Operationalizing Small Unoccupied Aircraft Systems for Rapid Flood Inundation Mapping and Event Response

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Abstract

Small Unoccupied Aircraft Systems (sUAS) offer the capability to collect rapid and accurate aerial survey data during flood response. The rapid collection of aerial flood data can potentially enable scientists to produce detailed geospatial products and related datasets in time for decisional support. A workflow for sUAS event response before, during, and after flood events is discussed.

Introduction

Flood impacts across the United States from 1988 to 2018 have led to 441 fatalities and nearly $114 billion in losses over that same period (National Oceanic and Atmospheric Administration 2019a). In 2011 alone, flooding caused a reported $5.7 billion in direct damages and 12 reported fatalities in the United States (National Oceanic and Atmospheric Administration, 2019b). Although the effects of floods on people are impossible to completely mitigate, and there is no way to guarantee protection of property, the U.S. Geological Survey (USGS) and other federal, state, and local agencies have demonstrated that the economic impacts and loss of life associated with flooding can be greatly reduced with more informed flood warning systems (EASPE 2002). Often, these flood warning systems employ flood inundation mapping and modeling efforts to gain insight for flood mitigation and event response. Small Unoccupied Aircraft Systems (sUAS) offer the capability to collect rapid and accurate aerial survey data that can be used in these flood inundation models. Rapid collections of aerial flood data (hereinafter as “data collects”) can potentially enable scientists to produce detailed flood inundation maps and related datasets in time for decisional support by local emergency responders, flood managers, and others.

The use of sUAS for hydrologic-data collection provides a cost-effective means to improve the quality and timeliness of flood mapping and modeling efforts through collection of high resolution (typically < 10 cm) imagery over areas tens of acres in size. Survey teams of as few as 1–2 people equipped with sUAS can be deployed during flood events to collect high resolution aerial imagery data for use in flood models (Wang 2015). The ability to put “eyes in the skies” at precise locations during flood events can be beneficial for emergency managers who need vital situational awareness information to aid in protection of life and property (Restas 2015). In addition to situational awareness and near real-time mapping of flooding extents, sUAS can produce a range of invaluable data such as images, video, multispectral, and thermal video. These data are being collected for validation of hydraulic models and science support among other things. Small UAS are also being used to map streamflow and velocities directly with computer vision techniques (Lewis et al. 2018; Tauro et al. 2016).

This paper presents a workflow for operationalizing sUAS data collection prior to, during, and after flooding events. Recommendations for how best to mobilize and perform required data collects as a part of flood event response are given. Specifically, perspectives on Federal Aviation Administration (FAA) and flight plan requirements, safety concerns, and data management of longer term projects are shared. Also, examples of the benefits of rapid event response and situational awareness are presented. Lastly, some perspectives on the establishment of long-term project management infrastructure, as well as lessons learned from our experiences with sUAS for event response are discussed.

Mission Planning and Operations

In the United States, national airspace authority and control is maintained by the Federal Aviation Administration (FAA). Prior to any sUAS flight, the authority to fly must be established. Currently, FAA-certified remote pilots can fly in Class G airspace below 400 feet above ground level (ft AGL) so long as the sUAS is operated more than the required distance away from the nearest airports (5 statute miles in most cases), visibility is greater than 3 statute miles (SM), and sUAS operations maintain at least a 500 ft vertical and 2,000 ft horizontal separation between the sUAS and clouds based on Title 14 of the Code of Federal Regulations, Part 107 (Electronic Code of Federal Regulations 2019; “Part 107 Rules” hereinafter). Additionally, remote pilots must maintain visual line of sight (VLOS) with the sUAS at all times. There are instances where flight authority in other controlled airspace can be obtained (such as during an emergency response), but this requires an application process for a waiver of specific requirements of the Part 107 Rules. Within the Department of Interior, there are means for gaining standing FAA approval for flight operations outside of Part 107 rules, including emergency response flights in temporary flight restriction (TFR) areas, night operations, and flights above the 400 ft AGL Part 107 Rules ceiling. For example, in the case of sUAS flights in support of the 2018 Kilauea volcanic eruption, waivers were approved for sUAS flights exceeding both the VLOS and the 400 ft AGL ceiling within the TFR area.

In river reaches where flooding is expected, or where there is an existing project is in place, pre-planning allows for quick response flights when the event occurs. A common approach is to pre-plan flight areas where authority exists automatically as indicated in Part 107 rules, for example in Class G airspace below 400 ft AGL. For agencies in the Department of Interior (including USGS), this preplanning is required and is documented in a Project Aviation Safety Plan (PASP) which states most details of planned flights for a particular area (U.S. Department of the Interior 2019). A PASP can be designed for single flight missions, or as a standing document for multiple flights over a specific area. Regardless of requirements, generating PASP is a valuable exercise, and can also aid in fast-tracking the FAA Part 107 Rules Waiver process if needed for a mission. This preplanning approach was recently used to safely collect aerial streamflow data during a flood using the Large-Scale Particle Image Velocimetry method (Lewis et al. 2018) during severe flooding in October 2018 on the Llano River in central Texas. The mission PASP was put in place prior to the event, allowing the sUAS crew to deploy within hours and capture the extreme flooding conditions (Figure 1).

