LAGARI 2018
Technical Design Paper for AUVSI Student UAS Competition

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Abstract

This paper presents the design and tests processes of the ZD-01 Mini UAV for the AUVSI Student UAS Competition 2018. Lagari UAV Team has been founded at Yildiz Technical University in 2013. In the past years, Lagari UAV Team created multiple innovative aeronautical & aviation projects and obtained various awards. This year will be the second year in the AUVSI SUAS competition for the team. Lagari UAV Team consists of undergraduate students from the department of Mechatronics Engineering of Yildiz Technical University. ZD-01 was designed, manufactured, developed and tested by Lagari UAV Team. The aircraft was manufactured with using advanced composite technologies to provide maximum reliability and safety during the flight. The avionics were integrated to the ZD-01 to complete all missions on the competition autonomously. Lagari UAV Team realized that the future of UAS is guidance, control and navigation systems. With this goal, the team efforts to develop the UAS with high performance and hi-tech. The system has capabilities such as high-performance image processing, customized user interface, long distance wireless communication, advanced composite manufacturing based on Ansys CFD analysis and customized algorithms for ODCL, Obstacle Avoidance and Air Delivery tasks.

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1. System Engineering Approach

1.1. Mission Requirements Analysis

Lagari designed and developed ZD-01 to accomplish all of SUAS competition tasks with paying attention to rules that based on ‘‘AUVSI 2018 Rules for SUAS Competition” document. All our work and task performance in last year was analyzed and weaknesses were identified. To achieve success in the competition, the importance of the tasks has been analyzed in detail. **Table 1** is shown our mission strategy.

Missions	Explanation	Executed Actions and Requirements
Timeline (10%)	• Complete this stage in minimum time (%80) • Needs to be completed under 45 minutes • Avoid from take a penalty (%20)	• Simulate the assembling in every test flight • Well-organized team • Well-prepared checklists for every stage
Autonomous Flight (30%)	• UAV needs to fly autonomously over waypoints (%40) • Refrain from safety takeovers (%10) • Capture the waypoints as close as possible (%50)	• Well-calibrated equipment (Air Speed, Compass, Accelerometer) • Investigate the log data after each flight • Over 15 hours autonomous flight which 10 hours were in the SITL (Software in the Loop) simulation
ODCL (20%)	• Object characteristics must be determined correctly (%20) • Localization of detected object (%30) • Correct file format while sending to the interoperability server (%30) • Autonomous detection (%20)	• Developing a deep-learning algorithm for detection the objects autonomously • A new algorithm for geo location calculation • Autonomous JSON file converter algorithm for communication with Interopability server
Obstacle Avoidance (20%)	• Avoid from moving (%50) and stationary (%50) obstacles	• Developing a new algorithm for obstacles
Air Delivery (10%)	• Drop an object to a specified position	• Well-qualified mechanic system • Give attention to calculation
Operational Excellence (10%)	• Professionalism, communication between members, reaction to system failures	• Well-defined personal responsibilities • Usage of walkie-talkie between the GCS and assembly team

Table 1: Mission Table

This year the team spent their time to fly autonomously, manufacture a new fuselage, develop algorithms for image processing and obstacle avoidance. Also, we designed new avionic boxes which is shown in **Figure 2** to accomplish all tasks in SUAS competition.

1.2. Design Rationale

Lagari will participate in the AUVSI SUAS Competition for the second time with nine undergraduate students. In the entire design and development process of ZD-01; all equipment was selected to maximize the task performance considering the team’s budget, capability and past years’ experience. Since budget is an important factor that limits us during the creation of the system, the team needs sponsors throughout the pre-competition process.

This year started with analyzing the system’s defects of last year’s UAV, Huma. The aim of the team was to eliminate the problems by improving the parameters that negatively affect our performance. Identified main problems are shown below:

- The fuselage caused too much drag and had non-essential space.
- The gimbal system was on the outside of the fuselage thus the camera was the first component to be damaged by any crash during landing.
- Cables and components in the fuselage were disorganized and scattered. It caused delay in debugging and solving problems.
- The mechanism of the air drop was not sufficient. It was difficult to mount back.
- Stall speed was too high for image processing and the air drop mechanism to work properly.

The team worked to find solutions to the identified problems within the frame of possibilities. The team's capabilities, budget and acquired experience played an important role in bringing these solutions to light.

In the design process, utter importance was given to the aerodynamic design of the fuselage, so it was completely re-designed from scratch. The idea behind it, was to produce as minimum drag as possible. Also, the size of the fuselage was reduced dramatically.

The gimbal system has been relocated to the inside of the fuselage within a bell glass to reduce drag and vibration. This improvement protects the camera system from crashes and makes the aircraft more aerodynamic.

To resolve the disorder in the fuselage, two avionic boxes were designed. The Payload Box (PB) contains the necessary parts for ODCL mission. The Control Box (CB) includes the essential components to fly manually and autonomously. Additionally, sockets were used for practical assembling. **Figure 2** illustrates the avionic boxes.

The wing area was increased to reduce the cruise speed. Thus, the aircraft can fly slower and capture more images from search area during the mission.

