Overview of the Uncrewed Aircraft System (UAS) Campus Survey Project at Texas A&M University-Corpus Christi

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Key words: UAS, Geo-Informatics, GIS, Facilities, Monitoring.

SUMMARY

This paper presents a summary of the use of small Uncrewed Aircraft Systems (UAS) platforms for photogrammetric mapping of campus infrastructure and facilities at Texas A&M University-Corpus Christi (TAMU-CC). Referred to as the UAS campus survey project, the application of small UAS equipped with digital RGB cameras for surveying and mapping of campus facilities began in 2014. The paper begins by highlighting the necessity of survey data and the advantages of UAS for aerial surveys over traditional ground-based methods employed at the university. The paper then elaborates on the genesis of UAS platforms used at the university from 2014 to the present-day including evolution from indirect georeferencing using a ground control point network to reliance on the direct georeferencing methods using UAS equipped with onboard Global Navigation Satellite System (GNSS) receivers capable of Post-Processed Kinematic (PPK) corrections. Moreover, the study investigates the benefits of integrating UAS products with traditional land surveying methods to obtain survey-grade accuracy from photogrammetric products derived from UAS. Finally, the paper explores the diverse applications of UAS survey products beyond facility management and infrastructure planning and dissemination methods. Overall, this paper provides a comprehensive overview of the progression of UAS mapping technology for geospatial data acquisition in support of facilities monitoring at TAMU- CC.

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1. ABSTRACT

This paper presents a summary of the use of small Uncrewed Aircraft Systems (UAS) platforms for photogrammetric mapping of campus infrastructure and facilities at Texas A&M University-Corpus Christi (TAMU-CC). Referred to as the UAS campus survey project, the application of small UAS equipped with digital RGB cameras for surveying and mapping of campus facilities began in 2014. The paper begins by highlighting the necessity of survey data and the advantages of UAS for aerial surveys over traditional ground-based methods employed at the university. The paper then elaborates on the genesis of UAS platforms used at the university from 2014 to the present-day including evolution from indirect georeferencing using a ground control point network to reliance on the direct georeferencing methods using UAS equipped with onboard Global Navigation Satellite System (GNSS) receivers capable of Post-Processed Kinematic (PPK) corrections. Moreover, the study investigates the benefits of integrating UAS products with traditional land surveying methods to obtain survey-grade accuracy from photogrammetric products derived from UAS. Finally, the paper explores the diverse applications of UAS survey products beyond facility management and infrastructure planning and dissemination methods. Overall, this paper provides a comprehensive overview of the progression of UAS mapping technology for geospatial data acquisition in support of facilities monitoring at TAMU- CC.

2. INTRODUCTION

Uncrewed Aircraft Systems (UAS), which are commonly referred to as drones, have made significant strides in recent years. One of the key areas of progress has been the enhancement of sensors and cameras, resulting in higher-quality imagery and more precise measurements. As a result, UAS have become particularly valuable for various applications such as mapping, surveying, and inspection (Colomina et al., 2008).

Advancements in software and algorithms have significantly improved the processing of imagery data collected by UAS for geospatial applications. One notable example is the use of Structure-from-Motion/Multi-View Stereo photogrammetry (SfM-MVS), which uses multiple overlapping images from different viewpoints to generate 3D models and maps. Referred to as SfM for short, or UAS-SfM when implemented on a drone, SfM algorithms can automatically identify common features in the images, calibrate and align them, and create a 3D model with high resolution and potentially accuracy dependent on the georeferencing and processing methods employed. These advancements have led to the widespread use of UAS-SfM photogrammetry for geospatial data acquisition various industries, as noted in (Bäumker et al., 2013).

