Surveillance for Intelligent Emergency Response Robotic Aircraft – VTOL Aircraft for Emergency Response

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The Surveillance for Intelligent Emergency Response Robotic Aircraft (SIERRA) project was formed to unite academia and emergency response units for assessment of the viability of UAVs for enhanced situational awareness. The goals of SIERRA, focusing on forest fire applications, are not only to have an eye in the sky but additionally to circumvent loss of life and limit property damage by utilizing a low cost, easy deployable UAV system. The main concept is that real-time data gathered coupled with an accurate predictive capability and rapid dissemination of processed information by the incident commander makes a very meaningful difference in disaster/emergency response. With the real-time monitoring capabilities and the capabilities of onboard sensors firefighters can see the real fire and its progression on any level of the Incident Command Structure. This paper presents the SIERRA system and summarizes limited tests conducted in collaboration with West Virginia forestry.

I. Introduction

On June 28th 2013 a strong thunderstorm passed through the area Yarnell Hill Arizona igniting multiple fires. At the time the fire was reported it was 1/2 acre in size. Through the next two days the fire grows to over 6000 acres. Due to severe drought and unpredictable winds the fire grew and often changed directions unexpectedly. A team of firefighters were working south of the fire when an unexpected wind change occurred causing the fire to drastically change direction. The fire was growing at a rate of 10-12mph. The fire crew fearing for safety retreated and made their way to a safety zone. As the fire progressed the team decided to deploy a shelter, they only had two minutes to do so before the fire would reach their position. Due to poor communication, situational awareness, and decision making all 19 firefighters lost their lives. During their escape no one from

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the Incident Command knew where they were or even which route they took. Without the use of technology and proper communication events like this one will probably occur again resulting in further loss of lives.

Every year, natural and man-made disasters cause loss of lives in addition to a cost of approximately $52 billion in US in the form of impact on economy, and public and private property damaged. During the period of 2000 – 2007, the US witnessed a total of 377 incidents where presidential emergencies were declared. Wildland fires have caused huge devastations on a very regular basis. This is evident from the fact that during last eight years wildland fires have consumed approximately 59 million acres of land as per the data provided by National Interagency Fire Center.

Apart from short term socio-economic impacts, large wildland fires have smoke-related health impacts, and long-term environmental impacts. Generation of real-time situational awareness is a critical component of any disaster management where incident managers need to make decisions and allocate resources. Data collection and its interpretation for generation of situational awareness, known as Emergency Informatics, is a major challenge in responding to any large-scale hazard or disaster. There are several reasons that contribute to this clearly perceived gap including: geographically distributed nature of large-scale disasters; time-critical constraints involved; socio-technical nature of the problem that involves interactions between different agencies and the general population; a disaster’s potential impact on life, quality of life, local economy; and destruction of vital infrastructure during disasters.

Recent advances in different areas of cyber-physical and information systems including sensing, communication, computing technologies, unmanned systems, and Geographical Information Systems (GIS) have provided an unprecedented opportunity to revolutionize the generation of situational awareness for augmented management and control of a large-scale disaster. However, despite these recent advances, from the scientific and engineering perspective, the problem is immensely challenging due to its multi-scale spatio-temporal nature, the overwhelming amount of data that needs processing in near real-time, large interdependencies and interactions between human and technological entities, heterogeneities in technological resources involved, and uncertainties inherent in any large-scale disaster.

The long-term goal of the SIERRA team is to develop a unique and commercially viable human-robot system which would enable generation of comprehensive situational awareness during natural and man-made disasters. The objective of this proposal is to develop a prototype of the Unmanned Aerial Vehicle (UAV) based incident command decision support solution for structural and wildfire fighting situations that will enable generation of accurate situational awareness by providing advantages in safety, cost, and ability to gather real-time data. The product, consisting of ground station software and a UAV platform with onboard sensing and communication facilities, would allow real-time UAV control, data processing, and visualization. Integrating real-time UAV sensory data into effective fire-predictor software will allow an incident commander to make timely and informed decisions which can optimize the resource allocation process and save lives.

The key issues are that not only the system should be inexpensive for its widespread use but also safe, user-friendly, and robust to situations that might happen in real-world. As a part of this project, we would develop a working prototype with all the required software and hardware with day-night operation capability. Real-world insights of firefighting community for developing the key features of the prototype would be obtained via close collaboration with the West Virginia Department of Forestry and Cincinnati Fire Department. This paper presents a brief review of the SIERRA system and provides an overview of preliminary field tests.