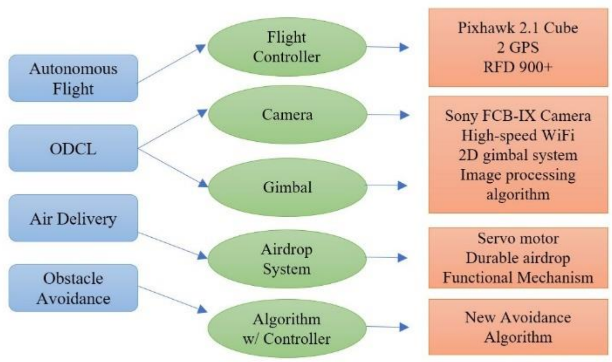


Figure 1: Flow diagram of decisions

Figure 2: Control Box and Payload Box

2. System Design

2.1. Aircraft

2.1.1. Airframe and Surfaces

- **Fuselage**

The fuselage is the most significant part of the aircraft. Since it will house all our electronic equipment and fitting elements, more attention was paid to its volume and strength. Different from last year, the fuselage was designed like shape of airfoil, so it causes less drag. Also, the volume of the fuselage was reduced by 39% and adjusted according to the components to be used. It was aimed to be easily accessible to all avionic boxes in the fuselage. It is possible to achieve high strength and lightweight material by advanced composite technology. After comparisons between other composite materials, it was concluded that carbon fiber was the right choice to meet our requirements. For this reason, the team decided to manufacture by using process of composite laying on the wooden mold with the vacuum method as shown in **Figure 3**.

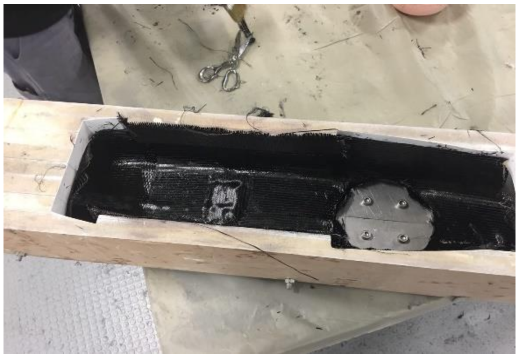


Figure 3: Composite manufacturing of fuselage

According to the result of the strength and load analysis, an extensive lamination plan was created. The fuselage durability was increased by using different types and amounts of carbon fiber on areas where the loading was most expected during the flight.

Wing slots were created on the fuselage with the purpose of easily mounting the main wings. Carbon fiber pipes were used to assembly wings and tails to the fuselage. To decrease fuselage weight and improve durability at the same time, carbon fiber pipe was also used between the fuselage and the tail part. The tail assembly was changed in this year because of the difficulties of detaching the tail from the fuselage. So instead of a 3D printed part, a carbon fiber pipe that covered the tail pipe was used to connect the tail to the fuselage.

- **Wings**

To get more lift force, ZD-01's wingspan was increased by 10 cm to 280 cm compared to the last years design. Wings taper off from the root to the tip so chord length at the wing roots are 330 mm and the chord length at the wing tips are 220 mm. Also, wing loading was reduced by increasing the wing area 16%.

Symmetric airfoil was used for the tail part. The elevator was designed for providing more lift during takeoff and the fin was also designed with the purpose of improving the maneuverability of ZD-01. The dimensions of the rudder were changed to increase its effect during the flight. The fin and the tail part were deliberated to be detachable from the tail pipe.

Figure 4: Vacuum Infusion on Wing Mold

XPS (Extruded polystyrene) foam was preferred as the main material of the wing's structure because it is cheaper than other foams and more ductile than balsa wood. Our own cutting mechanism with hot Ni-Cr wire was used during manufacturing process of main wings and the tail part as shown in **Figure 4**. The wing was casted with carbon fiber using vacuum method to obtain the final shape of the wings. The wings were supported by carbon fiber pipes as spars extending into the fuselage to increase the strength and durability. For easy transportability, wings were designed and manufactured to be detachable from the fuselage.

Figure 5: Wing Loading Test

- **Landing Gear**

ZD-01's landing gear was designed, analyzed and manufactured to provide the desired balance and durability. Tri-cycle landing gear was chosen due to the advantage of take-off/landing run and stability during taxi. The wheelbase of main landing gear was determined to provide the necessary force absorption during landing and stability during rotation. Landing gear was placed with respect to load ratio. The nose and main landing gears load ratio is 1:4.

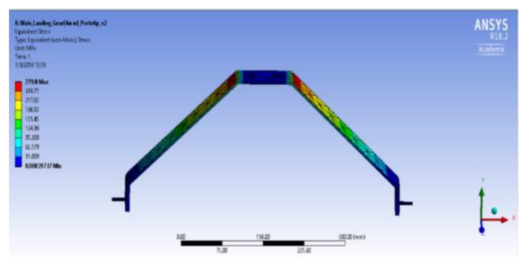


Figure 6: Landing Gear Stress Analysis

Calculations showed that the aircraft will resist up to 25 km/h of wind from the sides while taxing. The height of the landing gear was reduced from last year to be more stable. Landing gear was manufactured from carbon fiber. Areas exposed to the highest load according to ANSYS analysis (**Figure 6)**, were supported by extra carbon fiber. Different from last year, two layers of Kevlar were added to let it be more elastic. Also, two Rohacells were used to make it more durable.

