A SURVEY OF UNMANNED AERIAL VEHICLE (UAV) USAGE FOR IMAGERY COLLECTION IN DISASTER RESEARCH AND MANAGEMENT

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Abstract - The concept of employing unmanned aerial vehicles (UAVs) to acquire imagery for disaster research and management has progressed into actual implementation in recent years. UAV usage in disaster assessment, response and management is an active area of research. UAVs have been utilized following ecological, meteorological, geological, hydrological and human-induced disasters. The flexibility, safety, ease of operation, and relatively low-cost of ownership and operation facilitate UAV implementation in disaster situations. This paper provides a review of recent utilization of UAVs for imagery collection for disaster monitoring and management.

Keywords: UAVs, Unmanned Aerial Vehicles, disaster monitoring, disaster assessment, disaster management

Introduction
Unmanned aerial vehicles (UAVs) equipped with remote sensing instrumentation offer numerous opportunities in disaster related situations. When UAVs acquire photogrammetry-ready data with appropriate imagery metadata, the capabilities of UAVs for disaster research and management can be further realized. High-resolution images can be analyzed and used to produce hazard maps, dense surface models, detailed building renderings, comprehensive elevation models, and other disaster area characteristics. These data can then be analyzed using remote sensing methods or visual interpretation to coordinate rescue efforts, record building responses to the disaster, detect building failures, investigate access issues, and verify experimental disaster modeling. The data can also be gathered before a disaster in order to document immediate pre-event conditions of critical facilities and infrastructure, monitor susceptible environmental concerns, and document historical conditions and sites. This paper presents a review of recent papers regarding data acquisition and assessment prior, during and after disaster events.

Data Acquisition for Post-Disaster Assessments
The use of UAV imagery for post-disaster assessments has been explored in the capacity of both automatic and manual imagery assessments (Adams et al., 2010). This section presents select research of post-disaster studies in which UAVs were employed to collect imagery for assessment.

In 2005, Hurricane Katrina caused widespread devastation on the Mississippi Gulf Coast. Documentation of infrastructure response to such an event is an important objective in operations and research; however, the task can be hazardous, and collecting detailed information of an affected area while keeping costs down is typically challenging. Especially for large scale events, such as hurricanes, accommodations and provisions may not be available to survey teams for

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hundreds of miles, making field data collection even more difficult. Traditional assessment methodologies include both detailed and rapid ground surveys that have innate limitations caused by timeliness and breadth. Additionally, site access can be compromised as shown in Figure 1.

Figure 1 – Limited Access for Damage Survey Vehicles Following Hurricane Ike in Galveston, Texas

To remedy these limitations, Pratt et al. (2006) explored the utility of UAVs for conducting structural damage inspections of several multi-story commercial buildings damaged by Hurricane Katrina. Using a helicopter UAV equipped with a digital camera capable of both still and video imagery, the study found that UAVs have great potential for post-disaster data collection and assessment although implementation issues such as obstacle avoidance, site access, sensor coverage, and weather conditions were identified. In this study, site access and landing and takeoff environments were limited which required greater flight distances to areas of interest, thus restricting the UAV operator’s ability to keep the UAV in sight. The UAV was equipped with a GPS-based flight hold feature, which enabled the UAV to hover in-place once the operator flew the UAV to a desired position. This feature is advantageous when manually collecting imagery as the operator can remit flight controls to the semi-autonomous flight controller and then focus on camera controls to acquire the imagery. An important aspect of obstacle avoidance that merits further exploration is investigation of hovering tolerance, as obstacles near the UAV can be hazardous to the UAV’s flight (e.g. unseen wires, radio-transmission interference, and material interference with UAV control sensors). Downdrafts, wind shear, turbulence, and eddied flow surrounding buildings increased difficulties in UAV stabilization, a feat needed for high-quality imagery collection. Pratt et al. (2006) also identified several needed advancements in UAV capabilities for more effective post-disaster assessment, including the ability to return to the last known good communications point if communications between the operator and UAV are severed. Several of these advancements have been implemented in newer UAV systems.