II. Approach

The SIERRA Program recently converged to the following two Value Propositions after interviewing 103 potential users and collaborators, including high ranking fire Chiefs and industrial leaders:

- **Save lives and property by enhanced real-time information and decision making**: The proposed UAV based platform provides an unprecedented opportunity to gather real-time information for fire-fighting and search and rescue operations. Such capability, currently unavailable, will allow the incident managers to make decisions to save lives and suppress fire in most efficient manner.

- **Ease of use by first responders**: As opposed to other UAV platforms available in the market, this platform will provide push-button facility to operate the UAV and visualize the information. Such a capability is invaluable for non-pilots working in heavy stress situations.
The objective of SIERRA is to develop a UAV based platform prototype that would provide the fire-fighters with situational awareness in wildfire and structural fire scenarios. The overall concept is that the fire fighters would launch a UAV in the vicinity of a fire. Using an area map on ground control station, the user would provide an area that approximately encloses the fire. The user would also have option of providing approximate locations which would act as way points for the UAV. Based on this information, the ground control station would obtain a trajectory and feed that to the UAV. The UAV would then be directed to explore the area or visit these points and send back vision and infra-red video data along with other data such as from Global Positioning System (GPS) and Inertial Measurement Unit (IMU) sensors. This data along with other information such as topography, vegetation, and moisture conditions would be fed to fire propagation algorithms to generate not only current but also future fire conditions that would ultimately be used by incident managers to obtain an accurate situational awareness thereby providing them with the quintessential platform to make effective decisions.

The system outlook for SIERRA is to have a VTOL mutli-rotor UAV that can launch from remote locations with the capabilities of Day/Night operations. Using video and GPS data from the UAS enables the Incident Commander and other users to view the fire remotely and to monitor the fires progress. Further development allows for the integration with fire prediction software to improve the efficiency of response. All communication done during these fires is done with radios, with possibilities of miss communication causing the loss of life. Having a small, low cost UAV being deployed by crews allows not only for them to see the fires progression, but allows for the Incident Command to make the appropriate calls.

Figure 2. SIERRA Approach. The goal of the SIERRA Project is to have a VTOL aircraft with 'Click and Fly' capabilities and integration with fire prediction software.

SIERRA is a diverse group of students conducting research in the area of emergency response using UAVs. The work done by SIERRA spreads across two universities; the Principal Investigator Dr. Kelly Cohen of the University of Cincinnati and Dr. Manish Kumar of the University of Toledo. Some research being done currently includes fire prediction modeling, smoke removal filtering, and hotspots detection using infrared cameras.

The work being done in Real-time Predictive Modeling takes environmental conditions such as Weather (NOAA), Topography (Google Earth), and Fuel and Moisture Levels from the appropriate agency and combines them with the onboard GPS/IMU Data from the UAV to make a Fire Prediction Model. This model is then run through a Monte Carlo Simulation which takes varying wind conditions to show what the worst case scenario would be.
III. Development of Modeling and Controller Optimization

For a UAV that is operating in the conditions of a wildland fire the controller must be able to handle vortices that can occur in a valley or the turbulences caused by a fire. Using traditional methods of modeling we can predict the dynamic model of the rotorcraft using both aerodynamic and structural characteristics. The model created then is simulated and compared with flight data. Fine tuning of the comparison is used to create a more accurate model. For small-scale rotorcraft such as a quadropter these traditional methods become impractical due to their complex coupled aerodynamics.

A linear representation of the quadropter dynamics can be obtained using frequency-domain system identification. Using frequency-domain identification reduces errors and assists in determining the accuracy of the identified model. Using the Comprehensive Identification from FrEquency Response (CIFER®) program a closed-loop dynamic model of the quadrotor can be made. CIFER® has been applied in the system identification of both military and commercial aircraft and rotorcraft configurations. The model extracted from CIFER® that was compared to flight test data show a very accurate model was obtained. This model is used for the controller optimization so that a balance between responsiveness and stability is achieved.

Further comparisons can be done like shown in Fig. 4 where analysis of the frequency response of the pitch rate (q) can be seen. This model (blue dash line) matches both the Magnitude and the Phase of the flight data (red line). This shows that the model accurately represents the dynamics of the actual system.