2.1.2. Aerodynamics

While Lagari was planning their strategy for AUVSI SUAS 2018 competitions, the team aimed that the aircraft must have better aerodynamic stability and higher maneuverability to obtain maximum points from missions. The points that need to be improved from last year were identified. Asymmetric Eppler 214 airfoil with high camber ratio was used for improved stall characteristic of wings and to get more lift force at zero-degree angle of attack (AoA). To improve maneuverability, the Aspect Ratio (AR) was determined in accordance with the optimum AR range of sailplane aircraft models. The tapered trapezoidal wings platform was preferred for keeping the AR between 8-10. AR and

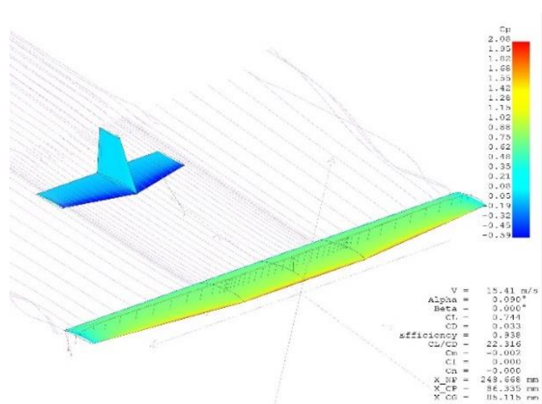


Figure 7: XFLR5 VLM Analysis

taper ratios are shown on **Table 2**. The main wings have four degrees of angle of incidence to allow us to provide higher C_L coefficient.

Because of manufacturing difficulty, the team has decided not to use dihedral angle on the wings. The most important factors in aircraft design processes are airfoil selection, center of gravity (CG) localization, wings-tail sizing and localization **[1]**. They were analyzed in low Reynolds numbers with COMSOL Multiphysics and XFLR5 CFD analysis programs which were based on Vortex Lattice Method (**Figure 7**).

The optimum aerodynamic values were determined with improved analysis. This year, some dimensions and parameters were changed so the following values were obtained:

- Cruise speed was reduced to 15 m/s and stall speed was reduced to 11 m/s.
- The wing's C_L was increased by 13 percent to 0.737 at zero-degree AoA.
- C_L/C_D ratio has reached 22.4 for wings and tail at zero-degree AoA.

Flaps were not found necessary on wings because of advanced aerodynamic C_L/C_D ratio and low stall speed characteristics. Ailerons' length was determined as %53 of half wingspan and width was determined as %24 of root chord. This sizing provided to the UAV desirable maneuverability.

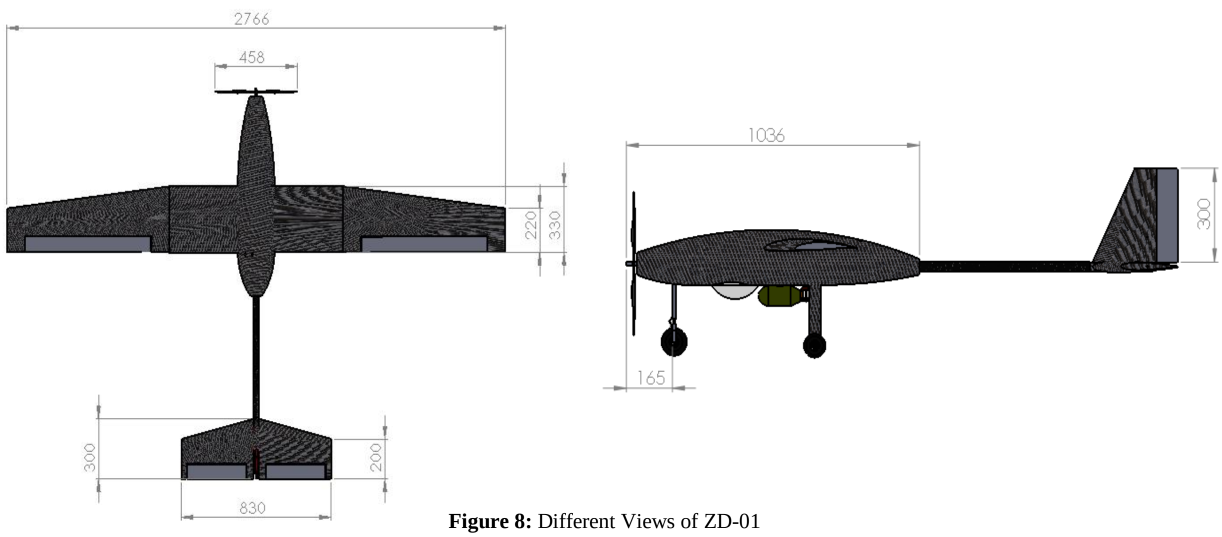


Figure 8: Different Views of ZD-01

GENERAL CHARACTERISTICS		PERFORMANCE		MAIN WING	
Length	1.95 m	**Stall Speed**	21 Kts (11 m/s)	**Airfoil**	E214
Total Wingspan	2.80 m	**Cruise Speed**	29 Kts (15 m/s)	**Span**	2.80 m
Empty Weight	3.50 kg	**Max Speed**	48 Kts (25 m/s)	**Area**	0.75 m²
MTOW	9.4 kg	**Wing Loading**	11.2 kg/m²	**Aspect Ratio**	8.9
Rate of Climb	250 m/min	**VERTICAL STABILIZER**		**HORIZONTAL STABILIZER**	
Minimal Turn Radius	20 m	**Airfoil**	NACA 0012	**Airfoil**	NACA 0012
Maximum Flight Autonomously	40 minutes	**Span**	0.30 m	**Span**	0.40 m
Operational Range	4 km	**Area**	0.07 m²	**Area**	0.20 m²
Operational Ceiling	450 m	**Aspect Ratio**	2.6	**Aspect Ratio**	3.2

Table 2: General Features of ZD-01

2.1.3. Propulsion and Power System

- **Propulsion**

Lagari decided to keep on using electrical motor because team has good experience from previous year. Extensive research about brushless dc motor was carried out by the team. Result of the research is shown in **Table 3.** AXI 5320/18 has better properties than the other models in terms of propeller size and required voltage.

