SRM-UAV

UAV CHALLENGE

MEDICAL EXPRESS-2016

DELIVERABLE 2

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3. Statement of Originality and Accuracy

We declare that this report is entirely the work of the team members listed below, and has not previously been submitted by us, or others for this challenge or any other similar event.

We have acknowledged external material with appropriate references, quotes or notes to indicate its source.

We declare that this report is an accurate record of activities carried out by us in preparing for this specific challenge. The events, data and other material contained within this report actually occurred and have been fully detailed.

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Ananth Karthikeyan (Fabrication Engineer)

4. Compliance Statement

Team Name: SRM-UAV

We declare that this report and the entry that it describes complies with the rules of the 2016 UAV Challenge, and that we enter with the intention of competing in the spirit of the challenge. Specifically we declare that our entry is compliant with the following topics and provide reference to within our Deliverable 2 document were our method of compliance is described:

Rules Reference	Topic	Compliance	Deliverable 2 reference
Mandatory / Essential *Non-compliance in this section will result in a No-Go finding unless there are significant and/or extenuating circumstances. Please read the rules in detail.* *If using two aircraft ensure both aircraft are considered and Deliverable 2 references are provided for each aircraft if necessary.*			
1.6	Maximum of two aircraft for the mission	✓ Compliant	5.Executive Summary
3.1.1	Must not be a commercial off-the-shelf complete system	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8. System Design
3.1.1	Must be capable of autonomous flight	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	5. Executive Summary
3.1.1	Must have a maximum gross weight of less than 100 kg (rotary) or 150kg (fixed wing)	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	6.Introduction and design approach
3.1.1	Must have continuous telemetry radio communication with the UAV Controller	□ Support aircraft Compliant	8.f. Radio equipment and frequency to be used and relevant licenses
3.1.1	Must have an easily accessible E-Stop to render the aircraft deactivated	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8.a System Diagram
3.1.1	Must have an external visual indication of state (armed, inert, disarmed)	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8.a System Diagram
3.1.1	Must have an arming switch	✓ Retrieval aircraft Compliant	8.a System Diagram
3.1.3	Must implement automatic (on-board) detection of crossing a Geofence Boundary	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8.e Geofence System design
3.1.4	Must include a flight termination system meeting all conditions	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8. c. Flight termination system design state machine diagram and transitions and 8.d. Analysis of the flight termination system
3.1.5 & 5.3.2	Flight termination method described and analysis provided of maximum distance outside Geofence	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8.d Analysis of flight termination system
3.1.6	All criteria for flight termination must result in immediate activation of flight Termination	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8.d Analysis of flight termination system
3.2.1	Flight in the Transit Corridor and Remote Landing Site must be Autonomous	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	5. Executive summary and 7. Landing Site Analysis Strategy

Rules Reference	Topic	Compliance	Deliverable 2
3.2.2	Must have a ground control station that provides a graphical display	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8.a System Diagram (autopilot telemetry)
3.2.2	Must provide an NMEA data feed from the ground station	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8.a System Diagram
3.2.3	Communication equipment must comply with ACMA regulations	✓ Compliant	8.f Radio Equipment And Frequencies
3.3.2 & 5.3.2	AMSL altitudes will be measured and reported as pressure altitudes	✓ Compliant	8.b Aeronautical Requirements
3.3.3 & 5.3.2	Correct aeronautical units used	✓ Compliant	8.b Aeronautical Requirements
3.3.3	Description of how aircraft will be maintained within its airspeed Envelope	✓ Retrieval aircraft Compliant □ Support aircraft Compliant	8.b Aeronautical Requirements
3.4.5	Pyrotechnic mechanisms have safety manual provided	□Compliant ✓Not Applicable	**NA**
5.2	Disclosure of sponsors and funding Sources	✓ Compliant	5. Executive Summary
5.3.2	Statement of originality and accuracy Included	✓ Compliant	3. Statement Of Originality and Accuracy
5.3.2	Executive summary provided	✓ Compliant	5. Executive Summary
5.3.2	Introduction and design approach Provided	✓ Compliant	6.Introduction and Design Approach
5.3.2	Landing site analysis strategy provided	✓ Compliant	7. Landing Site Analysis Strategy
5.3.2	System Diagram provided	✓ Compliant	8.a. System Diagram
5.3.2	Flight termination system design, state machine diagrams and transitions Provided	✓ Compliant	8.c. Flight termination system state machine diagrams and transitions
5.3.2	Geofence system design provided	✓ Compliant	8.e. Geofence System Design
5.3.2	Radio frequencies to be used and relevant licenses provided	✓ Compliant	8.f. Radio equipment and Frequencies Associated
5.3.2	Updated risk assessment provided	✓ Compliant	9.a. update Deliverable 1 risk assessment
5.3.2	Assessment of the risks associated with autonomously taking off and landing provided	✓ Compliant	9.b.risk with autonomous VTOL

5.3.2	Risk Management provided	✓ Compliant	10. Risk Management
5.3.2	Details of the system response to loss of data link provided	✓ Compliant	10.a.1 Response to loss of data link
5.3.2	Details of the system response to loss of GPS provided	✓ Compliant	10.a.2 Response to loss of GPS
5.3.2	Details of the system response to lock-up or failure of autopilot provided	✓ Compliant	10.a.3 Response to autopilot lockup
5.3.2	Details of the system response to lock-up or failure of the GCS provided	✓ Compliant	10.a.4 Response to lockup of GCS
5.3.2	Details of the system response to loss of engine power provided	✓ Compliant	10.a.5 Loss Of Engine Power
5.3.2	Details of fuel and/or battery management provided	✓ Compliant	10.b Fuel and Li-Po Management
5.3.2	Details of the management of other risks provided	✓ Compliant	10.c Management Of Other risk
5.3.2	Flight tests results provided	✓ Compliant	11. Flight Test result and discussion
5.3.2	Conclusions provided	✓ Compliant	12. Conclusion
5.3.2	Video provided showing the retrieval aircraft autonomously landing and taking off	✓ Compliant	5. Executive Summary

