ISTANBUL TECHNICAL UNIVERSITY

ITUNOM AUTONOMOUS AIR VEHICLE TEAM

AUVSI Student Competition 2016 Journal Paper

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PREFACE

ITUNOM Autonomous Air Vehicle Team was founded in April 2014 in Istanbul Technical University. As the team's second attempt to join the competition, ITUNOM is far more experienced than the previous year. All the mechanical, flight and power consumption characteristics of the aircraft learned from the last year is used to optimize this year's vehicle. The SUAS competition involves various system requirements, such as UAV design, autonomous flight, image processing, computer networking and aerial photography. Therefore ITUNOM is a multidisciplinary team, involving 2 aerospace engineering students, 3 aeronautical engineering students, 2 electronics and communication engineering students, 2 computer engineering students and 1 control and automation engineering student.

ABSTRACT

After all the mission requirements and different design rationales are considered, a coaxial quadrocopter vehicle is selected. Various tests are performed to determine optimum speed and altitude profiles for maximum flight time. Aircraft is controlled by a DJI A2 autopilot system. An open-source Pixhawk autopilot with a modified Mission Planner software is used as a mission control computer. SRIC mission is performed by an onboard Raspberry Pi 2 Linux computer. Images captured by a Galaxy K Zoom Android phone are downloaded to the image processing computer via 5 GHz WiFi link and processed autonomously by the software developed with LabView. While the mission hardware and software are being developed, vigorous testing of all systems is performed concurrently. After effectivity and safety of the mission systems are evaluated by tests, modifications and improvements are done accordingly. Seamless integration of all mission systems are verified by multiple complete system tests flights where the complete competition environment is simulated.

1. System Engineering Approach

1.1. Mission Requirements

AUVSI student UAV competition missions are categorized as primary and secondary. Teams have to perform primary missions first to get points from the secondary missions. According to the missions, UAV must perform four main tasks:

- Flighting autonomously for:
  - Take off
  - Waypoint Navigation
  - Landing
- Searching area for:
  - ADLC
  - Emergent Target
  - Off-axis
- Communicating during flight for:
  - SRIC
  - Actionable Intelligence
  - Off-axis
  - Emergent target
- Releasing object for:
  - Airdrop

1.2.Design Rationale

The main design principles of ITUNOM are safety and stability of the aircraft when carrying the payload which is needed to perform missions. Firstly, payload is determined according to mission requirements. Aircraft designed to carry this payload with minimum power consumption and fly threshold weather conditions stably. According to these principles, several fundamental design requirements are determined:

- Aircraft is chosen as multicopter because of its hover capability, stable flight and smaller area requirement for testing.
- Coaxial quadcopter is selected. Since, coaxial quadcopter is lighter and more agile than octocopter and it is more stable and safe than standard quadcopter.

Payload is designed to be reliable and modular to keep mission systems simple to test and control. Because of the modular mission systems, problems which might occur in a particular mission system does not affect others.

- Air Drop mechanism and algorithm are improved to increase airdrop accuracy.

- ➢ Image processing algorithm is ported to LabView environment for faster development and improved error management.
- ➢ SRIC mission can be controlled via HTTP server from any computer that is connected to ITUNOM's WiFi network.
- ➢ Air Drop, Off Axis and Interoperability missions are implemented on the Mission Planner software to perform these missions directly using Pixhawk.

1.3. Expected Task Performance

ITUNOM team improved the last year's mission systems according to the renewed mission requirements and experiences from the previous competition. GPS of the autopilot system is designed for high accuracy to enable quadcopter fly autonomously at objective precision during missions. Airdrop mechanism and algorithm is optimized to increase accuracy. Camera is selected to easily detect targets from 160 feet. According to these improvements, following missions are going to be attempted:

Table 1: Mission table

	Threshold	**Objective**
Autonomous flight (takeoff, waypoints, grid search, landing)	√	√
Target recognition and localization	√	√
Autonomous classification and localization of targets	√	√
Actionable intelligence	√	√
Off-axis target imaging	√	√
Emergent targets	√	√
Simulated Remote Information Center	√	√
Interoperability	√	√
Sense detect avoid		

1.4. Risks and Mitigation Methods

Risk mitigation planning is the process of developing back-ups and reduce threats to project objectives. Risk mitigation implementation is the process of executing risk mitigation actions.

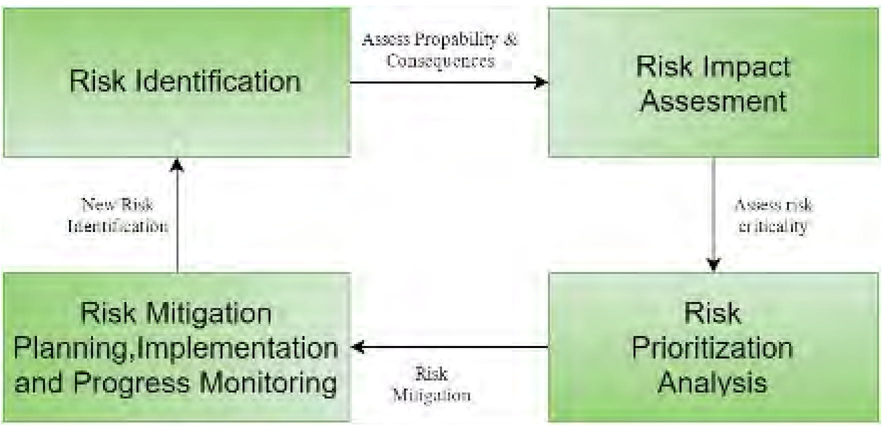


Figure 1. Mitigation diagram

Table 2: Prioritization process of risks with effects

Risks	Description	Effect Level	Probability	Mitigation
Inadequate Budget	Insufficient budget to buy new materials for testing and improving the system. Especially after the crash.	High (3)	Medium (2)	Highest endorsement possible is provided to ITUNOM by Istanbul Technical University. Several companies are contacted for sponsorship.
Crash during tests (Mechanical)	Structural failures of the vehicle chassis. Connection failures of parts. (Ex. loose bolts, failed adhesives)	High (3)	Low (1)	All component parts are checked before every test to ensure robustness.
Crash during tests (Electronics)	Failure of electrical and electronic subsystems due to loose connectors, overheating, ESD etc...	High (3)	Low (1)	All connectors are renewed and tested before the flight tests.
Lack of time management	Unscheduled project and not following the competition schedule. Delays and missing deadlines	High(3)	Low(1)	Team meets twice a week and team captain briefs the team about the competition schedule.
Lack of knowledge about rules (2016 rules)	Team can miss some important points about rules or rule changes.	Medium(2)	Low(1)	The new team members are studied the rules and prepared presentations.

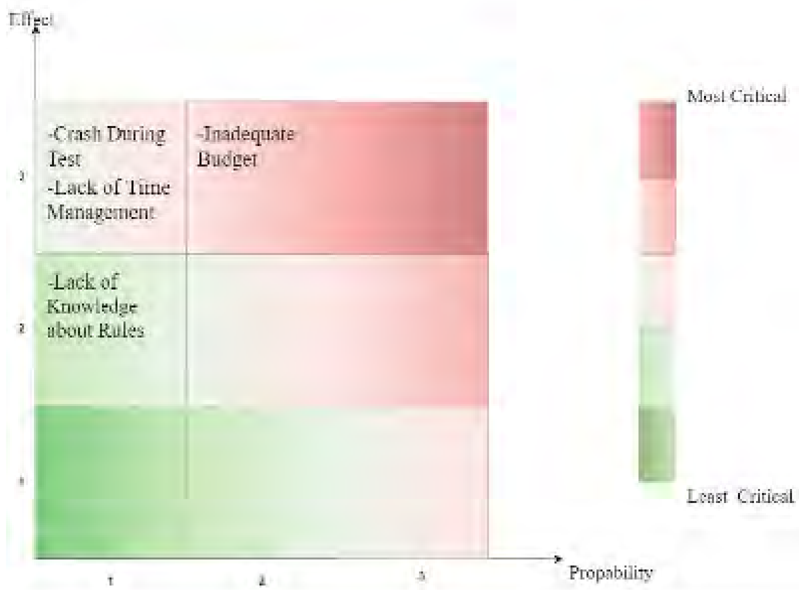


Figure 2. Effect and Probability graph

2.UAV DESIGN

2.1. Mechanical Design

2.1.1. Air Vehicle

According to the competition requirements, different types of vehicles were considered; fixed wing, helicopter and multicopter. As a result of detailed task analyses, multicopter was found to be most suitable for meeting these requirements. In the following table, properties and differences of the aircraft types are compared.