Motor Model	KV	Ampere(max)/Battery	Propeller	Weight of Model
AXI 5320/18	370	55A/6S Li-Po	18"x10"	9000 gr
AXI 5320/28	249	45A/8S Li-Po	20"x10"	8500 gr
Scorpion 4035	380	79.4 A/8S Li-Po	15"x8"	8200 gr

Table 3: Engine Comparison

- **Power**

There are three main power sources that consist of Li-Po cells which is 2280 mAh and 30 C in ZD-01. Each one of the cell can give

$$2280[mAh] * 30[\mathrm{C}] = 68.4[A]$$

to the system for instant time. Power sources and properties are shown in **Table 4.** In order to determine the flight time, ground test was performed. ZD-01 was pinned to the ground when the entire system was operated, and the current was measured. Result of the test showed that motor has drawn 18A in normal condition at %50 throttle. For this output, flight time calculation is shown below;

$$\frac{6[number\ of\ parallel\ units]*2{,}28[Ah]*60[convert\ to\ min.]}{18[A]} = 45[\mathrm{min}]$$

Battery	Connected to
6S/6P	Motor/Control box
3S/2P	Payload Box
2S/2P	Servo Motors

Table 4: Power Distribution

2.2. Autopilot

Through last year experiences with flight controllers, it was decided to use Pixhawk 2.1 Cube as the flight controller which is the upgraded version of Pixhawk 2.4.8 since it satisfies all subsystem requirements appropriately. Pixhawk is responsible for all autonomous flight missions of ZD-01 while providing high accuracy, high reliability and low risk. These following exclusive features of Pixhawk Cube 2.1 contributed to the selection process:

- A very powerful 32-bit processor with an additional fail-safe backup controller which has high accuracy and extensive memory.
- A Unix/Linux-like programming environment, integrated multithreading and open-source powerful development capabilities.
- It has three redundant IMUs (Inertial Measurement Units) board which is separated from the FMU (Flight Management Unit) system.
- Peripheral units include analog and digital airspeed sensors, telemetry, rangefinder, external multi-color LED indicators and external compasses etc.

In this year, flight control system of ZD-01 has been designed and integrated into a single Control Box System (CBS) to simplify the cable complexity inside the aircraft and make the system more reliable. All connections between CBS and peripheral devices were implemented according to Civil Aviation Safety Regulations (CASR). The CBS includes Pixhawk 2.1 Cube, RFD900+ telemetry radio receiver for long range serial communication, ppm encoder, 5V regulator, hardware safety button for emergency cases, radio receiver for safety pilot and D-Sub connectors. Additionally, autopilot system was connected with Payload Box (PB) in the aircraft via USB port. In case of any telemetry radio link breakdown, autopilot system will connect the ground station via PB. Also, this USB connection provides the autopilot backup power.

An open-source firmware called ArduPlane v3.8.4 has been used on Pixhawk since it has exclusive features such as PID controller, Extended Kalman Filter(EKF), L1 Controller to tune aircraft for optimized distinctive capabilities. So, it will contribute to execute effective autonomous take off, flight and landing during mission.

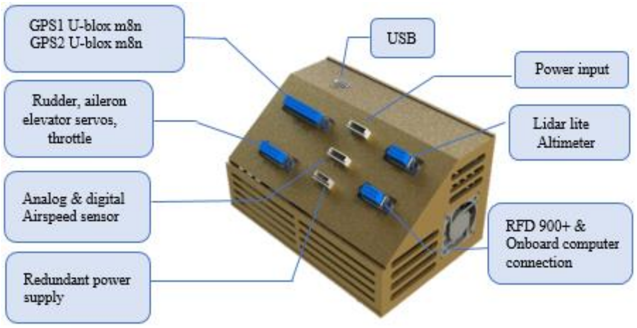


Figure 9: Autopilot System

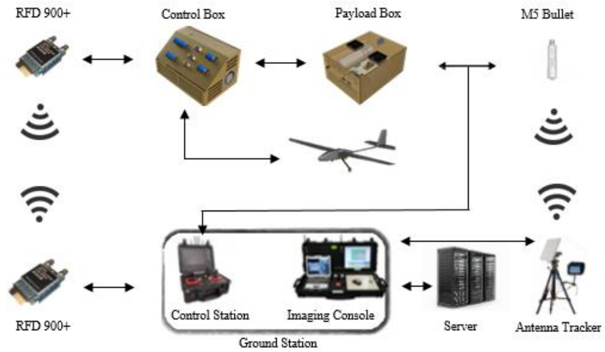


Figure 10: Whole System

PID controller is effective in autonomous flight. Thus, we executed several flight tests to tune PID parameters for the aircraft. Also, a guidance algorithm is used for path control named L1 controller **[2]**. The algorithm consists of two parts. Firstly, a reference waypoint is calculated along the trajectory to be followed. Secondly, lateral acceleration is calculated that intercepts reference waypoint. Moreover, data such as altitude, position, velocity, which are vital for the autonomous flight of the ZD-01, have been improved using Extended Kalman Filter (EKF) which is an optimal estimation algorithm to reject measurements with significant error **[3]**.

