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Development of Rotary Wing Mini UAS for Civilian Applications

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This research paper is about team Dhaksha's accomplishment in designing, developing and testing a slew of Rotary Wing Mini Unmanned Aerial Systems for entry into various international aerial robotics/unmanned aerial vehicle (UAV) competitions and civilian applications. Dhaksha, the Unmanned Aircraft System (UAS), developed by the team at Madras Institute of Technology (MIT) campus of Anna University, Chennai, Tamil Nadu, India, with its stable design presented stiff competition to other contestants during the May 2012 technology demonstration called UAVForge organized by Defense Advanced Research Project Agency (DARPA), Department of Defense, USA. Team Dhaksha on behalf of national defense research agency deployed their system as a test bed for Acoustic field testing and analysis. The team also deployed their UAS, for state police, in a religious festival, over a crowd of 20 lakh pilgrims during November 2012, to avail instant aerial images. UAS Dhaksha was deployed for investigation of structural strength of the India's tallest structure, a 300 m high Reinforced Cement Concrete (RCC) tower. Recently during the flash floods in the Himalayan river Mandakini at an altitude of 4200 m above mean sea level, Dhaksha assisted the forces in the relief and rescue operations by providing instant thermal/video images of the scene of disaster.

Keywords: Coaxial octa rotor; real-time control; low cost surveillance; UAVForge challenge; acoustic testing; thermal image fusion.

1. Introduction

While unmanned aerial systems otherwise called as drones were commonly used by the military for surveillance and other warfare operations, unmanned aerial systems are now being developed for much broader applications outside the military. In case of a natural disaster, like earthquake, flood, land slide or a manmade disaster like gas, radiation leakage, etc., where the site would be difficult to access or the subject area would be polluted, unmanned missions can play a key role. Similar would be the situation, in case of a high rise building, or an inaccessible high altitude terrain where often access for human being will be very difficult during disaster situations. These examples clearly illustrate the usefulness of mini aerial vehicles (MAV) for monitoring the damages and life existence with the help of various sensors. MAVs can be operated in tight spaces and can reach the targeted position with ease. In addition, this type of robots could also be used for preventing secondary disasters and for precise aerial delivery.

Today, unmanned aerial vehicles (UAVs) are an important part of scientific study both in military and civilian application domain. As a substitute for human piloted vehicles they prove advantageous in protecting human life in multiple dangerous environments. Their reliabilities in tough circumstances are much higher than their counter parts.

Amongst the many type of UAVs, fixed-wing vehicles have long-range since they are energy efficient, but they lack the hovering capability required for many UAV tasks. The Helicopters prove advantageous for surveillance and inspection tasks, since they can take-off and land in limited space and can easily hover above targets. But, unfortunately helicopters are very hard to control, and require more complex systems. However, multi rotor UAVs combine the advantages of hovering abilities, ease of control and maintenance and much simpler systems.

The design of a multi rotor UAV involves the integration of various steps such as basic structural design, choosing efficient power system, selection of sensors and developing algorithms and control law design. These steps cannot be

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treated separately. For example, one cannot design a vehicle without considering the sensory input or the controllers, as these steps are closely related to each other. In order to create an autonomous UAV, precise knowledge of the vehicle position and orientation is needed. This information can be obtained from Inertial Navigation Systems (INS) through inertial sensors and Global Positioning Systems (GPS). Typically, multiple sensors are used to overcome the limitations of individual sensors, thereby increasing the reliability and decreasing the errors. Vision sensors are primarily used for estimating the relative position of target like, a landing site or a ground vehicle.

A co-axial multi rotor is a basic multi rotor helicopter. It is an under-actuated, dynamic vehicle with four input forces and six degrees of freedom. Unlike regular helicopters that have variable pitch angle rotors, a quad rotor has four fixed-pitch angle rotors. The basic motions of a quad rotor are generated by varying the rotor speeds of all four rotors, thereby changing the lift forces. The quad rotor tilts towards the direction of the slow spinning rotor, which enables acceleration along that direction. Therefore, control of the tilt angles and the motion of the quad rotor are closely related and estimation of orientation (roll and pitch) is critical. Spinning directions of the rotors are set to balance the moments and eliminate the need for a tail rotor. This principle is also used to produce the desired yaw motions. A good controller should properly arrange the speed of each rotor so that only the desired states change.

The following are the goals desired and achieved by the co-axial multi rotor UAVs developed by team Dhaksha:

(i) Stable, autonomous hover with active control system taking dynamic information from sensors mounted on craft.
(ii) Stable hover, with addition of variations in altitude based on human input for thrust.
(iii) Stable hover, with addition of variations in altitude and directional movement based on human inputs for thrust, pitch, roll, yaw.
(iv) Ability to fabricate in-house (Division of Avionics, Department of Aerospace Engineering, MIT).
(v) Provide stable video/images to ground control station.

Team Dhaksha's prototype vehicle deployed for UAV-Forge competition is a coaxial eight rotor designed for autonomous outdoor flight. On every arm of the vehicle two motors and propellers were installed coaxially. This configuration is designed to fulfill the competition requirement.[1] The onboard control system is powered by a classical control. The experimental setup and flight test were done successfully.[2]

Team Dhaksha also conducted research on UAVs for surveillance tasks and information gathering. The results are being reported in this paper.