Figure 3. Air vehicle

Table 3: Comparison between different aircraft types

PROPERTIES	MULTICOPTER	FIXED WING	HELICOPTER
Performing quick and complex maneuvers	Best	Medium	Best
Navigating autonomously in structured and unstructured environments	Best	Worst	Best
Productivity and affordability	Best	Medium	Medium
Controllability	Best	Medium	Worst
Safety and stability	Best	Best	Best
Payload capacity	Best	Medium	Best
Producibility	Best	Worst	Worst
Flight speed	Best	Best	Medium
Flight time	Medium	Best	Medium
Testability	Best	Worst	Worst

Design parameters were created according to the tasks in the mission. Vehicle should have a capability of carrying different types of avionic equipment. In other words, vehicle is expected to work with extra weight, one of the most important design parameters. Different variations were tested according to lift capacity and flight time, which is the first step of the design process. As a result of tests, configuration with 8 rotor coaxial propeller multicopter design was decided to be used according to lift performance, efficiency of motors and stability.

Construction process is expressed step by step in the following section:

- **Frame**

It is determined that one of the most important elements of the design is choice of airframe. All of the other systems; flight instruments and payload rely on the airframe. Because of that, frame should be durable to endure heavy payloads.

Aerodynamic properties of the airframe was designed to decrease drag which is important for power

Figure 3. Sky Hero 850

consumption. Based on the requirements, composite materials which are commonly used in aviation are selected. Composite materials are very light and durable. Arms of multicopter are constructed from carbon fiber tube sections. Also X frame design is found suitable because it is strong, simple and its natural symmetry balances flight forces better.

Another important factor is vibration. Management of the excess vibration is very important for aerial imaging. The frame should have a capability of damping the vibration caused by the motors.

Sky Hero 850, the most suitable frame according to design parameters, was selected. One of the most important reasons for using a commercial frame instead of manufacturing one was limited time. Since SUAS is a system engineering competition, allocating a large portion of the limited time for integration of the mission systems provide more effective results. Also equipment available for manufacturing was not accurate enough to produce such a frame.

Table 4: Properties of the vehicle

LENGTH	2.3 ft
WIDTH	2.3 ft
HEIGHT	1.2 ft
GROSS WEIGHT	8.3 lb
TAKEOFF WEIGHT	14 lb

- **Propellers**

Propeller characteristics play an important role for the flight performance. In order to increase lift capacity and also decrease the response time of the motors, there is an optimum propeller diameter. As a result of comparison among many propellers, T-Motor 16x5.4 carbon fiber propellers were chosen.

Properties of T-Motor 16x5.4 carbon fiber propeller:

- Lightweight
- High-strength
- Prolonged hover time
- Less inertia
- Increased load capacity

- **Motors**

In order to maximize flight performance, different types of motors were compared according to their Kv, current draw, voltage, power, response time and temperature limits as seen in the table 5. Motors are used in coaxial configuration. Thrust per motor is calculated based on the weight of the multicopter. Motors that give the needed thrust at their 50 % rated performance are considered. Selection is also done according to whether the motor is suitable for the chosen propeller or not. Furthermore, current and voltage ratings are selected according to the battery properties. As a result, T Motor MN4012 400Kv was selected for optimized performance.

Table 5: Properties of the T Motor MN4012 400Kv

Model	Voltage (V)	Prop	Throttle	Current (A)	Power (W)	Thrust (g)	Efficiency (g/W)	Operating Temperature (°C)
MN4012 KV400	22.2	15x5	50 %	4.8	106.5	1010	9.48	54
			75 %	10.4	230.8	1730	7.49	
			100 %	16.2	359.6	2370	6.59	

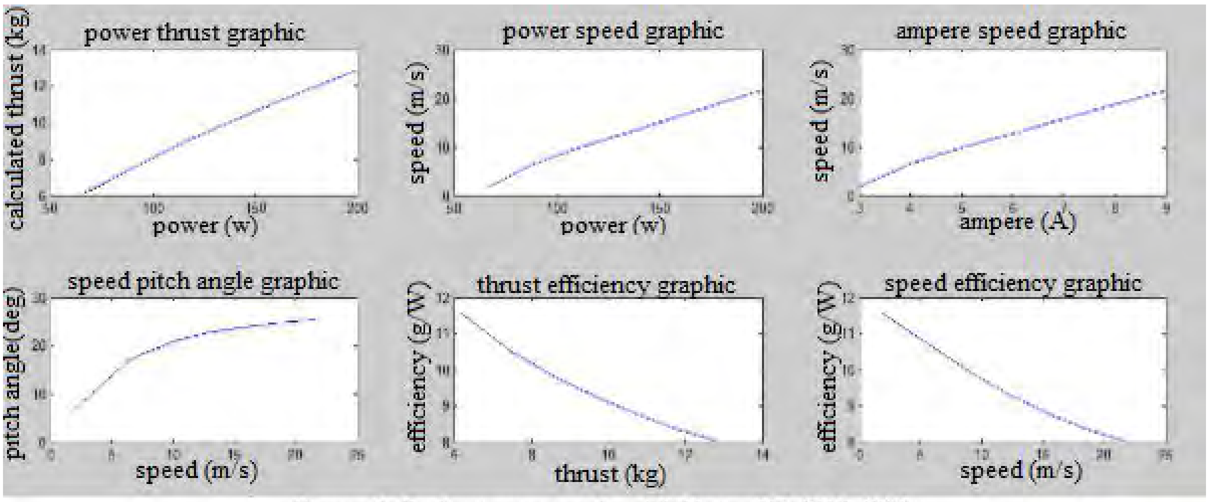


Figure 4. Performance graphs of T Motor MN4012 400Kv

According to the calculations, thrust needed during sustained flight (except takeoff and landing) is between 2.2 lb - 3.3 lb; thus, taking the tables into consideration, T Motor 4012 provides the best performance at this interval.