After doing many test flights in SITL and gaining experience, the team optimized all autonomous functions by testing separately.

Autonomous Flight	Time of Flight	Success Rate
Take-off	45 minutes	%90
Waypoint Navigation	6 hours	%95
Landing	20 minutes	%70

Table 5: Autonomous Flight Test

Mission Planner is used as ground control interface to communicate with Pixhawk via 915 MHz RFD900+ telemetry. This interface is a full-featured software for the open source autopilots and provide dynamic control for autonomous flight. We made some modification on the software since Mission Planner is an open source firmware. These modifications allow us to communicate with interop server. Also, the software was modified to perform obstacle avoidance mission.

Figure 11: Before Algorithm Detect Obstacle

2.3. Obstacle Avoidance

This year, the new algorithm which based on Rapidly Exploring Random Trees (RRT) was developed. Basically, RRT finds a route between two points, but it may select non-optimal path. So, Lagari developed Optimized Obstacle Avoidance Algorithm (OOAA). It adds new waypoints to the original path, in the circumstances of UAV capabilities, when a collision is calculated and send updated path to UAV. These new waypoints are offsetted 10 meters to the obstacle's radius due to accuracy of ZD-01's waypoint capture radius. OOAA was tested in SITL environment and **Table 6** shows results.

Numbers of	RRT	OOAA
Test flights	6	6
Stationary obstacles	24	24
Stationary obstacle avoidance	14	19
Moving obstacles	12	12
Moving obstacle avoidance	3	5

Table 6: Test Results in SITL

Figure 12: Updated Path with algorithm

2.4. Imaging System

2.4.1. Camera

Since camera is the main component for ODCL mission, camera selection is vital. Sony A6000, which was used last year, has high resolution but it can capture only 0.4 FPS and has low shutter speed. This year, image processing will be provided on real-time video. Using this method, manual object detection will be more efficient by scanning wider area. Sony FCB-IX 11 AP camera was chosen due to its lightweight, 10x optical zoom, live photo feature and price/performance ratio. The comparison is shown in **Table 7**.

$$Sensor\ Resolution = Image\ Resolution = 2 * \ Field\ of\ View(FOV)/\ Search\ Area$$

For Sony FCB-IX, according to formula above, FOV value is 92° and smallest feature value is 1 meter. Image Resolution is 208 x 208 pixels and needed resolution for obstacle is 40x40 pixels. Thus, our camera can support ODLC mission (720x600 pixels).

$$Scanned\ Area\ \ = 2 * \ altitude * \ \tan(\text{angle of view}(\text{AOV}))$$

For selected camera, AOV value is 46° and ZD-01 ‘s speed is 15m/s so area that scanned is 76.4 meters. Our camera can take 15-meter-long land in 5 different photos, so objects can be found easier.

$$Focal\ Length * \ FOV = Sensor\ size * \ Working\ Distace$$

To receive objects, our camera’s FOV (92°), focal angle(4.2-42mm) and sensor size (4.54mm diagonal), minimum altitude to fly for ODLC mission is 90 meters.

Features	Sony A6000	Nikon D3200	Chameleon3	Sony FCB-IX 11 AP
Resolution	24,3 MP	24,3 MP	2.8 MP	2.3MP
Weight	343g	505g	54.9g	95g
Auto Focus	Yes	Yes	No	Yes
Dimensions	120x67x45mm	125x96x76,5mm	44x35x19.5mm	39x44x65mm
Price	550$	400$	595$	438$
Live Photo	No	Yes	No	Yes
Zoom	4x	3x	No	10x
Shutter Speed	1/4000 sec	1/4000 sec	1/8000 sec	1/10000 sec

Table 7: Camera Comparison

2.4.2. Gimbal

2 axis gimbal which is controlled with storm32 control board, was used to fix the camera angle and reduce the vibration. 2 brushless DC motors and 3D printed parts were used in gimbal system. Last year, camera was placed under the fuselage and this situation caused excessive drag, to damage camera during landing and increased required energy to stabilize camera. Therefore, gimbal and camera were placed inside the UAV to reduce these effects in this year**.** Also the team added some exclusive features to gimbal such as pointing on a specified coordinate to focus on region of interest(ROI).

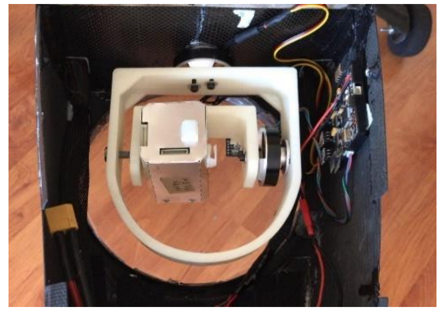


Figure 13: Gimbal System

2.5. Object Detection, Classification, Localization

2.5.1. Imaging Console

Imaging Console is an imaging interface that connects with Payload Box System (PBS) over 5.8 GHz frequency band via NanoStation and M5 Bullet. The Imaging Console is used to display location information of UAV, camera images and detected object information. It is also used to determine the gimbal angle and established an interop server connection. The interface is secured by user login panel. Autonomous detected object is monitored simultaneously from the Imaging Console. It also allows manual object detection if it is necessary.

Figure 14: Imaging Console Interface

2.5.2. Autonomous Detection

A new algorithm with deep-learning methods is developed. The object detection process consists of 3 steps.