Rules Reference	Topic	Compliance	Deliverable 2 Reference
5.3.2	Video provided showing the teams pre-flight set up and checks	✓ Compliant	5 Executive Summary
Highly Desirable			
7.2	"Soft Geofence"	☐ Implemented ✓ Not Implemented	
5.3.2	Deliverable 2: Max 23 pages.	✓ Compliant ☐ Non-Compliant	

Date: 12 APRIL 2016

Signed by a team representative, on behalf of all team members:

Printed Name: Bharat Mathur (Team Leader)

5. Executive Summary

SRM-UAV is a student-led research team at SRM University, India. Our prime focus is to develop end to end solutions for civilian and military applications of Unmanned Aerial Systems. We aim to make UAVs smarter so they can be safely incorporated into the civilian environment.

We have a multidisciplinary team that consists of students from various branches of engineering such as Aerospace, Computer Science, Information Technology, Electrical, Electronics, Mechanical and Mechatronics which has helped us to push beyond boundaries to create a state of the art system for our first ever attempt at UAV Challenge.

In order to realize the rationale of this competition, that is to help develop UAV technologies for the future, we have incorporated a high degree of autonomy and onboard processing with prime focus on the safety of personnel and property on the ground as well as that of the aircraft itself. All flight related operations such as vertical takeoff, vertical landing, cruise and transition from VTOL mode to fixed wing and vice versa are autonomous; these are controlled by the flight controller. As all our operations happen onboard, the flight controller is considered as a low level computer that works in coordination (depending on flight situations) with higher level computers such as Machine Vision computer, Flight Termination System, Master Controller and Communications Computer.

The Flight Termination System was developed after considering all major risks that could pose a threat to people, property and the aircraft itself. It is made to react accordingly in case any of these risks realizes.

All aspects of the mission can be monitored and controlled from the Ground Control Station.

Our results from multiple test flights and subsystems testing have been promising and we are confident to give an electrifying performance at Medical Express Challenge. Our onboard Machine Vision System for detecting Joe has proved to be extremely successful with a high success rate.

We are a completely university funded team with generous sponsorship from:

- T-Motor www.rctigermotor.com
- 3D Robotics www.3dr.com
- Maxamps Battery www.maxamps.com

Our flight video satisfying the competition requirements as per Section 5.3.2 can be found at: **https://youtu.be/8VfNYTa-5t8**

6. Introduction and Design Approach

In order of priority, our airframe design and system architecture are based on satisfying competition requirements, flight and overall safety, to help develop UAS technologies in accordance with the aim of the competition and autonomy. We have developed a single vehicle system and no support aircraft will be used. The overall system weight is expected to be around 17-20 Kg.

We will be using *SRM-UAV H-2*, which is a coaxial hybrid quadrotor aircraft, for the competition. This is an enhanced version of the *SRM-UAV X-2* that has been the team's pride for over two years. The design was chosen while keeping in mind the absence of a runway at the base (as per version 1 of rule book) and remote landing sites. The aircraft is robust, highly maneuverable and has a long range. It is also capable of hovering and flying at low speeds during the search operation. Extensive analysis was performed using Computational Fluid Dynamics and Wind Tunnel tests to minimize flow interference between the quadrotor propellers and the wing and tail. This ensures optimal performance in both configurations.

H-2 being a coaxial quadrotor has a high level of redundancy to even survive failure of up to two motors. After multiple simulations, tethered tests and flights, the hybrid quadcopter was chosen over the other design that was proposed in Deliverable 1 (Hybrid Tilt Rotor) because it proved to be more stable hence, safer and reliable.

The aircraft that will be used is a modified version of Mini Mugin 2.6m. This aircraft is being used as it closely relates to our design and its commercial availability made it economically feasible.

Considering time and budget constraints, we have followed the open source approach by using all open source hardware. Our system architecture was designed with safety as the first priority. This can be proved by our various failsafe mechanisms, risks taken into account for FTS, various other risk mitigation techniques, system status indication lamps and redundancies. Extensive flight and subsystem testing has been conducted using the actual aircraft and various other aircraft to ensure safety.

The aircraft uses an IC engine to propel it in fixed wing configuration and Lithium Polymer batteries to power the Brushless DC Motors (BLDCs) in VTOL mode. Lithium polymer batteries are the chosen energy source for all onboard computers as well due to their high energy density. The presence of so these Li-Po batteries along with fuel becomes risky in case of accidents. Owing to this, the batteries are stored in a custom fabricated, fire proof and puncture resistant case that was made using Glass Fiber Composite with a layer of Polypropylene. Also, a High Density Polyethylene (HDPE) fuel tank provides added safety as it is strong and has a high melting point (130^{o} C).

The IC engine is also equipped with a starter motor that gives it the capability to restart midair and also opens up the future possibility of onboard electricity generation to power the subsystems.

7. Landing Site Analysis Strategy

In accordance with the team's goal of developing a fully autonomous system, the landing site analysis is also conducted autonomously using an onboard computer.

A short distance before reaching the Remote Landing Site, the aircraft begins to slow down. As the airspeed reduces, the coaxial quadrotor jolts in to assist the fixed wing and provides the required lift. The machine vision system is activated and the aircraft scans the area in a 100 meter radius around Joe's last reported location at an altitude of 140 feet (AGL) using predefined waypoints. After Joe is detected, the system waits until the aircraft is at a safe distance from him and sends the autopilot a command to land along with the GPS coordinates of the landing location. The safe distance is around 35 meters in order to account for GPS inaccuracy and sudden wind gusts that could bring the aircraft dangerously close to Joe (<30 meters). After landing, power to all motors and engine ignition is cut off. The actuators are armed only after Joe loads the package and presses the arming switch. The engine will be restarted by the onboard starter motor and the vertical takeoff sequence would be initiated.