3. BACKGROUND

The history of using UAS for geospatial data collection at TAMU-CC dates back to 2013-2014 when the university started expansion on a secondary campus site. The university consist of a main campus located on Ward Island in Corpus Christi Bay, Texas, and Momentum Village, a smaller developing campus, referred to as Momentum Campus (Figure 1). Both were undergoing extensive construction projects. During this period, the Measurement Analytics Lab (MANTIS) with the Conrad Blucher Institute of Surveying and Science (CBI) at TAMU-CC was tasked with providing surveying support for campus administration. Referred to as the campus survey project, the principal goal of this project was to provide facilities administration at TAMU-CC spatial information to aid in the expansion and construction process as well as support other activities including facilities monitoring. Subsequently, this effort has continued to be an ongoing initiative (Starek et al., 2015).

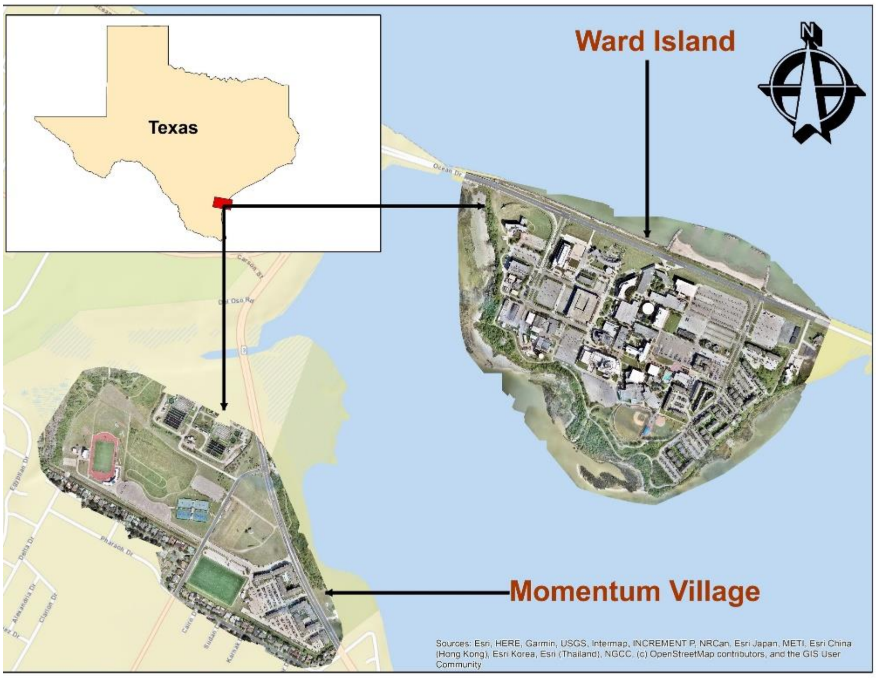

Figure 1: Location map of TAMU-CC.

The project initially began with a ground survey of the existing infrastructure at Momentum Village, which included collecting data on roads, buildings, sidewalks, and above-ground utilities. This survey was performed by a team of undergraduate students using survey-grade Real-Time Kinematic (RTK) GNSS and a total station, which took almost one semester to complete. However, as the demand for information grew, it became clear that the ground survey was slow and costly. As a result, the MANTIS lab started exploring the use of small UAS for performing aerial photogrammetric surveys of the campus to aid in planning and development monitoring. The initial effort began in 2013 with the procurement of a fixed-wing mapping-grade UAS, called the Sensefly eBee. Testing and evaluation of data collection and processing workflows, including accuracy evaluation, started off-campus until appropriate approvals were in place to conduct flights over campus.

Due to the University's close proximity to the Corpus Christi Naval Air Station, the MANTIS lab was required to complete a rigorous and thorough authorization process with the Federal Aviation Administration (FAA) of the United States to obtain a Certificate of Authorization (COA) that allowed the legal operation of permitted small UAS over the campus under certain restrictions including weekend operations only. The COA was initially obtained by the University in 2014, enabling the lawful operation of UAS in compliance with relevant FAA regulations as stipulated in the COA. Following the successful acquisition of the COA, the University commenced its UAS survey activities in compliance with relevant legal requirements. Table 1 shows evolution of UAS through time to conduct campus survey. After obtaining the COA, the team started performing routine UAS surveys of Ward Island and Momentum campus, quarterly to bi-annually, to provide geospatial information for campus facilities.