- **Deep Learning Algorithm**

Deep learning algorithms are developed to detect objects during the flight. For this operation, Convolutional Neural Network (CNN) method is preferred. CNN is a deep-learning layer structure that is used to obtain trained data and interpret the data during the flight. To get the required sample images, test flights were carried out to obtain 120.230 frame within 8 hours. 12% of the received images consist of objects which need to be detected. The obtained trained-data is uploaded to the system on the purpose of object detection missions.

- **Geo-Location Calculation**

Localization of the detected object is completed after a long and complicated process. The location data of the aircraft is taken from the CBS. The position of the object on the image is calculated by mean of the pixels

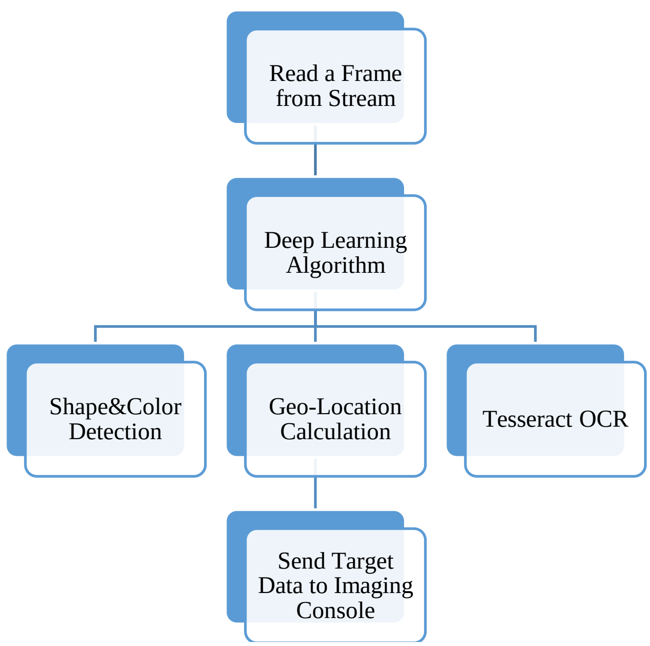


Figure 15: Deep Learning Algorithm

in which the object is photographed compared to the size of the photograph. Finally, a formula is obtained after adding the gimbal angle.

- **Shape and Color Detection**

The detected object is filtered by edge-detection processes and the area outside the object is deleted. This reduces the size of the image and makes the image-processing easier. The image shape is classified by KNN (K-Nearest Neighbors) Algorithm. KNN method was chosen because it has fast process time and high accuracy Moreover, images are converted from RGB color format to HSV color format because of its simplicity. It is determined which color range exists by choosing any of the pixels that are present.

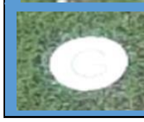
Target	Shape	Color	Letter	Letter Color	Comment
	75%	82%	56%	54%	The letter identify is difficult because the letter was near the edge lines.
	80%	85%	36%	47%	Difficult to identify characters because of the thin letters
	78%	89%	62%	67%	Overall good results
	32%	40%	55%	39%	Difficult to detect because of its small size and black color.
	81%	85%	12%	10%	Letter reading rate is too low due to sunlight shine

Table 8: Object Detection Test

- **Alphanumeric Detection**

The Tesseract OCR engine is used for alphanumeric character detection. This engine includes letters which are previously introduced to the related system. After the determination of the alphanumeric character, a color determination is performed.

Once the object detection process is completed, the image and its associated data are saved in the database where they are allocated. The data saved in the database is sent to the ground station to display in the Imaging Console.

2.5.3. Manual Detection

Continuous autonomous object detection procedures are followed from the ground station. If an object that appears in the photographs cannot be detected autonomously, the Imaging Console is used for manual detection. The object is marked on Imaging Console and manually entered alphanumeric, color and shape information. The information is stored in the database then sent to the Interop Server.

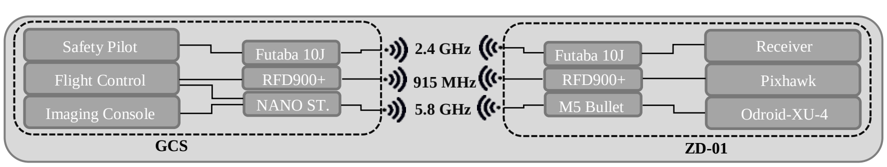
2.6. Communication

Undoubtedly, communication is one of the most important things for UAV, if data transfer is not provided properly then the aircraft cannot perform what is desired from it.

To give examples from this topic;

POSSIBILITIES	SOLUTIONS
• **Signal may reflect because of the carbon fiber**	✓ Attention to the position of the antennas
• **Excessive data**	✓ Using high bandwidth
• **Connection failed due to long distance**	✓ Using powerful aerials

Table 9: Possible failures



According to the result of analysis, the most suitable components are selected.

Figure 16: Block Diagram of Communication

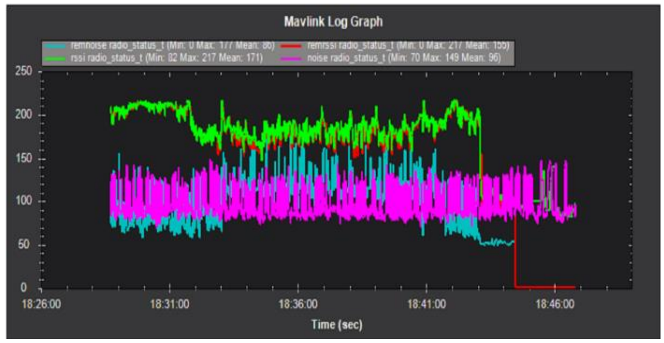
2.6.1. Safety Pilot Communication

Futaba 10J was chosen because after certain tests from last year, it was observed that Radiolink AT10II has not sufficient range and powerful signal. Also, Futaba has high quality in this market and it has high range capacity (2.45 mile). Device works on 2,4 GHz bandwidth.