The camera is mounted on a two-axis stabilized gimbal to keep it at an angle of 45° to the ground. This is done to get a better view of Joe in case he is standing and also to keep the camera pointed towards the ground even during maneuvering.

The image processing algorithm used to detect Joe uses the following steps:

1. <u>Image Acquisition:</u>
   To reduce processing time, instead of acquiring a continuous video, images are gathered at discrete intervals of time. The time interval is calculated to ensure a 50% overlap between images.
   $$time\ elaped\ between\ frames = \left[\frac{height\ of\ image * GSD}{100}\right] * \left[\frac{(100 - overlap\%)}{velocity\ of\ aircraft}\right]$$
2. <u>Pre-Processing</u>
   a. <u>CLAHE Histogram Equalization:</u>
      This is used to enhance the contrast of the image.
   b. <u>Median Blur Filter</u>
      This replaces the value of the central pixel with the median of all pixels. This filter effectively removes unwanted noise.

Figure 7.1: Original

Figure 7.2: Processed

3. <u>Processing:</u>
   a. <u>Conversion of image to HSV range:</u>
      The processed image is converted into an HSV image matrix to detect blue color (Joe's Jeans).
   b. <u>Finding the two largest blue contour:</u>
      The program finds all contours and uses the largest two for further processing.
   c. <u>Image Cropping:</u>
      The object (possible Joe) is cropped out by approximating its centroid and drawing a rectangle around it.
   d. <u>ORB feature detection:</u>
      This matches the features of the cropped image with that of the reference images.
   e. <u>Selection of good matches:</u>
      The best matching features are computed using Lowe's Ratio.
4. <u>Post-Processing:</u>
   The number of 'good' features is matched with the threshold. A threshold of 10 is used for *Figure 7.4.* Since the image produces 15 good matches, Joe is detected.
5. <u>Geotagging:</u>
   If Joe is detected, the centroid of his body is computed and its GPS coordinate is estimated. The landing location is calculated from this point.

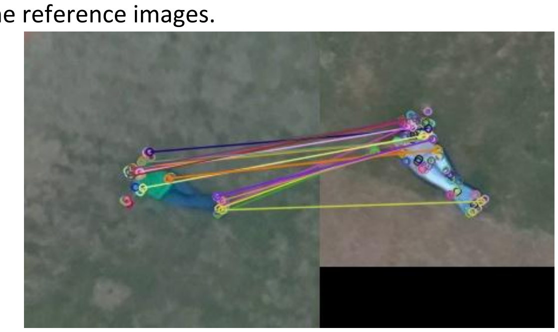


Figure 7.3: Reference **Figure 7.4: Joe**

A real time feed of images containing blue objects will be sent to the GCS to enable the possibility of a manual override if the computer is unable to detect Joe. In case the computer as well as the operator are not able to confirm Joe's detection after scanning the entire are, the system would consider the object with the most number of good matches as Joe and would initiate the landing procedure as mentioned above.

8. System Design

8. a. System Diagram

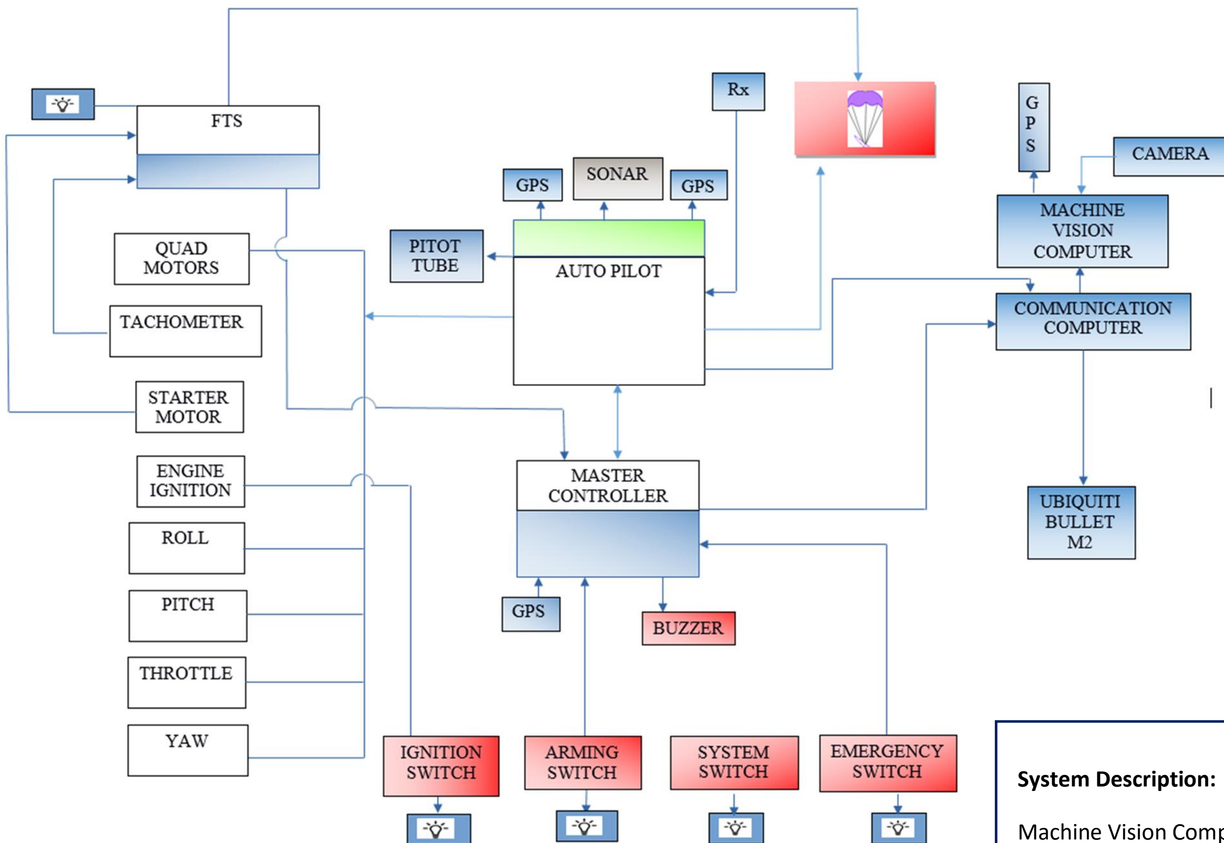


Figure 8.1: Onboard Systems

System Description:

Machine Vision Computer: Raspberry Pi 3

Communication Computer: Cubieboard 3

Autopilot: Pixhawk

Master Controller: Arduino Mega

FTS Controller: Arduino Mega

NMEA Embedded Computer: Raspberry Pi 2

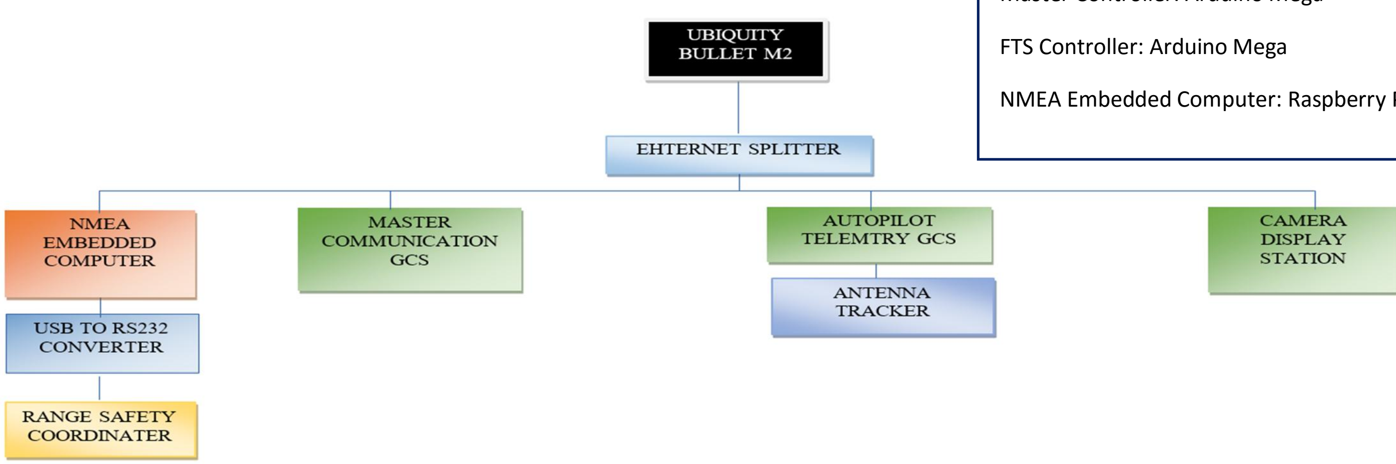


Figure 8.2: Ground Control Station

8. a. 1. System Switches

The aircraft is equipped with four easily accessible switches for safety and ease of use. Each switch is of a different color and has its own LED to confirm that it is in ON state. These switches are:

- **E-Stop Switch:**
  This is a red colored, circular, latching push button switch that is surrounded by a yellow color circular sticker for easy detection. When enabled, this switch cuts power from all actuators i.e. motors, engine's ignition, parachute and servo motors.
- **Ignition Switch:**
  This is a rocker switch used to power the engine's ignition.
- **Arming Switch:**
  This is a momentary push button switch that will arm the aircraft for takeoff from the remote landing site one minute after being pressed.
- **System Switch:**
  This is a rocker switch that provides power to all board computers and communication systems.

8. a. 2. System Status Indicators

Each switch has its own LED to confirm its ON state.
The aircraft is also equipped with bright LEDs to determine its current state.

- **Red:**
  This indicates that the aircraft is in armed state. This means that all actuators are powered.
- **Green:**
  This indicates that the aircraft is disarmed. This means that power to all actuators has been cutoff and the aircraft is safe to approach.

8. b. Aeronautical Requirements

All team members who will be present at the flight line and GCS are highly experienced with aeronautical systems, units and conversions. All our GCS software provide data as per the units mentioned in Section 3.3.3 of the rule book. Our autopilot (Pixhawk) is equipped with an onboard barometer and a Pitot tube sensor that provide the barometric altitude and airspeed respectively. All waypoints are set according to Feet above Ground Level (AGL) altitude.

The flight regime of any aircraft depends on the permissible speeds it can safely achieve without the loss of the aircraft, either structural harm or loss of structural integrity. For Outback Challenge our primary aim is the safety of the airframe. The flight regime was calculated and a V-n Curve was plotted in order to give a deeper understanding of the frame. The graph of airspeed vs. load provides insight into the stall region and the maximum Velocity within which the airframe is safe and operational.

The aircraft uses an onboard Pitot tube to measure its airspeed. The optimum airspeed is maintained by controlling the throttle on the basis of this.

