IMPROVING SPATIAL MONITORING OF DREDGING OPERATIONS: A SMALL UNMANNED AERIAL SYSTEM APPLICATION TO MAP TURBIDITY

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ABSTRACT

There is interest in developing small unmanned aerial system (UAS <25 kg) applications to improve spatial monitoring of dredge operations. UAS technologies offer a more viable and flexible alternative to conventional platforms such as satellites and manned aircraft. UASs fly at lower elevations and are capable of collecting imagery with high spatial and temporal resolution (e.g., 5 cm/pixel, 10 min revisit time); therefore, this technology can compete with traditional mapping solutions. This study demonstrated relatively uniform turbidity levels can be differentiated using high-resolution ground images on the centimeter scale calibrated to in situ water samples. Images are of turbidity near the water surface thus this application would be most appropriate for assessing turbidity near the surface or in shallow water habitats, relevant to, for example, sea grass beds and coral reefs. This approach will help produce evidence-based information about the dredge plume's scale to help engage the process of leveraging better-informed water quality regulations and dredging strategies.

Keywords: drone, dredging, turbidity, total suspended solids, monitoring

INTRODUCTION

Dredging operations resuspend sediment creating a plume in the water column. Assessment of the plume's spatial extent is important when complying with water quality regulations at the dredging and placement sites (Reine et al. 1998). Plume characterization focuses on the measurement of turbidity (nephelometric turbidity units-NTU) and total suspended solids (TSS in mg/L; Pruitt 2003). Such data along with knowledge of ambient conditions determines the impact of dredge or placement area plumes and can result in modification to dredging and disposal operations, if needed (Puckette 1998; Clarke and Wilber 2008). Dredging operations require monitoring, typically from manned vessels that have spatial and temporal limitations. In some instances, conventional methods (i.e., direct measurement) limit the quantification of a plume's extent on a larger spatial scale.

To improve spatial monitoring, images of turbidity have been obtained from satellites (Kutser et al. 2007) or manned flights (Roberts et al. 1995) and correlated to in situ water samples. However, satellite remote sensing technologies have many limitations depending on needs of an application. The coarse spatial and temporal granularities of satellite imagery may be impractical to use for determining the short-term impacts such as a dredge plume on a specific area. Satellites do not revisit areas often (e.g., one pass per day) and cloud obscuration can make imagery unusable. Manned aircraft provide higher spatial and temporal resolution imagery, but expensive image acquisition and operating costs make manned flights impractical on a routine basis. Cloud obscuration is still an issue as well. UAS technologies provide an inexpensive alternative for acquiring imagery (Watts et al. 2010). A UAS is a lightweight unmanned aircraft capable of manual, assisted, or autonomous flight. UASs fly at lower elevations and are capable of collecting imagery with high spatial and temporal resolution (e.g., 5 cm/pixel, 10 min revisit time); therefore can compete with traditional mapping solutions (Küng et al. 2011). A method used to integrate UAS aerial imagery with in situ water samples is presented. Georeferenced images of turbidity was integrated with geographical information system (GIS) to map the test area with a relative turbidity classification.

METHODS

The field study was performed at a distributary channel located near the mouth of the Atchafalaya River (29°26'58.52"N, 91°20'15.65"W) in southern Louisiana (Figure 1). The surface ranged from water in the channel area, to grass, shrubs, and trees in the area bordering the channel. Turbidity near the water surface was relatively low, homogenous (ca. 15-55 NTU) and originated from ambient sources. The UAS was hand-launched and landed in an area maintained by the Louisiana Department of Wildlife and Fisheries near the channel.

Figure 1. The study site and location of the distributary channel near the mouth of the Atchafalaya River, LA.

A line-of-site flight was conducted using an eBeeRTK (senseFly, Switzerland, sensefly.com), a fixed-wing ultra-light UAS equipped with a digital camera (Canon S110 Near infrared [NIR], Canon, Tokyo, Japan). This camera sensor acquires high-resolution images (12.1 megapixel) in the visible (green 550 nm; red 625 nm) and NIR (850 nm) spectrum. This lithium-polymer battery powered drone designed for autonomous flight, acquired geospatially tagged images over programmed flight paths. The eBee is hand launched, thus there is no need for a special catapult device or runway. When landing, the UAS glided downward and then was manually skid-landed.

The eBee was equipped with a Global Navigation Satellite System (GNSS; L1/L2, Global Positioning System-GPS and Global Navigation Satellite System-GLONASS). Absolute horizontal and vertical accuracy without ground control points (GCPs) was 3 cm and 5 cm, respectively, as reported by Roze et al. (2014). Achieving high accuracy without GCPs is an important time saving feature when competing with the simplicity of in situ turbidity measurements. The flight was programmed to systematically cover the test area with 75% lateral and longitudinal overlap. Images were directly georeferenced whereby the onboard GNSS and Inertial Measuring Unit determined the position and orientation of the camera. After the flight, a photogrammetry software was used to process the images to create an orthomosaic image of the test area. To maintain simplicity, only the geotag provided by the UAS autopilot determined image position and orientation.