4. EQUIPMENT

After obtaining COA, CBI began using two state-of-the-art UAS to meet the university's demand for accurate mapping and surveying. Sensefly eBee UAS was used for the first aerial survey (Figure 2). The Sensefly eBee UAS is a lightweight imaging payload, consisting of off-the-shelf digital cameras that weighed less than 0.45 kg, and is been modified for automated control and sensitivity in various electromagnetic spectrum regions, including visible and near-infrared. It is a fully autonomous fixed-wing UAS that excels in mapping and surveying applications. With a high-resolution camera and the capability to cover up to 12 square kilometers in a single flight, the Sensefly eBee captures detailed aerial imagery with a resolution of up to 5 cm per pixel. It's user-friendly software makes it easy to operate, making it a popular choice for surveying professionals(eBee, 2023). At the time, CBI's Sensefly eBee platform utilized a three-band RGB camera, along with a three-band near-infrared, green, and blue (NIRGB) camera, both of which possesses a resolution of 16.1 megapixels.

After Sensefly eBee wingtra UAS platform was used. For even more precise and efficient mapping, CBI incorporated the Wingtra One UAS (Figure 3). The Wingtra One is a professional-grade, VTOL (Vertical Take Off and Landing) fixed-wing UAS that is designed for high-precision mapping and surveying applications (Wingtra.com, 2022). Equipped with advanced mapping technology and a high-resolution camera, it can create detailed 2D and 3D maps with resolutions as low as 1 cm per pixel, quickly and efficiently covering large areas. The UAS is also equipped with advanced safety features for added peace of mind. Currently, CBI is using the Wingtra One Gen II UAS to capture imagery. This UAS builds on the advanced technology of its predecessor and incorporates even more features to enhance the efficiency and accuracy of mapping and surveying operation(Wingtra, 2023). Overall, Wingtra One Gen II is an upgrade over the original Wingtra One, offering a more robust design, longer flight time and range, more camera and payload options, enhanced GPS and navigation, and an improved user experience(Wingtra, 2023b).

Figure 2: The Sensefly eBee UAS launched at the university(Davis and Starek, 2014).

Figure 3: WingtraOne UAS platform (left) and captured UAS during the flight (right).

5. METHODOLOGY

4.1 Flight Design and Data Collection

The initial test flights that were conducted in June 2014, utilizing the RGB camera. Sensefly eBee UAS platform was used. The first flight was executed over the Momentum campus, flying at an altitude of 101 meters above ground, covering a 61-hectare area with 60% lateral image overlap and 75% longitudinal overlap. The camera focal length and flying height produced a ground sample pixel distance of roughly 3 cm/pix. The flight lasted approximately 30 minutes and resulted in around 200 pictures being captured. A week later, another series of flights were conducted to survey the main campus, consisting of two flights flown over the Island Campus to cover the approximately 111 hectares that make up the main campus, utilizing the same flight parameters as the initial flight. The total flight time for the main campus survey was about 70 minutes, and around 350 pictures were taken (Davis and Starek, 2014).

Following the adoption of the Sensefly eBee UAS, CBI began using the Wingtra One for their image acquisition needs. Flights are conducted either quarterly or biannually, with a Wingtra pilot in charge of flight planning and mission control. The flight are designed with 80% sidelap and 75% endlap. Usually, flight height is set to 120m. With the help of advanced camera, minimum GSD of about 0.7 cm/pix in achieved. Previously established base station location is used to provide PPK correction using direct georeferencing approach. The following Figure 4 shows the flight plan details of recent flight using Wingtra One Gen II UAS. Flight plan is done in WingtraPilot software provided by the manufacturer in in a tablet that comes with the drone. Also, the following Table 1 shows time line of UAS platform used from the year 2014 till now.

Figure 4: Snapshot of flight plan in WingtraPilot software.

