SRM-UAV

AUVSI SUAS 2015 JOURNAL PAPER

Figure 1: Team SRM-UAV with its graduating seniors

SRM-UAV, a student led research team at SRM University, Kattankulathur, India aims to participate in AUVSI's SUAS 2015 competition with its *Dabang* Unmanned Aerial System.
The system consists of a fixed wing aircraft controlled by the APM: Pixhawk autopilot system. There are two more onboard computers apart from the autopilot systems which are used to control the payload and mission specific subsystems. The imagery is obtained through a Canon 1100d DSLR camera, a FLIR Tau 2 thermal camera, a Sony 1/3 inch CCD camera and a Logitech BCC90 webcams. The system is capable of performing autonomous takeoff, landing, waypoint navigation while localizing and characterizing visual and IR targets on the ground and act as a Simulated Remote Information Centre (SRIC). It can also perform payload delivery to designated GPS locations. The autopilot enables the system to change its mission plan mid-flight to search for any emergent targets.

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1. Introduction

SUAS 2015 will be the first international competition for this two year old team comprising entirely of undergraduate engineering students. The aircraft used is largest one designed by the team till date. Also, this is our first aircraft which uses an Internal Combustion engine as its power plant.

2. Systems Engineering Approach

The entire system was designed to ensure the successful execution of the mission objectives without undermining the safety. Each subsystem was specifically chosen and designed according to the mission requirements.

3. Design Rationale

3.1 Aircraft

In preparation for SUAS 2015, SRM-UAV designed new airframe. The aircraft is a pusher configuration with a wingspan of 2.5m. It was designed to suite mission specifications and allow payload expansion which makes it useable for future projects. The tasks required the aircraft to be maneuverable with the ability to make bank turns of small radii and achieve rapid climb and descent. The estimated time to fabricate the aircraft with Carbon Fiber composite was calculated to be two months which would have left the team with very little time for testing and systems integration. The design was analyzed on ANSYS for its structure as well as airflow over the surfaces. The design was constantly iterated until desired results were achieved.

Due to budgetary and time concerns, it was decided to use a ready to fly airframe and therefore, a literature survey of ready to fly airframes with similar specifications which were suitable for carrying mission specific payloads was done.

Figure 2: Original Design of the Aircraft

3.2 Autopilot

The UAS uses the off the shelf Pixhawk autopilot from 3DRobotics Inc. This is a highly reliable and tested autopilot with thousands of users and developers around the world. Team SRM-UAV has immense developer experience with both the older Ardupilot as well as Pixhawk. Both these autopilots proved to be user friendly and easy to modify. Pixhawk was chosen because of its faster ARM processor over the Arduino based Ardupilot. Pixhawk also has support for redundant sensors which enhance its reliability and system safety.

3.3 Engine

The UAV uses a 2-stroke Internal Combustion gasoline engine as its power plant. The requirements from the engine were a high power output at minimum weight and compact size for higher endurance and more space for the subsystems. The fuel supply and the placement of the fuel tank was designed such that there is a constant fuel supply to the engine in any orientation of the aircraft. The constant fuel supply prevents the engine from stalling mid-air which ensures the safety of the entire system.
An engine starting mechanism is also used to restart the engine in case it stalls during the flight.

3.4 Payload

The wide range of tasks required the payload systems to work in coordination with the Pixhawk autopilot and perform a variety of operations. Execution process for each task was worked out and required payload components were chosen. Two Cubietruck embedded computers will be used to control the payloads. The computers will be responsible for handling all onboard machine vision operations, payload dropping, storing data for actionable intelligence task, geotagging images, storing of infrared images and SRIC task. The payload is designed to be highly reliable and robust. It is capable of functioning even in case of partial system failure as different payload systems are isolated from each other in functionality.

As machine vision is a highly CPU intensive process, one of the computers will be solely dedicated towards this and geotagging of images while the other one handles the remaining processes.

3.5 Imagery

Imagery of both visible spectrum targets and infrared spectrum targets is an essential requirement of the competition. Since, most of the tasks are related to imagery, proper selection of cameras was vital. The requirements from the cameras were high resolution images at fast shutter speeds and high brightness without distortion. Three electro-optical and 1 thermal camera will be used to obtain the photographs.