Another post-hurricane reconnaissance effort involved the joint use of an unmanned sea-surface vehicle (USV) and a micro UAV to help conduct post-disaster inspections of bridges, seawalls, and piers damaged by Hurricane Wilma and Ike (Steimle, Murphy et al., 2009). The Hurricane Wilma investigation is believed to be the first known demonstration of UAV and USV cooperation in any study (Murphy, Steimle et al., 2008). Intentions were to deploy the UAV and
USV simultaneously, but to independently survey damage; however, the USV operator experienced difficulties in control. To remedy the situation, the UAV was maneuvered in order to relay real-time aerial video of the USV to the USV operator. This investigation identified several future research initiatives including USV to UAV to operator communications, USV path prediction, and UAV imagery coverage of the USV and assessment area. A similar study comprising the joint use of a USV and UAV was conducted following Hurricane Ike (Murphy, Steimle et al., 2009). This study suggested that the UAV could be flown first to acquire imagery to create maps for USV navigation purposes before the USV is deployed.

Because of travel limitations caused by floods, dam failure, landslides, and infrastructure damage following 2009 Typhoon Morakot in Taiwan, a helicopter UAV was deployed to collect post-disaster imagery to support post-disaster reconnaissance, disaster restoration and reconstruction assessments (Chou et al., 2010). Camera calibration, photogrammetric techniques, and aerial triangulation were utilized in imagery collection and analysis to produce quality digital elevation models (DEMs). The study regarded the use of UAVs for post-disaster assessment as an item of significant value, suggesting that development of a UAV-based disaster data collection protocol for such events would be worthwhile.

Recent earthquakes have also seen UAV deployment for post-disaster imagery collection in L’Aquila in 2009 (Quaritsch, Kruggl et al. 2010) and Haiti in 2010 (Huber, 2011). Following the L’Aquila earthquake, quad-copter UAVs furnished with a camera evaluated the application of UAVs for fire service response (Murphy, 2011). After the Haiti earthquake, a private company flew a small UAV to assess orphanage damage in remote mountains near Port-au-Prince (Huber, 2011). The UAV relayed real-time imagery that indicated that the orphanage’s critical infrastructure was intact, allowing rescue efforts to concentrate on other areas of need, rather than spending critical time required to travel to the remote orphanages (VT Group, 2011). Furthermore, A United States Air Force Global Hawk UAV conducted a reconnaissance mission in Haiti to determine the damage and usability of its roads and airports. The long-endurance capability of the UAV greatly contributed to its use in this operation. The Global Hawk UAV flew daily missions from Maryland to Haiti due to insufficient infrastructure near or in Haiti. A typical mission lasted 14 hours and collected up to 700 high-resolution images (Petcoff, 2010).

In March of 2011, Japan endured a devastating earthquake and subsequent tsunami. Fukushima Daiichi nuclear facility was significantly damaged in the event and consequently began to emit radiation. This hazard complicated repair and traditional reconnaissance efforts as humans were advised to avoid the area. To remedy the imagery collection issue, remotely operated UAVs were deployed to the area. A United States Air Force Global Hawk UAV equipped with telescopic, infrared sensors was used to determine the effectiveness of attempts to cool the reactors (Ackerman, 2011). Additionally, a T-Hawk Micro Aerial Vehicle outfitted with special radiation sensors completed five reconnaissance missions of the Fukushima Daiichi (Reavis and Hem, 2011). The T-Hawk UAV was able to acquire hours of video and valuable imagery data at lower altitudes than the Global Hawk due to its smaller size and nimble, single rotor flight design.
Data Acquisition for Rapid Response

Advances in UAVs instrumentation have enabled semi-automated and even fully automated map creation, a valuable tool for rapid response. Collecting photogrammetric-quality imagery with the appropriate metadata facilitates the rapid creation of UAV imagery-derived maps. These maps can then be used to aid in disaster response efforts as they contain up-to-date spatial information.

