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Implementation of Unmanned Aerial Systems Using Close-range Photogrammetry Techniques (UAS-CRP) for Quantitative (Metric) and Qualitative (Inspection) Tasks Related to Roadway Assets and Infrastructures: Final Report

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16. Abstract
The primary purpose of this implementation project is to educate and inform TxDOT staff on FAA rules and regulations and TxDOT policy governing the use of UAS for TxDOT projects. The TxDOT Unmanned Aircraft System (UAS) Flight Operations and User's Manual (FOM), developed as part of the preceding research and highlights of the preceding research were presented at nine training sessions conducted at various TxDOT locations. The implementation project included UAS flight operations and data collection to further investigate the use of the technology and as further validation of the FOM. Field data collection included both quantitative (metric) and qualitative (inspection) tasks including the collection of data for towers, intersections, and buildings. Traffic control was necessary for some tasks but no driver distraction was noted during the field operations. This is an indication of the effectiveness of the rules and guidelines contained in the FOM for safe UAS operation. Vendor feedback further provided valuable input regarding the effectiveness of the FOM. The results of this implementation project validate the use of UAS as an effective data collection tool for metric and inspection tasks.

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Final Report

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EXECUTIVE SUMMARY

The need for conducting safe infrastructure inspection and mapping using unmanned aerial vehicles was the motivation behind the development of the Unmanned Aircraft System (UAS) Flight Operations and User's Manual (FOM) by TxDOT. The manual and the rules and regulations it contains will ensure the safe and efficient use of UAS for TxDOT projects.

This implementation project is a follow-up to the previous research project. One of the primary tasks of this follow-up project was to disseminate the FOM information at various training sessions in select TxDOT district locations. Nine training sessions were conducted in offices in El Paso, Houston, Dallas, Fort Worth, Austin, Corpus Christi, Lubbock, and San Antonio. An all divisions meeting was also held at TxDOT Austin headquarters. Each training session included a comprehensive presentation of the UAS Flight Operations Manual and a brief review of the completed research project 0-6944. The training sessions helped inform TxDOT staff on policies ensuring the safe use of UAS. This effort was important because of a growing interest in using this technology.

The project included an additional validation of the suitability and effectiveness of the rules and requirements contained with the FOM. Field data collection tasks, including tower inspections, intersection mapping, and building mapping, were conducted by UT Arlington. Two UAS vendors out of ten contacted were selected to perform the planimetric and topographic mapping and bridge inspection tasks, respectively.

The training helped answer questions about the use of UAS. Each participating entity followed the TxDOT FOM and completed the task requirements. All of the UAS data collection tasks were successful, as they were performed by closely following the FOM guidelines. Data collected was analyzed and submitted to the project monitoring committee (PMC) and subject matter experts (SMEs) from different districts and divisions. Feedback from the SMEs indicated that the UAS results provided data similar to that of traditional methods. The cost-effectiveness, speed, and safety of the UAS methods were recognized as major benefits of UAS applications. Overall, this implementation project was successful in educating TxDOT staff on the safe and effective use of UAS technology while, at the same time, investigating additional uses of the technology and providing further validation of the FOM.

CHAPTER 1 INTRODUCTION AND BACKGROUND

The introduction of UAS for civilian applications has created interest in using the technology by state departments of transportation (DOTs) agencies. Two types of unmanned aerial vehicles (UAS), fixed and rotary-winged, are predominantly used by transportation agencies around the world. The fixed type has a single rigid wing across its body that allows it to fly longer flight distances at high speeds, similar to manned airplanes (Tahar and Ahmad, 2012). The rotary-winged type achieves lift from the continuous rotation of its propellers to provide vertical and horizontal movements similar to manned helicopters. A third type called vertical take off and landing (VTOL) type of UAS is also gaining prominence recently.

Research in the use of unmanned aerial vehicles (UASs) for managing infrastructure was conducted by the University of Texas at Arlington (UTA) as part of TxDOT project 0-6944 that spanned eighteen months. The outcomes of this research project include the development of the TxDOT Unmanned Aircraft System (UAS) Flight Operations and User's Manual (FOM), as well as initial evaluations of using unmanned aerial vehicle close-range photogrammetry (UAS-CRP) technology for infrastructure performance assessments.

TxDOT Unmanned Aircraft System (UAS) Flight Operations and User's Manual (FOM)

The FOM was prepared to assist the UAS crew in executing safe ground and air operations. It includes topics on flight crew requirements, the Safety Management System (SMS), flight planning rules, project risk assessment (PRA), traffic control plans, submission of forms, health and safety plans, emergency procedures, the Downed Aircraft Recovery Plan (DARP), and accident reporting. The SMS helps in identifying and mitigating safety risks and hazards to perform safe, efficient, and effective UAS operations. The flight planning rules describe the files and information that need to be submitted with the standard flight plan format. The PRA defines situations that require pre-approval from the TxDOT UAS coordinator (TxDOT-UASCoord@txdot.gov). The health and safety plan provides the UAS staff with guidance on ways to be in a sound health condition while executing activities before and during data collection. The in-flight emergency plan provides step-by-step procedures to follow if an emergency arises during the flight. The DARP explains the steps to follow for the safe retrieval of a crashed UAS. The accident reporting section outlines the procedures involved in reporting an accident.