Still imagery is captured from a Canon DSLR camera. This will be gimbal stabilized along the roll and pitch axis and pointed vertically downwards. These images will be stored in a SD card and will be used for manual identification of target objects.

A Logitech webcam will be used for onboard machine vision to detect the various characteristics of the targets.

A Sony 1/3 inch CCD camera which is mounted on a manually controlled gimbal is used to provide a First Person View for the pilot to take control in case of emergencies. This camera will also be used to capture the off-axis target.

The thermal camera is also pointed downwards and its imagery is stored as well as fed into the onboard computers for automated characteristics identification.

3.6 Communication Systems

Communication Systems play a vital role in the functioning and safety of a UAS. Considering the size of the Navy Air Base, a long range solution was required. Hence, a communication system was designed to provide a communication link with the ground station for up to 10 kilometers. It consists of four different links from the UAV to the ground control station.

These links include autopilot telemetry data, first person view live video feed, pilot remote control and SRIC and payload communication link.

3.7 Air Drop

The air drop system was specifically designed while keeping safety as a priority. Care was taken to prevent any unintentional releases of the package. To ensure this, a manually actuated mechanism was used in conjunction with an autopilot actuated release mechanism.

The manually actuated mechanism consisted of mechanical linkages attached to two servo motors. These linkages are placed such that without any manual actuation, even if the autonomous actuation takes place, the package will not drop as manually actuated mechanism prevents the doors from opening.

The autonomous release mechanism is electromagnetically actuated directly by the on board computers on reaching a designated GPS location.

3.8 SRIC

SRM-UAV will aim to complete only the threshold of the mission which requires the aircraft to download an image at the SRIC server. A remote desktop connection between the ground station and an onboard computer. The communication will take place through an ASUS RT-N12HP Wi-Fi Router.