2. The Unmanned Aircraft System (UAS)

The design looks like an eight rotor helicopter, which a single person can carry and operate reliably and safely in adverse weather conditions and provide instant imagery anytime an aerial vantage point is needed. The rotorcraft weighs less than four kg, hovers quietly overhead for more than 40 min and can patrol at speeds up to 60 kmph. The frame is made of carbon tubes/rods attached to a plastic hub thereby forming a + or x shape. At the other end of the carbon tubes motor-propeller assemblies are attached. The operator uses a small portable control unit to command it to hover or fly in any direction at varying speeds. The design is incredibly stable and also features ground-tracking and obstacle avoidance capabilities. Operator training and workload is minimized through a streamlined design and user interface. Video imagery is transmitted to the handheld ground control station and distributed to decision makers for real-time viewing.

Further, the model can also be scalable into various sizes for e.g. a micro UAV for tracing holed up militants in various anti-terrorism and homeland security applications. The team is also exploring various possibilities of self-powered solar UAVs and UAV for radiation surveillance in and around nuclear power stations, disaster relief and for unmanned riot control applications.

2.1. *Hardware configuration of the coaxial system*

This section discusses the hardware used in the development of the multi rotor. Hardware platform construction is the core in building a UAV system. Although the miniature rotorcraft UAVs are diversified in size, shape, payload, and applications, all of them share a similar system configuration. More specifically, the proposed mini rotorcraft UAV system is to consist of the following four parts:

(i) A radio-control (RC) system
(ii) An avionic system for collecting in-flight data, performing automatic control algorithms, executing mission-oriented tasks and communicating with the ground station
(iii) A manual control system consisting of a pilot and a wireless joystick
(iv) A ground station system for monitoring the flight parameters of the UAV and communicating with the avionic system

Figure 1 shows the hardware configuration of the flight control system. A microcontroller (CPU 1) is used as the main controller. A 100 Hz Attitude Heading Reference System (AHRS) for attitude control and i2c motor controllers to guarantee efficient driving of the eight brushless direct

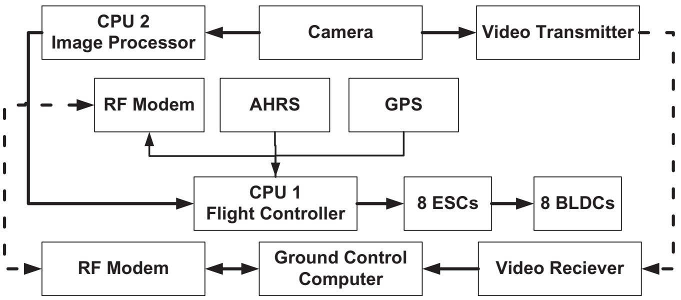

Fig. 1. Hardware block diagram.

current (BLDC) motors has been used. For the outdoor trajectory following, a 10 Hz GPS is used for navigation.

A 900 Hz wireless jam resistant data modem for two way communication between the ground control station and the vehicle has been used. For the future purpose of image processing, a Snapdragon processor (CPU 2) that is expected to process the image data and generate Simultaneous Localization and Mapping (SLAM) is used. The video transmitted to the ground is to be captured and stored in computer. Some of the commercially available hardware components have also been used.

2.2. *Motor validation and PWM to angular velocity mapping*

The motors had to be tested to ensure approximately similar characteristics amongst them. In order to do this a test apparatus was created to hold the quad rotor stationary as the PWM counts were ramped up.[3] The angular velocity was captured using a tachometer and an oscilloscope.

As the blade passes through the tachometer, the tachometer measures two pulses per revolution. In addition to angular velocity, motor voltage, current and PWM counts were also recorded and tabulated for each of the four motors. Resulting plot is shown in Fig. 2. The average was taken because the plots of the individual motors were all very close. This greatly simplifies the process as just one function could be used to map the feedback.

2.3. *Experimental setup*

After the multi rotor assembly is finished, the options of experimental setup are considered. One of them is hanging up the quad rotor body with a rope. This keeps the system at a constant height. The two other translations and the three orientations are free. However this setup has a disadvantage. When the system sways sideways the connected rope creates a decoupling action which stabilizes the overall system to certain extent. Another option of experimental setup is the one with a spherical joint. It prevents the three translations but not three rotations. The available spherical joints are tested but their friction rates are found to be effectively high. Finally, rope assembly is decided to be used in the test bench. The rope was passed through an opening in the top PCB gyro board and connected to the center of the cross frame, which reduced the couples that had been caused when an offset was given to the rope-frame connection.

The final system is hanged with a rope from the center of gravity. And each motor end is loosely supported with ropes in order to prevent large, uncontrolled sways and to establish safety during working. The bundle of signal cables that are extended from the quad rotor are winded together and extended close to the axis of the center of gravity in order to reduce the torque created by the wires.