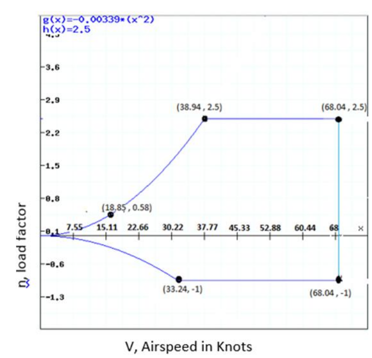


Figure 8.3: V-n Curve

8. c. Flight Termination System Design

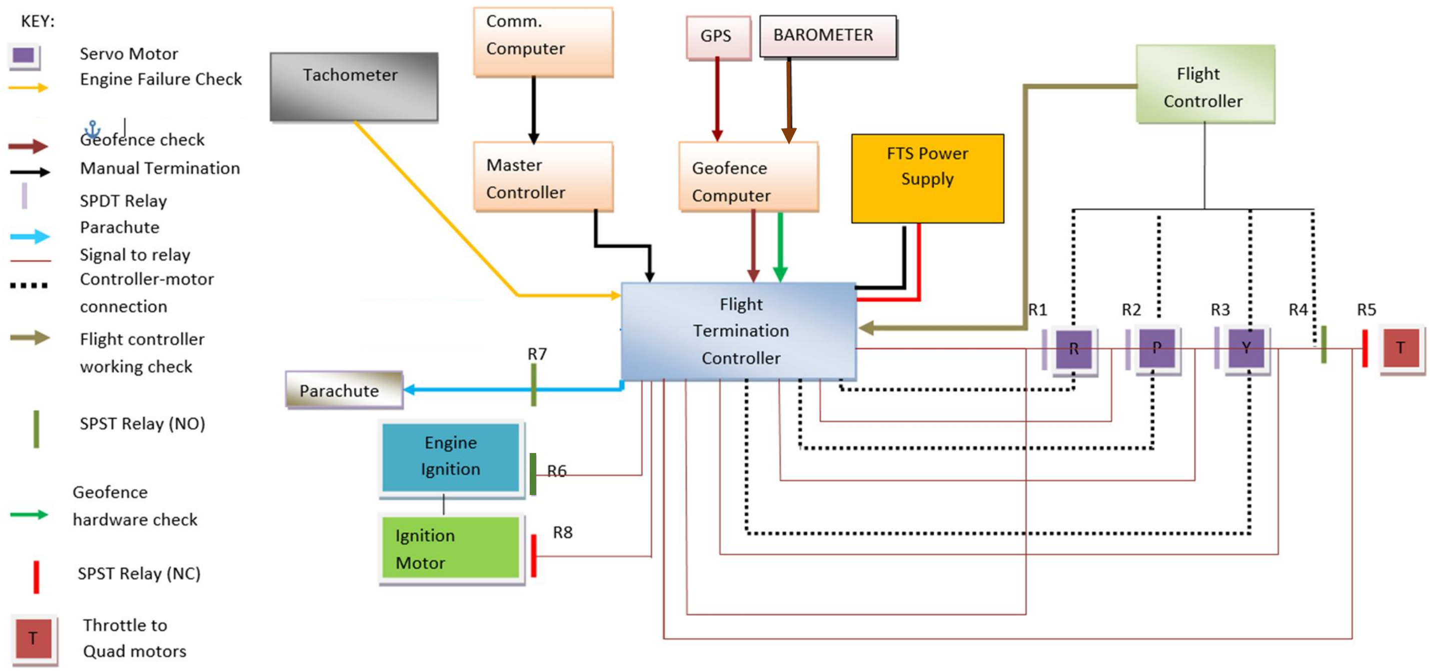
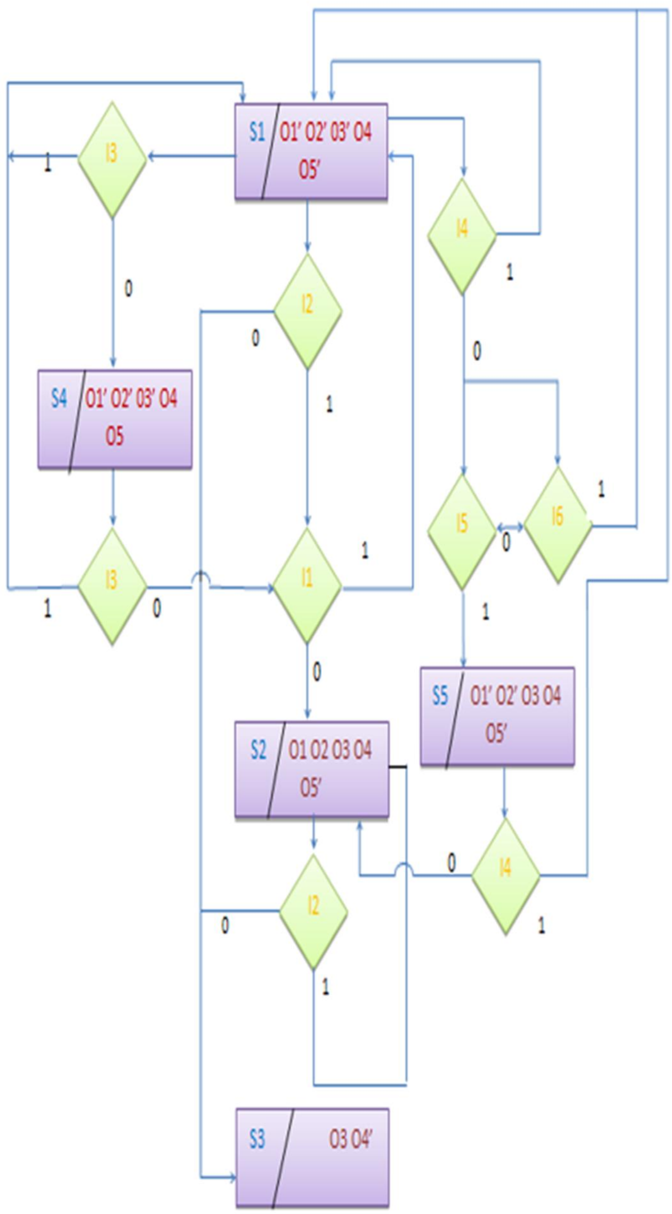


Figure 8.4: Flight Termination System



STATES:

S1: FTS controller not activated
S2: FTS controller activated
S3: FTS controller failed
S4:1 attempt to restart engine mid-air
S5: Aircraft loiters for 2 minutes and tries to re-establish to communication link

CONDITIONS:

I1: None of the signals, ignoring engine rpm, sent to the FTS controller is 0
I2: FTS controller is working (R4 is powered)
I3: Engine rpm is not zero
I4: Communication link is healthy
I5: Loss of communication link in the transit corridor and at the base until landing at the remote landing site and after completion of take-off from the remote landing site.
I6 Loss of communication between initiation of autonomous landing & completion of autonomous take off to the point from which it initiated landing*
***As the aircraft had a healthy communication link at this point**

OUTPUTS:

O1: R1, R2, R3 are connected to FTS controller to for appropriate deflection of control surfaces to initiate flight termination
O2: Power to ignition (R6) is cut off
O3: Parachute is deployed (R7 power is cut off)
O4: Throttle to BLDCs is connected (R4 is powered and R5 is not powered)
O5: Ignition motor is ON (R8 is powered)

SIGNALS SENT TO THE FTS CONTROLLER

1. Flight controller heart beat
2. Geofence computer heart beat
3. Geofence breach signal (0 if it breaches)
4. Manual termination signal (0 if it needs to be terminated)
5. Engine RPM
6. Communication link healthy

Figure 8.5: FTS State Machine Diagrams and Transitions

8. d. Analysis of Flight Termination System

The Flight Termination System is completely designed as per the specifications mentioned in the problem statement and other possible risks that might require termination of the flight.

The system has its independent power supply system that can keep it running for around 3 hours that is more than twice of our maximum flight time.

Type of Failure	Method of Detection	Method of Flight Termination
Geofence Breach	Geofence breach is detected by the Geofence system described in Section 8. e.	Standard termination procedure is followed (mentioned below)
Failure of Geofence System	The geofence system sends a ‘healthy’ signal to the FTS controller.	Standard termination procedure is followed (mentioned below)
Manual Termination Request	Serial command can be sent from the Master Communications Computer on the GCS.	Standard termination procedure is followed (mentioned below)
Autopilot Lock-up	The autopilot sends a constant PPM signal to the FTS. Loss of this signal signifies a problem in the processor or the timer of the autopilot.	Standard termination procedure is followed (mentioned below)
Engine Failure	A tachometer attached to the crankshaft gives RPM feedback to the FTS.	The system attempts to restart the engine once using the onboard starter motor failing which the standard termination procedure is followed as mentioned below.
Failure of FTS Controller	This is a purely electrical system that is activated in case of loss of power.	In this case, normally open relays that are otherwise powered cut throttle to motors, engine ignition and deploy the parachute. The relays mentioned are R4, R6 and R7 from Section 8.c.
Loss of data link	UDP packet loss detected by the communications computer.	The aircraft loiters for 2 minutes and tries to reestablish communication link. Flight is terminated if it fails to do so. In case the data link is lost after the aircraft has initiated landing at the remote landing site, it will continue its landing. If there is no data link at the time of takeoff from the remote landing site the aircraft will attempt an autonomous takeoff and hover at the point where it initiated its landing. Flight will be terminated if the aircraft is unable to reestablish communications. Please refer Figure 8.5 and Section 10.a.1.

Table 8.1: Analysis of FTS

The standard flight termination procedure is as follows:

- Throttle closed to BLDCs
- Cut off engine ignition
- Full up elevator
- Full right rudder
- Full down on the right aileron
- Full up on the left aileron
- Deploy parachute

Descent Analysis after Flight Termination:

This section deals with the aircraft in two different configurations, namely fixed wing and VTOL:

- Fixed wing:

  As per the rulebook the termination is to be assumed at the maximum altitude and maximum velocity. So, the allowed Service Ceiling of 1500ft and maximum velocity of 64.81 Knots is assumed.

On flight termination, the Parachute is deployed slowing the aircraft down by retarding its forward motion and then reducing its descent rate. The parachute has a drag coefficient value of 2.20. Combined with the stated assumption. The airframe would achieve a terminal velocity of 9.5 Knots (4.9 m/s). Which is nothing but the descent rate.

Considering the aircraft to be a projectile, the distance traversed outside the geo-fence is the range of this projectile. Hence, we get a Range of 12.5 m.

- VTOL:

The multirotor is same as far as flight termination is concerned. The rate of descent would be the same as in fixed wing configuration.

The parachute chosen is Skycat IFC-96-S. This is a purely electrical system and doesn't use any explosives or CO_2 reducing the risks associated with conventional Pyrotechnic activation.

8. e. Geofence System Design

A separate embedded computer connected to a U-blox LEA-6H GPS receiver and a barometric pressure sensor comprise the Geofence system. As required by the problem statement, this system is separately powered from the Flight Termination System battery.

The system provides two types of signals to the FTS; a healthy state signal and a geofence breach signal. The system uses an in-house developed algorithm that is based on Point in Polygon method to detect whether the aircraft is within the geofence boundary.

For vertical geofence, barometric AMSL values are used.

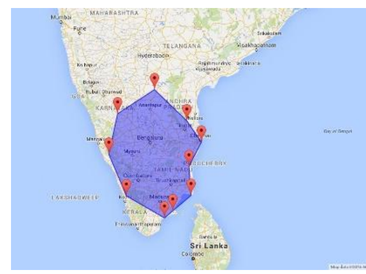


Figure 8.5: Geofence

For added simplicity and safety, a GUI has been developed to show the geofence vertices and polygon on a map while entering the GPS coordinates.

An independent system was preferred over the in-built geofence feature in the autopilot for better safety, flexibility and ability to make more complex geofence polygons.

8. f. Radio Communication Equipment

We'll be using only a single 2405-2475 MHz directional link to the aircraft. This 150 Mbps link handles all the communication of all our system with the Ground Control Station. The module used is Ubiquiti Bullet M2. This frequency and module were chosen as they are in accordance with ACMA regulations as per *Radio communications (Low Interference Potential Devices) Class License 2015 Schedule 1* and do not need a license.

