NAVASOTA RIVER
FLOODING PROJECT

SUPPLEMENTARY MATERIALS

USING DRONES FOR RIVER CHARACTERISTICS

DECEMBER 2022

RIVER CHARACTERISTICS

Dr. Robin R. Murphy, Raytheon Professor of Computer Science & Engineering, Texas A&M University & Center for Robot-Assisted Search and Rescue and Justin Adams, Senior Researcher and Drone Pilot, Center for Disaster Risk Policy, Emergency Management and Homeland Security Program, Florida State University

Methodological Overview

The primary mission was to gather orthomosaics (individual images tiled together into a single map), digital surface elevation maps (DSM), and point cloud maps (a different type of DSM) of two parcels along the 60-mile stretch of the Navasota River, plus reconnaissance video from the two parcels and around five bridges.

The project had access to three unmanned aerial vehicles (drones): the senseFly eBee X fixed wing, a DJI Mavic Pro 2 rotorcraft, and a DJI Mavic Pro rotorcraft (see Figure 2). The senseFly eBee X is capable of carrying single pull-and-play sensor payloads. The three payloads were used: a Soda 3D camera, an Aerial X camera, and a RedEdge multispectral camera. The eBee X system also had a real-time kinematic (RTK) receiver to improve GPS accuracy but could not be configured to work correctly and the lower GPS accuracy did not impair production of the data products. The DJI Mavic rotorcrafts have built in cameras.

Figure 2 senseFly eBee X fixed-wing drone on left, DJI Mavic Pro 2 on top of gear bag on right.

Areas Covered

Figure 3 provides an overview of the areas covered by the unmanned aerial system (UAS). The ellipsoids are notional and do not reflect the true paths. Figure 4 provides an example of one path on the Upstream parcel. The project collected a total of 5,395 images over 824 acres, capturing approximately 15.6 miles of the Navasota River between State Highway OSR and Highway-6. The data was collected through 16 flights over four days from landing zones at two parcels (near Iola and Anderson, TX) and five bridges crossing the river (State Highway OSR, Highway 21, County Road 162, Highway 30, and Highway 6).

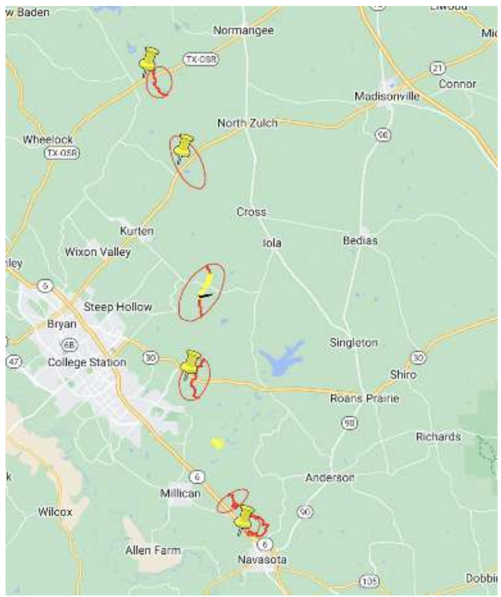

Figure 3 Areas of the river where imagery data was collected by UAS. Yellow pins are an artifact of merging maps together.

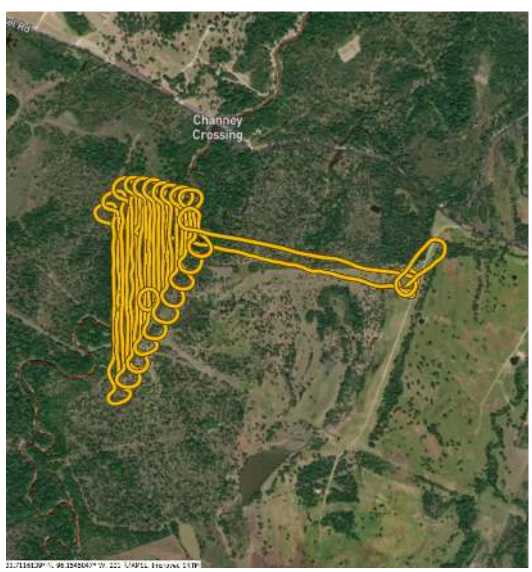

Figure 4 Example of flight path of the eBee X for the upstream property. Note that the take off and landing area was far from the river, highlighting the dense terrain and lack of direct access.