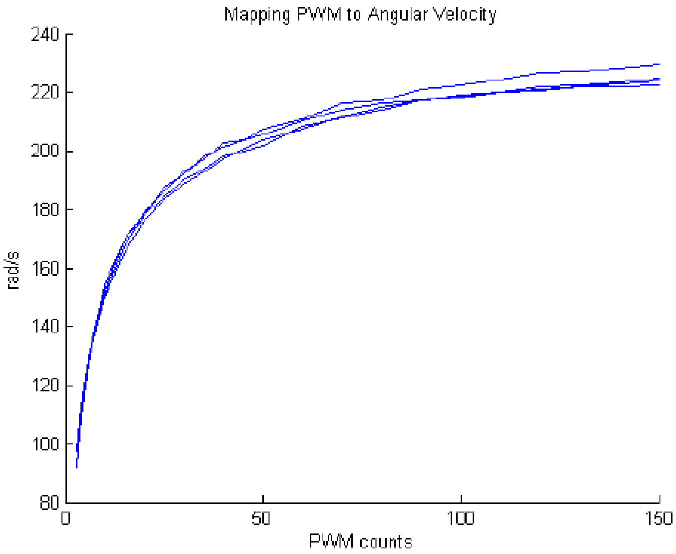

Fig. 2. Speed versus PWM.

Fig. 3. Experimental setup.

2.4. *Eliminating sensor noise*

Vibration Noise is intrinsically present in the accelerometers. In order to filter that noise eighth-order Butterworth filters are placed at the outputs of the accelerometer in the SIMULINK code. Measurements before and after filtering the accelerometer outputs are given in Figs. 4 and 5. Note that the disturbance is given by pushing the system on an x–y plane.[4]

From Fig. 4 it is clearly evident that the signal has almost disappeared under the noise. After the signal is filtered with an eighth-order Butterworth low pass filter the signal becomes distinguishable and the pattern of motion can be seen in Fig. 5.

2.5. *Test bench*

After, all the parts are assembled together the final system looks like the one shown in Figs. 6 to 8.

2.6. *Ground control station*

The last essential part of the overall unmanned system is the ground control station. Its main responsibility is to realize effective communication between the avionic system and the ground users and pilot. To fulfill this aim, the ground station possesses the following fundamental capabilities:

(i) Displaying and monitoring the in-flight status
(ii) Displaying images captured by the onboard system
(iii) Generating and updating flight trajectories
(iv) Sending control commands to the flight

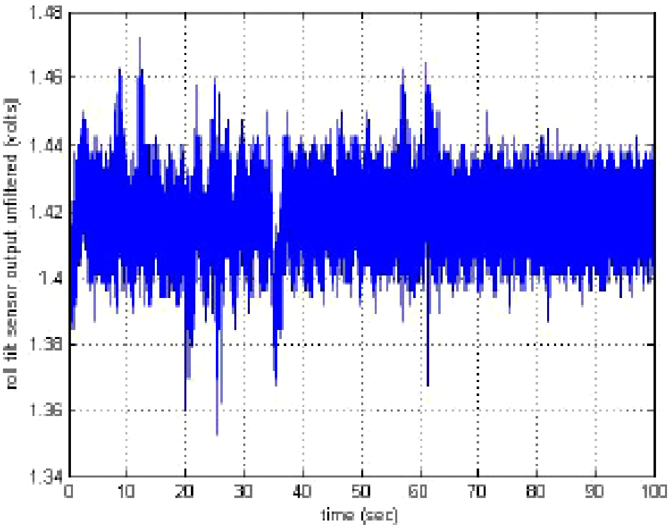

Fig. 4. Unfiltered sensor output for roll angle.

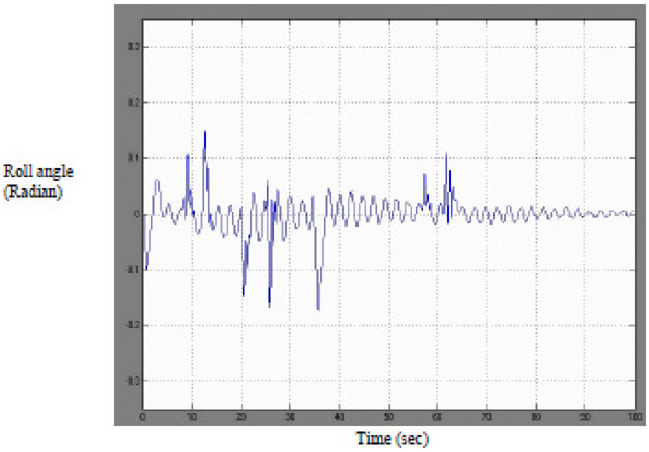

Fig. 5. Filtered roll angle measurement with an eighth-order Butterworth low pass filter with 10 Hz bandwidth.

Fig. 6. Assembled coaxial quad.

Fig. 7. Coaxial quad in flying mode: UAVForge fly off site.

Fig. 8. Worm's eye view of the coaxial quad.

(v) Facilitating the ground piloted control or automatic control, especially in unexpected situations such as emergency landing and cruise.
(vi) Logging in-flight data.[5]

2.7. *Navigation guidance and control*

The UAV is built with the idea that it can be controlled in both autonomous and radio controlled mode. The team has decided to implement autonomous mode to increase the versatility of the entire system and also for out of sight and long distance missions (if required). Manual overriding of autonomous mode to manual mode and vice versa is also programmed. The NGC block diagram is as shown in Fig. 9.