The FOM also includes information about the TxDOT UAS program team that reviews the flight plans, traffic control plans, pre-approval forms, and other forms that are submitted (TxDOT-UASFlightPlan@txdot.gov) before field operations.

Infrastructure Asset Monitoring

Frew et al. (2004) used a modified airplane to demonstrate the vision-based autonomous following of a road. Vision systems are small in size and lightweight, due to their passive type of data collection and processing. Frew processed the collected data in the field and measured the relative distance and orientation between the aircraft and the road. Zhang (2008) used a computer stationed on the ground for real-time communication with the UAS. The flight position was continuously monitored, and control commands were sent to the onboard navigation assembly. The "washboarding", or the corrugation effect on the unpaved road, was identified in the form of closely spaced valleys and ridges (Zhang, 2008). The Michigan DOT (MDOT) conducted a bridge deck inspection safely using UAS and realized 90% cost savings compared to traditional inspection practices (Asphalt Institute, 2016).

Other applications include geological mapping and infrastructure analysis. Tziavou et al. (2018) conducted aerial mapping of a coastal area, using fixed-wing and rotary-wing UASs. Tziavou concluded that the level of detail in geological maps obtained from the aerial orthomosaics is comparable with that of traditional methods with the UASs requiring one-fifth of the time to collect the same details (Tziavou et al., 2018). Unmanned aerial data was also used to obtain navigable 3D models that render a better visualization of the infrastructure condition (Puppala et al., 2018).

UAS data collection methods that complement traditional methods are gaining popularity as more agencies research UAS and their innovative applications. Many departments of transportation (DOT) are using UAS for various infrastructure inspection applications (Tony, 2018). The most common applications reported by the agencies are photography and surveying of construction sites, bridge inspections, traffic and pavement monitoring, tall light pole inspections, and emergency operations. Congress et al. (2018) conducted a comprehensive calibration analysis of the total system that comprises an unmanned aerial vehicle and the optical camera mounted on it. As part of the previous research project, aerial data of an existing pavement section was collected to monitor the presence of any issues caused due to underlying problematic soils (Congress, 2018).

Howard et al. (2018) provided details regarding the use of UAS for the military, recreational, public sector, commercial, and construction purposes. Workplace hazards might exist, either caused by or avoided by using a UAS, and information about them would help in effectively implementing this technology. Howard proposed that a database of UAS-related injuries would help mitigate those situations in the future and would enhance the safety of the workers.

This implementation project (5-6944-01) was performed to disseminate the FOM information and to perform five tasks, as part of infrastructure asset data collection, that relate to tower inspections, intersection mapping, building mapping, planimetric and topographic mapping, and bridge inspections.

CHAPTER 2 PROJECT TASKS

The implementation project was divided into three tasks, with corresponding deliverables, and includes:

- Task 1: Project Management
- Task 2: Training
- Task 3: UAS District Missions

Task 1: Project Management

This project began in September 2018 with a kick-off meeting. The performing agency i.e., UT Arlington (UTA), coordinated and communicated with the project managers (PMs), project monitoring committee members (PMCs), and the point-of-contact persons from districts to plan and organize the tasks. UTA coordinated with the receiving agency, TxDOT, to organize three project progress meetings with the PM and PMC during the six-month project. Activities performed every month and works planned for each succeeding month were compiled and submitted to TxDOT as a part of the monthly progress reports (MPRs). A project summary report (PSR2) was submitted with this implementation report (IPR1), as part of the deliverables for Task 1. The project ended with a close-out meeting that was held in San Antonio in February 2019.

Task 2: Training

As part of the implementation project, comprehensive training on the FOM, and a brief introduction of the completed research project 0-6944 were provided during meetings with TxDOT personnel from eight districts: El Paso, Houston, Dallas, Fort Worth, Austin, Corpus Christi, Lubbock, and San Antonio. There was also an all divisions meeting held at TxDOT Austin Headquarters. Training materials, prepared as part of this implementation project and approved by the PMC, were used for the training sessions. One of the training sessions was also recorded and made available to the PMC. The data collection task undertaken in Lubbock was combined with the training session. The data collection tasks were briefly discussed during the training sessions in Lubbock and San Antonio training sessions.

Task 3: UAS District Missions

The flight tasks under Task 3 included both qualitative (e.g., inspection) and quantitative (e.g., metric) data collection. Tower and bridge inspections were classified as qualitative tasks, whereas planimetric and topographic mapping, intersection mapping, and building mapping tasks were classified as quantitative tasks. During the qualitative tasks, TxDOT SME actively participated in the field data collection. During some of those inspection tasks, the SME viewed the aerial view of the assets on an additional screen in real-time. The SMEs were able to provide instructions to the RPIC on UAS placement and desired camera angles towards the assets. As part of the quantitative tasks, TxDOT provided survey support by establishing ground control targets, check points, and traffic control points as required.