Data Collection Process

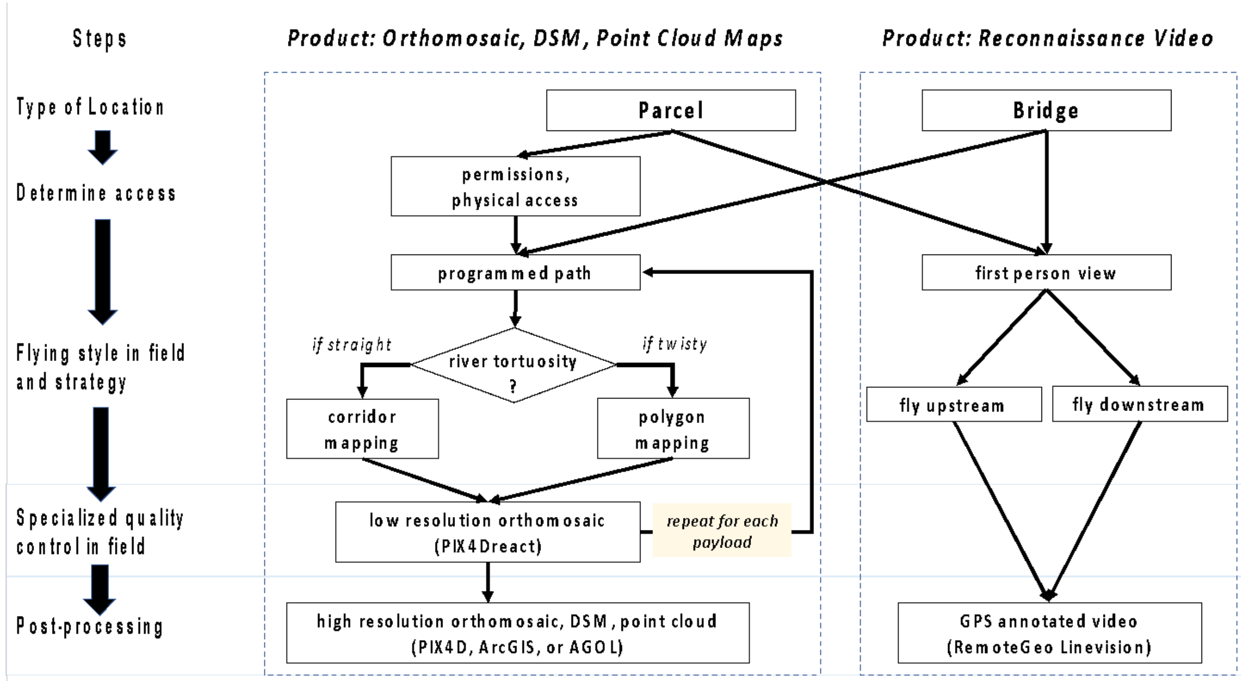

Figure 5 Data collection methodology.

Figure 5 shows the methodology used for the UAS effort. This is more general than the workflow for river mapping described in Rusnák's 2018 article.[i] As seen on the left, the basic steps are: determine the location and mission; determine the access (airspace and physical) to that location; apply an appropriate flying style and strategy for the mission, platforms, and payloads; perform specialized quality control in the field; and then perform post-processing. The diagram in the center and on the right name specific software packages as these are either the only packages that can perform those functions or are the packages commonly used by planners. For example, any one of the three major packages (PIX4D, ArcGIS, AGOL) are capable of post-processing imagery into orthomosaics, DSM, and point clouds, while RemoteGeo Linevision is the recommended package for post-processing first-person view reconnaissance video.

The data collection process is detailed on the following pages. It should be noted that the areas upstream and downstream of the bridges were only flown for reconnaissance video. However, these areas could have been mapped with the rotorcraft, though covering a much smaller area than with the fixed-wing eBee. The eBee could not be used by the bridges due to the lack of a sufficiently large take-off and landing area.

Type of location. The key areas were tied to landowner parcels. A secondary mission was to gather reconnaissance video from five bridges crossing the Navasota River. The river along the parcels was sufficiently large to use a fixed-wing for mapping, while the video reconnaissance along the parcels and upstream/downstream of bridges could be done with rotorcraft.

Determine access. Once the locations were specified, the project had to determine airspace access and physical access as most parcels were gated. In terms of airspace access, UAS could fly to 400 ft AGL and there were no regulations preventing imagery acquisition. In addition to physical access to gated properties, the drone team had to determine locations that were near the river and had enough open space to launch and land. Both properties were heavily wooded range land with cattle, with the upstream property having a wide meadow on a hill overlooking the river and the downstream property having a field with two oil pads that was suitable for launching and landing.