2.6.2. Telemetry Communication

This link is used for telemetry connection between the Pixhawk and GCS. RFD900+ was selected for this part of the communication because its high range capacity (>40 km depending on selected antenna). Devices work on 915 MHz bandwidth.

Against any breakdown in communication we have done a 1.5 km test and team focused on telemetry signal power. Graph in **Figure 17** from the GCS shows that the change in telemetry power. Just in case, team took precautions about this subject by doubled communication link using the payload link. Pixhawk and Odroid XU-4 are connected as serial. If any trouble occurs in telemetry channel. These devices communicate by using MAVLink protocol. Pixhawk sends the telemetry data to Odroid XU-4 and it sends this data to GCS via M5 Bullet. **[4]**



Received noise on the aircraft

Received noise on the ground

Recieved signal on the ground

Recieved signal on the aircraft

Figure 17: Signal Power

2.6.3. Payload Communication

5.8 GHz bandwidth was chosen because of the excessive data. Furthermore, the payload data link must achieve high transfer rate because this link transfer images which has a big data size. This year these components were chosen which is shown in **Table 10.**

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	Ubiquiti Bullet M5
Dimensions	15,2x3,7x3,1 mm
Weight	180g
Frequency	5,8 GHz
Power Consumption	0,6W

	Ubiquiti Nanost. M5
Dimensions	294x31x80mm
Weight	400g
Frequency	5,8 GHz
Power Consumption	14,6-16,1 dBi

Table 10: Properties of Antennas

- **Antenna Tracker**

The GCS antennas must be relative to the aircraft position. To provide this, the team mounted the NanoStation M5 on the tracking platform. Platform is controlled with 2 servos. They receive the location of the aircraft from GPS. Arduino which is the controller of the platform, calculates the angles, platform heads towards to ZD-01. It also includes tail camera receiver. This link works on 5,8 GHz bandwidth.

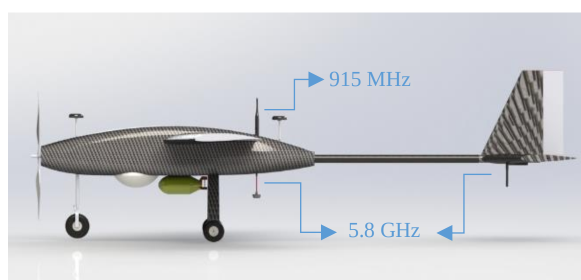

Figure 18: Locations of Antennas

Team gave much more importance to position of the antennas. Previous year, telemetry and payload antenna's position were on the side of the plane. When fuselage is between antennas, signal could be interrupted. Because ZD-01's fuselage made by carbon fiber as same as Huma's fuselage and carbon fiber creates faraday cage. To prevent this, all antennas were located as shown in **Figure 18**.

2.7. Air Delivery

2.7.1. Design

Firstly, the requirements were listed for this task. The system should be easily manufactured and detachable from the fuselage. It was located near the CG in order to keep the aircraft stable after the drop. To increase the accuracy of the airdrop system, a rapid and high-quality algorithm was developed. ABS (Acrylonitrile butadiene styrene) was used as a material for low weight and durability of the water bottle shell.

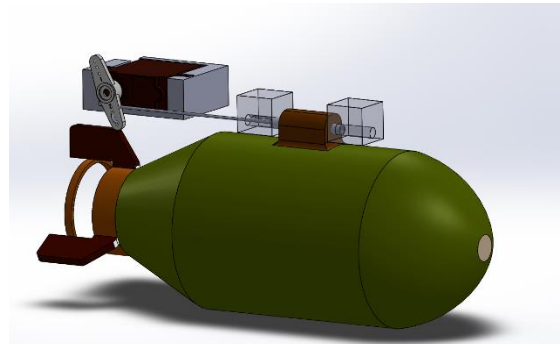

Figure 19: Air drop mechanism

The challenge that we had with the drop system was lack of space in the fuselage. To overcome the challenge, the drop system was designed in a simple and effective way. Also, it was placed outside the fuselage. The system consists of two 3D printed parts, servo, wire and fiberglass tube. It operates as shown in the **Figure 19.**

2.7.2. Algorithm

The algorithm works as described; when the airdrop mission is started, the Mission Planner starts to calculate the distance between the UAV and the airdrop position. This calculation is done with taking into consideration the UAV's speed, wind speed, altitude and the system delays. The separation is triggered by the servo mechanism when it reaches the airdrop range. Range is calculated by the algorithm with help of these formulas:

$$D = C_D * \varphi * V^2 * A * \frac{1}{2} \qquad t = \sqrt{\frac{2h}{(g - a_{drag})}} \qquad X = V_{UAV} * t - a_{drag} * \frac{1}{2} * t^2$$

2.8. Cyber Security

In our unmanned aerial vehicle, many security precautions and communication protocols are used in order to provide security in communication system.