Suzuki et al. (2008) investigated two methods to create real-time hazard maps using UAV-collected digital imagery and sensor data (e.g. positioning and attitude) transmitted to a ground control system. The first method creates a mosaic image of optical imagery collected in video mode; the second method orthorectifies the imagery, projects them onto a map, and enables images to become integrated in a GIS database. An experiment was conducted in Kanagawa, Japan to explore the functionality of the hazard map produced using each method. It was determined that the second method created a more desirable user interface for sharing disaster information and developing disaster recovery plans. This was due to the matching of imagery with map coordinates, thus allowing the robust functionalities of GIS software to be fully utilized.

Marenchino (2009) presented another study regarding rapid map creation for disaster response. The UAV used in this study was a fixed wing system, equipped with autonomous flight capabilities, a digital camera, and photogrammetric sensors. The UAV conducted automatic image acquisition using an electric control system that initiated imagery collection based on a predetermined flight plan. Digital imagery was collected and attached to its flight telemetry in order to perform photogrammetric analyses. Imagery was then enhanced using filters and feature extraction and image matching procedures. The UAV system was equipped with sensors for attitude measurement; however, the accuracy was inadequate for direct georeferencing needs. To remedy this situation, a dense surface model (DSM) of the surveyed area was created. The imagery was rectified, features were extracted, and images were matched. A triangulated irregular network (TIN) of points containing inherent coordinates was then used to create an orthoproduction. In addition, the combination of the orthophotos and the DSM information created a model to measure distances, areas, and volumes, thus presenting itself as a tool of interest for mapping areas in need of disaster response. Marenchino’s study demonstrated the potential for rapid mapping using imagery collected by UAVs and highlighted the idea of triple stereoscopic coverage for multi-image matching. Only three images were suitable for processing; however, limiting the results of the study.

Data Acquisition for Management and Monitoring

Risk mitigation is an integral component of disaster management. Many critical infrastructure facilities with high loss potential implement preventative measures to address vulnerabilities. Employing UAVs in this phase is becoming more prevalent. A recent example in the literature of UAV-based infrastructure management and monitoring pertains to gas transmission pipelines (Hausamaan et al., 2003), where two scenarios for UAV pipeline inspection systems are proposed. The first system utilizes a small, lightweight, low-altitude UAV with a flight duration rating of 5 to 6 hours. This system requires a data communications link between the UAV and ground control system, as well as an on-board image pre-processing tool for obstacle avoidance due to the UAV’s low altitude flight conditions. The second system employs a mid-altitude
UAV (i.e. greater than 1000 meters) with a flight duration rating approaching 30 hours. At mid-altitudes, the UAV is above the clouds, warranting the need for a radar sensor, but eliminating the need for obstacle avoidance technology as it is above most obstacles. The addition of a radar sensor results in the need for a more robust communications link between the UAV and ground control system. Both proposed UAV systems use optical/infrared sensors to collect pipeline imagery; however, the second system calls for a more advanced processing system as the radar data and optical/infrared imagery are collected simultaneously. Hausamaan et al.’s study identifies the lack of UAV flight regulations as a major issue and the need for a near-real-time system for detecting pipeline issues as an area for future development.

The application of a vision-based UAV navigation system in disaster situations is an item of interest due to displacements of infrastructure following events. Such occurrences limit the accuracy of GPS control navigation which is based on estimated on predetermined infrastructure locations. Rathinam et al. (2008) cites the effects of earthquakes as an example of the need for such a navigational system. Following the 1995 Great Hanshin Earthquake in Japan, the Hanshin Expressway shifted several meters, affecting the correlation of pre-event spatial data with post-event locations.

In preparation for potential disaster-related usage of vision-based UAV navigation, Rathinam et al. (2008) conducted a canal-following study involving two experiments using a fixed-wing UAV equipped with a digital video camera. An algorithm was developed to identify structures within the UAV-collected imagery and navigational directives based on these structures were relayed back to the UAV. The first experiments had a vision based look-ahead distance of 175 meters with the camera tilted to 10 degrees with respect to the yaw axis of the plane. The second had a vision based look-ahead distance of 150 meters with the camera tilted to 15 degrees with respect to the yaw axis of the plane. The two experiments utilizing vision-based navigation control followed the canal for over 700 meters and resulted in a track deviation error of approximately 10 meters from the centerline of the structure which was deemed reasonable by the authors.