Within one-hour, post-flight in situ water samples (500 ml) were collected to correlate with UAS images. Due to low water currents, wind, and relatively homogenous turbidity conditions, the samples were considered representative of the acquisition time of aerial images. Within the UAS image acquisition area, collection of water samples occurred at 14 sites. Sampling locations were determined in the field and were considered representative for monitoring the study area (<one km^2) mapped by aerial images (Figure 2). Each sampling location was marked using a GPS (Trimble SPS 5800, Sunnyvale, CA). Plastic bottles (250 ml) rinsed with water from each location were refilled with water collected near the surface (top 15 cm). The samples were used for laboratory analysis of turbidity and TSS. To minimize microbiological decomposition of solids prior to analysis, samples were kept at 4°C. Post-sample processing in the laboratory utilized a turbidimeter (Hach 2100Q, Loveland, Colorado) to measure turbidity of the hand-collected samples. Values used represent the mean of three turbidity measurements taken from each sample (Table 1). For TSS, 100 ml samples were transferred into a filter apparatus and a vacuum applied to the apparatus passed all water through the pre-weighed filter (0.45 µm, Millipore, Billerica, MA, USA). The filter and contents were dried at 105°C overnight then reweighed to the nearest 0.0001 g using an analytical balance (MS104TS, Mettler Toledo, Columbus, Ohio, USA).

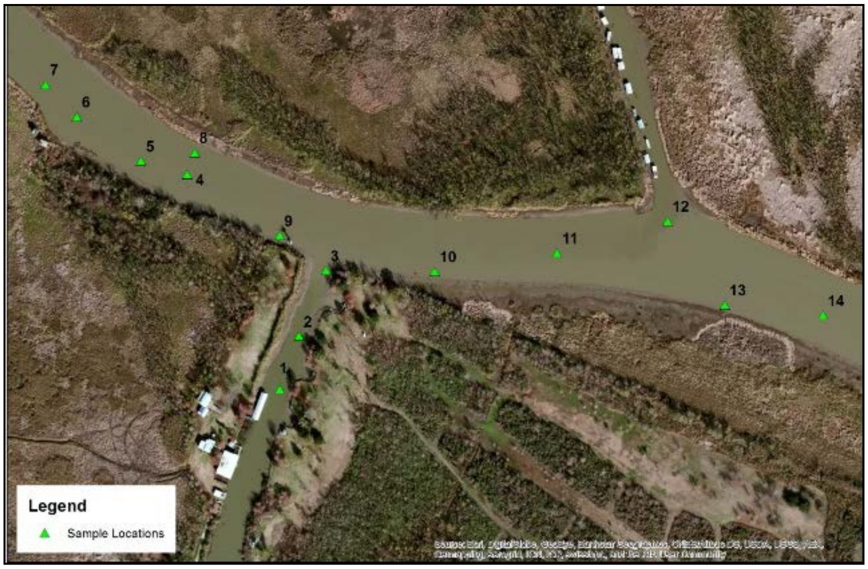

Figure 2. Water sampling sites in a distributary channel near the mouth of the Atchafalaya River, LA, on 22 June 2016.

Table 1. Results of water quality measurements taken of samples collected near the water surface (top 15 cm) on 22 June 2016.

	Laboratory		Field Location and Time		
Sample	**Turbidity (NTU)**	**TSS (mg/L)**	**Latitude**	**Longitude**	**Time**
1	15.7	19	29.448287	-91.33823	11:49:32 AM
2	16.1	18	29.448753	-91.338029	11:53:02 AM
3	24.3	26	29.449329	-91.337747	11:54:12 AM
4	49.8	53	29.450196	-91.33914	11:57:02 AM
5	49.1	54	29.450323	-91.339605	11:58:12 AM
6	48.1	50	29.45072	-91.340248	12:00:07 PM
7	47	52	29.451009	-91.340563	12:03:27 PM
8	47.4	58	29.450388	-91.339059	12:06:07 PM
9	49.9	60	29.449646	-91.33821	12:08:42 PM
10	54.3	76	29.449307	-91.336642	12:11:42 PM
11	51.8	66	29.449455	-91.335401	12:14:27 PM
12	47.9	59	29.449724	-91.334275	12:16:57 PM
13	48.8	58	29.448976	-91.333709	12:19:37 PM
14	50.5	58	29.448872	-91.332715	12:21:42 PM

The orthomosaic overlaid with water sample locations was used to create a map and a color bar to display the relative concentration estimates of turbidity of the pixels representing the channel. The Semi-Automatic Classification Plugin for Quantum GIS created a relative turbidity classification by manually selecting and classifying training areas in the orthoimage using a manual delineation (Congedo 2016). Without a color reference, precise and accurate measures of turbidity were not possible. However, observations of the data suggest that regions of lower spectral intensity in the waterway represented lower NTU values. This pattern was evident in the water samples collected at various locations. Segmenting the intensity values into two categories produced a map such that areas classified within the lower intensity category were estimated to represent areas of turbidity below 25 NTU.