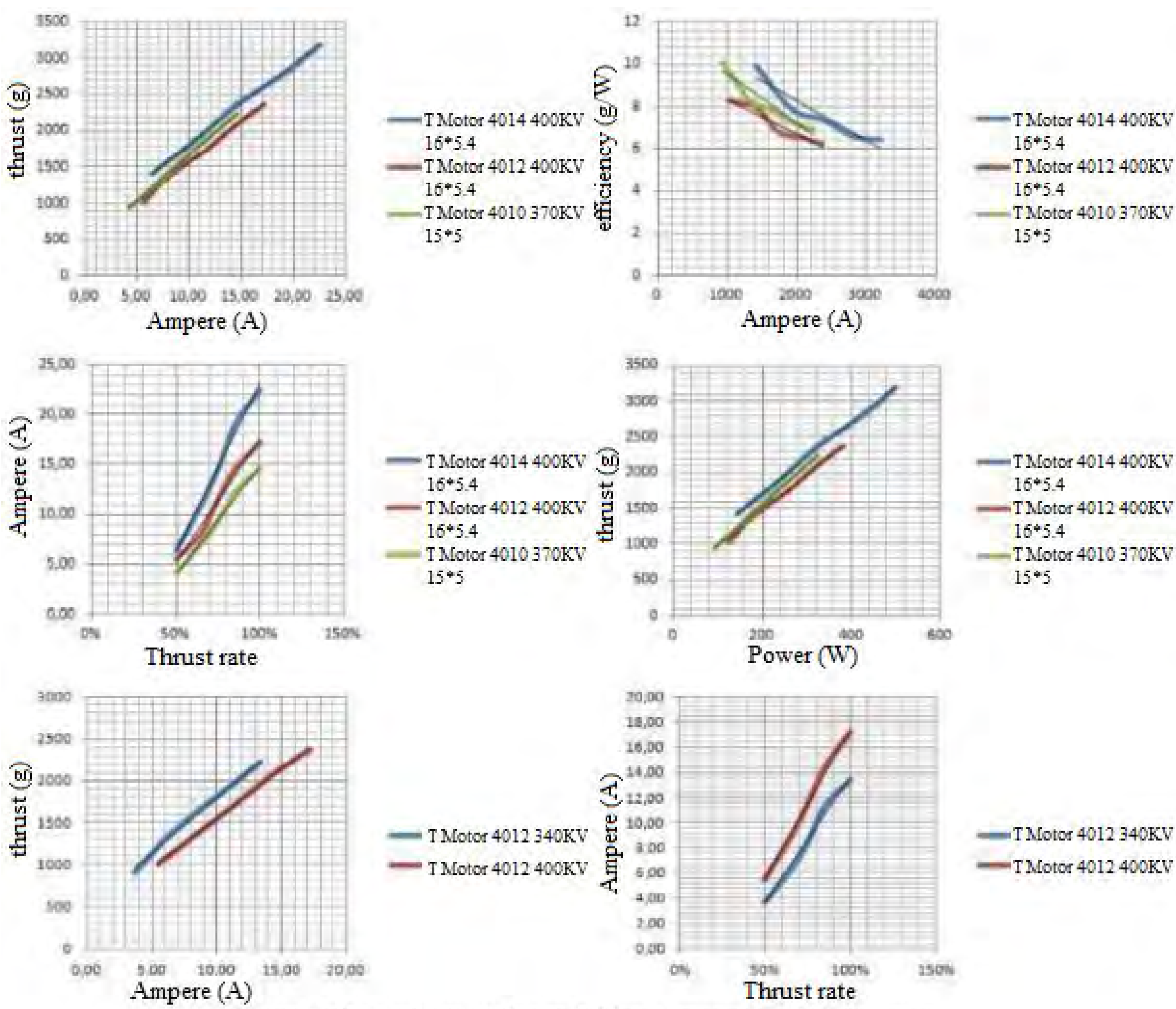


Figure 5: Comparison of chosen T Motor among the other T motors

2.1.2. Airdrop

Airdrop mission consists of main case and a moving hatch. Airdrop system is designed by Solidworks and produced by 3D printing.

Moving hatch attached to a metal gear servo to release the bottle. Airdrop case is located outside of vehicle so it is easily accessible. System is not only lightweight but also easily detachable from the vehicle.

Figure 6. Airdrop release mechanism

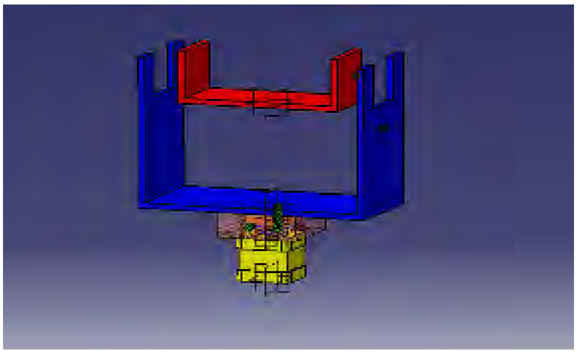


Figure 7. Antenna Tracker

2.1.3. Antenna Tracker

WiFi link uses a directional panel antenna at the ground station and an omnidirectional antenna on the vehicle. Since the directional antenna has a narrow beam angle, it must be always pointed to the vehicle.
In order to perform tracking, an effective "antenna tracker system" was designed. Systems takes GPS coordinates of air vehicle and also its base. By calculating difference of these two coordinates, system determines antenna heading and elevation.

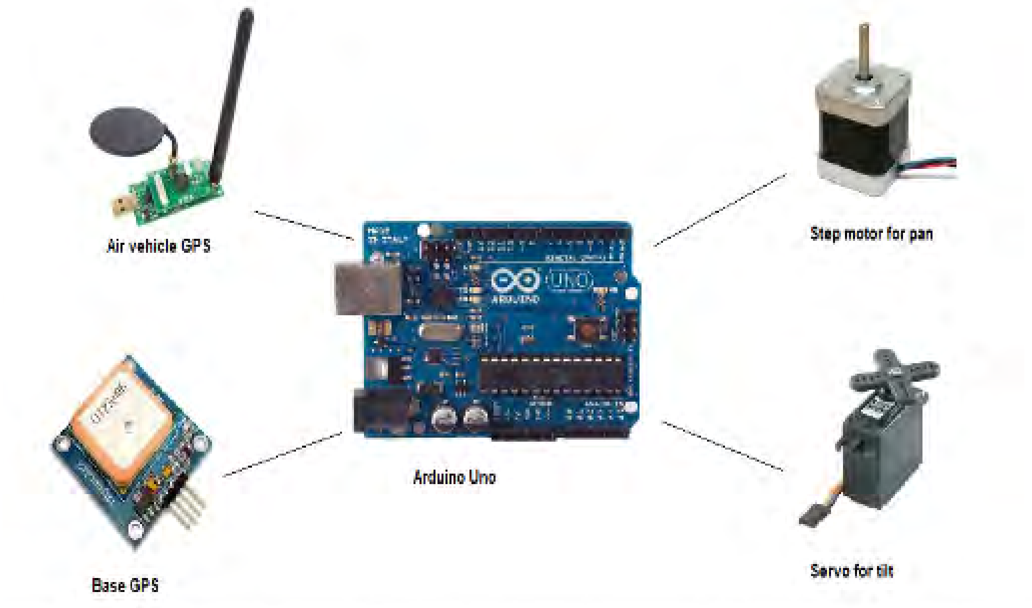


Figure 8. Electronic design of Antenna Tracker

2.1.4. Gimbal

Vehicle needs to dampen vibrations for clear images. 2-Axis servo gimbal is selected for rough damping. Gimbal includes 2 micro servos, carbon fiber plates and a camera gimbal adapter that is produced by 3D printing.

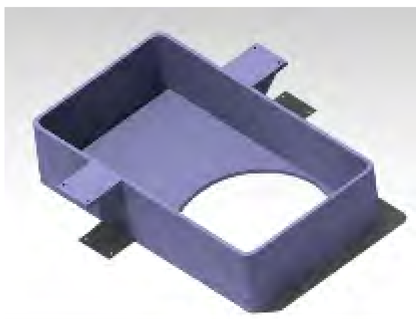


Figure 9. Camera gimbal adapter

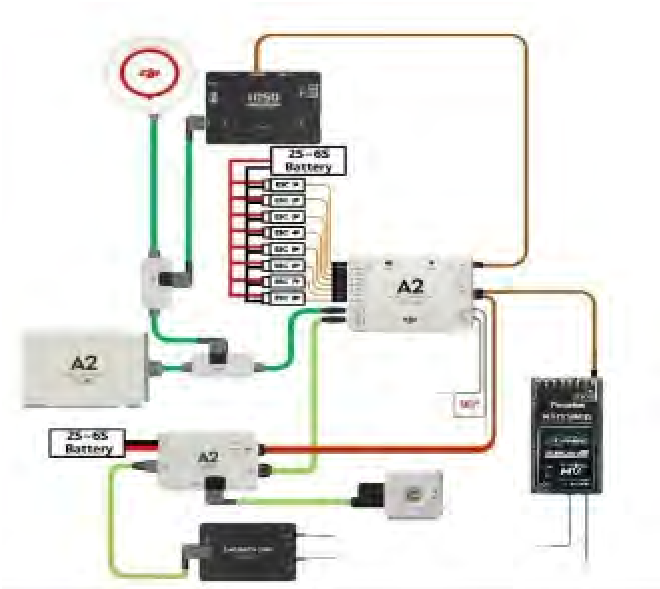


Figure 10. Autopilot System

2.2. Autopilot System Design

DJI A2 is used as autopilot. It is one of the most appropriate autopilots due to having high control and multiple servo outputs for 8 rotors coaxial multicopter.