Autonomous take-off and landing is a critical task and thus at this point, taking off is done using radio transmitter and then the autonomous mode is activated and while landing, the system is switched back to Pilot-in-Command (PIC) mode, i.e. radio transmitter. Using the ground control software, a circular pattern waypoint is provided which the UAV must fly through. In GCS, a provision to simulate the UAV mission before actually flying the real UAV is made.[6]

2.8. *Wireless data transmission*

The camera is tested within the university campus and it is interfaced with a video overlay board transmitter and a receiver at the GCS. The GCS receives the real-time video signal from the camera transmitter. The still images and videos are captured and stored (Fig. 10). The video being captured now can be used for the purpose of identification of the target and in surveillance operations.[7]

2.9. *Risk assessment and safety measures*

Safety for the mission is a very important consideration. During the trial flights and during the mission, the safety of the person and property are of the utmost importance. The team has defined the safety requirements for the mission

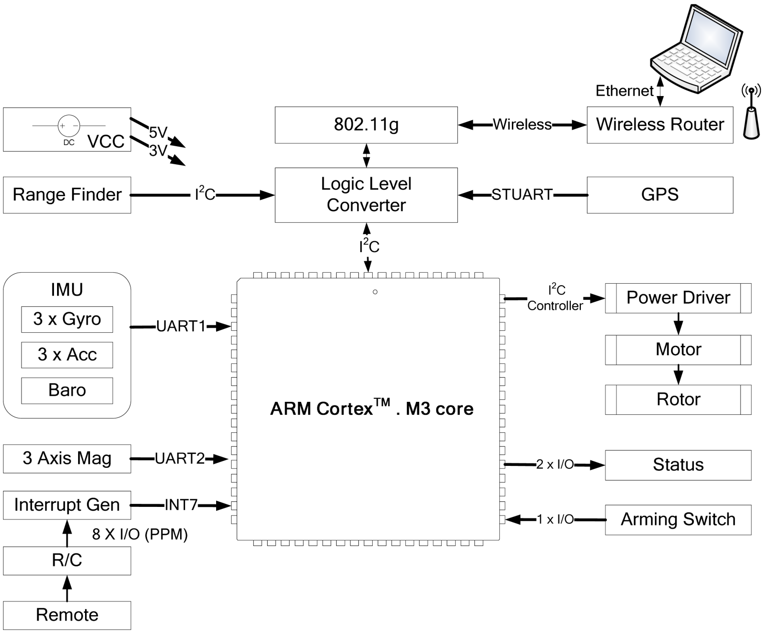

Fig. 9. NGC block diagram.

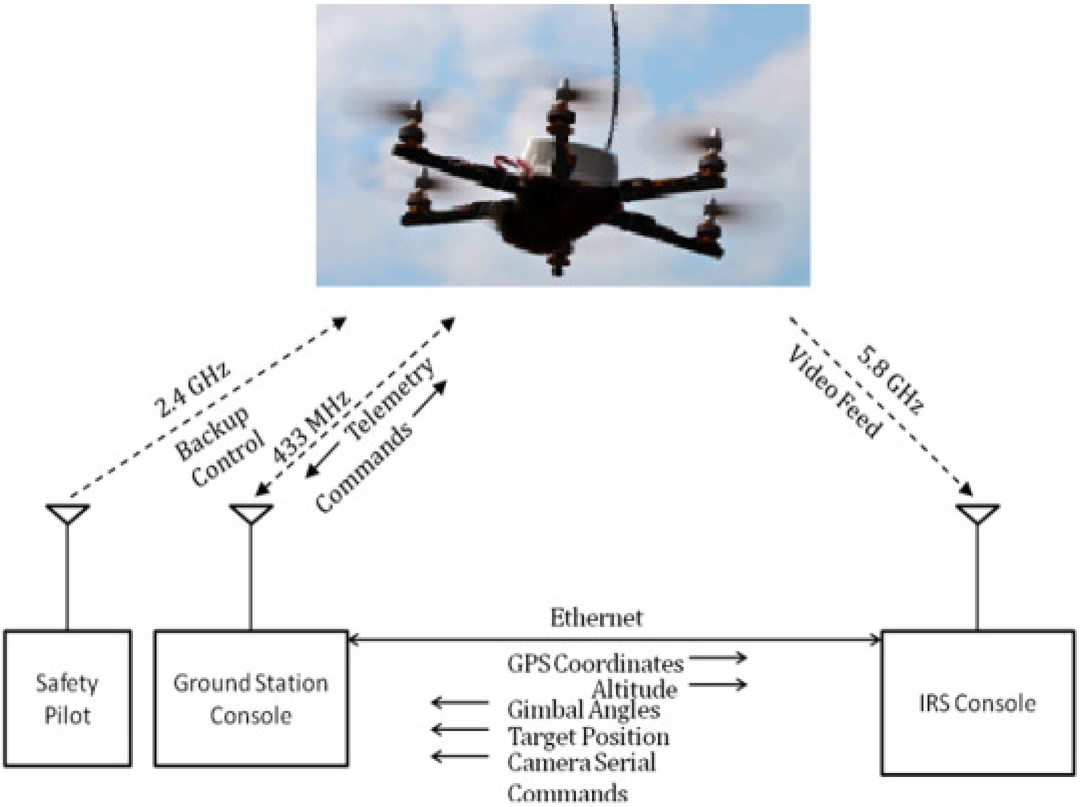

Fig. 10. Wireless communication and data links.

and thus single point failure during testing were identified and analyzed to keep it to minimum.

The GCS has also been programmed to indicate if the battery voltage is below the requirement and the same will be displayed in the ground control station so that necessary action can be taken.

To ensure that the motor vibration does not affect the autopilot, a damping foam and firm mounting has been used, so that the autopilot is not disturbed from its original position.

