ISTANBUL TECHNICAL UNIVERSITY ITUNOM UAV TEAM

AUVSI SUAS 2018

Technical Design Paper

Figure 1 - Lodos

Abstract

The technical design paper provides information about how Istanbul Technical University Unmanned Aerial Vehicle Team (ITUNOM UAV Team) got prepared for AUVSI SUAS 2018 competition. ITUNOM UAV Team has designed a rotary wing vehicle, which is self-manufactured totally. Design of the hexacopter, named *Lodos*, is explained broadly in the paper. That is followed by the description of manufacturing, the test evaluating and analysis processes. *Lodos* is capable of flying autonomously, carrying the payload, capturing the image and processing it, communicating with ground station safely. Cyber security and safety of the system is another crucial factor, while there is a large amount of data sent during communication. The Team consists of 11 undergraduate students from the fields of Computer Engineering, Control & Automation Engineering, Aeronautical Engineering, Electronics & Communication Engineering. *Lodos* is produced by these students in coordination.

CONTENTS

1. Systems Engineering Approach

This year, a person in need and a fire that needs to be extinguished are simulated in the mission demonstration. The vehicle, *Lodos,* was designed to achieve autonomous flight, obstacle avoidance, object detection, and air delivery.

1.1 Mission Requirement Analysis

The system design is based on having stable and long durance flight to complete missions which are autonomous flight, obstacle avoidance, object detection, classification, localization, and air delivery. *Table 1* describes mission description and requirements.

Task	Description	Mission Objectives
Timeline (10%)	• Complete the flight and post-processing missions in 45 minutes (80%) • Avoid from timeout (20%)	• Accomplish tasks as soon as possible
Autonomous Flight (30%)	• Minimal takeover into the manual flight (40%) • Follow the waypoint sequence (10%) • Making arrival radius as 100 ft (%50)	• Follow the waypoint sequence as close as possible. • Score will be graded as max (0, (100 ft − distance) / 100 ft)
Obstacle Avoidance (20%)	• Avoid stationary obstacles(50%) • Avoid moving obstacles(50%)	• The algorithm to escape from obstacles. • Design a UAV that can act agile enough.
Object Detection, Classification, Localization (20%)	•Detect standard object's characteristics: shape, shape color, alphanumeric, alphanumeric color, and alphanumeric orientation(20%) • Determine the objects' location at least 150 ft radius (30%) • Send the object information that obtained in first flight (via USB) (30%) • Detect objects autonomously (20%)	• Adequate imaging system to detect and analyze objects • Adequate image processing system to obtain objects characteristics • Adequate communication system between autopilot and image processing computer to achieve localization • Objects' location will be graded for max(0, (150ft − distance) / 150ft)
Air Delivery (10%)	• Disperse the bottle on air delivery location	• Adequate autopilot system to achieve precise GPS location • Score will be graded as max(0, (150ft − distance) / 150ft)
Operational Excellence (10%)	• That will be graded according to team's professionalism	• Well practiced and prepared team and healthy communication

Table 1 - Mission Requirement Analysis

The competition analysis shows that system should be based on stable and durable flight. In order to achieve autonomous flight mission completely, the system must be capable of flying autonomously including takeoff, landing and high rate of capturing waypoint thanks to qualified autopilot and GPS system. According to experiences that gained from previous years, ITUNOM UAV Team and *Lodos* have potential to achieve autonomous flight.

Obstacle avoidance mission requires an agile UAV and well-developed algorithm. Avoidance will be performed either by the operator or by Dronekit library which is a product of autopilot system. Requirements for the object detection, classification and localization mission are provided from last year's imaging system. As a result of tests, the imaging system has proved its quality lots of times.

The air delivery system needs high precise GPS system and also need a stable frame. The last year's air delivery success illustrates that multicopter frame is the best choice for this mission.

Lodos is capable of hovering for 37 minutes and 25 minutes of operational time. This is seen to be enough to complete all missions without pitstop. Operational excellence requires well practice and ITUNOM UAV team started to test the new designed UAV in 2017.

Because of the advantages of multicopter, autonomous flight, obstacle avoidance, and air delivery will be executed with high success. In spite of higher cost, the new design is made for higher payload capacity. Although the avionic systems and mechanical parts are chosen among lightweight, total weight is 11,7 kg which is still too heavy for a UAV. The enhanced payload capacity provides more options for avionics systems that means more computational force and improvement in image processing system.

1.2 Design Rationale

This year, ITUNOM UAV Team started to work with the fund from the previous year's budget, $3000, until making new sponsorship agreements with the companies around the university campus. Fortunately, university's location is so sufficient that team did not have difficulty in taking financial supports. In addition to being in an adequate condition about finance, all decisions were well-directed and wastage was avoided. In this condition, the team made its creations and improvements.

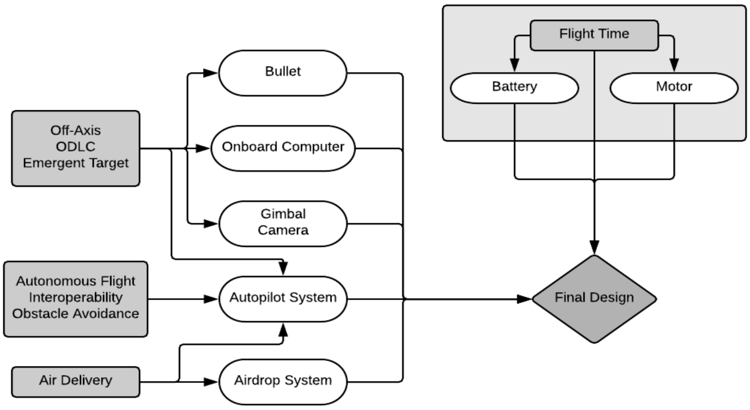

Figure 2 - Flow of Decision

Lodos is designed as a hexacopter to be able to carry a heavy DSLR camera and an advanced mission computer, as ODCL is the main mission in the competition. Regarding that, achieving all missions requires a durable and stable flight in as short as possible time. This challenge force the team to choose a reliable and well-known autopilot, Pixhawk 2.1, with the experience from previous years. As a result of that, the team has enough experience to achieve autonomous flight successfully. The satisfactory performances in these two main missions with a reliable vehicle may conclude with success for the team.