COMPONENT	RISKS	MITIGATION	FALLBACK PLAN
Telemetry	Jamming	A second telemetry communication over 5.8 GHz is preferred.	Return to home plan of Pixhawk starts. If no connection in ten minutes, fail-safe landing occurs.
Wi-Fi Link	Spoofing	WPA/WPA2 security and encryption	None.
Wi-Fi Link	Monitoring	WPA/WPA2 security and encryption	If any monitoring is detected, database locks itself and secures the data.
RC Receiver	Hacking	RC transmitter and receiver are paired before competition, and FHSS prevents others from hijacking the link without knowing the initial seed.	Change the flight mode over the Mission Planner and continue the flight.
RC Receiver	Jamming	RC receiver is placed on the bottom of the airplane to guarantee the connection.	Change the flight mode over the Mission Planner and continue the flight
GPS	Jamming	Two GPS modules are placed on different places to make connection safe.	Airplane waits 3 mins. for connection. After that failsafe mode starts.

Table 11: Mission Table

3. Safety, Risks & Mitigations

Several sub-teams from different disciplines work together during manufacturing and integration of UAV. Throughout this process, there are many hazardous situations that may affect the health of team members and the efficiency of manufacturing. These risks are considered in detail at the beginning of the process. Thus, manufacturing has been tried to be completed successfully considering these risks. Lagari kept safety at the forefront, analyzed risks and took precautions according to those risks.

3.1. Development Risks & Mitigations

There might be accidents and injuries during the manufacturing and testing of systems. To avoid such situations, team leaders take necessary precautions to ensure the safety of all team members. A person named Turquoise Man was chosen for the flight tests. This person inspects the team's safety factors in manufacturing and testing and makes the necessary warnings. For instance, to remind you that in the engine test you have to stop 30cm from the propeller.

On the other hand, some problems such as equipment breakdown, faulty manufacturing or even an injury of a member may cause delays on the whole process. Thus, Lagari prepared a checklist which is applied before every-flight to ensure operability of the whole system. After testing all subsystems one by one, all subsystems has been integrated into the entire system. Some of important risks are shown in **Table 12**.

Risks	Explanation	Severity	Mitigation
Exposure to toxic chemicals during manufacturing	Exposure of chemical materials to chemical agents may cause injuries.	Medium	-Use of appropriate safety equipment, such as gas mask with canister, proper gloves, security glasses, etc.
Electric shocked	These devices may expose the team members to burning, injuries, and so on.	Medium	-Grounding were taken in critical tasks using electricity.
Contact with hot and sharp tools	They can puncture team members or aircraft.	Critical	-Sub-team leaders guide the team members on using of those equipment.

Table 12: Development Risk Management

3.2. Mission Risks & Mitigations

	Types of Risks	Risk Situation	Likelihood	Severity	Risk Factor	Mitigation
Competition Mission	Loss of RC link	Loss of signals leads to aircraft crash	Infrequent (1)	High (3)	3	-High power antennas preferred -Double RF receivers fixed on the bottom surface of fuselage. - Return To Launch mode initiated in case of 1 minute signal loss.
	Poor avoidance algorithm	Leads to mission failure	Rare (2)	Medium (2)	4	-Proprietary algorithm preferred to obtain the best avoidance method.
	Inaccuracy of GPS Data	The aircraft cannot properly orient and reach the desired location.	Rare (2)	High (3)	6	-Double blended GPSs with EKF algorithm. -Double GPSs located as far away from magnetic fields as possible.

Autonomous Flight	Loss of power to Pixhawk	Complete loss of control of aircraft leading to crash.	Infrequent (1)	High (3)	3	-Triple redundant power to autopilot by power module, BEC to servo and USB from Payload Box
	Failure of avionic components	It leads failure of flight or even any crash.	Frequent (3)	High (3)	9	-Two avionic boxes named payload box and control box were designed to reduce any failure.
	Failure of Autonomous Control Algorithm	Insufficient autonomous flight	Infrequent (1)	High (3)	3	-Backup autonomous flight mode embedded into Pixhawk as a fail-safe mode.
Testing	Cable connectivity error	A cable fault that occur during flight may cause the aircraft to crash.	Frequent (3)	High (3)	9	-Connector and cable assemblies fitted in the fuselage. -Sockets used at the ends of the cable.
	Damage to Li-Po Batteries	It may cause fire in the UAV.	Frequent (3)	High (3)	9	- Covered Li-Po Batteries with a hard plastic material to make them rigid. - Insulated cells with a nonflammable rubber.
	Vortex wind druing landing	It can cause damage on landing gear or fuselage	Infrequent (1)	High (3)	3	-Using strengthened and spare landing gear and fuselage.

Table 13: Risk Management

Likelihood factors are rated as Frequent, Rare and Infrequent. Severity is rated as High, Medium and Low respectively numbering as 3, 2, 1. Following calculation is manipulated (Risk factor = Likelihood x Impact). If risk factor is less than 3, it is acceptable for risk management. Otherwise it is unacceptable and a specific mitigation is needed

4. Conclusion

This paper summarizes a work done by students from the Mechatronic Engineering Department of the Yildiz Technical University in preparation for the AUVSI SUAS 2018. Throughout the year, the Lagari designed, developed and tested the ZD-01 system with an improved software for payload control and an enhanced hardware for flight control. Advanced algorithms were written to accomplish competition tasks. Numerous ground and flight tests were conducted to confirm the UAS capabilities and assured its excellence in the SUAS competition.

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