When command link is lost, the Autopilot will immediately and automatically initiate "RETURN HOME" and the GCS will attempt to reacquire command link.

R/C receiver is sufficiently protected from spurious command signals as long as R/C transmitter signal is active. If transmitter signal is lost, R/C receiver switches (default) control to autopilot. When GPS signal is lost, First Pilot View (FPV) technique will be used for safe landing.

3. Case Study I: UAVForge Flyoff Technology Demonstration

Conceptualized six years ago by the faculty and a set of dedicated doctorate scholars of the Aerospace Engineering Department at the MIT, the project took off at the international drone Olympics, otherwise called the UAVForge, in 2011 following hours and hours of research work. While the process of developing the design for the small unmanned vehicle was on, the team came across the news about a drone competition being organized by DARPA.

The website of UAVForge[1] throws light on how tough the competition was structured. The challenge involved is, flying the drone on a two mile stretch and landing it on a tiny structure and then transmitting the video back to the ground station. The difficulty here was the fact that once the drone crosses the 200 meter distance, it vanishes from visibility. From then on, the skill of the team in utilizing onboard technology to cover the remaining distance solely decides the success of the drone.

With participants from 152 countries, the competition had three highly difficult levels that tested the durability as well as the innovation brought to the table by the teams.

In Milestone 1, the first stage, the teams were elaborated on the challenge for the small drone they were developing. The teams were asked to submit a 60 s concept video to advertise their skills, design sketches, vehicle components, algorithm behaviors and other such technical details; "Team Dhaksha was ranked 38 at this stage."

Milestone 2: In the second stage, the website says, "Competing teams are asked to demonstrate the early flight behaviors and capabilities of their air vehicle system. They may also showcase other innovative and creative aspects of their air vehicle system design and performance." This is when the drone was really built and the competition slid from the concept to the implementation stage.

In this milestone, "The team upped its status to rank two". The reason for such a vast improvement in stage two was because the team was able to materialize in full the concept submitted in the first stage. Many other teams came up with extravagant ideas which really were not possible to implement.

Following this, the team was asked to do an hour-long live demonstration of their vehicle which was monitored by experts from DARPA, USA via video conferencing. This, the third Milestone, happened on the campus of Anna University in Guindy, Tamil Nadu. The demonstration went smoothly and Team Dhaksha topped the list of 12 teams which were shortlisted after this stage and called to Fort Stewart in Georgia Atlanta, an army installation for final fly off.

Final Fly off: The terrain in which the team was asked to operate the drone in Fort Stewart was challenging to say the least. The team took only one model whereas others had five to six spare ones. During the baseline attempt post trial, the team's drone lost video and data link, however the UAV held position in a very stable controlled descent and hovered at approximately 40 feet[1] above the ground level. The UAV was landed manually after 13 min of autonomous hovering over the trees. During the second attempt, the vehicle lost signal and crashed midflight after a hover for about 10 min at an altitude of 80 feet near to target because the pine trees, about 100 feet in height, blocked signals that operated the drone. The team then set right the crashed drone in a matter of hours, impressing the judges. In the meantime, the team also made a minor tweak to the design which at last helped the team to reach the mission destination.

The yagi antennae used to guide the drone were always placed on the ground. However, given the unique situation, the team designed and built a small yagi antenna at the competition site itself and placed it in the UAV. This transformation ensured that Dhaksha completed the task of flying two miles, a manual landing on the building and transmitting the video for a shorter duration.

4. Case Study II: UAV in Acoustic Field Testing

In this work, rotary wing micro air vehicle is used as a test bed for acoustic field testing and analysis. The vector sensor was positioned at one meter height above the ground and data were captured for nearly 620 s by flying the MAV model around a one mile radius. The generated outputs were sampled at 20 kHz and the data were processed in overlapping blocks, each containing 8192 samples with 50% overlap between two consecutive data blocks. The sample photo of acoustic field testing is in Fig. 11.

Fig. 11. Gunshot location test.

A signal emitted by an UAV at time δ arrives at the microphone at time t.

$$t = \delta + \frac{R(\delta)}{c}, \tag{1}$$

where $R(\delta)$ is the distance from the aircraft to the microphone at time δ and c is the speed of sound.

$$R(\delta) = [R_c^2 + v^2(t-\delta_c)^2]^{\frac{1}{2}}. \tag{2}$$

The instantaneous frequency received at the microphone is given by

$$f(t) = f_o \frac{d\delta}{dt}, \tag{3}$$

$$f(t) = \frac{f_o c^2}{c^2 - v^2}\left[1 - \frac{v^2(t-\delta_c)}{(R_c^2(c^2-2) + v^2c^2 + (t-\delta_c)^2)^{\frac{1}{2}}}\right], \tag{4}$$

where f_0 is the unshifted frequency, v is the UAV speed, δ_c and R_c are the time and slant range, respectively at closest point of approach. Equation (4) is the required model for the acoustic detection of vehicles based on Doppler Effect.[8–10]

The data collected were sampled and the spectrogram study was carried out. This study shows the possible detection of transients as well as harmonics pattern of vehicle due to Doppler Effect. By selecting the proper points in the harmonics pattern and substituting the same in the above mentioned Eq. (4) reveals enough results for the validation of model. Figures 12 to 14 show the transients and transit response of the vehicle. Figures 15 and 16 represent the slant range and elevation which shows that the maximum peak occurs when the vehicle was exactly over the sensor.