Last year's vehicle *Tulpar* was created as an octocopter by the team but it was team's first experience and had some mechanical problems. Gaining some experience encouraged the team to build its own UAV again. As frame of *Lodos*, using Carbon-Fiber has been preferred for its being durable, rigid and vibration-proof while being light. Landing gear is decided to consist of 3 Carbon-Fiber legs as it is enough to touch the ground with 3 points not to topple. It is angled and short enough in order not to cross the line of vision of the camera which is placed at the bottom of the vehicle. Landing gear's height is decided regarding the arm length in order not to block folding it. Arm length was determined according to propellers' dimensions, to prevent them hit each other.

Lodos meets the requirements of all missions. For the imaging system, the camera has been chosen for its image quality due to sensor size, the maximum angle of view, battery life, weight and compatibility with the companion PC. A 2-axes gimbal is designed for the camera to take noise-free images. *Lodos*'s maximum speed is optimized in order not to affect the photo health negatively. For transferring the images which are processed by mission computer, the team uses a Wi-Fi link with between Bullet and NanoStation with an antenna tracker on the ground. Last year, the team used 433MHz as telemetry, but this year RFD 900x has been preferred as it has much more range and it is more reliable with the encrypted data link. As *Lodos* is a rotary wing, air delivery mission is easily performable for the team. Horizontal speed of the UAV will be zero, so the motion planned to be a free fall. Hitting the bull's eye is a simple matter with a servo mechanism which is triggered from the Ground Control Station (GCS). The team uses Mission Planner as GCS software, which is compatible with the autopilot. It provides functions for required mission data. Via Mission Planner, it is also possible to create new waypoints autonomously to fulfill for Stationary Obstacle Avoidance mission. After the obtaining obstacle data, the new flight plan is uploaded to the autopilot via telemetry and *Lodos* avoids the obstacles. During the whole flight, aggressiveness and speed of the vehicle are adjusted for efficient flight time and battery life.

2. System Design

2.1 Aircraft

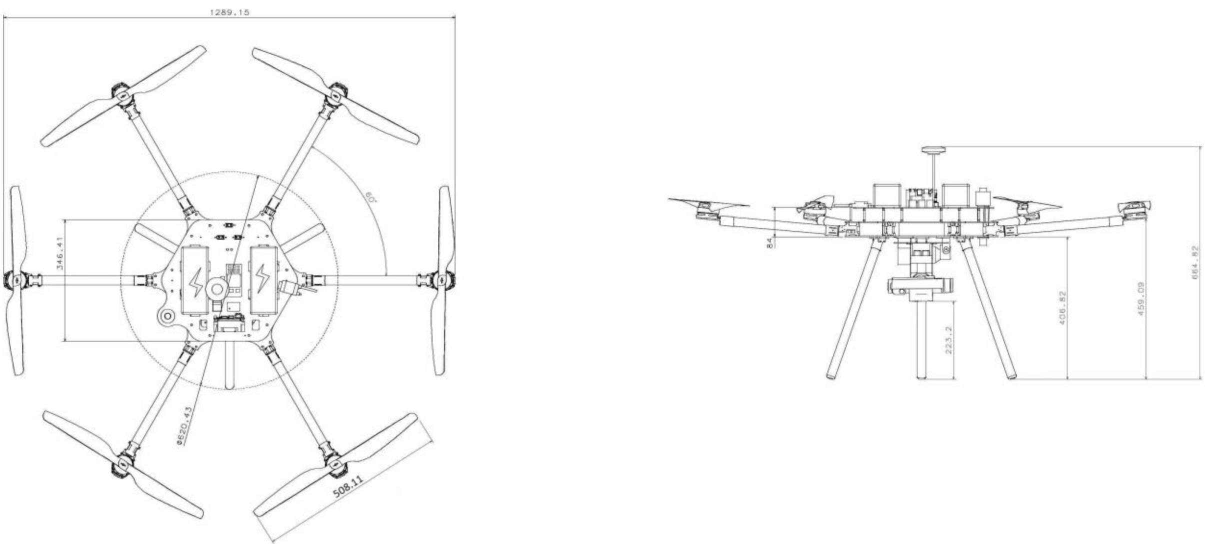

Figure 3 - Lodos Technical Drawing: Top, Front(in mm)

Technical Specifications	
Length	665 mm
Width	1290 mm
Empty Weight	9460 g
Propeller Size	20*6 inch
Motor	T-motor U7 V2.0 280KV
Payload Weight	1710 g
Batteries	2x16000mAh 15/30C 6S1P LiPos

Performance	
Max Speed	28 km/h
Flight Time	23 min
Max Takeoff Weight	23000 g
Max Tilt Angle	48 °
Operational Range	6000 m

Table 2 - Specifications of Lodos

2.1.1 Airframe

Lodos is a custom designed UAV that satisfies team's requirements for the competition. Mechanical sub-team designed and produced the frame as a hexacopter with 3 carbon fiber layers and a landing gear which includes 3 legs, as shown in *Figure 3*. The angle between one arm and frame is 5 degrees. This is a tradeoff between loss of thrust and stability. On the top plate, autopilot, GPS system, RFD 900x, RC receiver and batteries were placed. Mission computer, Nvidia Jetson TX2, could be placed either between the top and bottom plates or on the top plate, whether the team wants to use the larger carrier board of the computer. The geometry of the middle plate, Figure B, lets the team reach into the vehicle and work easily by unbolting 12 screws instead of dismantling the whole frame. This geometry provides a useful place for the computer. The bottom plate carries the air delivery mechanism and a camera gimbal which is also custom designed. This design approach makes the vehicle components to be easily reachable as desired. In conclusion, team preferred to design and build its own frame instead of buying a ready-to-use one.