Table 1: Timeline of UAS platforms used.

SN	**Date**	**Model**
1	2014-2017	Sensefly eBee
2	2017-2018	Sensefly eBee Plus
3	2018-2022	Wingtra One
4	2022-Present	Wingtra One Gen II

4.2 Ground Control Network and Quality Control

Initially, GCPs were used to improve the georeferencing accuracy of mapping products at the start of the project. However, the switch from the Sensefly eBee to the Wingtra platform led to a significant increase in mapping accuracy, rendering GCPs unnecessary. Instead, a set of checkpoints were used to validate the accuracy and precision of the mapping products during post-processing. The project uses the NAD83(2011) horizontal reference system and the NAVD88 vertical reference system, both in state plane with units in US survey feet. To convert ellipsoidal height to orthometric height, GEOID2012 and GEOID2018 are employed. To maintain up-to-date information on the control network, ground surveys are conducted biannually. Figure 5 illustrates the distribution of GCPs on Ward Island.

Now, in 2023, the Septentrio NR3 GNSS receiver equipped with features such as one-touch logging, an all-in-one base, rover operation, and 4G/LTE connectivity, which streamline data collection and transmission is being used to get ground control data. This device gives horizontal accuracy of 0.6 cm and vertical accuracy upto 1 cm. A series of ground control targets are obtained and utilized as checkpoints to ensure the accuracy of the collected data. The rover pole is set at a height of 2 meters, and the epoch is set to 10 seconds, in order to maintain consistency and reliability throughout the data collection process. The raw positioning data are transmitted to the Online Positioning User Service (OPUS) and underwent a correction in order to obtain the final location. The utilization of this survey-grade GNSS receiver and careful data collection protocols ensured the acquisition of high-quality, accurate ground truth data in this study.

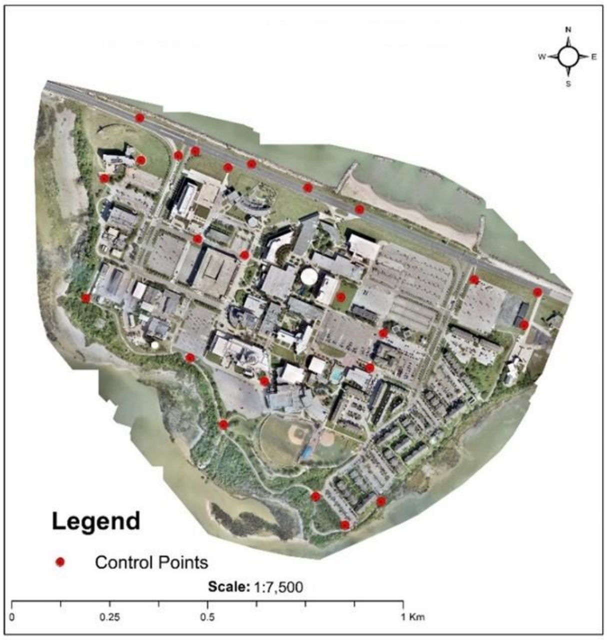

Figure 5: Ground Control distribution of Ward Island.

4.3 Data Post-Processing Methods

To estimate the 3D structure from the overlapping UAS imageryu, the SfM-MVS technique was employed, and commercial post-processing software applied to adjust filters, reduce noise and eliminate outliers in the point cloud generation. Initially, after capturing imagery with the original Sensefly eBee, Postflight Terra 3D SfM software was utilized for post-processing to generate a densified 3D point cloud, digital surface model (DSM), and orthomosaic. With the advancement in commercial SfM software, the rteam has progressed into using Pix4Dmapper and Agisoft Metashape, resulting in significantly improved SfM performance and more accurate mapping products. Figure 6 shows an example of the standard SfM-MVS photogrammetry workflow employed by many commercial software (Starek et al., 2022)