For the given unmanned vehicle, the velocity, height, RPM of the propeller and the blade rate are obtained as

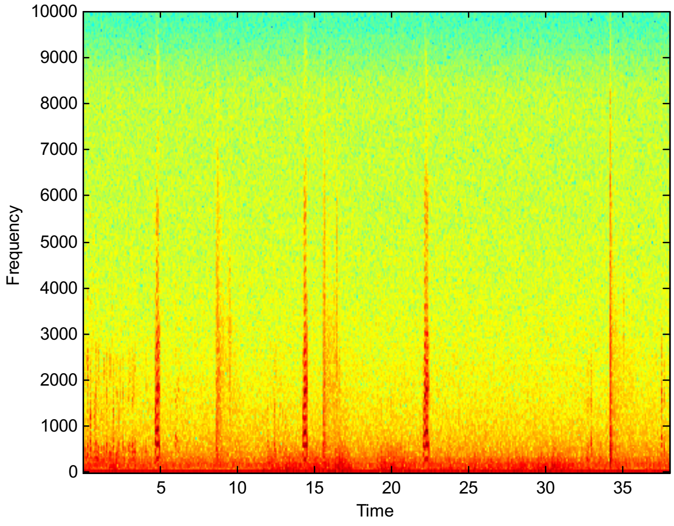

Fig. 12. Transients recorded during gunshot testing.

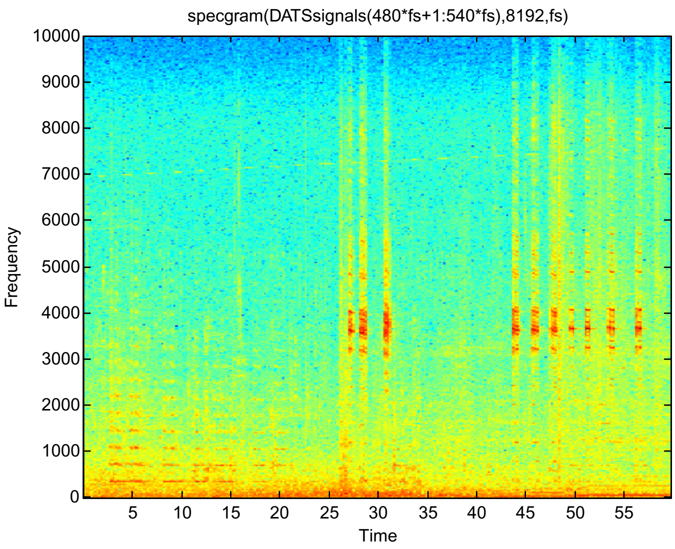

Fig. 13. Motor cycle sound recorded during transit.

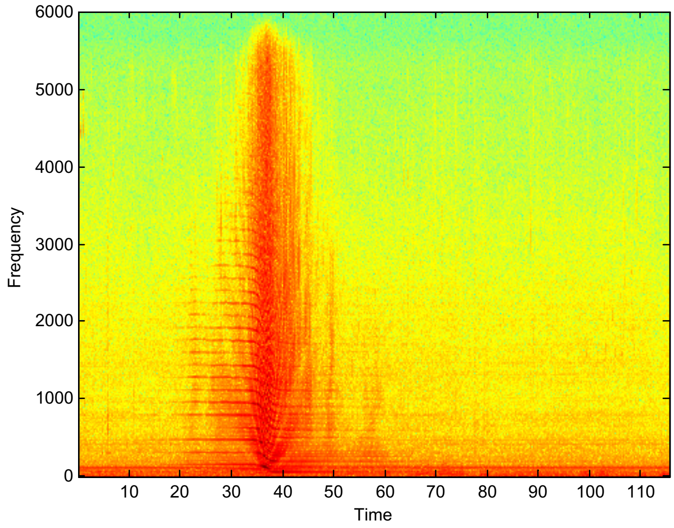

Fig. 14. Doppler effect.

$V = 63.3$ m/s (Mach: 0.19), $h = 57.9$ ft, RPM of the propeller = 11681, blade rate = 23,361, $fo = 389$ Hz.

5. Case Study III: Structural Tower Testing

This is about the investigation of structural strength of the India's tallest structure, the 300 m RCC tower using Dhaksha UAV. Unmanned inspection devices are a new way to

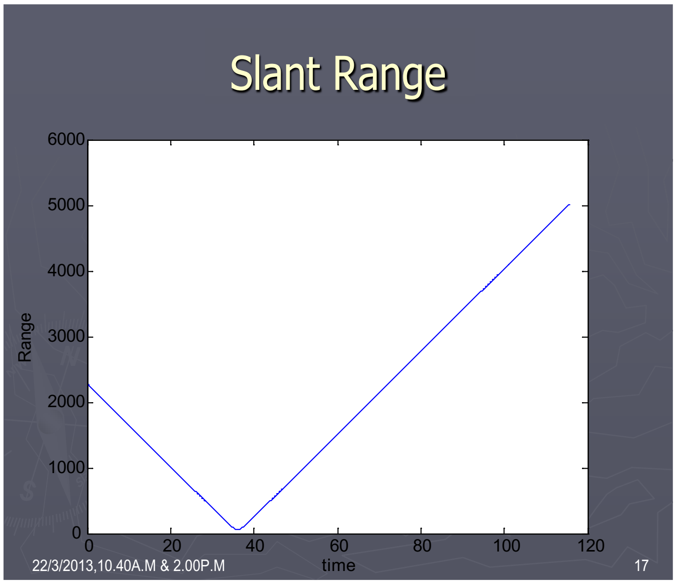

Fig. 15. Slant Range calculation.