Component	Weight	Component	Weight
Frame	2660	Power Distribution	430
Batteries	4000	Imaging System	1000
Autopilot and Gps	200	Air Delivery System	350
Bullet M5	150	Telemetry	30
Motors and Propellers	2140	Companion Pc	210
TOTAL		11170g	

Table 3 - Weight of Components(grams)

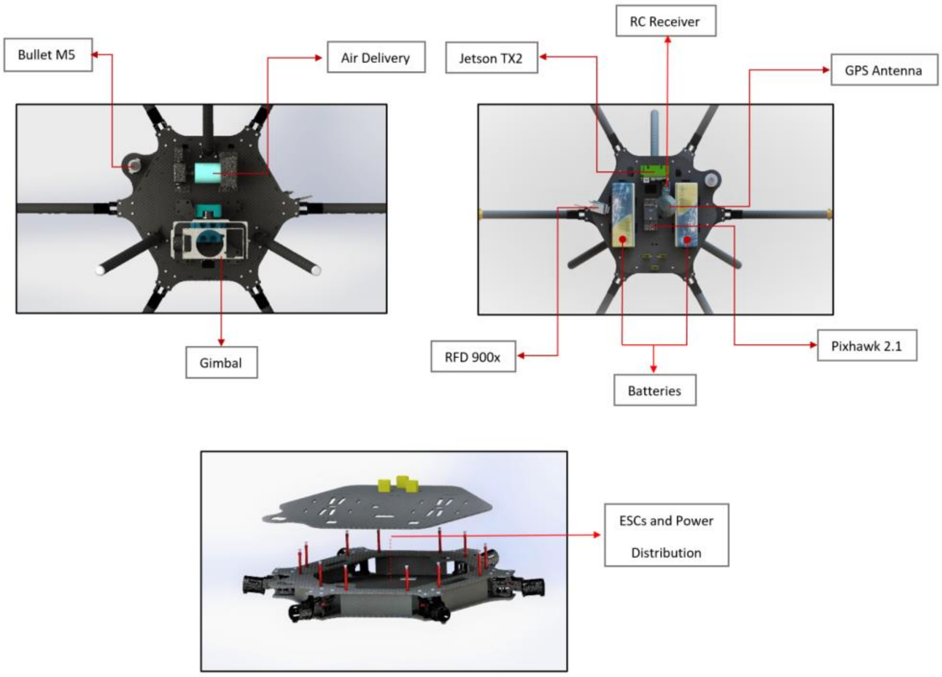

Figure 4 - Labelled Diagram of Airframe

2.1.2 Propulsion System

Lodos needs to fly approximately 25 minutes for being able to attempt all of the missions. To provide the flight time with predicted weight, 12 kg, the team decided on propulsion system and chose T-Motor U7-V2.0 280 KV and 20*6 inches folding Carbon-Fiber propeller.

Throttle	Current(A)	Power(W)	Thrust(G)	Efficiency(G/W)
%60	8.4	202	1907g	9.46
%65	10.05	241	2124g	8.81
%75	14.24	342	2717g	7.95

Table 4 - Properties of T-Motor U7-V2.0 280 KV

Lodos is powered by a pair of 16 mAh 15C Li-Po battery in parallel. The maximum current that one single motor consumes is 27.4 A. While lightness and safety are number one priority, T-Motor Flame 70A is chosen.

2.1.3 Aircraft Testing

- One motor of *Lodos* can give maximum 4 kg thrust which causes bending on arms. *Figure 5* shows color-coded total deformation on one arm of the vehicle. It can be seen that the end point of the arm is bending 1.46 cm upwards which means the angle between the arm and frame is 7 degrees at full throttle, which causes only 30 grams of loose in thrust. It does not seem to be a problem for the team.

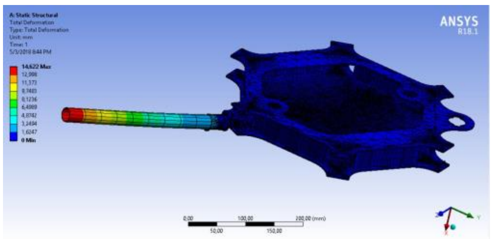

Figure 5 - Color-coded Total Deformation

- To complete all of the missions, 20-25 minutes of time is needed and *Lodos* is designed to have that flight time regarding calculations. As the result of first hover test with %15 remained battery as a precaution, hover flight time with all up weight is 37 minutes which satisfies the requirements and is compatible with the calculations.

- Calculations and technical data show that 20 inches carbon-fiber propellers must be used in *Lodos*'s propulsion system. Additionally, a comparison test was done between folding and fixed carbon-fiber propellers. The goals were to determine the effects of being foldable and to see how winglet, which prevents wing vortexes, influences thrust and current values. As can be seen in *Figure 6*, folding propellers have more efficiency, thus they have been chosen to be used.