RESULTS AND DISCUSSION

One line-of-site flight conducted on 22 June 2016 acquired images of the distributary channel. Weather conditions were a wind speed of 1 mph from the south-southeast with a max wind speed of 5 mph; visibility 10 miles; and scattered clouds (above flying area). The UAS covered an area of approximately 150 acres at a height of 180 m with a ground resolution of 5.2 cm/pixel. Acquired images produced a 3D point cloud and mesh, a digital surface map, orthomosaic, and classification. A map created by classifying the orthomosaic image visually estimated water quality parameters based on a color scale (Figure 3). Combining the map overlay with in situ water samples allowed for evaluation of turbidity and TSS concentrations over a much broader area. The high ground resolution (5.2 cm/pixel) offered sufficient contrast for areas with relatively homogenous turbidity (i.e. < 25 or > 25 NTU).

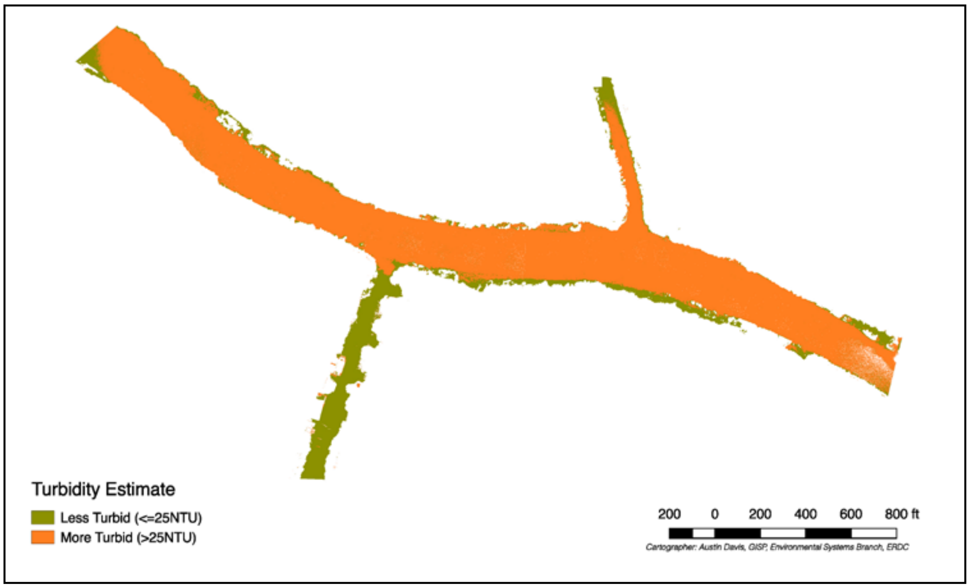

Figure 3. Map of estimated turbidity levels and total suspended solid concentrations correlated with in situ water samples of a distributary channel near the mouth of the Atchafalaya River, LA, on 22 June 2016.

When visually estimating turbidity with UAS images, it is important to correlate turbidity levels with spectral signatures to predict related water quality parameters. If the turbidity-spectral signature relationship is weak or spectrally uncalibrated it may only be useful for establishing general trends but will be unable to provide an accurate visual estimate. To develop an accurate characterization and classification system for turbidity measurement using UAS imagery, placement of sub-surface spectral calibration panels within a subset of the images should help perform spectral calibration. Further, the calibration panel should be associated with a turbidity sensor to help predict turbidity across the geographic space. However, even when successfully calibrated, Lui et al. (2003) found the models are site specific and require daily calibration. Therefore, additional flights and in situ sampling are required daily to build accurate maps. Automation of these processes with, for example, turbidity data loggers could help decrease effort. Currently, the discrimination of turbidity levels using UAS images does not provide the real-time turbidity monitoring data collected in near real time in the field from a manned vessel and from data loggers.

Although there may be limitations to real time data retrieval, UASs still have the potential to increase the spatial assessment of sediment plumes in comparison to conventional manned vessel methods while providing the necessary accuracy (Vogt and Vogt 2016). In terms of a dredging operation, the movement of plumes and dissipation over space and time is important for predicting potential impacts associated with dredging. The nature and extent of a dredge plume is mostly the result of the dredge type, hydrodynamics and sediment characteristics. A plume may exhibit systematic patterns of distribution, influenced by local weather conditions, tidal currents and other conditions from the onset of the plume to resettling; but such conditions may only persist for short periods before changing, especially near the dredge. Therefore, it may be challenging, for instance, to collect water samples that are representative of the aerial images. However, even if calibration fails to provide accurate measurement, georeferenced images can still provide relative estimates as evidence of the plumes’ spatial scale and proximity to sensitive habitats that manned vessels could not otherwise easily obtain.

CONCLUSION

UAS technologies offer a more viable and flexible alternative to conventional platforms such as satellites and manned aircraft. This study demonstrated relatively uniform turbidity levels can be differentiated using high-resolution ground images on the centimeter scale relatively calibrated to in situ water samples. Images were of turbidity near the water surface thus this application would be most appropriate for assessing turbidity near the surface or in shallow water habitats (e.g., sea grass and coral reefs). UAS acquired images will likely help to support better-informed regulations and dredging strategies by improving spatial monitoring.

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