rotary wing aircrafts also have the luxury of hovering (maintaining a fixed location), while fixed wing aircrafts need continuous movement to generate lift. It is possible that not having the ability to remain in a fixed location can make certain aspects of the project more difficult (17).

Figure 13 shown below is the Senior Telemaster that last year's group was planning on using to go to competition. This aircrafts large wingspan generates a substantial amount of lift which allows for the addition of further electronics such as a camera, GPS, and autopilot system.

Figure 13- Last Year's Design Group Senior Telemaster (1)

Concept 3: Helicopter

Helicopters are common and used throughout the private and public sector alike. They utilize a single large rotor that provides all of the thrust for the aircraft. This rotational motion causes a torque on the helicopter which is overcome by a mechanically-linked tail rotor. Larger rotors tend to be more efficient in terms of thrust. Because of this, a helicopter design would likely be more efficient than a quad-rotor of a similar weight (20).

The helicopter flight characteristics change whenever it gains any kind of airspeed, whether from wind or translational movement. This is because the lift produced by the blades depends on several factors, one of them is airspeed. If the helicopter is moving forward, for example, the blades on the forward-moving part of the rotation will have a higher air speed than those on the aft ward-moving portion. This issue is resolved by a swash plate, which adjusts the pitch of the rotors as they move into or away from the direction of airflow. As the swash plate rotates, it pushes pitch control rods which physically change the pitch of the rotor blades (21).

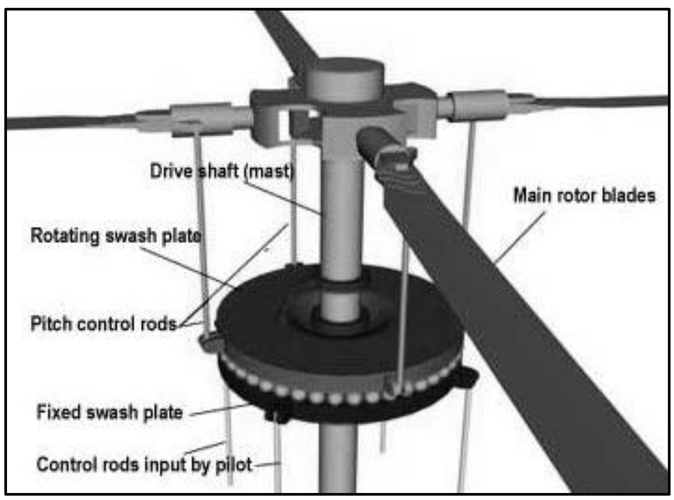

Figure 14- Illustration of a wash plate

This mechanism is also responsible for tilting the aircraft when motion in a particular direction is desired. There is some overlap here in that the same mechanism is used to change the pitch and the roll of the aircraft. The yaw is controlled by the tail rotor. A balance must be maintained in maneuvering this type of aircraft, in that when a portion of the thrust is used for horizontal movement, that portion of thrust is taken away from lift. Piloting a helicopter is a continuous stream of corrections.

The primary advantages of this airframe are that it capable of hover and it is popular, which makes finding support in the way of parts, experience or knowledge easier when compared to the quad rotor. High cost and particularly catastrophic consequences of a possible crash are the major drawbacks.

Concept: Autonomous Software

The rules for our design competition explicitly state that our air vehicle must be able to accomplish waypoint navigation as well as area search, both completely autonomously. Therefore choosing the system for autonomous flight is extremely critical. Our task to design an autonomous air vehicle is unique in that there is a very large hobbyist community associated with these vehicles. That fact combined with our relatively small budget has led us to choose the route of seeking open source software for automation. We considered two separate, open source software suites for our air vehicle, Paparazzi, and ArduPlane.

The first autonomous software considered was Paparazzi Tiny V2.11. It is the product of the Paparazzi Project and the Tiny is an all-inclusive autopilot system complete with an integrated GPS receiver (22). Figure 15 shown below is an assembled Paparazzi Tiny (v2.1) autopilot system. The right side of the board houses the GPS receiver as well as the various input pins (sensors, power supply, etc.) while the left side houses the logic unit including the processor (23).

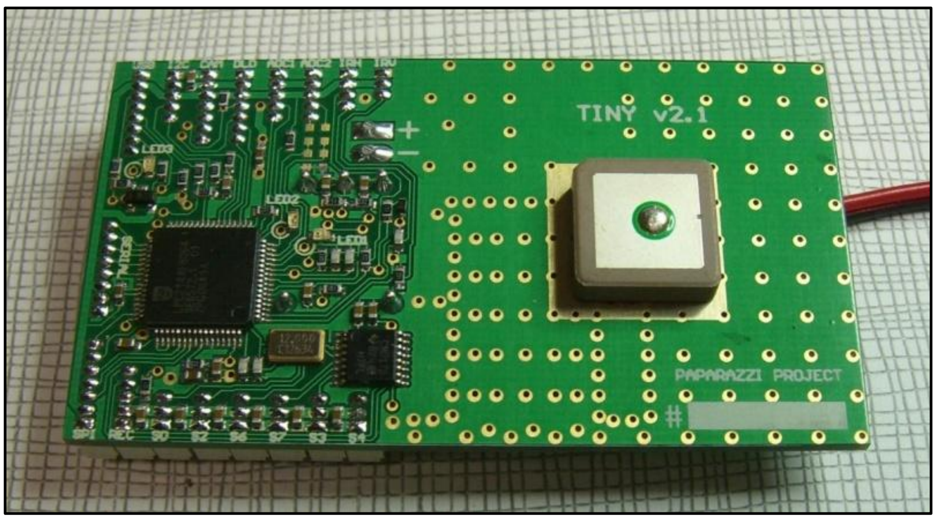

Figure 15- Assembled Paparazzi Tiny (v2.1) autopilot system (26)