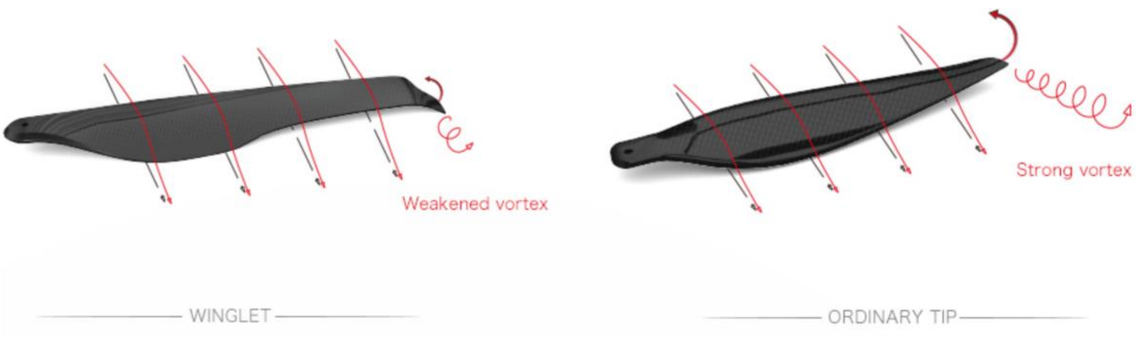

Figure 6 - The Effect of the winglet on Propellers[1]

- Sudden current changes may affect the compasses on the UAV and it may cause a fatal failure. Therefore, the team found it necessary to make a magnetic interference test and see whether the change affects the compasses too much or not. The results showed that maximum interference value, 8%, is far below from the warning limit which is 30%.

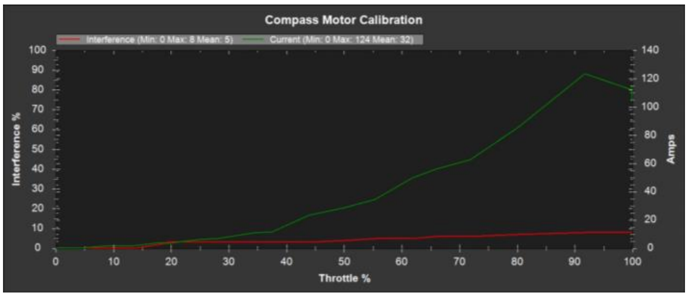

Figure 7 - Magnetic Interference Test

2.2 Autopilot and Ground Control Station

2.2.1 Autopilot

In order to achieve the autonomous flight task, the autopilot system must carry out the autonomous takeoff, landing and flight during competition. ITUNOM UAV team decided to use Pixhawk 2.1 (The Cube) as autopilot because of its reliability and multi-functionality. The most important feature that differs Pixhawk 2.1 from other Ardupilot autopilots is its hardware. Besides, Kalman Filter and 3 redundant IMUs provide much more accurate positioning data. Also, HERE GPS system ensures 12 inches precision horizontally.

The team has an experience on Pixhawk 2.1 from the previous years. It uses Ardupilot software which provides open source software and multi-functionality. Ardupilot software has been chosen as autopilot software because it is commonly used and the community support helps to solve problems easier. Furthermore, Ardupilot provides the most advanced and various flight logs which enable reaching possible problems and solutions. Pixhawk 2.1 autopilot provides high precise autonomous waypoint capture, taking photo due to coordinates, and servo output rail for specialized missions as airdrop and gimbal.

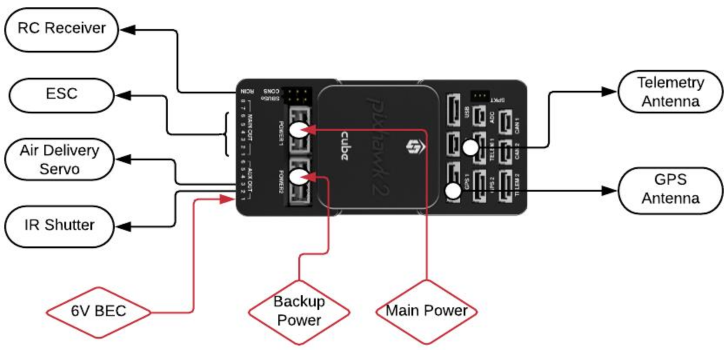

Figure 8 - Autopilot Connections

One of the best parts of Ardupilot might be enabling control UAV by an algorithm. It is an essential feature to control UAV for achieving various missions. Dronekit-SITL is a product of Ardupilot allows observing vehicle simulation. The simulated vehicle can be controlled by the algorithm and observe the mission execution. All the auxiliary outputs and autonomous flight can be visualized on GCS and analyzed for the algorithm improvements.

The most important thing of the autonomous flight is the capability of executing stable flight. In order to do that, autopilot must have the capability of controlling with various parameterized vehicles (i.e. size, weight, center of gravity). Pixhawk 2.1 has autotune function to regulate the PID coefficients according to vehicle dynamics. In sequence, it checks the vehicle response for roll, pitch and yaw separately. After the autotuning, responses of the vehicle improved apparently.

Pixhawk 2.1 and HERE GPS system satisfy the waypoint capture and accuracy missions. On account of maximizing the waypoint accuracy points, the waypoint radius adjusted to 2 feet and UAV waypoint command adjusted to 1 second loitering on given coordinates. At the consequence of these settings, the average distance from the coordinates satisfies 2 feet radius with 95% success rate.

2.2.2 Ground Control Station

Mission Planner is used as GCS software for communicating with Pixhawk 2.1. It can create waypoint sequence and assign a task to the each of them and upload it to autopilot via telemetry. Mission Planner program has been customized in order to meet mission requirements of SUAS Competition. Air Delivery, Off Axis Target, creating waypoint automatically and Interoperability Missions are operated from this interface. After the flight, logs can be visualized and analyzed. UAS position, obstacles, mission positions, search and flight areas can be visualized by GCS. Additionally, critical data as altitude, flight time and remaining battery can be shown.

Figure 9 - Mission Planner Interface

2.3 Mission Computer

Sony A6000 has high resolution because the image size is very high and that slows down the transfer rate for long range. In order to bring a solution, it is decided to use a high speed mission computer as Jetson TX2. The advanced GPU of Jetson TX2 provides high image processing rate. Furthermore, mission computer will be used for communication with autopilot to localize the images. The manual image processing mostly depends on mission computer. Jetson TX2 will get the coordinates of the center of the image from autopilot and receive the image from Sony A6000. After the detection and localization algorithms, the detected objects will be sent to the GCS with their coordinates and orientation of the UAV. Thus, the size of the transferred image is reduced to 1/500 ratio. Also, the transferred images are addressed for manual and autonomous image processing systems, separately.