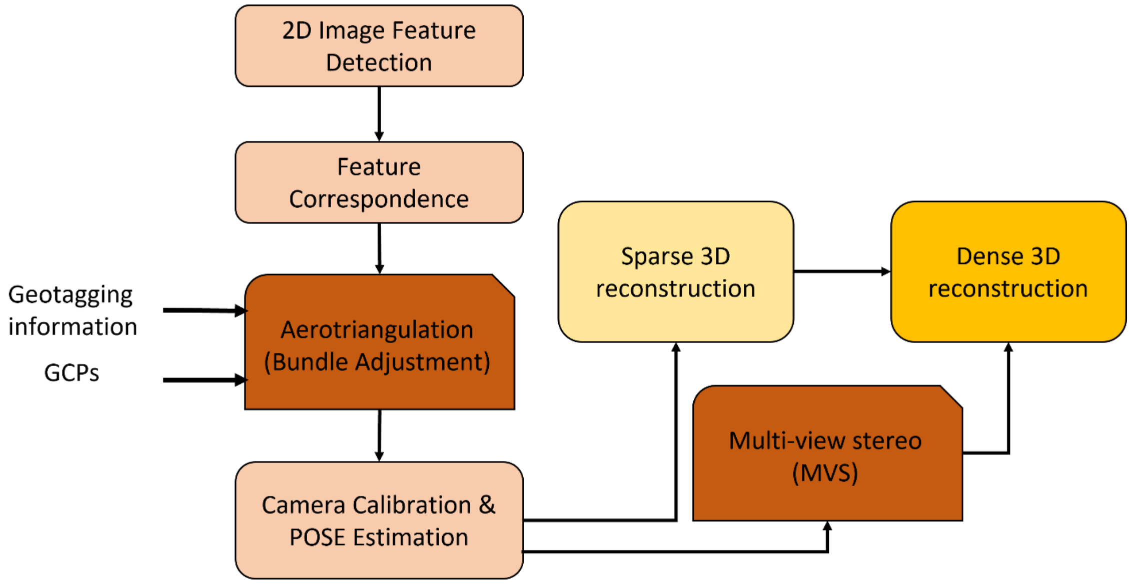

Figure 6. SfM workflow(Starek and Wilkinson, 2022).

4.4 Developing Geoportal

Once the imagery is captured, it is processed using SfM photogrammetric software to produce various mapping products, including Orthomosaic, DSM, 3D point cloud, and 3D tiled models. Next, GIS software is utilized to convert the Orthomosaic to tiled layers, which are then published on the ArcGIS Online platform. Using the ArcGIS Online platform, web mapping applications, 2D/3D tiled layer dashboards, and detailed story maps of the project are developed. Finally, a geoportal is created by combining all these visualization products, enabling users to easily access and interact with the mapped data in a user-friendly manner.

6. RESULTS

1) Mapping Products

The UAS surveys conducted using Wingtra in 2022 and Sensefly eBee in 2017 generated Standard Mapping products such as a densified 3D point cloud, DSM, and orthomosaic. These products are presented in Figures 7, 8, and 9 for the Wingtra survey and Figures 10, 11, and 12 for the Sensefly eBee survey.

Figure 7: Orthomosaic of TAMUCC campus created from imagery taken using Wingtra.