During sUAS flight missions, the highest priority is safety. Flights must be done in a manner that protects people, property, and the aircraft and its payload. Once on site, preflight examination of the immediate airspace for ground and aerial hazards can prevent most accidents before they occur. Suitable takeoff and landing space may be difficult to find when attempting to fly during large flood events. By using a visual observer(s) (VO)—a crew member who provides an extra set of eyes on the flight area to watch for ground and aerial hazards—sUAS pilots can promote safe flight by mitigating risks associated with flying in more confined or dynamic environments.

Typical sUAS science missions will produce hundreds of individual images encompassing the flight area. It is important to consider how data will be managed from initial collection to when the data are publicly released as required by the USGS Public Access Plan (U.S. Geological Survey 2016). Processing steps, like Structure from Motion (SfM) photogrammetry (Fonstad et al. 2013), can produce multiple gigabytes of digital data for even small flight area missions. In the field, we implement a "rolling backup" approach where numbered data cards are immediately removed from the sUAS after landing during a mission.

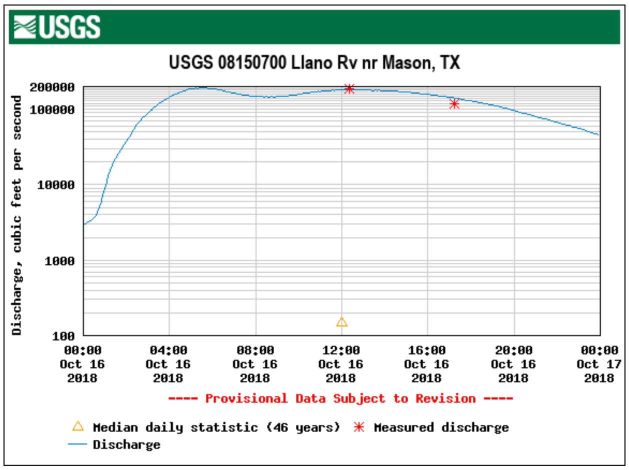

Figure 1. Flood hydrograph of the Llano River near Mason, Tex. for event October 16, 2018, where sUAS was used to measure streamflow (U.S. Geological Survey 2019). Red asterisks indicate field measurements. The second measurement at 17:13 was acquired with sUAS.

In the field, the contents of data cards are first copied to a laptop computer and then to a solid-state hard drive. Once the contents of the data card have been successful copied and the contents have been verified, the next numbered data card in sequence is used in the subsequent sUAS flight. During most missions, we travel with at least eight data cards, enabling sUAS crew to fly eight missions without fear of overwriting any one data card. Upon returning to the office, the collected data are copied to a network drive that is regularly backed up. This rolling backup procedure becomes invaluable when flight conditions are dynamic, or the mission requires multiple or continuous flights. In missions that require rapid data handling and processing, assignment of one crew member as "data handler" can enable quick turnaround on provisional products. The data handler's role on a sUAS crew is to operate a field laptop, facilitate the rolling backup process, and process initial data into the maps needed for emergency responders. Often, initial processing is done at a lower precision to enable quick turnaround of data products for decisional support, many times within hours of the sUAS flight; full quality processing of the datasets are generated later for analysis and publication. For example, in 2018 Kilauea volcanic eruption, orthomosaic aerial maps and terrain models of the lava flow field were immediately processed in the field by the data handler, and provisional maps delivered to the Forward Operating Base (FOB) for evaluation within 2 to 5 hours from when the sUAS began flying. In at least one case this level of turnaround was fast enough that subsequent requests for specific flights were made from the FOB in the same day as the previous data collects.

In some cases, sUAS flights during events can be used to provide valuable situational awareness (SA) to emergency responders. The primary objective of emergency responders is the protection of life and property during events. Small UAS can provide real-time “eyes in the skies” to view ground conditions in areas that are either difficult, unsafe, or impossible to reach over ground. If flights are planned as a part of providing SA, extra steps should be taken to ensure safe flight. Planning should include providing room and space around the remote pilot so that they can focus on flight. One approach is to use either a separate monitor or live feed system to clone the view of the ground control system (GCS) display during flight. The power of a such a system is hard to overestimate. During the response to the 2018 Kilauea volcanic eruption, the USGS was tasked to provide advanced SA of the developing lava flow field in a 24/7 rotation for several weeks. To ensure safe flight conditions, a live streaming setup was used to broadcast the Ground Control Station view during flight to a FOB on site. Emergency responders were in radio communication with the sUAS crew and could make requests for where to deploy sUAS assets. During flight, responders remotely viewing the live stream often made SA requests over the radio or cellular phone even while the sUAS was airborne.

Conclusion

This paper presents a workflow for planning operationalization of sUAS for flood mapping work prior to, during, and after flooding events. Small UAS provide a low-cost and effective means to rapidly acquire hydrologic data to improve the quality and timeliness of flood mapping, as well as provide real-time situational awareness in flooding emergencies. Through careful preplanning, it is possible to respond quickly to events, potentially providing datasets in time for decisional support.

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