Using the CONDUIT® environment the flight controller is optimized and verified using flight testing. Compared with the...
legacy controller a more stability margins and damping is attained. Figure 5 shows the comparison of the quadrotor flight characteristics before and after controller optimization. The model output (green dash line) and the flight data (blue line) matches very well, which is a proof that the quadrotor system accurately predicted by the extracted model. Furthermore, compared with the legacy controller output (red line) the optimized controller output is less oscillatory.

IV. Preliminary Results

The work being done by SIERRA has been tested in the field using fixed wing aircraft in the past, but recently SIERRA has conducted live wildland fire testing using multirotor UAVs. In November of 2013 the team in conjunction with the West Virginia Division of Forestry conducted a 4 acre prescribed burn. This burn allowed for the testing of infrared cameras and new stabilized camera systems. The team was led by the Team Lead, Bryan Brown where two systems were tested. The main objective for this test was to validate the using a rotorcraft in a wildland scenario and the ability to carry an infrared camera. It was observed that although the rotorcraft had limited endurance with respect to their fixed wing counterparts, the rotorcraft proved itself to the emergency responders on site.

The rotorcrafts ability to take-off in a small clearing and simple controllability appealed to the firefighters and further partnership could be made. The collaboration between the West Virginia Division of Forestry and SIERRA has led to SIERRA placing a student out in the field to continue research full time. This research included the training of firefighters on the flight, control, and maintenance of UAVs.

To show the real-world capabilities of SIERRA the team conducted 2 non-wildfire related scenarios in the fall of 2014. These scenarios were stated as follows:

The first scenario involves a search and rescue of a lost hunter and the second in a reported illegal fire.

Scenario #1: Search and Rescue of Lost Hunter
While tracking a wounded deer a hunter has lost his direction and has been reported missing for 36 hours. He is presumed injured and his last location known was in South East summit of Coopers Rock State Forest. It is also known that he is wearing an orange safety vest.

Response:
The team was given a location that the hunter could be and was tasked with creating a search pattern and use both visual and infrared cameras to locate the missing hunter. Once the hunter was found the GPS coordinates of his location were plotted on Google Maps and given to Search and Rescue teams.

Results:
The team arrived at the site and set-up the UAV and began the search. The search pattern cross sketched like similar search patterns used by the WVDOF. Within minutes of flight the hunter was found in a sparse clearing using a live video feed to the ground station. The hunter can be seen lying on the ground in Fig 6.


Figure 6. Missing Hunter. Real-World scenario showing use of UAV to find a missing hunter. Seen in white circle, his orange vest is easily seen with the contrast of the leaves below.

Scenario #2: Illegal Fire in State Forest
During the fall months the low humidity, high winds, and fallen leaves can cause the smallest fires to burn out of control within minutes. This is why the many areas put bans on fires in wooded areas even if it’s a campfire. During a routine flight the team notices some smoke near an old logging cabin. The Team is tasked with finding the source of the fire and image the area until the proper authorities arrive.

Response:
The team launches a UAV and during a 360 degree sweep sees the smoke and moves towards the area.

Results:
As the team gets closer to the fire the infrared camera is engaged and they are able to see the fire on the ground. From the infrared the team is able to identify the fire size and see anyone around the fire (seen in Fig 7).

Figure 7. Infrared image of small fire. Image shows a small circular white area where fire is and 2 easily identifiable people. Further flying can show temperature of the fire.
One of people on the grounds begins to flee into the woods and the team uses the UAV to follow. The team can switch between both infrared and colored cameras to follow the suspect. The screenshot in Fig. 8 shows the person running from the UAV.

Figure 8. Person running. Image shows a person running easily identifiable in video due to movement. The 'suspect' could not hear the UAV flying above him.

V. Conclusions & Future Work

The SIERRA Team continues to work the West Virginia Division of Forestry to develop and test algorithms for the enhancement of situational awareness. The teams hope that the results of the real-world tests will help push for the development of more partnerships and opportunities for research in the future. The team’s next goals are to combine the algorithms developed into a ground station that is straightforward for the firefighters to use out in the field. Further development with the infrared camera will allow for the autonomous detection of fires and using image processing techniques for search and rescue operations.

SIERRA will continue to pursue its goals of creating a low cost UAV for Emergency Response and will be conducting training for the Division of Forestry in 2015. The next steps will include developing doctrines that will help establish guidelines and maintainance manuals for emergency response personell. To assistance with training a unique ground control station is being created. This ground control station will allow for the Incident Command to be able control the UAV, view personell on the ground, and maintain a careful watch on any fire from a safe location. The ground station must not only be simplistic to use but offer the Incident Command the tools to keep their first responders safe.

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