	UDOO Quad	Raspberry Pi 3B+	NVIDIA Jetson TX2
Price	$135	$35	470$(with carrier board)
Dimensions	110x85x22 mm, 110g	82x 56x19.5 mm, 50g	52x55x120 mm, 220g
Processor	CPU NXP i.MX 6 ARM Cortex-A9 Quad core 1GHz + Atmel SAM3X8E ARM Cortex-M3 CPU(Arduino Due)	Broadcom BCM2837B0 quad-core A53 (ARMv8) 64-bit @ 1.4GHz	HMP Dual Denver 2/2 MB L2 + Quad ARM® A57/2 MB L2
RAM	1GB DDR3 RAM	1GB LPDDR2 SDRAM	8 GB 128 bit LPDDR4
GPU	Vivante GC 2000 + Vivante GC 355 + Vivante GC 320	Broadcom Videocore-IV	NVIDIA Pascal™, 256 CUDA cores
Connections	2x USB2.0, 2x USB Micro USB, CSI Camera Serial Interface(CSI), GPIOs, Ethernet	4x USB 2.0, Ethernet, GPIOs, Camera Serial Interface (CSI), Display Serial Interface (DSI)	CAN, UART, Ethernet, SPI, I2C, I2S, GPIOs, USB 2.0

Table 5 - Mission Computer Comparision

Chosen mission computer, Jetson TX2, includes a specially developed Linux environment, supports more APIs, and is supported by NVIDIA's entire development toolchain. The card offers a very flexible and attachable platform by presenting the varied hardware interfaces. The kit has been preferred for image processing, transferring cropped frame and communication with autopilot, whereas 256 cores are capable of doing 256 different commands at the same time. Additionally, CUDA was used for execution of parallel tasks to save time.

2.4 Obstacle Avoidance

In order to achieve the obstacle avoiding mission, ITUNOM UAV Team developed an algorithm to detect a collision and generate the new waypoints to avoid from collision autonomously. The GCS is also in charge of uploading new generated collision-free waypoints.

The obstacle avoidance software uses RRT (Rapidly Random Tree) as avoidance algorithm. Because of the high speed of the algorithm, it allows executing moving obstacle avoidance. Sequentially, it is required to simultaneously edit waypoints, which is enabled to be done by Dronekit.

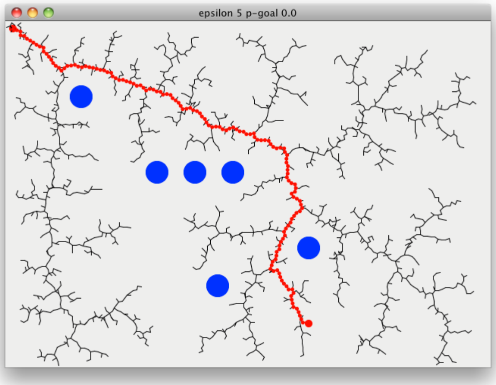

Figure 10 - RRT Algorithm Example[2]*

Firstly, the algorithm detects if there is a collision with taking points on waypoint line with a certain interval. If there is any point that distance to the center of the obstacle is smaller than its radius, there is a collision for that waypoint. Then the RRT algorithm is applied to avoid. RRT algorithm assigns a point around target waypoint and takes a step towards to it. Unless the new step has a collision, it continues to take steps. The algorithm assigns the target waypoint as a random point in every 10 cycles and tries to reach it to make the process faster.

In order to secure the vehicle, the algorithm is tested on Dronekit simulation. After having sufficient flights, the algorithm is tried on the vehicle. As an added precaution for moving obstacles, if obstacle crosses the line to waypoint with very closely to the vehicle. The algorithm also checks the new waypoints and if waypoints have a dangerous angle with respect to vehicles direction, it cancels the waypoint and saves the old waypoint as a target. Although a collision happened, the vehicle is saved from over-aggression, because it may lead UAV to fail.

The obstacle avoidance mission requires much more practices as the system must be tested on a real mission and the consequences must be examined. The stationary obstacle avoidance may also be executed by operator help because our vehicle can follow the waypoints easily the success rate is 100%. The moving obstacle avoidance is executed with 60% success ratio.

2.5 Imaging System

As a result of evaluation of the previous year's performance, certain improvements were required in imaging and transferring system. Assessment of previous year's imaging systems performance revealed the following problems:

- the workload created by taking time-lapse photographing on UAV computer
- lack of access to the camera interface due to other processes running on UAV computer
- the image transfer queue due to the image must be transferred to the GCS

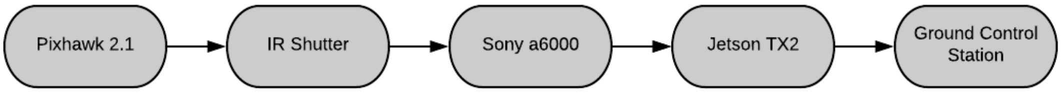

Figure 11 - Imaging System

2.5.1 Camera

The camera was chosen to satisfy the requirements of image processing task. High resolution frames and sufficient computing power are required for both manual and autonomous target recognition. Quality of input images is a crucial factor to obtain good results from image processing algorithm. By considering all these requirements, ITUNOM preferred Sony A6000 DSLR camera to others. Table 6 shows the most important specifications of the camera for the mission.