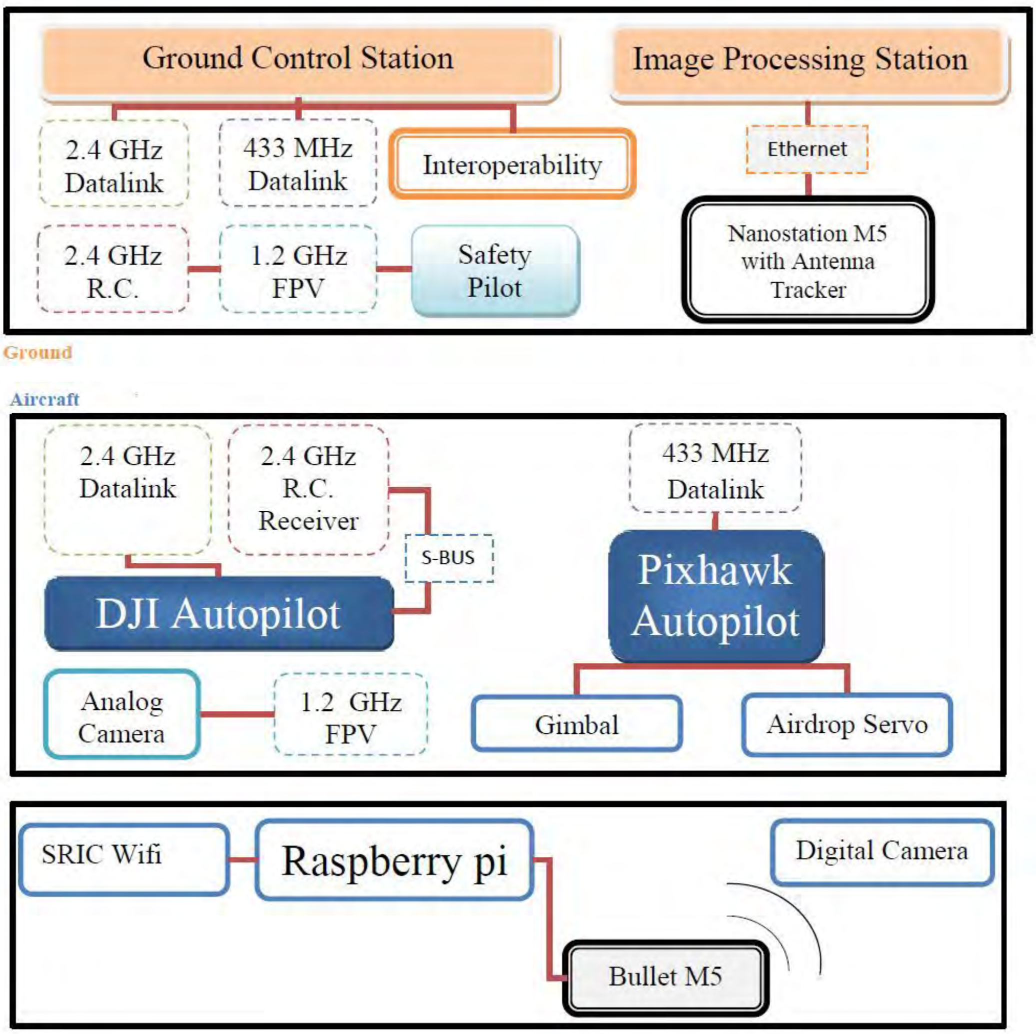
The main duty of the DJI A2 is controlling the UAV and communicating between ground station and air vehicle. Since DJI A2 is reliable and has more accurate GPS than other autopilots, it is chosen for this duty.

2.2.1. GPS Accuracy

The unmanned systems' most common problem is localization. Without using any algorithm or sensor fusion, GPS gives unacceptable data for UAS. As a result, GPS system of the UAS must be very accurate. Because of optimized localization algorithms, DJI A2 gives very accurate location data. System guarantees ± 1.5 feet vertical error and ± 4.5 feet horizontal error for favorable weather conditions.

2.3. Payload System Design

Block diagram 1: Full system scheme



2.3.1. Mission Computer

As a result of comparisons, Raspberry Pi 2 is chosen as a Mission Computer because of its small dimensions, low power consumption and powerful hardware. Raspberry Pi 2 has a 900 MHz Quad-core CPU and 1GB RAM. These properties are more suitable for the missions than those of the Raspberry Pi B+. Turning to power consumption, the Raspberry Pi 2 consumes 1.5 Watts which is quite reasonable for the planned flight duration. Also its dimensions allows the easy placing of the Raspberry Pi 2 on the air vehicle.

Table 6: Comparison of mini computer system

	Raspberry Pi 2	**UDOO Quad**	**Raspberry Pi B+**
Dimensions	85 x 56 x 17 mm	110 x 85 mm	85 x 56 x 17 mm
Processor	900 MHz Quad Core ARM Cortex A7	1 GHz Quad Core ARM Cortex A9	700 MHz ARM CPU
RAM	1 GB DDR2 RAM	1 GB DDR3 RAM	512 MB SDRAM
Power Consumption	1.5 Watts	3.65 Watts	1 Watt

2.3.2. Digital Camera

Table 7: Comparison of candidate digital camera systems

	Samsung Galaxy K Zoom	**Sony DSC-QX10**
Dimensions (W x H x D)	137.5 x 70.8 x 16.6 mm	62.5 x 61.7 x 61.7 mm
Weight	200 g	105 g
Resolution	20.7 Megapixels	18.2 Megapixels
Battery Life	Good	Medium
Image Quality	Good	Good
Optical Image Stabilization	Available	Available
PASM Modes	Available	Available
Aperture	f/3.1 (W) – f/6.9 (T)	f/3.3 (W) – 5.9 (T)
Shutter Speed	1/2000 s	1/1600 s
Remote Control (via WiFi)	Available (via custom Android application)	Available (via Sony Camera Remote API)
Picture Transfer (via WiFi)	Available	Available
Onboard GPS Receiver	Available	No

Quality of input images are very important to obtain good results from image processing algorithm. High resolution, blur-free images are crucial to differentiate shapes and letters from background. Noise and blur significantly decreases detection rate and also increases false detection rate. Acquiring images with adequate quality employs significant challenge for lightweight digital cameras. Since the camera operates on a fast moving platform, fast shutter speed is necessary to capture sharp images. Also image stabilization is an important factor, because vibrations caused by engines and aerodynamic forces are directly transferred to camera mount. Elastic feet and 2-axis servo gimbal is used to decouple some of the vibration from the camera but majority of the flight vibration is eliminated by the integrated optical image stabilization system. Both candidate cameras have integrated sensor-shift optical image stabilization systems. Samsung Galaxy K Zoom is selected thanks to its significantly better battery life and more customizable Android operating system.

2.3.3. Analog Camera and FPV Link

First Person View (FPV) system is necessary for safety and surveillance. Selection of the FPV camera is based on its weight and size because of the limited payload capacity. Cameras with CMOS sensors are more lighter and smaller than others.

Figure 10. FPV camera

2.3.4. WiFi Communication

Mission Control Station, Mission Computer and Android Camera are connected to each other with WiFi connection to enable image and data transfer between them.

- **UAV WiFi Module and Antenna**

Comparing various devices, Ubiquiti Bullet M5 is selected for building an access point on the vehicle.

Table 8: Comparison of wifi modules on the UAV

	Ubiquiti Bullet M5	Ubiquiti Rocket M5	Groove 5SHPn	Ubiquiti PicoStation M2-HP
Dimensions	152 x 31 x 37 mm	110 x 85 mm	177 x 44 x 44 mm	130 x 20 x 30 mm
Weight	180 g	250 g	193 g	100 g
Working Frequency	5 GHz	5 Ghz	5 GHz	2.4 GHz
Power Consumption	4 Watts	8.5 Watts	11.5 Watts	8 Watts
Power Output	600 mW	500 mW	1300 mW	1000 mW

As can be seen in the table above, Ubiquiti Bullet M5 is lighter and smaller which brings mobility. Also efficiency factor is important when selecting WiFi module for the aircraft because of limited onboard power. Efficiency factor is defined as:

$$Efficiency\ Factor\ = \frac{RF\ power\ output}{power\ consumption}$$

RF power output and power consumption figures are collected from each modules datasheet. Bullet M5 has efficiency factor of **0.15** which is the lowest value, means that Bullet M5 is the most efficient. Cloverleaf antenna is suitable for Bullet M5 because it is an omnidirectional antenna.