The system is capable of providing up to 20 Km of semi Line of Sight communication.

9. Risk Assessment

9. a. Updates from Deliverable 1

The updated risks and changes made in the design to account for these are as follows:

Risk	Design Changes since Deliverable 1
Higher stability of Design 2 over Design 1	The coaxial configuration of Hybrid Quadcopter gives redundancy, more robustness, stability and reliability as compared to the Hybrid Tiltrotor
Mid flight engine failure	None
Low Fuel	The fuel tank is capable of carrying twice the quantity of fuel needed for the flight. Hence, a fuel level sensor was deemed unnecessary.
Uneven surface at Remote Landing Site	None
Maintaining geofence	A custom Geofence algorithm based on Point in polygon method, running on an independent onboard computer froms the geofence system
Rains during flight	The engine remains unaffected during rains. Tiger U8 Pro motors are used as they as dust and wateroproof. Onboard electronics are placed inside the glass fibre fuselage which is water resistant
AutoPilot Failure	The flight controller will send a constant PPM signal to the FTS failure of which will result in flight termination
GPS Failure	Redundant GPS on flight controller
Low Battery	If this occurs before takeoff, the system denies the arming signal. If this occurs during flight, a message is sent to the ground station and the operator can decide what action to take.
Software and Autopilot Bugs (During testing)	Multiple software simulations, subsystems tests and tethered tests were conducted to ensure system safety
Parachute Failure and Entanglement	None
Autopilot Telemetry Failure	The aircraft being a fully autonomous system would continue its mission
Mechanical and structural failure	None
Failure of Flight Termination Sytem	Throttle to all motors and ignition to the engine is cut and parachute will be deployed electrically
LiPo Battery Protection	Batteries are stored in a custom fabricated, fire proof and puncture resistant case that was made using Glass Fiber Composite and Polypropylene
Failure of Geofence System	The geofence computer sends a 'healthy' signal to the flight termination computer failure of which results in flight termination
Injury to personnel around the aircraft due to unintentional actuation of motors or engine	An emergency switch mounted on the exterior of the fuselage will always be engaged while the aircraft is on the ground and personnel are working around it
Burn injuries due to hot surfaces around the engine	Attachment of an engine cowling
Damage to electronics due to electrostatic discharge from engineers	All personnel are required to ground themselves by wearing electrostatic wrist bands
Rescue of lost aircraft	Flight logs on the ground can be monitored from the ground station to predict flight path and trajectorys

Table 9.1: Update Risks for D1

9. b. Risks associated with autonomous takeoff and landing

As we are using a hybrid aircraft, it performs Vertical Takeoff and Landing. Hence all the risks mentioned are specifically for VTOL systems.

Risks associated with autonomous takeoff and landing are as follows:

Risk	Mitigation
BLDC Failure	The configuration used is highly redundant. It is theoretically capable of surviving failure of upto two motors. If the autopilot detects any abnormality such as unusual tilting high descent rate, the parachute will be deployed
Variance in GPS	GPS gives an inaccuracy of 2.5 to 5 meters. Hence, the takeoff and landing location with no obstructions in this region should be chosen
Chosen landing location is unsuitable	A live camera feed is given to the GCS. A manual override command can be sent to abort landing or change the landing location
GPS Failure	Use of multiple GPS receivers gives redundancy and reduces the possibility of such an event.
Accidental launch	The system is unable to takeoff until the emergency switch is released and the arming switch is activated
Accidental arming of actuators	The emergency switch, if engaged, prevents actuation even if actuators are armed
Takeoff on low battery	The autopilot will deny the arming command if it detects that the battery is low during takeoff
Propeller breaking or chipping due to stones and pebbles	High quality carbon fibre propellers are used
ESC Failure	ESC failure will cause failure of a BLDC. This can be survived due to the redundancy. In case an of any instability, the parachute will be deployed.
Autopilot lockup	This will intiate flight termination
Engine Failure	The starter motor will attempt to restart it. The flight is terminated if its unable to do so.
Misinterpretation of AMSL and AGL while feeding waypoints	Our engineers have tremendous experience in their respective fields which prevents such errors. This risk can further be eliminated by using a GUI to visually display locations of waypoints.
Unscrweing of BLDC	Threadlocking glue will be used along with split washers on all mounting screws
Drift due wind gusts	The high thrust to weight ratio ensures stability of the aircraft in high wind speeds
Wrongly entered geofence coordinates	The GUI used to enter the coordinates shows all geofence vertices and the geofence polygon. This reduces chances of this risk

Table 9.2: Risks associated with autonomous takeoff and landing

10. Risk Mitigation

10. a. 1. Response to loss of data link

Loss of data link is determined by loss or reordering of packets.

In case a data link loss is detected for more than 10 seconds, the aircraft will be put in loiter mode and will try to reestablish communications. If the link is not established in 2 minutes, flight termination will be activated.

If a data loss is detected after the aircraft has initiated landing procedures at the remote landing site, it will continue its descent.

If the aircraft is unable to reestablish the link till the time Joe presses the arming switch, it will initiate takeoff and proceed towards the last point where a healthy communication link was detected. This point is assumed to be the point at which the landing procedures were initiated and will be located 40-60 meters vertically above the landing location. The takeoff is considered to be complete after the aircraft reaches this point. If the aircraft fails to reestablish a link even after 2 minutes of hovering at this location, flight termination will be activated.

Even though our communication system is designed to provide a semi line of sight communication up to a range of 20 Km, this response procedure was chosen due to the high probability of a data link loss during the landing phase as the communication would no longer be line of sight.