Figure 6 Access point from a well pad on the downstream parcel. Note that it is a considerable distance from the river.

Flying style in field. In order to plan for a mapping mission, the team chooses the specific programmed path. As per the workflow process in Figure 5, if the river is relatively straight, a corridor-style of path is advantageous. This path is generally set to a width (e.g., 600 feet) and is optimized for long transects and minimizes data away from the river. If the river is twisty, the team should specify a large polygon which covers more of the extraneous surrounding area but is actually faster to execute. Free flying along the river does not require planning but it does require the pilot to dynamically adapt the altitude to the distance; elevating the UAS to stay within wireless range as it moves away from the launch point, though staying under the 400' AGL limits imposed by the FAA.

Figure 7 Comparison of corridor path on left with polygon path on right for the downstream parcel. Corridor path over the twisty portion of the river is slower due to turns. Polygon is faster but covers extra area.

Specialized quality control in the field. Ideally a UAS team always checks after each flight to see that imagery was captured. More specialized quality control is to use the specialized proprietary PIX4Dreact software package to run a low-resolution map, which takes only a few minutes. If the map cannot be created from the images ("does not stitch" in common parlance), then the pilots can determine why and re-fly the mission while they still have access to the location.

Post-processing. The imagery has to be post-processed using specialized proprietary for-fee software, most commonly PIX4D (Agisoft is a similar package), into maps that can be incorporated into ArcGI or ArcGIS Online. First person video can be displayed with a geotagged path using the RemoteGeo Linevision software package. It should be noted that post-processing can be done either on a high-performance computing laptop, a desktop, or the cloud.

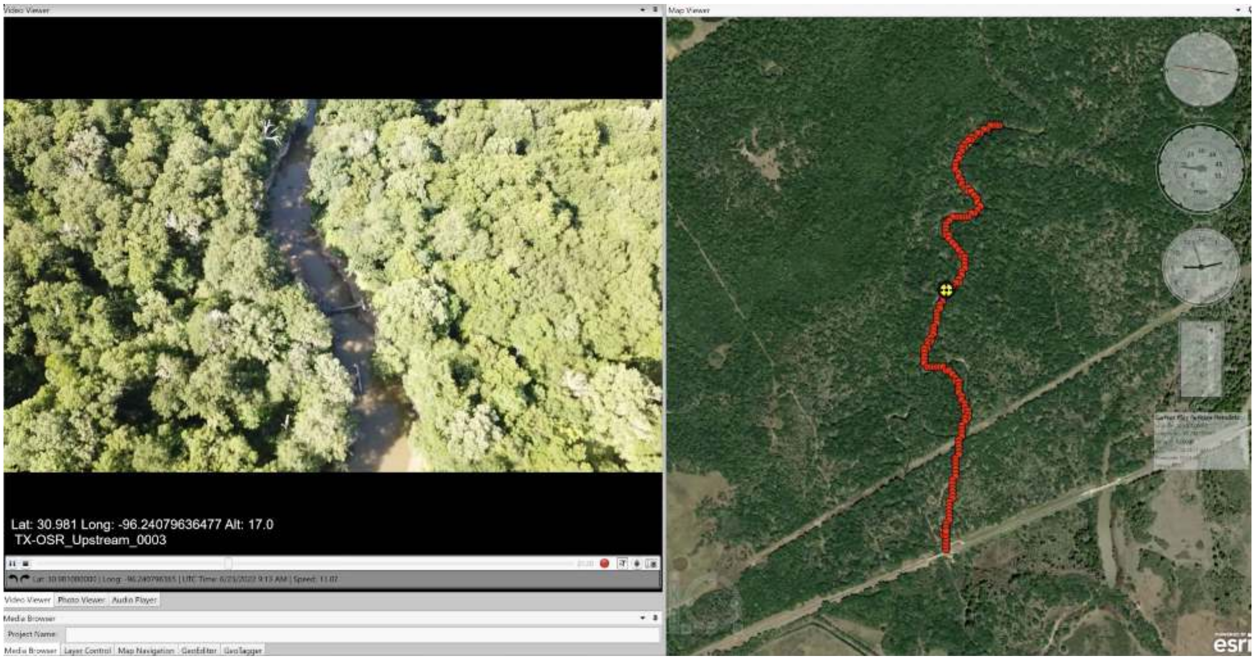

Figure 8 Still from Linevision showing presence of debris in video image (left) and location of UAS along its path (right).