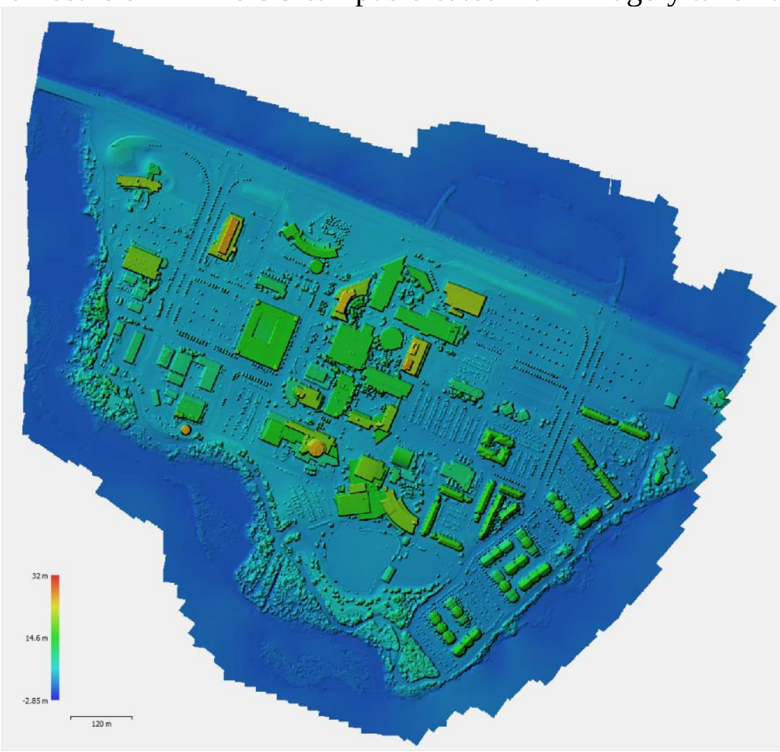

Figure 8: DSM of TAMUCC campus created from imagery taken using Wingtra.

Figure 9: 3D point cloud of TAMUCC campus created from imagery taken using Wingtra.

Figure 10: Orthomosaic of TAMUCC campus created from imagery taken using Sensefly eBee.

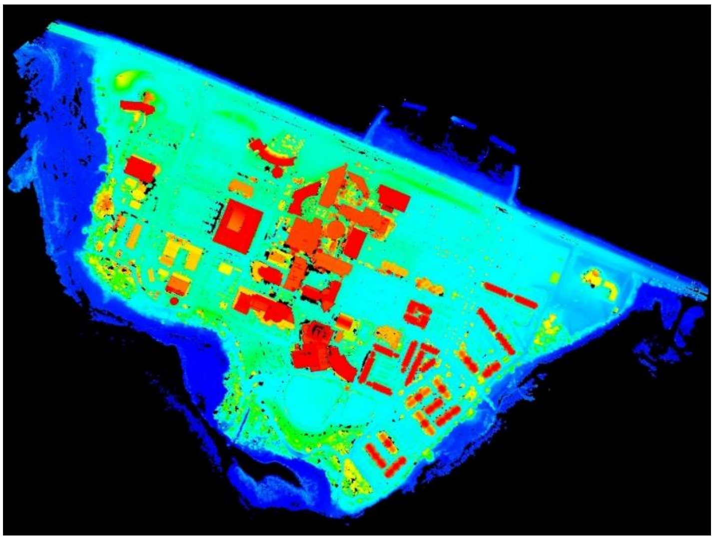

Figure 11: DSM of TAMUCC campus created from imagery taken using Sensefly eBee.

Figure 12: 3D point cloud of TAMUCC campus created from imagery taken using Sensefly eBee.

2) Examples of Data Applications

At the beginning of an UAS survey, mapping products such as orthomosaics were used as a base layer to view the landscape and estimate planning needs. This solved problems for engineers who previously had to use an arbitrary coordinate system with outdated rubber sheeted imagery. Figure 10 illustrates how UAS imagery can assist planners in fitting designs for a proposed baseball field on campus.Nowadays, these same orthomosaics are used as a basemap to display subsurface utilities. In Figure 13, we can see an example of how orthomosaic imagery is used as a base layer to map hot water pipes on campus. This innovative use of UAS technology has improved the accuracy and efficiency of subsurface utility mapping, which is critical for infrastructure planning and maintenance.