4. UAS Block Diagram

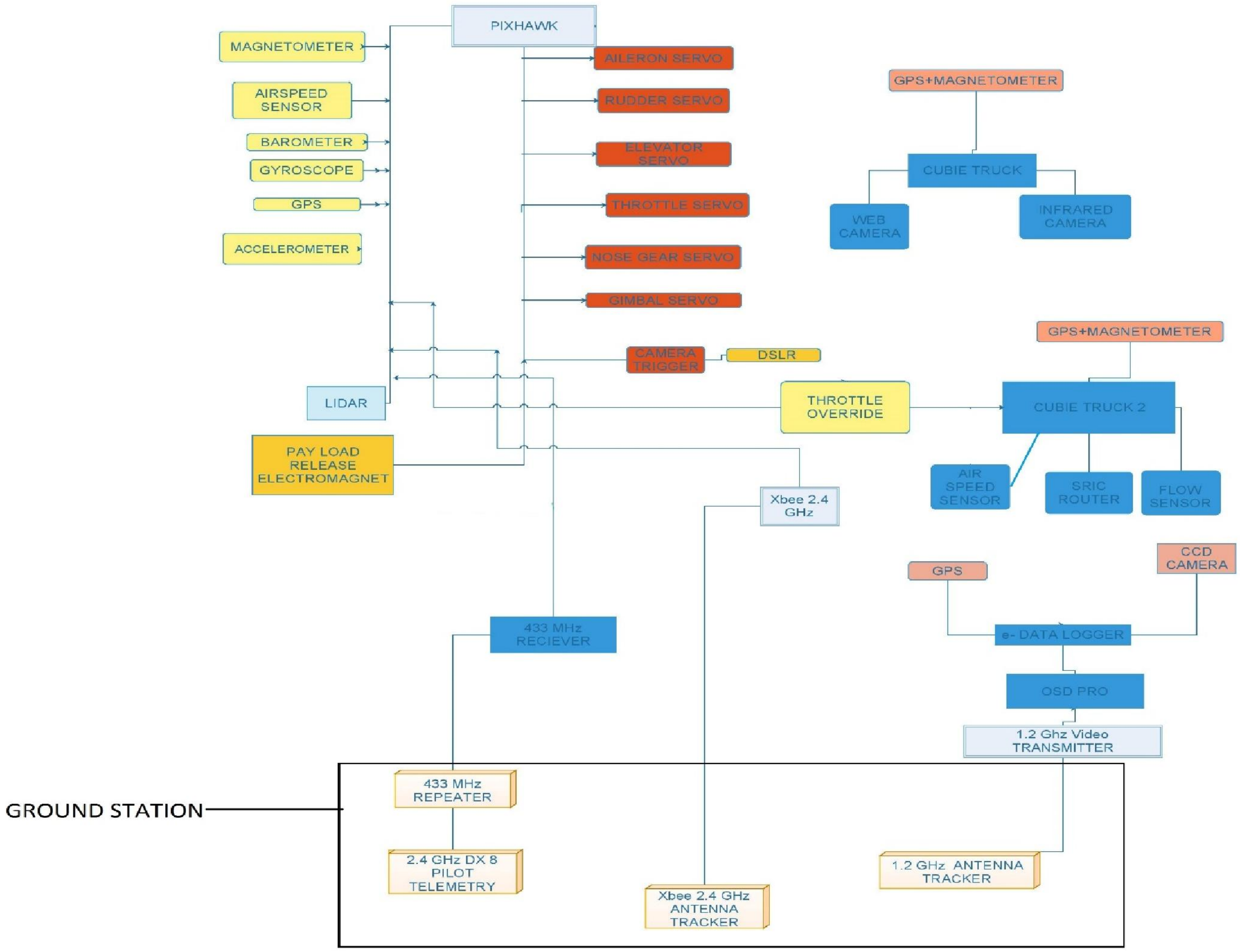

Figure 3: Subsystems Block Diagram

5. UAS Design

5.1 Aircraft

The aerial vehicle chosen as per the design rationale is a Mini Mugin 2.6m. It is a pusher type, twin-boom airframe with a wingspan of 2.6 meters with conventional takeoff and landing.
The pusher configuration ensures a direct flow over the empennage and provides more space inside the fuselage. The pusher configuration also prevents the engine exhaust from flowing into the view of the camera.

Figure 4: Mini Mugin 2.6m at the airstrip

The fuselage of Dabang is made up of fiberglass composite and balsa wood. It uses a nose steering tricycle landing gear of carbon fiber.
The wing is easy to assemble, attached to the fuselage with fasteners near the trailing edge.
The twin-booms are made up of carbon fiber and are attached to the underside of the wing using fasteners.
An H-Tail is used to avoid flow disturbances on the horizontal and vertical stabilizers. Several structural modifications were made to the factory fabricated airframe to ensure crash sustainability and durability.
Areas with high stress concentration were mapped and were strengthened by custom made carbon fiber parts. These areas include landing gear, nose cone, airdrop bay, camera attachment locations, points of attachment of twin booms to the wings and underbelly of the fuselage.

This helped increase the operational life of the system while adding just a small amount of weight.
Custom made laser-cut plywood boards were used to create sections inside the fuselage for easy and rigid placement of subsystems, autopilot and batteries.

The design specifications of Dabang compared with the team's original design are listed in the table given below:

Specifications	**Design Value**	**Mini Mugin**
Length	2.05 m	2.05 m
Wingspan	2.5 m	2.6 m
Wing Chord	34 cm	34 cm
Wing Area	.85 m^2	0.884 m^2
Empty Weight	4.7 kg	6.5 kg
Payloads	4 kg	4 kg
Fuel Weight	4.26 kg	4.26 kg
Maximum Takeoff Weight	13 kg	15 kg
Cruise Speed	100 Km/Hr	120 Km/Hr
Stall Speed	35 Km/Hr	35 Km/Hr
Endurance	100 minutes	120 minutes

Table 1: Aircraft Specifications

The fuselage of Dabang is made up of fiberglass composite and balsa wood. It uses a nose steering tricycle landing gear of carbon fiber.
The wing is easy to assemble, attached to the fuselage with fasteners near the trailing edge. The twin-booms are made up of carbon fiber and are attached to the underside of the wing using fasteners.
A T-Tail is used to avoid flow disturbances on the horizontal and vertical stabilizers. Several structural modifications were made to the factory fabricated airframe to ensure crash sustainability and durability.
Areas with high stress concentration were mapped and were reinforced with custom made carbon fiber parts. These areas include landing gear, nose cone, airdrop bay, camera attachment locations, points of attachment of twin booms to the wings and underbelly of the fuselage.
This will increase the operational life of the system with the addition of just a small amount of weight.
Custom made laser-cut plywood boards were used to create sections inside the fuselage for easy and rigid placement of subsystems, autopilot and batteries.