The expected height of our antenna tracker is 10 feet. Considering the curvature of the earth, at a distance of 11 Km, the communication remains line of sight till the time the aircraft is approximately 4 feet off the ground. Thus, the aircraft remains in the air without a data link only for a few seconds of the flight.

The flight termination system will be active at all times even in the absence of a data link and flight termination will be initiated in case any event requiring flight termination occurs such as: geofence breach, autopilot lock-up etc.

10. a. 2. Response to loss of GPS

The aircraft is carrying multiple GPS receivers onboard for various systems such as the autopilot, geofence system, master computer and machine vision computer.

- Loss of Autopilot GPS

  The autopilot is equipped with two GPS receivers for redundancy. There is no specific user defined response for this situation as it would make the aircraft breach the geofence which automatically leads to flight termination.
  A message will also be sent to the GCS from which the user can decide whether to terminate the flight.

- Loss of Geofence System GPS

  The geofence computer sends a constant 'healthy' signal to the Flight Termination System. In case of loss of power to the geofence computer or loss of GPS signal, this signal is cut off which automatically leads to flight termination.

- Loss of GPS on Master Computer

  The GPS on the master computer is responsible for supplying NMEA data to the Range Safety Coordinator. In case of loss of GPS and absence of this data, the operator and Range Safety Coordinator may decide to manually terminate the flight.

- Loss of GPS on Machine Vision Computer

  The machine vision computer mainly uses its GPS for geotagging the images, detecting Joe's location and determining a suitable landing location. In case of GPS loss the system will command the autopilot to loiter at the current location and wait to reestablish GPS signal. The operator can now manually select a suitable landing location for the aircraft to land.

10. a. 3. Response to Autopilot lockup

The autopilot sends a constant PPM signal to the Flight Termination system. The absence of this signal signifies a malfunction in the processor or the timer. This will hence, lead to flight termination.

10. a. 4. Response to lockup or failure of GCS

The aircraft being a fully autonomous system is capable performing fully autonomous flights without any communication link to the ground control station.
Hence, the aircraft will continue its mission while the GCS computer is rebooted.

10. a. 5. Loss of Engine Power

The aircraft is equipped with an onboard engine starter motor. In case of engine failure, the Flight Termination system will attempt to restart it once failing which it will initiate flight termination.

10. b. Fuel and Li-Po management

The total energy on the onboard battery will be 550 Watt-hours. This includes Li-Po batteries which are used to power BLDCs and other electronics and NiMH batteries that are used to power the engine ignition. This gives the system the capability to run in VTOL configuration for 20 minutes and power its systems for almost 90 minutes which is a lot more than the flight duration of 60 minutes.

The engine requires approximately 750 cc of fuel to propel the aircraft for 1 hour. Our onboard fuel tank has a capacity of 1200 cc. Hence, providing around 50% extra reserve fuel.

The Li-Po the batteries are stored in a custom fabricated, fire proof and puncture resistant case that was made using Glass Fiber Composite with a layer of Polypropylene. Also, a High Density Polyethylene (HDPE) fuel tank provides added safety as it is strong and has a high melting point (130^{o} C).

These help to reduce the risk of fire and explosion in case of a crash.

Component	**Energy Consumption (Watt-hours) for 1 hour of operation**
BLDC Motors	386
Raspberry Pi	10
Cubieboard 3	10
Pixhawk	2.5
Servo Motors	7.2
Arduino Mega	2.5
Ubiquiti Bullet M2	12
Engine Ignition	30
Total	460.2

Table: 10.1 Approximate Energy Consumption

10. c. Management of other risks identified in risk assessment

The risks along with their mitigation techniques are provided in Section 9.

11. Flight Test Results and Discussion

Multiple software simulations, hardware in the loop tests, tethered fights and test flights were conducted using various types of aircraft for subsystems testing and to understand the aircraft's behavior.

11.1 Team Preparedness

Till the date of submission of this report, the following tasks and tests have been completed:

- Mini Mugin 2.6m was modified, reinforced and converted into a hybrid aircraft
- Successful autonomous flights to check the aircraft's behavior in VTOL, transition and fixed wing mode
- Completed successful tests of the Machine Vision System. The system is still undergoing tuning but the current detection rate is 94.7%
- Completed Geofence system testing
- Fabricated and tested the fire and puncture proof battery box
- Successfully tested the communication system
- Tested individual components of the FTS on the ground
- Aerodynamic effects of the hybrid configuration were studied on the basis of which aerodynamic surfaces were positioned in the most suited location

11.2 Flight Test Results

Even though we have had only a couple of flights with the actual aircraft, the subsystems testing and flight tests performed using other smaller aircraft were satisfactory. Hence, the design is considered to be stable.

A custom autopilot system was designed using two Pixhawk autopilots. This design changed to a single Pixhawk after the release of the latest ArduPlane firmware that provides support for hybrid aircraft.

11.3 Remaining Tasks for the competition

- System Integration
- Assembly of the Flight Termination System
- Mounting and testing of the parachute
- Range testing of the communication system
- Integration of multiple links over a single communication link
- Tuning of Machine Vision System

11.4 Joe Search Algorithm

Even though a variety of search algorithms are possible, our aim was to use the one that gave us the best chances of locating him. The aircraft will be traversing across parallel linear paths inside the search area. As the aircraft will be in Quadrotor mode during the search, this trajectory covers the most area and helps predict his location accurately.

12. Conclusion

The capability of our aircraft and subsystems to satisfy competition requirements and complete mission tasks at the UAV Challenge Medical Express 2016 has been tested and demonstrated. We are confident that our system would be able to give the expected performance.

Our preflight checks and other safety procedures that have developed from risk assessment of each and every component and our three years of experience have played a vital role in ensuring aircraft and personnel safety in our flight tests.

Our progress so far for this competition has been as per our expectations apart from a few unexpected delays. We are confident that we will be able to integrate all our subsystems to give an unnerving performance at our first ever attempt at UAV Challenge.