Specifications	Value
Pixel count	24.3 Megapixels
Remote Control Type	Optional wired, IR or Wi-Fi
Shutter Lag (notes)	Full AF lag, Multi-area AF mode = 0.151s
Sensor size	366.6mm2 (23.50mm x 15.60mm)
External Connections	USB 2.0 High Speed, Wi-Fi

Table 6 - Properties of Sony A6000

Sony A6000 was chosen for its lightness and high resolution which is 24.3 MP. Because image processing algorithm requires clear and noise-free images, APS-C was chosen as a light sensor that provides more light to each pixel. Furthermore, the camera offers remote control over options, such as optical zoom and angle of the aperture. Its large scaled shutter speed and ISO values allow working on different weather conditions and luminosity levels.

Due to the previous year's problems, this year UAV imaging system has been mostly changed. Firstly, instead of photographing in a certain time interval, frames are captured due to location. After mapping out a route on search area, our software creates the mission points that are planned-locations for taking photos. In order to manage that, autopilot system uses an IR shutter as a trigger. When UAV reaches those points, autopilot autonomously triggers the camera with shutter, then the camera takes a shot.

While these geotagged photos provide the exact location of the vehicle, geolocation of targets is getting easier for image processing system. Additionally, imaging system does not take unnecessary photos and GPU workload is decreased as an advantage of taking photos due to location.

2.5.2 Gimbal

This year it is decided to make the gimbal system changed. Unlike the previous year, usage of a brushless gimbal was decided. It is concerned not to let landing gear lessen the angle of view and not to spoil the center of gravity of the drone as the team's first priority by designing the mechanical system and deciding the gimbal location in the system. The team decided to use dampers as vibration absorbers and carbon fiber as the main structural hardware of the system because of the carbon fiber's efficiency about robustness/lightness ratio. Furthermore, an Alexmos SBGC-32 bit was used as a controller due to its price/performance ratio. Besides, two brushless gimbal motors were provided to maneuver the two axes of the structure as a result of their optimization for gimbal systems.

Figure 12 - Gimbal

2.5.3 Imaging System Testing

Observing the stability of the system and its efficiency for competition requirements are the purposes of imaging system tests. Firstly, the stability of the system is ensured by long-term operation and working on different weather conditions, such as gimbal vibration test on windy weather. Measurements (battery and temperature) and system logs (vibration graphs) have shown the necessity of improvements on camera battery and gimbal motors. After these observations, the camera has been fed by the main power distribution. Instead of servo gimbal, brushless one was preferred with examining the vibration graphs, thus gimbal dampers were changed.

Secondly, system efficiency tests have two main objectives: taking photos from various altitudes to determine the optimal height focal length and shutter speed, computing delays between trigger orders and image transfers. Up to now, using the minimal focal length of 16 mm (the widest field of view) that is available on the A6000 shows that this resolution is enough for the mission demonstration. Furthermore, it was determined that the optimal shutter speed value should be between 1/400 and 1/1000 under multiple levels of daylight.

2.6 Object Detection, Classification, Localization

Image processing is a method to perform some operations which can be used for detection, classification and localization of targets on an image. OpenCV (Open Source Computer Vision library) has been decided as the optimal source to get the targets from the frame. After some researches and tests, it became obvious that new developments and algorithms in OpenCV are instantly developed in the C++ interface. Therefore, using proper functions of OpenCV in C++ language would be much more efficient than other methods. The system consists of three parts; detection, localization and classification

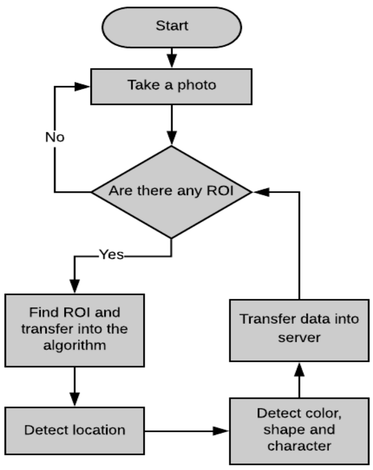

Figure 13 - Image Processing Flowchart

2.6.1 Object Detection

In the beginning, varied algorithms and methods were analyzed. Eventually, it was determined that developing new one might be more flexible and understandable. A captured image from the camera is firstly prepared for processing by splitting into BGR (Blue, Green, Red) color space. While the effect of glinting and reflection makes difficult to get the region of interest (ROI), some image smoothing algorithms (blurring, noise reduction etc.) are applied. The resized image that contains the only ROI frame operates faster due to the number of pixels.

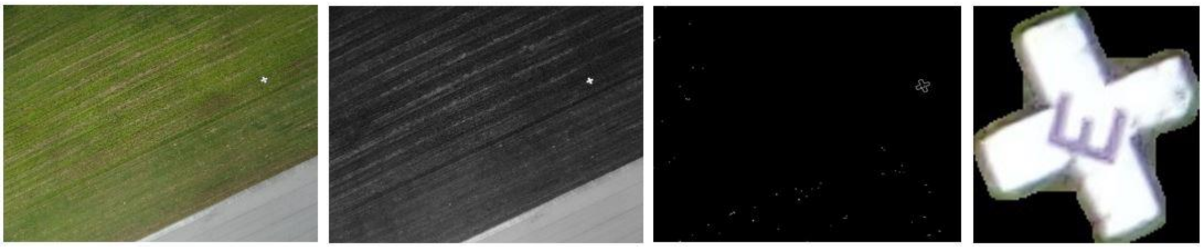

Figure 14 - Finding ROI

The interoperability server provides exact location coordinates of the Off Axis target, whereas obtained data are used for new waypoints in Mission Planner that UAV will not cross the fly zone limit. After computing an angle that gimbal has to rotate relating to the UAV's height, direction and distance to the target, an image will be captured for processing and saved to a USB.

2.6.2 Classification

The arranged image is sequentially transferred into color detection, shape and character recognition parts of the code. For color detection, the algorithm finds color of the internal contour (character color) area with determining the color of the external (shape color) one previously. When it comes to shape and character recognition, Convolutional Neural Network (CNN) has been preferred due to its accuracy, rapidity and being an advanced method.