5.2 Propulsion System

DLE-30, 2-stroke gasoline engine will be used as the propulsion system for *Dabang*. The engine has an electronic ignition system for better performance and easy starting.
The system makes use of a pumper carburetor which consists of a diaphragm attached to the crank shaft. This diaphragm sucks the fuel from the fuel tank thus, preventing the engine from stalling.

Specification	**Value**
Displacement	30.5 cc
Bore	36 mm
Stroke	30 mm
Weight (Including Engine, Muffler and Ignition)	1.1 Kg
Power Output	3.7 HP
Type of Ignition	Electronic
No. of Cylinders	1
Fuel Tank Capacity	6.3 L
Fuel	Gasoline
Type Of Carburetor	Walbro Diaphragm Carburetor
Propeller	19x8

Table 2: Propulsion System Specifications

Figure 5: Engine

Figure 6: Ignition System

The crank shaft of the engine is connected to a DC motor by means of a gears and a clutch mechanism. This system is used to restart the engine in case of any midair engine failures. This also provides scope for use as an alternator to generate power for subsystems and recharge batteries during flight which is still under research.
The engine restart system is fully autonomously controlled by the Cubietruck on-board computer. It utilizes a flow sensor attached to the fuel supply line. When the rate of flow drops below a threshold, the clutch mechanism is engaged and the motor is run for a fixed duration to restart the engine.

5.3 On-Board Computing

Onboard computers refers to all embedded computers apart from the autopilot which will be used to perform tasks which are not essential for aircraft to fly but are essential for the mission tasks.
Two Cubietruck embedded computers running Lubuntu, a Linux based operating system will be used.

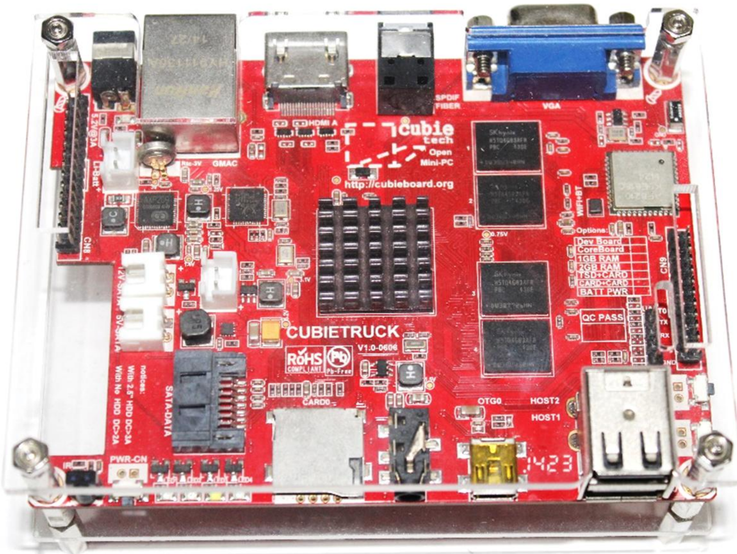

Figure 7: Cubietruck Computer

The tasks performed by two computers are as follows:

- Image processing (For electro optical as well as IR camera)
- Simulated Remote Information Center (SRIC)
- Engine Starter Motor Control
- Storing off-axis target images
- Package Drop
- Actionable Intelligence Task Data Transfer

The specifications of the Cubietruck computer are as follows:

Processor	ARM Cortex-A7
Graphics Processing Unit	Mali-400 MP2
RAM	2 GB DDR3 at 480 MHz
Memory	8 GB Built-in NAND, Micro SD slot, SATA 2.0 port
Connectivity	LAN port, Onboard Wi-Fi adapter, 2 USB ports

Table 3: Onboard computer specifications

5.4 Communication Systems

The UAS uses 4 communication links in total at different frequencies to avoid interference. The system is designed in order to provide a communication range of up to 10 kilometers.
The details of the communication system are shown below:

Link	**Frequency**	**Module**	**Ground Station Antenna Tracker (Yes or NO)**	**Ground Station Antenna**	**Onboard Antenna**	**Power**	**Direction of Link**	**Purpose**
Autopilot Telemetry	2.4 GHz	XBee Xstream	Yes	Parabolic Grid 24 dBi , Whip 15 dBi	Whip 5 dBi	50mW	Uplink and Downlink	To get live data from autopilot and send mission specific commands.
Wi-Fi	2.4 GHz	Asus RT-N12HP Wi-Fi Router	No	Whip 15 dBi	2 x 5 dBi Whip		Uplink and Downlink	For SRIC task and to download image Characteristics for Actionable Intelligence task.
First Person View	1.2 GHz	Video Transmitter	Yes	Patch 14 dBi	Whip 5 dBi	800mW	Downlink	For live First Person View to the pilot and off-axis task.
Pilot Telemetry	433 MHz	Arkbird Repeater	433MHz	No / Whip 5 dBi / Whip 5 dBi	1400mW	Uplink	For long range Pilot control.	

Table 4: Communication System

5.5 Autopilot

Pixhawk autopilot from 3DRobotics Inc. is used to control the UAS. This gives it the ability to perform autonomous takeoff, landing, navigation and camera gimbal stabilization.
The autopilot is connected to auxiliary sensors like LiDAR, GPS, Magnetometer, Pitot tube and a two way telemetry from the ground control station to obtain real time status of the aircraft as well as send mission related commands.
The LiDAR enables highly accurate altitude measurement for up to 40 meters. This helps improve the takeoff and landing performance and softens the impact on landing which enhances the life of the airframe.

Figure 8: Mission Planner Software

GPS and Magnetometer are used to detect the aircraft's position and heading which are essential for autonomous navigation.
The Pitot tube is used for accurate airspeed measurement thus, preventing the aircraft from stalling due to low airspeed. It also helps the aircraft maintain the most efficient airspeed which enhances its performance.
The autopilot is equipped with redundant GPS and power supply. In case of a weak signal or failure of one GPS receiver, the other one can take over in order to safely complete the mission and bring the plane back to the ground.
The autopilot along with its independent power supply is also powered through the servo motors so that even if the autopilot battery drains out, it can be powered through the avionics battery.
It is also equipped with a separate failsafe processor. In the event of a communication loss from the ground station or low battery, the UAV can be pre-programmed to return back to its take-off location and land itself.
If it is required to contain the aircraft in a particular airspace, a no-fly zone can be created. If the aircraft goes across this area, it is automatically commanded to return to take-off location.

5.5.1 Software in the Loop Simulation (SITL)

Before actual flight of the aircraft, the autopilot was tested on JSBSim software. The SITL simulation virtualizes the autopilot hardware and environment. It is an extremely useful tool for fast and safe testing.
SITL was used on a Linux based computer. It communicates with the autopilot hardware using MAVProxy protocol and commands can be given through mission planner.

The systems which were simulated through SITL are:

- Automated Takeoff
- Automated Navigation
- Automated Landing
- Response on contact with no-fly zone
- Response during failsafe

Various parameters controlling the aircraft behavior in the above mentioned tasks were studied, tested and iterated until satisfactory results were obtained which were later used in actual flights.

4.6 Ground Control Station (GCS)

The ground control station was designed for easy transportation and lightest possible and minimal equipment required for a high performance, long range UAS. The UAS is designed to be fully autonomous and thus requires almost negligible human interference during flight.
The ground station equipment consists an autopilot terminal, a payload terminal, a radio transmitter for pilot control, an LCD screen, two antenna trackers and three antenna stands.

The antenna trackers and mounts are designed to be portable and are made up of light weight Carbon Fiber composite.

In total the ground station can be operated by only four people. The personnel required at the ground station include one person responsible for monitoring the autopilot status and mission planning, one pilot, one payload operator and a person to monitor overall communication systems. All ground station equipment is powered by a portable inverter which makes it robust and operable in remote areas.
The antenna trackers are fully autonomous and work on the basis of Received Signal Strength Index (RSSI) and relative GPS and altitude of the aircraft and GCS.

Figure 9: Ground Station

The autopilot telemetry, being the most vital communication link makes use of dipole antenna along with the parabolic antenna linked through a diversity controller. This controller is used to switch between the antennae depending on the signal strength. This feature improves close distance communication link with the autopilot and enhances the overall safety of the system.

5.7 Image Analysis

The image processing is performed on OpenCV using Python. All this processing takes place on-board the aircraft.