The pros for the Paparazzi Tiny are as follows. The system comes completely assembled and integration with individual air vehicles is very clear and concise on their wiki page. Size and weight are also a positive for this system; it measures in at 70.8mm x 40mm (smaller than a credit card) and weighs just 24 grams fully assembled. The Tiny is also carries the benefit of having multiple protection systems built in to the module, including a 3.3V line regulator, a 5V switching power supply to regulate voltage sags from inductive or capacitive loads, as well an emergency kill switch (22). Lastly, the Paparazzi community is very large and it would be a great benefit to have help from enthusiasts if problems occur with the system.

The cons for the Paparazzi Tiny are as follows. It is a Linux based autopilot module and because no student in our group has experience with Linux operating systems, debugging and error checking could become extremely time consuming. Also because Paparazzi is a completely open source community, there is no official hardware vendor of the Paparazzi Tiny and therefore our team must find a third party vendor. The main page of Paparazzi Tiny lists two suggested hardware vendors, but unfortunately both appear to no longer sell the assembled Tiny. This manifests a problem with actually locating a unit as well as not having a price reference to compare with the other autonomous software suits.

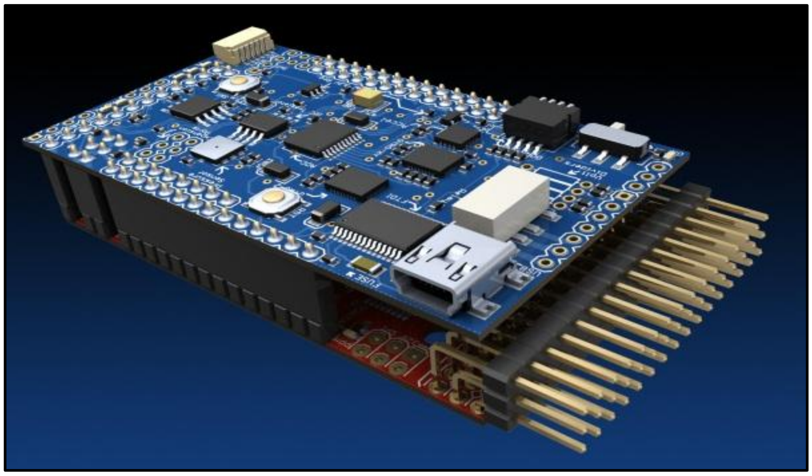

Figure 16- Assembled ArduPilot Mega autopilot system (26)

The next autonomous software considered for our aircraft is ArduPilot Mega which utilizes the hardware of the open source Arduino Mega microcontroller along with an ArduPilot module to provide a completely assembled autopilot system to any RC aircraft (24). Figure 16 shown above is an assembled ArduPilot Mega autopilot system. This figure shows the two boards of the system, the module on top is the main processor board with either an Atmega1280 or an Atmega2560 processor (depending on the Arduino Mega) and below that is the Inertial Measurement Unit (IMU) which houses the sensors such as gyroscopes, accelerometers, voltage monitors, etc. (25)

The pros of the ArduPilot Mega are as follows. Just as the Paparazzi Tiny, the ArduPilot Mega comes fully assembled and ready to implement, which means more time can be spent on other aspects of our design. Unlike the Paparazzi system, the ArduPilot Mega is specifically designed for a fixed wing aircraft and thus will be significantly easier to implement. The system also has a built-in failsafe in case radio communication is lost between ground control and air vehicle.[5] The ArduPilot is also a windows based system which our team has much more experience with. The most significant benefit of utilizing the ArduPilot Mega is that it comes with an open source ground control software, “Mission Planner,” which satisfies a requirement of our competition that we have a ground control computer to monitor the location of our aircraft and status of the mission. Mission Planner also includes built in waypoint navigation using Google maps as well as area search.

Figure 17- Graphical user interface (GUI) of the Mission Planner software

An example of the graphical user interface (GUI) of the Mission Planner software is above in Figure 17. The graphical user interface (GUI) of the Mission Planner ground control software included with the ArduPilot Mega software. The window on the right displays the current location of the air craft using Google maps. The window on the top left displays the heading information of the air craft and the bottom left window can be used to read sensors/gauges from the aircraft. (27)

The cons of using the ArduPilot Mega package are as follows. The system utilizes the microcontroller from the Arduino Mega which can be relatively weak when compared to the microprocessors the Linux based Paparazzi Tiny can be implemented with.

Conclusion:

Depending upon the successful completion of these tasks, team six has a major goal of entering our vehicle in the Association for Unmanned Vehicle Systems International (AUVSI) Competition held in June of 2013. In order to be able to compete in this competition our team will use a majority of the previous technology and improve on the specifications of it. A couple of the biggest challenges that we expect to face is setting up the FCB Block Camera and programming the autopilot system. The camera has a special set of directions that are not easily accessible and the autopilot needs to have the proper program in order to follow all the requirements of the competition. Team six is very motivated and ready to take this senior design project to the next level by not only competing but also placing.

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