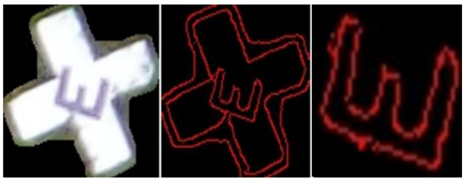

Figure 15 - Derivation of Character

Initially, the captured image will be processed on UAV's computer to search for ROI. After sending found ROI to Autonomous Recognition Interface the values will be observed in GCS. If results from autonomous processing are incorrect with respect to the cropped frame, manual intervention will be realized in GCS. The parameters relating to coming image, which could not be processed autonomously, will be entered in Manual Recognition Interface.

2.6.3 Localization

The actual location of the UAV and center point values of the original frame is certain, then the localization algorithm must continue with determining the center point of ROI. After identifying flight direction, pixel difference between center points of original photo and ROI, and equivalent actual location value of pixel difference, real coordinates are found.

2.6.4 Tests and Improvements

Recognition system was tested by taking varied factors into an account: weather condition (sunny, cloudy, etc.), different colors, altitudes and locations. The parameters in the code were changed to maximize the flight altitude, as minimizing the flight time. After evaluating tests, optimal values attached to the algorithm.

Figure 16 – Tests in Different Weather Conditions

In seven months' time interval Haarcascade, SIFT and Tesseract have been tried as different Optical Character Recognition (OCR) systems. In the end, Tesseract was chosen as the efficient method for character recognition.

As a result of the tests mentioned in *Table 8*, the team concluded with optimal altitude is 70m, so our algorithm has been set to this altitude.

Method Name	Success Rate
Haarcascade	%50
SIFT	%65
Tesseract	%85

Table 7 - Accuracy of Methods

Success Rate(%)						
Altitude	Shape Color	Shape	Character	Character Color	Orientation	Geolocation
40	90	80	75	90	75	75
50	90	80	75	90	75	75
60	85	70	65	80	65	65
70	80	60	55	75	60	60
80	75	50	50	75	50	50
90	65	40	40	60	40	40
100	55	30	20	50	25	25

Table 8 - Success Rate by Different Altitudes

2.7 Communications

The communication system is one of the most important parts of the competition because all of the mission requirements are transported via the communication system. In order to secure communication between UAV and ground station, three precautions are taken. First one is not allowing to overlap with other subsystems. The second one is having long range capability for competition. The each of communication parts tested and results are satisfied the requirements. The results were longer than 2 miles and satisfied the competition requirements. The last one is the protection of data. In order to provide the security, telemetry uses 128-bit encryption, Wi-Fi communication uses WPA2 and radio controller uses Futaba FASST and S-FHSS protocols.

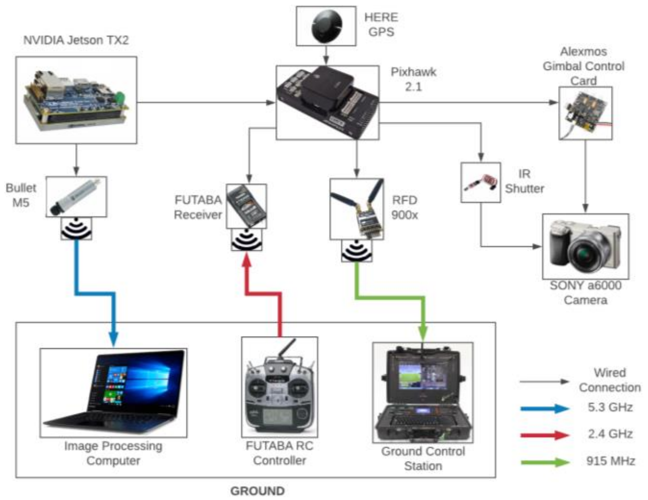

Figure 17 - Communication System

2.7.1 Interoperability

Mission Planner is modified to meeting interoperability requirements, such as taking mission and obstacle data and transferring the location and orientation of the vehicle, simultaneously. All mission elements can be seen on the Mission Planner interface by GMAP API in real time. The benefit of modifying Mission Planner as interoperability interface is making easier to operate missions.

2.7.2 Telemetry

RFD 900x is used as telemetry module because it can satisfy all of the requests. It provides the communication between Pixhawk 2.1 and ground station. The ground transceiver has been connected to ground station computer via USB, and the transceiver to the Pixhawk 2.1 via CAN bus. Telemetry uses mavlink protocol and transmits data such as altitude, velocity, location.

2.7.3 Pilot Communication

In the case of autonomous flight fail, Futaba T14SG radio controller will be used for manual takeover. Futaba T14SG works in 2.4 GHz bandwidth. The receiver has been directly connected to autopilot via S-BUS.

2.7.4 Wi-Fi Communication

In order to transfer the images which are taken by the camera on UAV to image processing system on ground station, the wifi communication system uses Ubiquiti Bullet M5. The wifi communication system works on 5.3 GHz bandwidth.

For transferring the images from Ubiquiti Bullet to ground, it is needed to a durable communication system. Thus the directed antenna is used for more powerful and durable communication. ITUNOM UAV Team produced the antenna tracker for tracking the UAV autonomously. In order to track the UAV, antenna tracker uses 2-axes which are called pitch and yaw axis. The system uses one step motor that is used for controlling yaw movement, whereas it is capable of 360-degree rotation and one high torque servo motor that is used for pitch movement, because of usage simplicity. The communication system of antenna tracker is provided between Bluetooth module which is connected to Arduino and the ground station that transfer the UAV's location data from Dronekit.