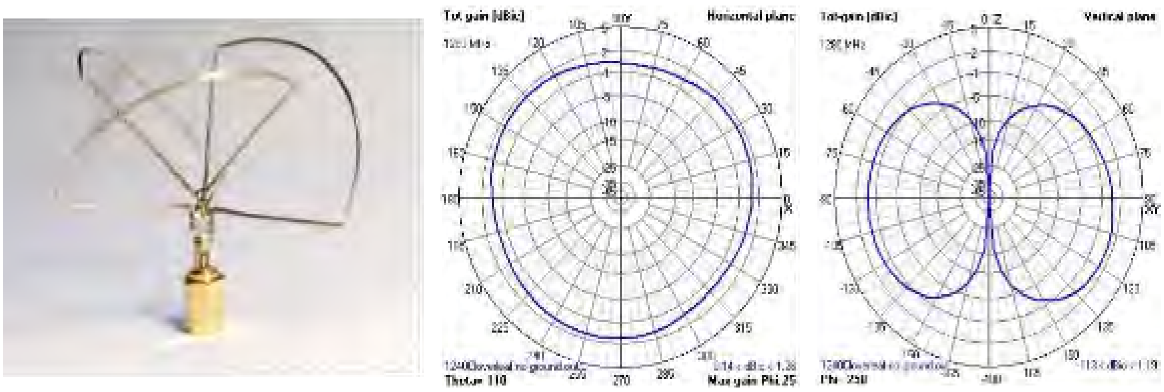


Figure 11. Cloverleaf antenna and its radiation pattern

As can be seen in the radiation pattern, the antenna has beam angle of 360° horizontal and ≥95° vertical with right-handed circular polarization.This means when the antenna is perpendicular from the ground, it radiates in the horizontal axis most strongly. Also its working frequency is 5.8 GHz which is proper value for the Bullet M5. In accordance with these informations it is decided to place antenna with 45° degrees from vertical axis on the UAV considering the mobility of the vehicle. In addition, LMR 240 low loss antenna cable is used for connection between wifi module and clover leaf antenna for minimum cable loss.

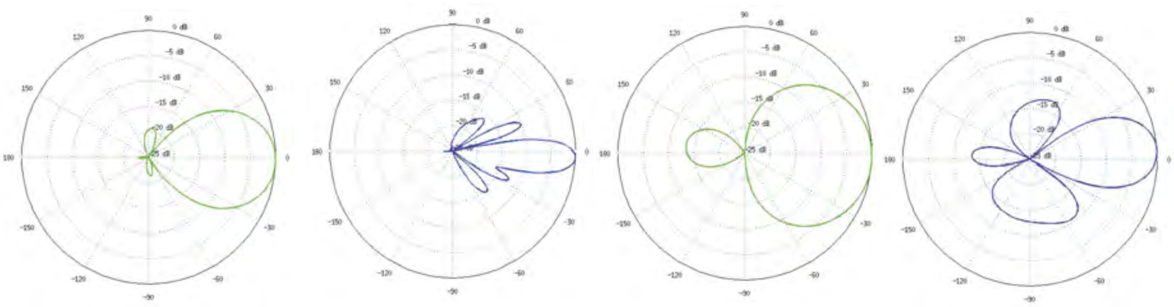
- **GCS Wifi Module and Antenna**

Ubiquiti Nanostation M5 is chosen for ground WiFi and antenna system. M5 is going to connect to the access point on the UAV.

Table 8: Comparison of wifi modules on ground station

	Ubiquiti Nanostation M5	**UBNT Ubiquiti AirMax AM-5G17-90**	**Ubiquiti NanoBeam M5-400**	**Ubiquiti AM-V5G-TI 60-120 Sector Antenna**
Dimensions	264x80x30 mm	367x63x41 mm	420 x 420 x 275 mm	721x149x75 mm
Weight	400 g	1100 g	1753 g	3720 g
Working Frequency	5 GHz	5 Ghz	5 GHz	5 GHz
Antenna Gain	14- 16 dBi	16 - 17 dBi	25 dBi	20 dBi

As can be seen in the table above, It has suitable dimensions for the antenna tracker system and suitable gain for long range communication. Also considering that the antenna is going to be carried from Turkey to USA, dimension is an important factor. Ubiquiti Nanostation M5 has its own antenna with WiFi module. Its antenna has dual linear polarization.



Vertical Azimuth Vertical Elevation Horizontal Azimuth Vertical Elevation

Figure 12. Dual linear antenna and its radiation pattern

As can be seen in the radiation pattern, the antenna has beam angle of 43° (H-pol) / 41° (V-pol) / 15° (Elevation). Antenna tracker has been designed according to these information.

2.3.5. Pixhawk Datalink

Pixhawk data link is second telemetry data link of ITUNOM's UAS. It is crucial since it is the data link which telemetry data of Interoperability mission come and off axis, airdrop missions controlled.

2.3.6. DJI Datalink

DJI 2.4 GHz Datalink is used to communicate with DJI A2 Autopilot from the ground station. Telemetry data is downlinked and navigational data is uploaded using a proprietary protocol. Ground transceiver is connected via USB to ground station computer. Vehicle side transceiver is connected to the DJI Autopilot system via CAN bus.

2.4. GCS System Design

2.4.1. Ground Station Interface

DJI Ground Station Interface has many advantages for creating waypoints and editing them. The waypoints can be saved and loaded any time. Ground Station shows the distance between waypoints and that helps to create a flight zone and scan the search area. The waypoint properties including positions, altitudes and velocities can be changed during flight. This makes emergent target mission and dealing any emergency situation easier. Interface also shows vehicle’s instantaneous speed, altitude, battery voltage and the distance from the home point. The vehicle can be recalled with *Go Home* button in any case.

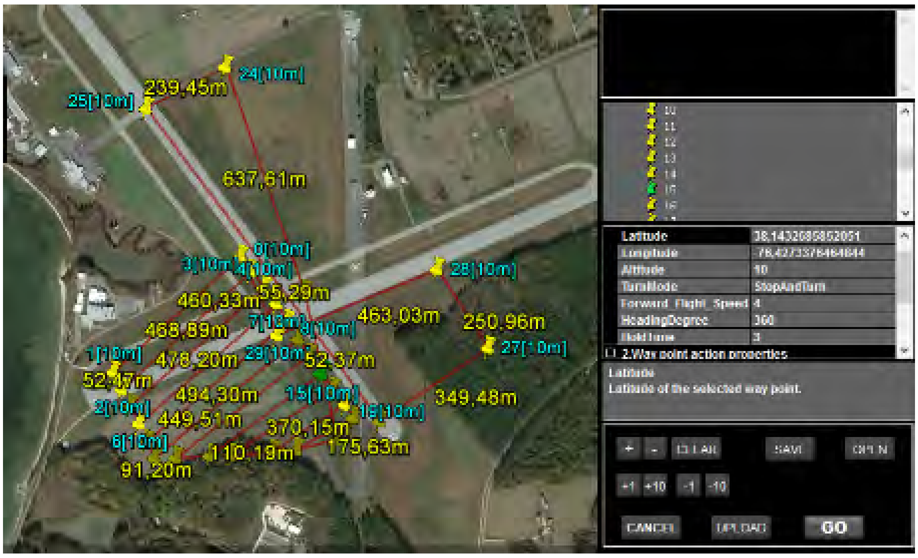


Figure 13. Ground station interface

2.4.2. Mission Planner

Mission Planner is an official open source Ground Control software for Pixhawk. Mission Planner program is customized according to mission requirements of SUAS Competition. Air Drop, Off Axis Target and Interoperability Missions are operated from this interface. Mission Planner is also used as the data collecting and logging center. All mission telemetry and battery data are collected in this GUI and logged for analyzing later. Obstacle data from Interoperability server are visualized by this interface with UAS position, other mission positions, search and flight areas.

Figure 14. Customized mission planner interface

2.4.3. Image Processing Interface

To accomplish search area tasks, image processing system is developed in LabVIEW environment that provides an easy-to-use interface. There are two interface, one of them is used for manual detection and other one is used for automatic detection.