Data Collected

Date	Location	Type of Flight	Sensor	Images	Acres	Miles	Time
5/20/22	Landowner 1	Ortho	SODA3D	375	200		30
5/20/22	Landowner 1_162 N	Video	RGB	0	0	1.3	3
5/20/22	Landowner 1_162 S	Video	RGB	0	0	1	7
5/23/22	Landowner 2	Corridor	SODA3D	1291	100		55
5/23/22	Landowner 2	Ortho	SODA3D	921	244		62
5/23/22	Landowner 2_River	Video	RGB	0	0	1.5	25
5/26/22	Landowner 1	Ortho	SODA3D	985	70		49
5/26/22	Landowner 1	Ortho	SODA3D	466	70		28
5/26/22	Landowner 1	Ortho	RedEdgeMX	1068	70		49
5/26/22	Landowner 1	Ortho	RedEdgeMX	289	70		21
5/26/22	Landowner 1_River	Video	RGB	0	0	1.5	15
6/23/22	Crossing TX-6	Video	RGB	0	0	2.5	20
6/23/22	Crossing TX-30	Video	RGB	0	0	2.5	20
6/23/22	Crossing TX190-21	Video	RGB	0	0	2.5	20
6/23/22	Crossing TX-OSR	Video	RGB	0	0	2.5	20
				5395	824	15.3	424

Figure 9 List of flights.

Table 1 lists the flights. All data and post-processing visualization are available in the project repository.

Key Findings

The purpose of the UAS effort was to provide parcel level data collection from unmanned aerial vehicles (drones) imagery that would enable the larger team to identify and understand the impact of unintended obstructions (e.g. debris, property dams, erosion, etc.) on locally reported flooding and to assess permitted development in the floodplain that may be contributing to localized flood problems, such as roads, culverts, crossings, fences, etc. **While it is beyond the expertise of the UAS team to conduct the analysis, the effort did produce findings as to 1) blockage, 2) payload and platform utility, 3) operational or work process considerations, 4) dataset for land-use and CV/ML research, and 5) future research directions.**

Findings on Detection of Obstructions

Figure 10 Obstructions on the County Road 162 bridge

The effort clearly demonstrated that *UAS imagery can be used to identify and understand the impact of unintended obstructions and development in the floodplain.* The 5/20/22 flight of the Navasota River from the County Road 162 bridge captured imagery of obvious debris and blockage (see Figure 10). This is an obvious example, however, the UAS team did not examine the video and data collected in detail and rely on the land-use experts to note any other obstructions.

Findings on Payloads and Platforms

The field offers four practical findings on payloads and platforms for effectively collecting land use data with UAS.

1. *In terms of platforms, fixed-wing UAS such as the eBee are superior to rotorcraft for mapping in terms of coverage and time, while rotorcraft, such as the popular Mavic Pro 2 used by many municipalities, can map smaller areas and are the only choice for video reconnaissance.*

2. *The post-processing of imagery into orthomosaic maps and digital surface maps is notably influenced by dense tree canopy and wind.* Dense tree canopy interferes with "stitching" the images into maps; the leaves and sunlight reflected on the leaves confounds the algorithm. The movement of leaves in the wind further undermines the stitching algorithm. In terms of sensor payloads for the eBee, the Soda 3D and Aerial X were able to collect imagery that could be stitched, but the RedEdge multispectral imagery could not be stitched.

3. *The production of usable data products is also impacted by wind, which interferes with the data collection not just the content of the images.* In high winds, the fixed-wing platform is buffeted by wind and thus the camera may not be pointing in the expected direction and produce the appropriate image overlap. For example, neither the Soda 3D or Aerial X payload produced imagery from the 5/20/22 mission that could be stitched into maps. This was because the drone was flying in high winds at the limit of its recommended performance (30 mph with gusts 35-40 mph), which disrupted the camera angles and created moving leaves and swaying trees.

4. *Dense tree canopy over the Navasota River poses barriers to analysis with the current set of payloads and the most likely solution is a Lidar payload.* The SfM map production methods produce DSM, not true digital elevation maps (DEM). In open areas without forestation or where the vegetation is presumed to be at the same height, the DSM is a reasonable approximation of the DEM. For determining the Navasota River bank boundaries, their slope, and any changes over time, these assumptions do not hold. The canopy clearly extends over the river and completely obscures it in many images (see figure 11).