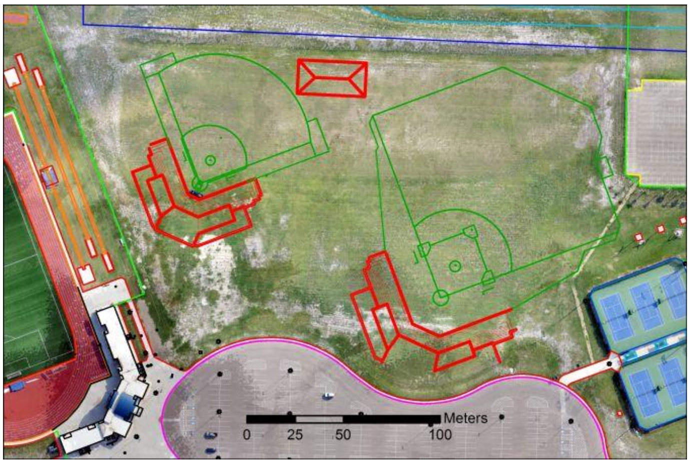

Figure 6: Plans for baseball field overlaid on UAS orthomosaic(Starek et al., 2015).

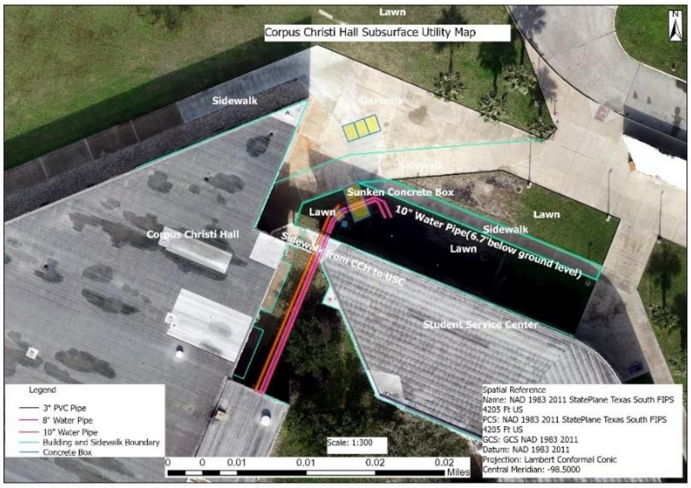

Figure 14: Subsurface utilities overlaid on UAS orthomosaic.

3) <u>3D Modeling and Campus Time Series</u>

Figure 15 provides an excellent example of how UAS products stored can illustrate changes over time. This figure displays a series of images that depict the before and after conditions of the construction of Tidal Hall, showcasing the significant changes that took place from 2014 to 2018.

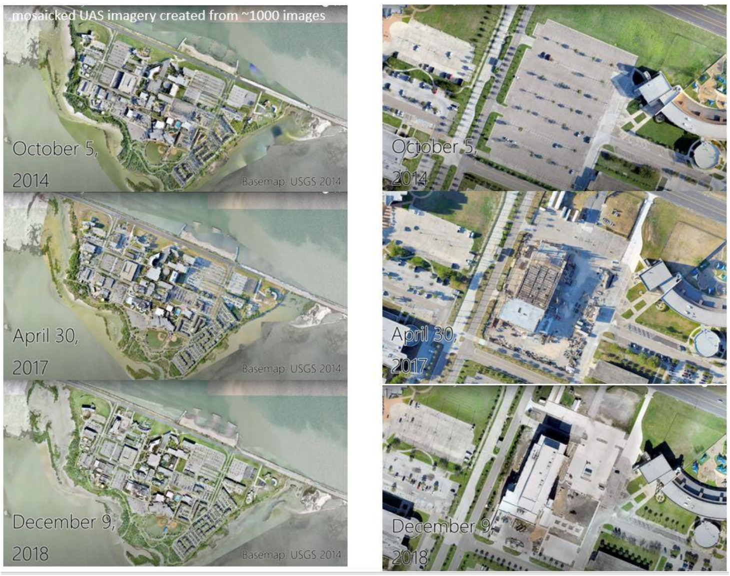

Figure 15: Image showing landscape change from 2014-2018 on campus.