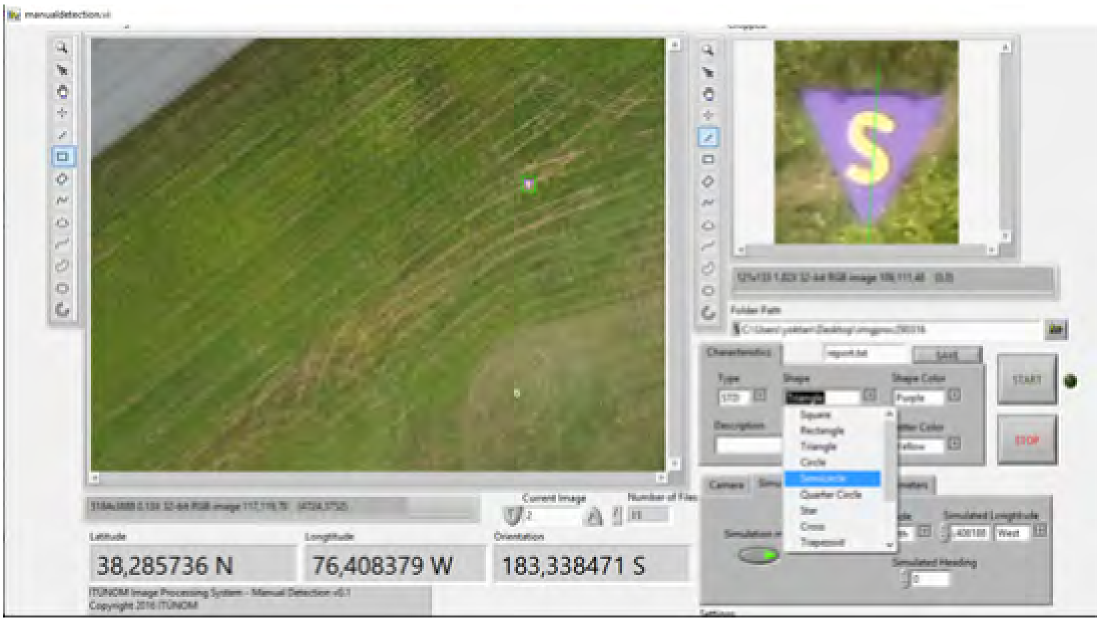


Figure 15. Manual detection interface

As shown in Figure 15, manual detection interface has two image boxes. Larger image box displays raw captured image and adjacent toolbox can be used to zoom and manipulate the image. If a target is detected by the operator, he/she encloses the target with ROI rectangle tool. Selected ROI is cropped and shown by the application on a smaller image box. After that, a line is drawn to mark letters orientation. Geolocation and orientation of the target is automatically calculated using the ROI and the marking line. Other characteristics of the target are manually entered. Save button is used to add target information to report file and to save cropped target image.

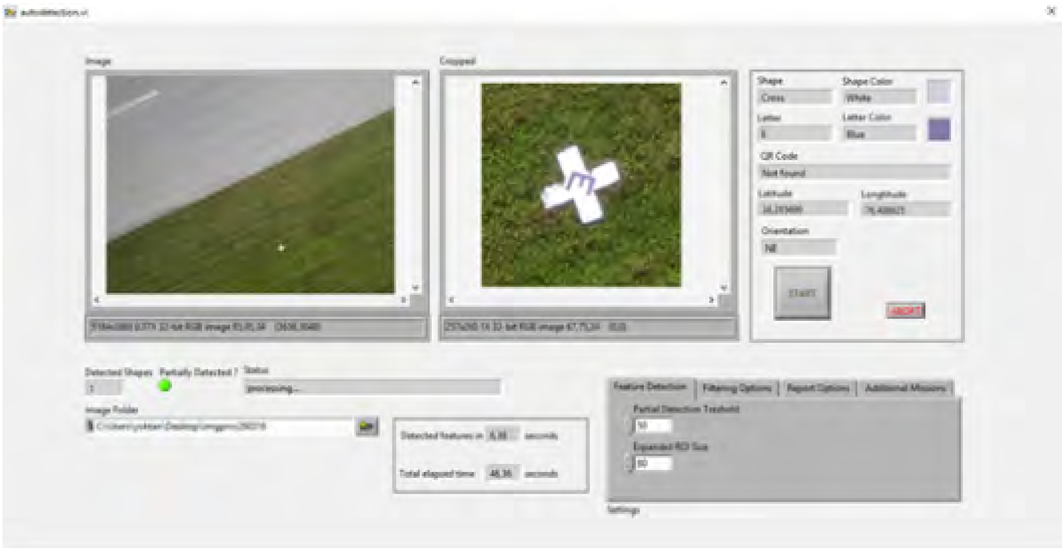


Figure 16. Automatic detection interface

As shown in Figure 16, autonomous target detection interface has two image boxes. First image box displays raw captured image. If a target is detected autonomously, ROI of the target is cropped and shown by the application on second image box. Characteristics of target are detected autonomously by the image processing algorithm. After that, target information is added to report file and found target image is saved. Characteristics of the found target, timing information and status are displayed. Also a settings block that provides various adjustments about image processing algorithm is present on the front panel.

2.4.4. SRIC Interface

To perform SRIC task, an HTTP server is built to start and finish mission from ground station. The interface is designed as an HTML page that controls downloading and uploading.

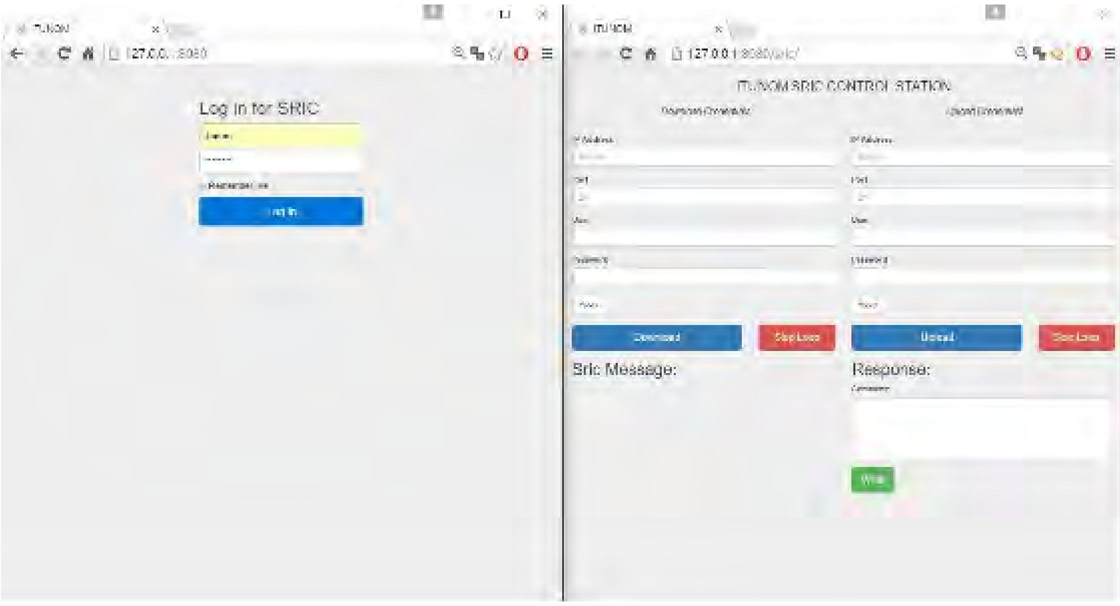


Figure 17. SRIC task interface

2.5. Mission Planning

2.5.1. Waypoint Sequence

The waypoint followed in a significant part of the searching area.While tracking waypoint sequences, some criteria are considered. Waypoint sequence affects flight time and imaged area. Considering the area can be captured by the camera during flight, waypoints are determined in a way to have no unviewed area in shortest flight time. There is an example sequence as shown in figure 18.