The image processing algorithm follows the following techniques:

- Image De-blurring

  As the aircraft will be moving at a high velocity during the clicking of the photos, image de-blurring is the first step in image enhancement.
  Weiner deconvolution filter is used to remove motion blur from the images. It works in the frequency domain, attempting to minimize the impact of deconvolved noise at frequencies which have a poor signal-to-noise ratio.

$$G(f) = \frac{H^*(f)\, S(f)}{(H(f))^2\, S(f) + N(f)}$$

  Where:
  G (f) and H (f) are Fourier transforms of g and h at frequency *f*
  S (f) is mean power spectral density of input signal *x (t)*
  N (f) is mean power spectral density of noise *n (t)*
  Superscript * denotes complex conjugation

- Smoothing

  Image smoothing is done using a Kalman Filter.

$$x_k = F_k x_{k-1} + B_k u_k + w_k$$

  Where:
  F_k is the state transition model which is applied to the previous state x_{k-1}
  B_k is the control input model which is applied to control vector u_k
  w_k is the process noise which is assumed to be drawn from a zero mean multivariate normal distribution with covariance Q_k
  $w_k \sim N(0, Q_k)$

- Target Segmentation

  A graph-cut based technique is used to separate the target from its background.

- Template Matching

  The extracted image is matched with pre-loaded templates and is sorted out based on its type (QR code, IR image, Visual Range Target).

- Quick Response Code

  OpenCV library, *ZBar* is used to decode QR codes.

- Color Identification

  If the target is of visual range, color identification is performed. This is perform by generating a Hue Saturation Value (HSV) histogram. The highest peak of the histogram identifies the background color and the second highest peak identifies the color of the letter.

- Shape Recognition

  Contour detection on a binary image is performed for shape identification.

- Optical Character Recognition

  Tesseract OCR is trained to read the character sets of a variety of commonly used fonts. This is then used to detect alphanumeric characters on the targets.

- Target Localization

The GPS coordinates of the center of the image are known and from these, the exact location of the object will be calculated.
The data required for the calculation is coordinates of the center of the image, altitude and heading. All this data will be collected from sensors such as GPS, barometer and magnetometer which are connected directly on the Cubietruck.

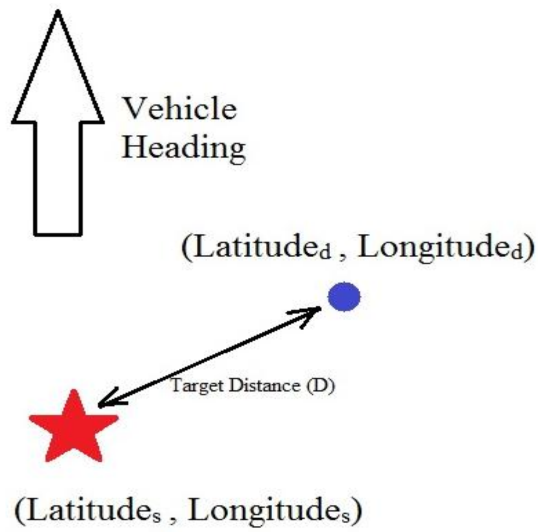

Figure 10: Target Localization

$$latitude_s = a\sin((\sin(latitude_d) * \cos\left(\frac{D}{R}\right)) + (\cos(latitude_d) * \sin\left(\frac{D}{R}\right) * \cos(heading)))$$

$$longitude_s = longitude_d + \operatorname{atan2}(\sin(bearing) * \sin\left(\frac{D}{R}\right) * \cos(lattitude_d), \cos\left(\frac{D}{R}\right) - (\sin(lattitude_d) * \sin(lattitude_s))$$

5.8 Image Acquisition

The aircraft image acquisition system consist of three electro-optical and one thermal camera.
Still images are captured by a Canon 1100d DSLR for manual analysis after landing of the aircraft. This camera is mounted on a roll stabilized gimbal. The gimbal is operated in *Nadir* mode such that the camera is always perpendicular to the ground. The DSLR camera provides high quality images for easy identification and classification of the targets.
A Logitech BCC90 webcam is used for onboard image processing. The imagery from this is directly fed into the on-board computer which processes the images for classification of target features. This operation is done autonomously by the Cubietruck on-board computer.
A FLIR Tau 2 thermal camera is used to detect the infrared targets. This camera is also directly connected to the Cubietruck for image processing and feature identification. The IR photographs will also be stored in the onboard memory for manual analysis.
A Sony 1/3 inch CCD camera is used to provide li First Person View at the ground control station so that the pilot can take control of the aircraft in case of any emergencies. This camera is mounted on a manually controlled gimbal and will also be used for the Off-Axis Task.