A more dynamic system for autonomous navigation in disaster areas such as that of vision-based navigation was further investigated by Soleimani et al. (2010). This study proposes a technique for a vision-based UAV navigation system utilizing Disaster Invariant Features (e.g. features that are likely to remain intact before and after events). This investigation suggests using road networks following the 2010 Haiti Earthquake for localization purposes.

Quaritsch et al. (2010) identified the need for comprehensive imagery acquisition for an area to support disaster assessment and monitoring, rather than focusing only on specific structures. They present an approach for optimization of waypoints for GPS-based autonomous UAV flight to collect imagery for an area containing both target areas and forbidden flying zones. Optimization parameters included sufficient coverage of the area of interest, avoidance of forbidden areas, and reduction of flight time and number of images acquired. Results of the study concluded that the optimization approach covered the area of interest completely, while the control approach omitted a small percentage of the observation area. The optimization approach also collected more coverage in the forbidden areas than the control approach achieved. However, factors of concern included flight time and communications bandwidth.
DeBusk (2010) presents a case study on a proposed UAV system designed to track, monitor, warn and provide relief-response information for tornadoes. The study proposes guidelines for developing, manufacturing, storing, launching, and deploying a disaster relief and emergency response UAV. The UAV would fly a certain path ahead of weather fronts in order to collect meteorological data, which can be used for weather prediction. Input from the operator as well as multiple organizations involved with tornado prediction, monitoring, and response would update autonomous flight objectives. Additionally, when conditions favor tornado formation, the vehicle would fly into a position to gather data for detecting tornado formation. If a tornado spawns, the UAV will track the twister and collect damage imagery for use in first-responder support.

Agricultural asset monitoring is an important initiative in disaster management. Frankenberger et al. (2008) investigated the ability of low-altitude UAVs to collect photogrammetric-quality imagery of ephemeral gullies in order to create DEMs. Issues such as image blur and scale arose during the research. Image blur stemmed from the UAV’s altitude/speed ratio. Increased flight speed helps to improve aerial coverage, an issue that arises from low altitudes; however, this results in image blur. A balance between aerial coverage and quality imagery capable of photogrammetric analysis was suggested. Additionally, a concern with scale was noted. This comes from the inherent characteristics of ephemeral gullies (e.g. rills and shallow slopes), that must be properly defined when performing assessments. An optimization of the elevation (Z coordinate) resolution to collect low-altitude imagery for DEM creation is stated as an area of further research. The Z resolution betters as the distance from the camera to the terrain increases; therefore, low-altitude imagery faces challenges when elevation is a key item used for assessment.

**LSU CAPTURE Lab Technology**

The Louisiana State University Condition Assessment and Prediction using Technology to enhance oUtreach, Research and Education (CAPTURE) Lab has purchased a Mikrokopter Oktokopter XL for use in disaster-related imagery collection methodology investigation. This UAV is equipped with a high resolution digital camera capable of acquiring still and video imagery of interest. Real-time access to telemetry, flight control, altitude, and roll, pitch, and yaw angles is available to the operator as needed. Preprogrammed flight plans are achieved using the UAV’s GPS waypoint capabilities. Furthermore, the UAV’s octo-rotor platform allows superior maneuverability and stability as well as vertical takeoff and landing (VTOL). The UAV is currently being developed and is planned for operation in Fall 2011.

**Conclusions**

This paper provides a survey of UAV usage for imagery acquisition in the field of disaster research and management. UAVs provide a low-cost means for imagery collection, and inherent characteristics such as small size and maneuverability make UAVs a viable option for disaster events. UAVs have been utilized with great potential following Hurricanes Katrina, Wilma and Ike; Typhoon Morakot; and the 2009 L’Aquila, 2010 Haiti and 2011 Japan Earthquakes. Each event presented different opportunities and lessons that will mold the promising future of UAV usage for imagery collection in disaster management and monitoring.
References