4) <u>Integration of Geospatial Artificial Intelligence (AI)</u>

Geospatial AI methods are currently being employed on the high-resolution UAS orhomoaics for object detection and automated mapping. Presently, deep learning methods are being explored to map palm trees on campus using the UAS imagery. As shown in Figure 16, the detected palm trees in the orthomosaic demonstrate the efficacy of this approach for counting the number of palm trees. By providing accurate data on the number of palm trees in the campus, this method will aid in keeping an accurate record of trees and can help in the decision-making process for planting or removing trees when required. Additionally, in hurricane-prone areas like Corpus Christi, this approach can be utilized to document the number of palm trees before and after a hurricane event, aiding in the assessment of the hurricane's impact on the trees in the region.

Figure 16: Palm tree detection in UAS imagery using a deep learning method.

5) Information Dissemination using Geoportal

For the information dissimination and visualization geoportal has been used. Geoportal consist of web mapping application showing 2D and 3d tiled layers of campus as shown in Figure 17, web map containing multitemporal imagery layera collected starting from 2014 UAS survey to till now, and the story maps explaining details about the project and all the information related to project and works being conducted till now. The following Figure 18 and Figure 19 shows the interface of published web map and story map.

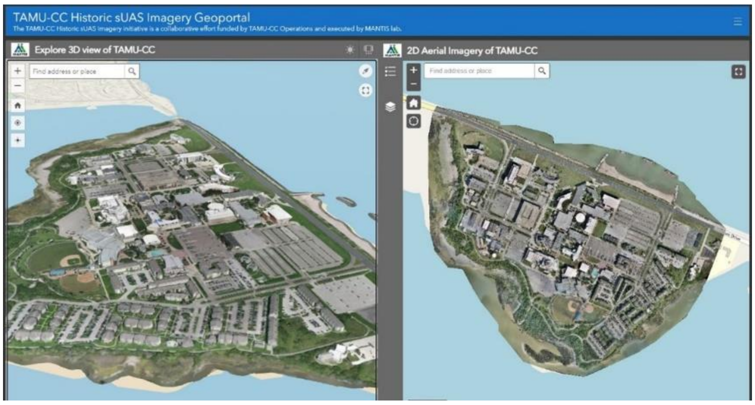

Figure 17: Snapshot of interface showing dashboard containing 3D and 2D layers of campus.

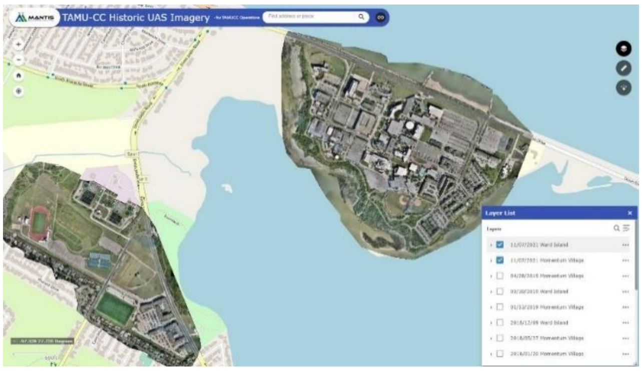

Figure 18: Snapshot of interface showing web map of campus.

Figure 7: Snapshot showing interface of StoryMap of campus.

7. CONCLUSION

The integration of UAS data and GPS data has had an immediate impact on infrastructure planning projects at the university, as the accuracy of the products obtained from UAS provides survey-grade accuracy. The use of UAS has proven to be a time-saving and efficient method for campus surveying. Moreover, the use of different types of UAS platforms, from fixed-winged Sensefly eBee to hybrid VTOL Wingtra, has further increased the accuracy of the photogrammetric products obtained from UAS flights. The Orthomosaic, a product obtained from UAS flights, has proved to be particularly useful for facility management and new infrastructure planning. The accurate imagery obtained from UAS flights has also found applications in research labs, where they are being used for geo-informatics research. In 2023, the COA was renewed to enable UAS surveys to be conducted on campus in the future. Future work could focus on the development of UAS-based monitoring systems that can provide real-time information on changes to the campus and surrounding areas.

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