2.8 Air Delivery

The system consists of two small and simple parts. The first part can be rotated by a servo motor to release the bottle from the lid part and second part is fixed and just carries the back side of the bottle as can be seen in Figure 18. The system is designed for taking simplicity as number one priority. The bottle is not covered by any substance in case of a failed explosion. Also, delivery will be executed at 60 meters to make sure that bottle explodes. Before the execution, *Lodos* will wait for 2 seconds at the delivery point. There will be a free fall motion because the horizontal speed of the UAV will be zero during the load release. The 3D printed system, shown in *Figure 18*, is made of ABS plastic to be sturdy and lightweight.

Figure 18 - Air Delivery Mechanism

2.9 Cyber Security

Communication System	Risk	Mitigation	Backup Plan
RC Link	Jamming	---	If somehow connection is lost, the autopilot will change flight mode to RTL.
	Hacking	Since receiver and transmitter are connected to each other before flight and S-FHSS protocol is preventing others hacking RC link.	Try to give RTL command from GCS.
Telemetry Link	Monitoring	AES encryption, FHSS	---
	Jamming	---	After losing telemetry link, we can send orders to the onboard computer with Wi-Fi link in order to control autopilot via the wired connection.
GPS Receiver	Spoofing	Here GPS(M8N) has spoofing detection which can alert the GCS in a spoofing condition.	Safety Pilot will take over the control and will land the vehicle.
	Jamming	Here GPS(M8N) has jamming detection which can alert the GCS in a spoofing condition.	Safety Pilot will take over the control and will land the vehicle.
Wi-Fi Network	Monitoring	WPA2 security, encryption protocol	---
	Jamming	---	Flight doesn't get affected because mission demonstration goes on. The team gets cropped images after landing. This is a tradeoff between actionable and manual image processing.
	Hacking	WPA2 security, encryption protocol	RTL

Table 9 - Cyber Security Protocol

3. Safety, Risks & Mitigations

Safety is an essential part of research and development. In order to make environment workable and provide safety, some instructions are created to follow. For AUVSI SUAS competition, Risk & Mitigation section is grouped as developmental risks & mitigation and mission risks & mitigation.

3.1 Developmental Risks & Mitigations

The development risks and mitigations are handled as different approaches for each subteam individually. In order to secure the safety, each subteam has own checklist. Additionally, subteams are supervised by experienced members from the previous year. All subteam members are informed about safety instructions and first-aid help. The general risks & mitigations and risk levels are listed below:

Developmental Risks	Mitigations	Risk Level
Injuries occurred during tests	• No indoor testing with propellers • Except flight propellers are taken out • During takeoff and landing, everyone stays away more than 30 feet • After set-up, only flight operator can interfere with vehicle	HIGH
Injuries relating to electronics	• The inexperienced members of the team can only work with subteam leader • The workplace always must be kept clean (No possibility to short circuit) • Batteries are stored in their special Li-Po bags	MEDIUM
Injuries caused by improper use of tools	• Working with experienced members of the team	MEDIUM

Table 10 - Developmental Risks

3.2 Mission Risks & Mitigations

Even though the preparations are done completely and systems are tested many times, the unexpected incidents can occur. Most of them are listed and a precaution list is prepared for emergency situations. ITUNOM UAV Team prepared themselves for these possible problems and each team member is trained for these situations.

Risk	Occurring Possibility	Mitigation	Action
Telemetry Loss	Low	- External Voltage Supply - Test the range of telemetry - Check USB connection	- Failsafe mode will be activated or manual takeover will be done
RC Link Loss	Low	- Test the range of RC Link	- Activate the failsafe
Low Battery	Medium	- Check the battery before flight - Visualize the remaining battery during flight	- Emergency landing
Imagery (Wi-Fi) Link Loss	Medium	- Test the range of Wi-Fi link - Usage the antenna tracker and directed antenna	- Reset connection - Callback the vehicle and try to fix it
Entering No-Fly Zone Area	Low	- Check autonomous waypoints before the flight - Manual takeover - Check connections	- Try run away from no-fly zone area autonomously or manual takeover will be done
Crash on Competition	Medium	- Checklist control before the flight	- Try to fix the vehicle

Crash on Testing	Medium	- Checklist control before the flight - Backup UAV	- Try to fix the vehicle or continue test with backup UAV
Mechanical Trouble	Medium	- Checklist for mechanical parts - Analyze the mechanical parts under stress	- Unless it is repairable, execute flight with backup UAV
Autonomous Flight Failure	Low	- Check all compass and IMU data before takeoff - Checklist control - Check weather conditions	- Manual takeover, callback and check flight logs
Air Delivery Mechanism Failure	Low	- Check delivery mechanism before the flight	- Rest of the flight will be executed same
Motor or propeller failure during flight	Medium	- Propulsion system components are selected to be robust and reliable - The mechanical parts are preserved well all the time	- Failsafe will be activated. Even one motor or propeller fails, the autopilot can land the vehicle safely.
Moving Obstacle Avoidance failure	Medium	- Moving obstacles may cause aggressive movements that may cause a crash. In order to prevent it, the algorithm analyzes the dangerous waypoints and cancel the avoidance	- If the code cannot pick over aggressive points, the moving obstacle avoidance algorithm will be terminated

Table 11 - Mission Risks and Mitigations

4. Conclusion

For the time being the past year, ITUNOM has committed itself to manufacture Lodos which is believed to be the team's substantive UAV for oncoming AUVSI SUAS competitions. Team clamped down about the previous year's mistakes and failures. Lodos was designed to carry various payload system. In addition, its design improved during flight tests for obtaining the best results during missions. The most of mechanics, avionics and software systems designs are stared all over. Even though the processes were complicated, the team overcame the difficulties. Lodos and our systems were tested on simulation of competition and results showed that ITUNOM UAV Team is ready for AUVSI SUAS 2018.

5. References

- [1] http://store-en.tmotor.com/goods.php?id=394
- [2] https://nakkaya.com/2011/10/27/path-finding-using-rapidly-exploring-random-tree/