Figure 11:Canon 1100d

Figure 12:FLIR Tau 2

Figure 13:Logitech C930E

Figure 14:Sony 1/3 inch CCD

5.9 Air Drop Task

The entire airdrop task is completely automated and is processed by the Cubietruck computer.

A wind tunnel test of the toy egg was performed to calculate its coefficient of drag.

The aircraft will be flown in a direction perpendicular to the direction of drop in order to measure the crosswind with an airspeed sensor.

This data is fed into the Cubietruck which will calculate the deflection due to crosswind, trajectory range and will estimate the GPS coordinate of the release location.

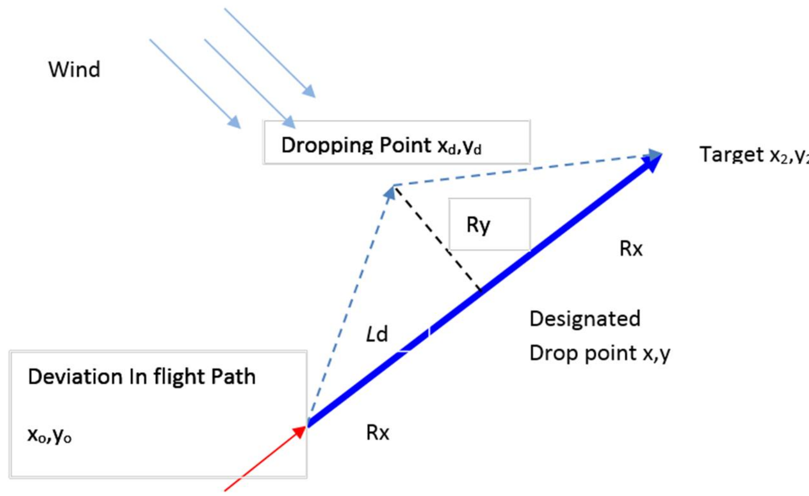

Figure 15: Air Drop Task

A manual failsafe mechanism made up of linkages controlled by servo motors is used to enhance system safety and prevent accidental drops.

The main actuation of the package is performed by an electromagnetic release mechanism which is actuated through the autopilot when commanded by the Cubietruck.

The mechanism is designed in such a way that without the release of the manual failsafe the electromagnetically actuated release pin will not move. Thus, preventing an accidental drop.

Electromagnets are used as they have a lesser lag as compared to other actuation techniques which enhances the accuracy of the drop.