Figure 11 Example from the downstream parcel of the narrow river and dense canopy

Two possible approaches to acquiring DEM with UAS are to 1) apply additional DSM software or 2) shift to a Lidar payload that has foliage penetrating capabilities. Note that flooding or recovery may not occur in winter when deciduous trees have dropped their leaves. There are two notable DSM software “fixes.” One is the method where the type of vegetation is used to infer river bank and bank condition (e.g., that certain trees stop at a river bank).[ii] This approach seems applicable for larger rivers where the canopy does not extend completely across the river and for rivers without surrounding standing water. The other method is a software method that uses computer vision/machine learning to distinguish patches of ground from trees, then infers the DEM from the connection of the patches in the DSM.[iii] It is not clear that the method will work for the extreme canopy conditions that were encountered, but it may be worth exploring. A more promising, albeit expensive, alternative would be to consider a Lidar payload for use with the TAMU DJI M600 rotorcraft platform. UAS Lidar is expensive, generally $50,000 to $100,000 for the sensor plus processing fees to convert the data to maps. The reliance on a rotorcraft means that a smaller area will be surveyed. It should be noted that lidar can produce erroneous results for river monitoring.[iv]

Findings on Operationalization of UAS for Flooding Events

The project offers three insights for operationalization of UAS for flooding events by emergency managers and pre-disaster mitigation planners.

The potentially most impactful insight is that **data collection flown from bridge easements may be the most practical, especially for flooding events with small (non-navigable) rivers and bayous.** Flying from bridge easements simplifies access on demand during or after a flooding event, as there is no need for landowner permission and physical access to gated parcels. Bridges are also likely locations for debris creating unintentional dams. The disadvantage of flying from bridge easements is the unfavorable trade-off of smaller areas and longer flight times by using a rotorcraft instead of a fixed-wing.

A second insight is team composition. Instead of thinking of the UAS team as consisting of only pilots, it may be advantageous to have an embedded hydrology or land-use subject matter expert involved in video reconnaissance flights. A subject matter expert to direct zooming and viewing angles can ensure that the data captures the most useful information.

A third insight is that the pilots need specific skills and training. Flying in the wild or during a flooding event is different from flying for a road construction site or real-estate photography. Skills and the use of advanced techniques, such as corridor mapping and having access to specialized software packages such as RemoteGeo linevision, are needed. An outcome of this project can be a training program for flooding events.

Contribution of Dataset for Land-Use and CV/ML Research

The project contributes an imagery dataset for land-use research and for computer vision/machine learning research. Assuming that there are no privacy issues with the landowners, the dataset could be made open source.

Future Research Directions

The use of UAS to gather data was basic and highlighted opportunities to benefit pre-disaster mitigation and evidence-driven land-use policy. One such opportunity is to explore algorithms to autonomously detect debris[v] and to determine streamflow during a flooding event.[vi]

[1] Rusnák, M., Sládek, J., Kidová, A. & Lehotský, M. (2018). Template for high-resolution river landscape mapping using UAV technology. *Measurement, (115)*, 139-151. https://doi.org/10.1016/j.measurement.2017.10.023

[2] Tan, Y., Wang, S., Xu, B. & Zhang, J. (2018). An improved progressive morphological filter for UAV-based photogrammetric point clouds in river bank monitoring. *ISPRS Journal of Photogrammetry and Remote Sensing,* (146), 421-429, https://doi.org/10.1016/j.isprsjprs.2018.10.013

[3] Lee, G., Choi, M., Yu, W. & Jung, K. (2019). Creation of river terrain data using region growing method based on point cloud data from UAV photography. *Quaternary International, (*519), 255-262. https://doi.org/10.1016/j.quaint.2019.04.005

[4] Tan, Y., Wang, S., Xu, B. & Zhang, J. (2018).

[5] Lucía, A., Schwientek, M., Eberle, J. & Zarfl, C. (2018). Planform changes and large wood dynamics in two torrents during a severe flash flood in Braunsbach, Germany 2016. *Science of The Total Environment, (*640-641. 315-326, https://doi.org/10.1016/j.scitotenv.2018.05.186

[6] Zhao, C. S., et al. Streamflow calculation for medium-to-small rivers in data scarce inland areas. *Science of The Total Environment,* (693), 133571. https://doi.org/10.1016/j.scitotenv.2019.07.377.