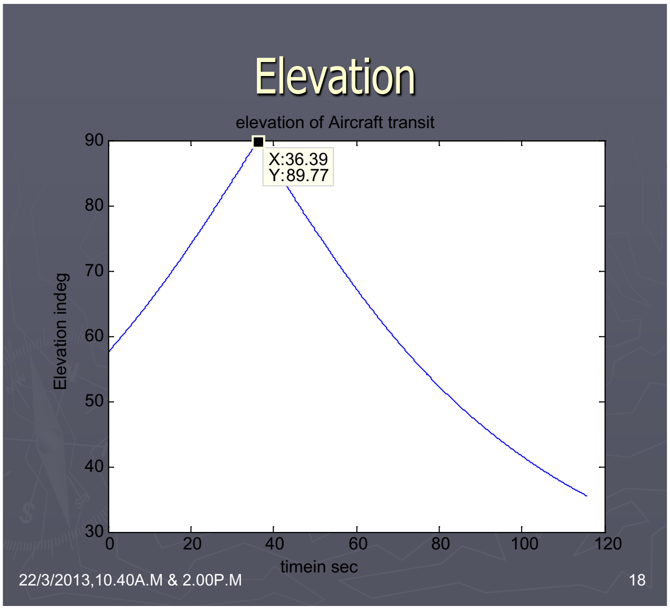

Fig. 16. Elevation calculation.

inspect tall structures, thereby increasing the number of daily inspections while eliminating the risk of personal injury. The system provides the aerial platform for any type of viewing and recording, for determining present conditions, and/or for documentation of completed repairs and inspections, etc.

The ability to survey the area from above provides an "eye in the sky" perspective on current conditions or damages. Features of the vehicle include full auto take-off, waypoint (GPS) tracking, and auto landing. The ability to know the exact location of the camera at any given moment allows for complete documentation while the inspection is in progress.

The primary objective of the mission was to capture clear and detailed images/videos of the tower structure for efficient crack mapping of entire outer surface of the tower. On deployment, within few minutes of takeoff, Dhaksha reached the top of the 300 m tall tower, carefully examining the structure from many angles. When performing the tower inspection, the first step was to achieve a position adjacent to the components of interest. This can be quickly achieved by positioning the UAV as close to the tower and below the desired final position, and taking off to climb to the desired height. The system flew around the tower in circular and vertical flight for closer and wider angle views. As it flew, it filmed in HD video. The vehicle was able to see the flaws in the structure viz., cracks, internal structural damage, steel frame exposure and rusting due to sea breeze erosion, peeling off and caving in, etc. The vehicle automatically maintained a position hold while the operator pointed the camera at each point of interest. Clicking on the component of interest in the video stream sent a high resolution image/video to the GCS for immediate and post analysis. The ground control station received live video/images and is able to see what the UAV sees as it flies. Skilled technicians monitored the flight and requested the UAV pilot to go back or to zoom in as it flies. Because the GPS location and altitude are visible on the ground control station as the vehicle flies, you can pinpoint the areas needing attention, repair, or just another look.

Fig. 17. Structural damage assessment by UAV.

Fig. 18. Examination in different position.

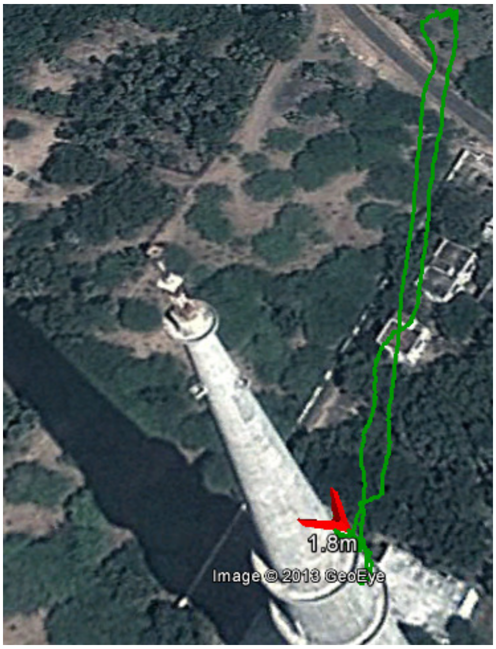

Fig. 19. Programmed navigation.

Critically, in contrast to the traditional joystick operated small UAVs, the Dhaksha's map-based point navigation system allowed the operator to focus on the inspection rather than the flying. While this is being done all personnel were safely on the ground, incurring no risk whatsoever, the main objective of an aerial unmanned mission. The cost of inspection is reduced and the quality of the inspections has actually been improved because the UAV uses better optics to view and record what it sees.

6. Case Study IV: Visual and Thermal Image Fusion for UAV-Based Applications

UAVs can be equipped with a variety of imaging/sensor payload, which operates semi-autonomously or autonomously. The platform may have a small or medium size still-video or video camera, thermal or infrared camera systems, airborne light detection and ranging (LIDAR) system, or a combination thereof. All these different kinds of cameras are an effective sensor tool which is portable, weightless and can be airborne in a platform on the UAV.