$$V_t = \sqrt{\frac{M * g}{0.5 * \rho * s * C_d}}$$

Equation 1: To calculate terminal velocity of the egg

$$R_x = \frac{V_{0x} * V_t}{g}$$

Equation: To calculate range of trajectory

$$R_y = \frac{V_{0y} * V_t}{g}$$

Equation: To calculate lateral shift due to wind

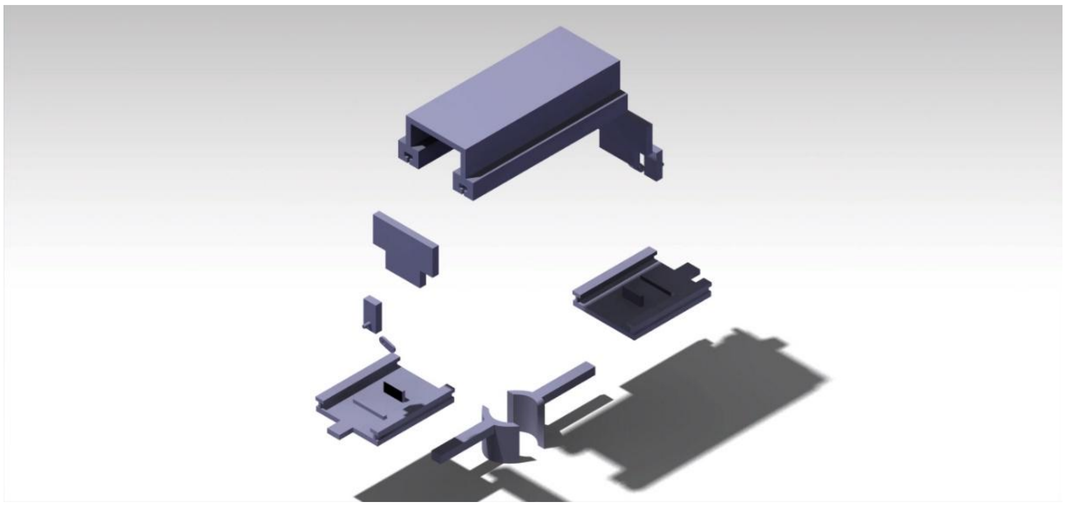

Figure 16: Air drop mechanism

5.10 Power Supply System

The power system consists of two separate batteries. One battery will be used to power the autopilot and payload systems while the other one will power avionics.
For the autopilot and payload systems 4-cell 1000 mAh Lithium polymer battery is used which supplies the various payloads through independent voltage regulator circuits. The avionics will be powered by a 2-cell 1800 mAh Lithium polymer battery. A separate 6 Volt, 300mAh NiMH battery will be used to power the engine electronic ignition system for the gasoline engine.

In total the power system is designed to supply constant power to the subsystems for a period of 100 minutes at 80% discharge which is the safe limit for Lithium Polymer batteries.

5.11 Simulated Remote Information Center

The team would aim to meet the threshold criteria for the SRIC task.
Thus, a photograph/text file will be uploaded from the ground station to the onboard computer and from that it will be downloaded on the SRIC server.

The data transfer is performed manually from the ground station with the help of a remote desktop connection to the onboard computer.
The data will be transferred from the aircraft to the SRIC server after manually logging in and establishing a connection with it.
During the transfer process, the aircraft will be made to loiter above the SRIC to maintain the payload within the communication range.

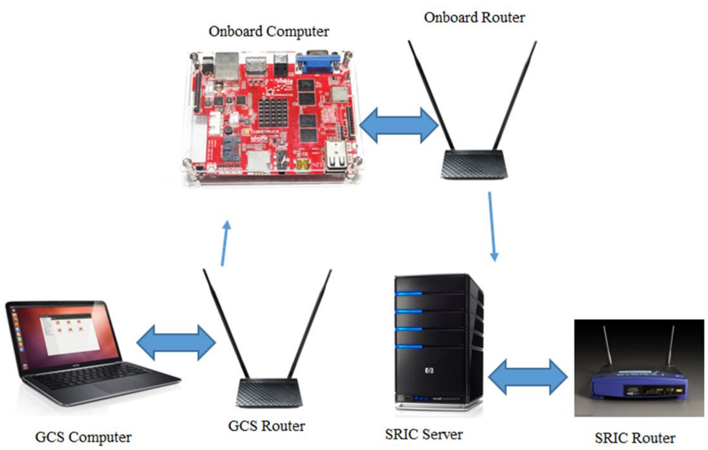

Figure 17: SRIC Data Flow

5.12 Actionable Intelligence Task

The actionable intelligence task requires the UAS to autonomously detect characteristics of the targets with an accuracy of $\pm$ 75 feet and send them to the ground while still in the air.
After the characteristics of the images are analyzed, the images will be stored in the onboard memory. The characteristics (GPS location, shape, alphanumeric etc.) will be saved in a separate text file.
Before landing, the aircraft will be made to loiter over the runway and these images and files will be downloaded to the ground station by means of the Wi-Fi adapter on the onboard computers. These images and their properties will be compiled and submitted for judging.

6. CONCLUSION

Team SRM-UAV from SRM University, Kattankulathur, India, in its maiden attempt to step into international light at SUAS 2015 has designed and tested its aircraft with a systems engineering approach in accordance with the mission requirements for the competition. The UAS is capable of completing the mission objectives as given by the competition problem statement. Extensive testing and iterations were performed on the airframe, payload systems and software in order to achieve the desired results which boosts the team towards successful completion of nine out of eleven mission tasks which are specified in the competition rules. Despite being the first attempt with all the hard work and time to account for, the team has good hopes to get through the competition with flying colors.

AIM HIGH. FLY HIGHER.

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