Figure 18. Waypoint sequence

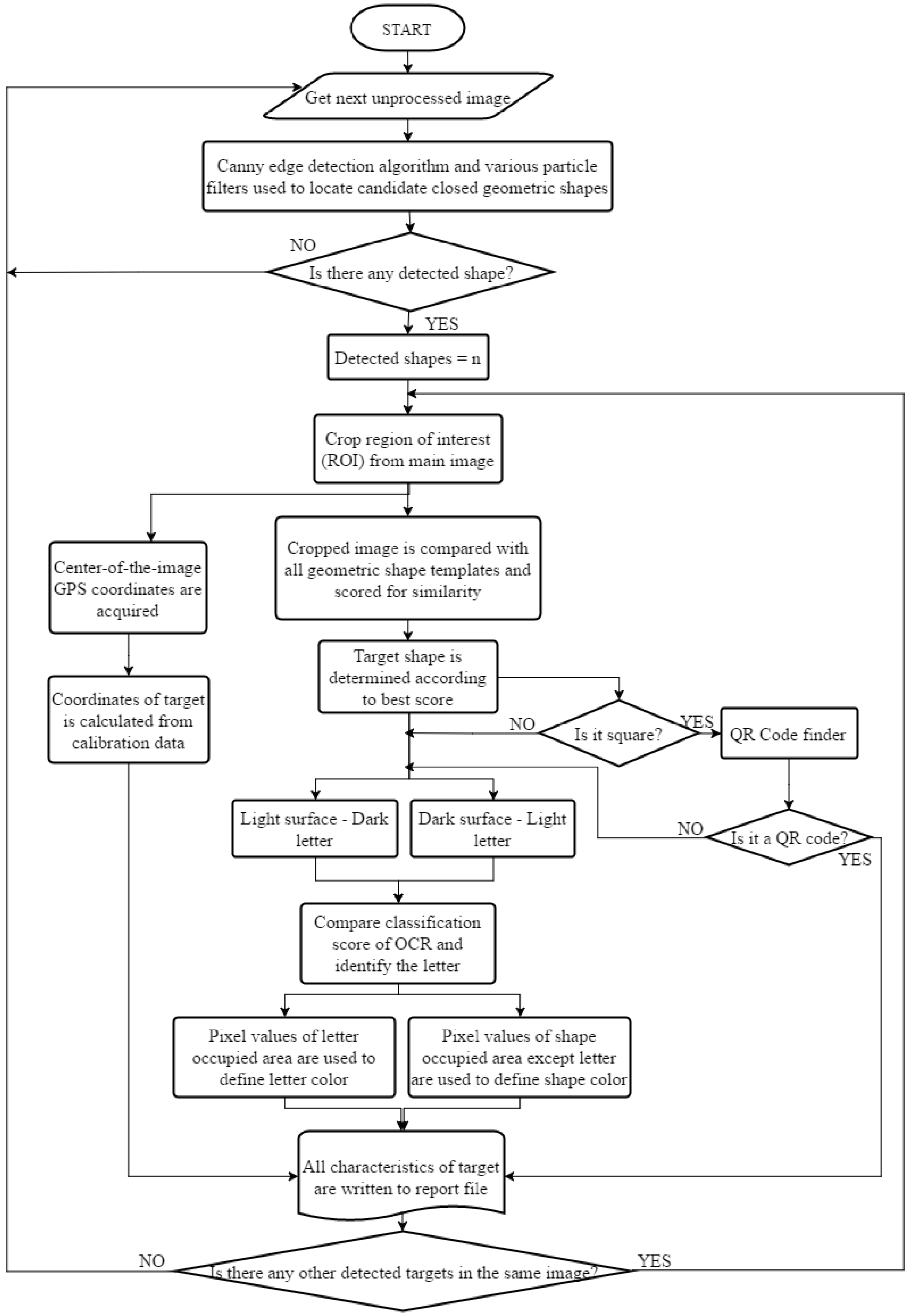
2.5.2. Search Area Task

Image processing software is developed with National Instruments LabVIEW 2015 environment using NI Vision Development Module. Captured images are transferred real-time to image processing PC via Wi-Fi link using WebDAV protocol. GPS NMEA sentence that is matching in time with the corresponding image is also downloaded and saved to image processing PC. Latitude, longitude and heading are extracted from the NMEA sentence and used for geolocation calculation of the related image.

WebDAV file transfer tool is also developed on LabVIEW and runs separately from the main image processing software. File download can be paused anytime and selected intervals may not be downloaded.

Image processing algorithm used in real-time automatic target detection is available on block diagram 2. A tool that helps human operator to locate targets by eye is also developed. Captured images is shown to the operator via this tool and targets are manually selected by operator. Selected targets' coordinates are automatically calculated using the geolocation data and target properties are manually entered by the operator.

Block Diagram 2: Image processing algorithm



2.5.3. SRIC

In order to perform SRIC task, an HTTP server has been run in Raspberry Pi computer. The server is reachable from a browser page which is designed to control mission process. A Python script runs with the server and performs downloading, displaying and uploading text file. When the air vehicle enters the area, Raspberry Pi tries to connect repeatedly until connection is successful. After it connects the WiFi network, the script downloads the text located at the given path and display it on the browser page automatically. Text file is generated from browser page according to text file that is downloaded. Finally generated text file is uploaded to the SRIC server by Python script automatically.

2.5.4. Airdrop

Airdrop is operated using mission planner interface by Pixhawk. When Airdrop script is activated, customized Mission Planner starts to calculate distance between UAS position and Airdrop position. Distance which airdrop bottle must be released also calculated using UAS speed, altitude and system delay for release time.

2.5.5. Off Axis

Off Axis mission is operated from Mission Planner interface. Mission planner interface shows the position of the mission locations and UAS. Mission Planner is also customized to control camera gimbal of UAS from ground station using a USB joystick.

2.5.6. Interoperability

Interoperability is operated from Mission Planner interface. Telemetry data is downloaded from UAS via Pixhawk datalink. Incoming data is uploaded to competition server using “Cookie Web Client” class which is developed using .NET. Mission Planner is customized to automatically upload UAS telemetry data and download obstacles and server information data to Mission Planner. Obstacles are visualized at Mission Planner in real time using GMAP API. Server info data are parsed and visualized by labels in Mission Planner.

3. Test and Evaluating Results

3.1. Flight Test

As a result of flight tests, Sky Hero 850 with DJI A2’s wind resistance may up to 16 KIAS (8 m/s). UAV’s forward velocity limit is limited by ground station at 40 KIAS(20 m/s). Also UAV’s descent speed is limited by Ground station at 10 KIAS (5 m/s). DJI A2’s GPS guarantees maximum 1.5 feet vertical error, thus autonomous takeoffs and landings can be performed precisely. Also DJI guarantees maximum 4.5 feet horizontal error, so UAV can arrive determined position accurately.

3.2. Current, Battery Life and Flight Time Test

In competition, it is planned to use 12000mAh Li-Po battery. Experimental current test graphs are below;

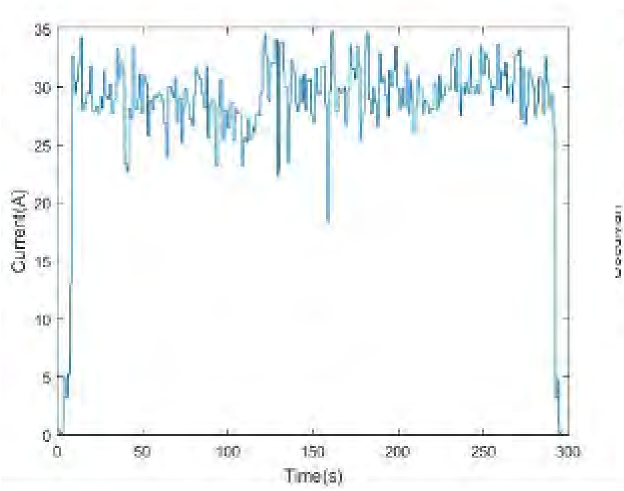


Figure 19. Current - Time Graph

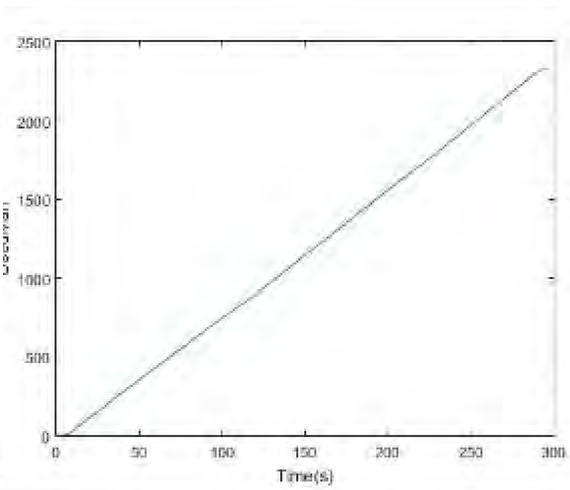


Figure 20. Used mAh - Time Graph

According to data in figure 20, with a 12000mAh Li-Po battery, maximum 25 minutes flight can be performed. For 30 minutes in competition, two 12000mAh batteries will be used for two 13-15 minutes flights.