Amongst the twin imaging platforms, thermal images have a valuable advantage over the visual images. Thermal images do not depend on the illumination; the output is the projection of thermal sensation of the emissions of heat of the objects. This unique merit gives rise to effective segmentation of objects. Ultimately, surveillance measure using an UAV gets improved.[11–14]

Fig. 20. UAV with thermal Camera flying through fog.

Thermal imaging cameras produce a clear image in the darkest of nights, in light fog and smoke and in the most diverse weather conditions. There has also been an increased interest in thermal imaging for all kinds of security applications, from long-range surveillance at border crossings, truck and shipping container inspection, to the monitoring of high-security installations such as nuclear power stations, airports, and dams. But thermal imaging has a lot more to offer than just a night vision solution for security applications.

With the development of various new imaging sensors arises the need of a meaningful combination of all employed imaging sources. Hence, Image fusion of visual and thermal sensing output adds a new dimension in making the surveillance more reliable. Target tracking during instances of smoke, fog, cloudy conditions, etc., gets improved. With conditions of same background color, perception of target becoming unnoticed gets eliminated with thermal image inclusion, and hence image fusion gives complementary information. A holistic system which represents the combined fused data is perceived at the control level of the UAV's.

Hence, team Dhaksha decided to try this novel concept and the team developed many simulation results. The team seized an opportunity to practically test the concept when the Himalayan river Mandakini at Uttarakhand was in flash floods, the area being at an altitude of 4200 m above mean sea level.[15]

As the fate of several thousands of people remained unknown in flood-ravaged Uttarakhand, the National Disaster Response Force (NDRF) decided to deploy the Team Dhaksha drones to locate missing persons. On hearing reports that several persons were still missing in Uttarakhand and that rescue workers were unable to access certain pockets, Team Dhaksha decided to apply thermal fusion technique. In the event of any person being alive in the debris or a pile of bodies lying underneath, the thermal camera can sense temperature variation and track his/her location. High quality visuals of inaccessible terrain will be captured by the high definition (HD) camera.

Fitted with thermal and high definition cameras, the drone was on many sorties for a few weeks. Fresh rains slowed down the process during the early stages even then the team had managed to fly the drone in unfavorable weather condition. Visual and thermal images/videos were transmitted to ground control station (shown in Fig. 22). The visual image gives a realistic human sensing view. The thermal image shown in Figs. 21 to 23 identifies the target, with the temperature difference coming into the picture with objects possessing different emissivity values.

Fig. 21. White spots are the hot spots.

Fig. 22. Thermal image.

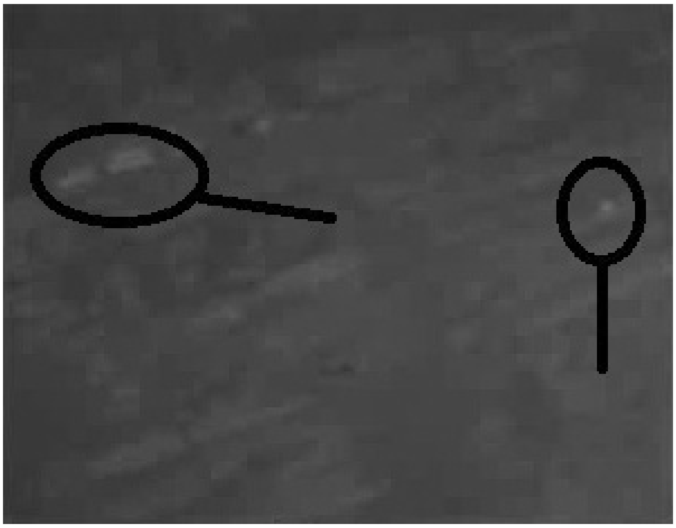

Fig. 23. Thermal signatures during the aerial search operation.

Visual and thermal image fusion had been done in due course and the fused image used for target tracking.

7. Conclusion

A family of autonomous multi rotor aerial vehicles had been developed by the team. The aim of the project was to have a fully functional multi rotor system capable of autonomous outdoor operations. The design and construction of the physical structure of the team's vehicle was a success both in terms of stability and strength of the craft, and in terms of weight reduction. The team also succeeded in writing fully functional software for the control of the motors and implemented this software code on a commercially available microcomputer. The team obtained visible results with an oscilloscope set up, to read the sensor and operator inputs and PWM outputs.

Telemetry link from ground control to the aircraft is currently done with a dedicated radio modem with short range (5000 m), but due to the modular design, replacement by other telemetry hardware with much higher range is comparably easy. Payload data can be stored on solid state memory, allowing high volumes of data storage and easy handling of data after landing.

Three prototypes are available for civilian applications with payload capacity ranging from 300 to 2000 g and are suitable for many purposes.

Based on the above practical drone deployments, the team had been awarded 160,000 USD for providing UAV systems to the state civilian law enforcement agency.

The scope of growth in the Civilian applications could be even larger as has been seen in the other fields e.g. Internet, Civil aviation and Information Technology which were initially military applications but are a part and parcel of the common man's life today. Having developed prototypes of varied dimensions indigenously and given the team's proven track record, the ability to meet any of the customer mission requirements any time at short notice and reasonable costs would be the major strength of the team.

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