3.3. Air Drop System Test

According to final rules water bottle must fall in 30 feet radius to achieving objective. The first results of flight test was only good enough to achieve threshold. Main distance from the target was 83 feet. Releasing mechanism and algorithm delay were the main problem for achieving the objective. After improving the release mechanism and algorithm, average test results were 23 feet off.

3.4. Off-Axis System Test

To achieving the off-axis mission, it is decided to using gimbal system. There were two problems for this mission those were gimbal stabilization and distance from the no flight zone line. After adjustments for altitude and gimbal, target can be found accurately.

3.5. Search Area Task Tests

Search area task was tested during test flights. As shown in figure 21, several targets that has different shapes, alphanumeric and color, was manufactured in order to simulate search area task. In order to determine optimum parameters, different test flights performed at various altitudes and lighting conditions such as, sunny weather, overcast and dusk. Several QR targets are also tested to demonstrate QR target mission.

Figure 21. Targets samples from test flights

Test results are shown in table 9, including rate of success. Algorithm was developed based on previous competition photos. Thus, success rate is greater when using this image set.

Table 9: Image processing success rates from test flights

		Success Rate						
Altitude	**Detection Rate**	**Shape**	**Target Color**	**Letter**	**Letter Color**	**Orientation**	**Geolocation (CEP)**	**Comments**
45 m	50%	50%	60%	0%	10%	-	-	Focus is not proper.
45 m	60%	70%	70%	10%	15%	-	-	Sunset light affect success rate adversely.
45 m	80%	60%	80%	30%	30%	-	30 m	
55 m	70%	50%	60%	10%	10%	-	30 m	Height is not proper.
45 m	80%	60%	70%	40%	40%	80%	15 m	
45 m	100%	80%	80%	100%	80%	-	-	Previous competition photos are used.

4. Safety Considerations

4.1. Design Safety Considerations

One of the most important concept that must be taken into consideration for UAV designing and operations is safety of the system. This concept can be handled for different subsystems; mechanical, avionics, communication.

In the design section; foreseeable risks are identified according to the working environment and missions that will be performed by the UAV and then risk mitigation measures were planned. Design is based on a main safety criteria; UAV must be operable in any emergency condition.

Table 10: Risks and Mitigations (*3:High *2:Medium *1:Low indicates risk levels)

Foreseeable Risks In Design Section	Risk Mitigation Solution	Risk Level
Motor Failure	System is capable of being operated up to 4 engines.	2
Mechanical Deformation as a Result of Crashing	Composite material is used according to its high toughness and deformation mechanism.	3
Fire	The places where power distribution ports and body in contact covered by fire resistant material.	1
Separation in Joints According to Mechanical Vibrations	Damping materials were used in junctions.	1
Foreign Object Damage	Motor covers were used in order to avoid FOD.	1

4.2 Flight Safety

The first precaution before a flight test is finding a proper and safe area. In this area, GPS signals, air navigation, distance to military bases and airports, weather conditions, topography and human activity are the most important points to consider for safety.

All flight tests are performed in Istanbul Technical University where is close to our workshop. Before flight, safety pilot has to check connection and location of payloads and parts of vehicle using a checklist. To increase the visibility of the vehicle, luminous materials are used. During flight, any loses of datalink signal are overcome with turning back to it’s home point by the system’s failsafe protection.

Failure	Alert	Action	If recovered	If not recovered
DJI Datalink Loss	Warning on DJI GCS	Switch to Atti Mode	Continue Mission	Fly to HP (Home Point) and Land
Pixhawk Datalink Loss	Warning on Mission Planner	Switch to Atti Mode	Continue Mission	Fly to HP and Land
RC Link Loss	Warning on DJI GCS	Trying to connect	Continue Mission	Fly to HP and Land
Low Battery	Warning on DJI GCS	Emergency Landing	-	-
Entering no-fly zone	Warning on Mission Planner	Engage geo-fence	Continue Mission	Fly to HP and Land
DJI Ground Station Crash	No screen output	Switch to Atti Mode	Continue Mission	Fly to HP and Land

Pixhawk Ground Station Crash	No screen output	Switch to Atti Mode	Continue Mission	Fly to HP and Land
Collision	-	Emergency Landing	-	-

5. Conclusion

ITUNOM Unmanned Air Vehicles Team has revised its strategy according to experiences gained in 2015 AUVSI SUAS. Mission systems were improved, more effective methods were developed. Unlike last year; risks, mitigations and mission tests were given more importance. It made system more safe and also gave a predictable success rate. All of the mission systems have been tested and they are continuing to be developed. ITUNOM Unmanned Air Vehicles team is ready for AUVSI SUAS 2016 and wish to have a good competition for all participants.

6. Cyber Security

UAVs are being used for critical operations, including offensive, reconnaissance, surveillance and other civilian missions. That is why they must have invulnerable security systems. Being prepared against the cyber attacks is significant part of UAV missions.

There are possibly three components of UAV Systems which are vulnerable to attack;

- UAV
- Ground Control Station
- Communication Link

UAV: There might be cyber attack via embedded trojan horses.
Ground Control Station: Mostly software based attacks might be attempted.
Communication Link: Third-party locations which uses the same communication link might access the UAV's electronic systems via hacking, eavesdropping etc.
These Cyber attacks which are described above are used for modification of existing information or fabrication of new information. Modified or fabricated information might be used for taking control the UAV or getting intelligence.

6.1. Precautions

- **Software Solutions**

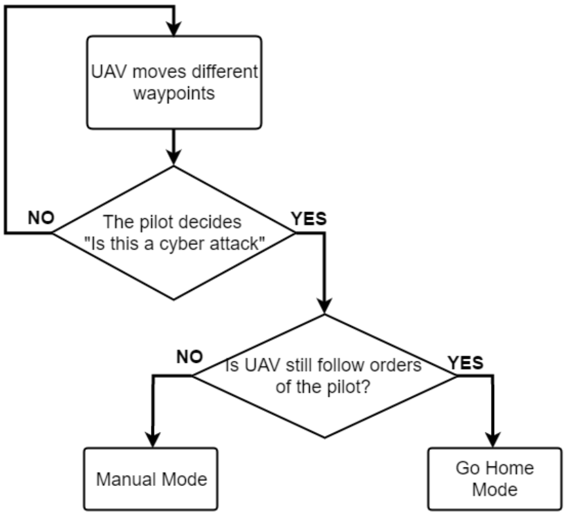
In order to defend from cyber attacks WiFi communication between ground station and UAV is encrypted using WPA2-AES protocol which is the most secure option. An access credential is required to reach network. In addition a login page is designed to SRIC task which prevents to access to unknown user's attempts.

- **"The System Aware" Solutions**

Another precaution is "The System Aware" solutions. According to Horowitz (2016), "The System-Aware nomenclature is based on the fact that this class of solutions depends on detailed knowledge of the design of the system being protected."(p. 40) The system can realize that it is under cyber attack by two ways. One of them is a software that monitors illogical behaviors reports inconsistency and perform the cyber attack protocol. Other way is manual detection of inconsistencies. These inconsistencies can be categorized as likely cyber attacks. The pilot decides that system is under attack. Then Cyber attack protocol is started.

ITUNOM team has not developed a software that monitors cyber attacks because of limited time. However developing a software for cyber attacks has been planning for next year. Instead of software solution, ITUNOM team has developed cyber attack protocol which is for manual detection of cyber attacks.

ITUNOM Cyber Attack Protocol



References:

Horowitz, B.M. (2016, April). Cybersecurity for Unmanned Aerial Vehicle Missions. *Signal,* 70(8), 40.