Five tasks including bridge inspection, tower inspection, planimetric and topographic mapping, intersection mapping, and building mapping, respectively, were planned as part of this implementation project. These tasks included multiple inspection missions conducted at various locations (and hence multiple UAS flights). Three of the five tasks were accomplished by the University of Texas at Arlington (UTA). Tower inspection task included five missions to inspect three communication towers, a water tower, and a high mast lighting tower, respectively. Intersection and building mapping tasks were conducted by separately mapping an intersection and a building, respectively. Planimetric and topographic mapping task was performed by a consultant, whereas the bridge inspection task was not performed due to scheduling issues. Validating FOM was one of the key objectives of this task, in addition to comparing the benefits and limitations of UAS data collection with those of traditional methods.

Tower inspections were conducted by UTA at Lubbock, Kaufman, Corsicana, Fairview, and Calallen. UTA mapped the intersection and building located in Seguin. Vendor 1 conducted the planimetric and topographic mapping of an intersection in Tyler. Vendor 2 was scheduled to collect the aerial imagery of the Fred Hartman cable-stayed bridge in Houston, to inspect the condition of the bridge deck, pylons, and the cable connections; however, the inspection was canceled when a barge hit the column of a nearby bridge, resulting in traffic diversions onto the bridge scheduled for UAS inspection.

All of the above discussed tasks, except the bridge inspection, were accomplished with a UAS crew comprised of RPIC and a visual observer who monitored the airspace during the UAS operations in the field.

Task 3.1: Bridge Inspection

The inspection of the Fred Hartman Bridge in Houston was planned to be conducted by a vendor. The scope of the inspection included capturing still images and videos of the bridge spans between the two pylons on each of the two bridge spans. The four pylons were planned to be inspected with high-definition still images and videos of the front and back faces of each pylon. The areas near the cable connections were of particular interest to the bridge SME. The deliverable for this task was not completed as the task was canceled due to scheduling problems resulting from the barge strike.

Task 3.2: Tower Inspection

UT Arlington inspected two communication towers located in TxDOT's Dallas District and one communication tower in the Lubbock District. A water tower located in Dallas District and a high mast lighting tower in Corpus Christi District were also inspected by UTA. Four of these towers did not require the FAA authorization for flying UAS, as they are located in class "G" airspace; the inspection of the water tower required an FAA authorization due to its location in Class "D" airspace. The locations of the towers are provided below. All towers except the high mast tower were inspected to identify the conditions of the communication equipment mounted on those towers. The purpose of the high mast tower inspection was to see why the pulley assembly was causing problems in the operation of the lighting assembly on the high mast tower.

1. Communication Tower in Kaufman County, Texas is located at 3948 South Houston Street, Kaufman Texas 75142 (Location Coordinates: 32° 34' 1.2216" N, 96° 19' 25.6656" W).
2. Communication Tower in Corsicana, Texas is located at 100 SW County Road 1000, Corsicana, Texas 75110 (Location Coordinates: 32° 2' 26.1312" N, 96° 32' 21.5448" W).
3. Water tower in Fairview, Collin County, Texas is located at 500 State Highway 5, Fairview, Texas 75069 (Location Coordinates: 33° 8' 16.7964" N, 96° 38' 24.1476" W).
4. Communication Tower in Lubbock, Texas is located at 135 E Slaton Hwy, Lubbock, TX 79404 (Location Coordinates: 33° 32' 7.5876" N, 101° 50' 22.218" W).

5. High Mast Tower in Calallen, Texas is located at 4602 Cornett Drive, Corpus Christi, TX 78410 (Location Coordinates: 27° 51' 52.4412" N, 97° 37' 22.7892" W).

Task 3.3: Planimetric and Topographic Mapping

Vendor 1 conducted planimetric and topographic mapping of the intersection of West Grande Blvd. and South Broadway Avenue in Tyler, TX 75703 (Location Coordinates: 32° 16' 47.5392" N, 95° 18' 21.6216" W). The project site includes two 6-lane intersecting roads that are located in a heavily trafficked urban area. There is a large culvert on the north side; a substation on the southwest side; distribution lines running on both sides of the intersection in both north/south and east/west directions; and two large transmission lines that are approximately 150 ft. high, running east to west. All these features were mapped, using the UAS data collection.

Task 3.4: Intersection Mapping

UT Arlington conducted the mapping of the intersection of Eastwood Drive and Preston Drive along the Farm to Market Road 466 (FM 466), located at 1587-1599 FM 466, Seguin, TX 78155 (Location Coordinates: 29° 33' 49.8996" N, 97° 56' 9.8988" W). The road legs of the uncontrolled intersection were undivided. Due to the high-speed traffic entering the intersection along FM 466, a proposal for upgrading the uncontrolled intersection to a roundabout was put forward. Hence, the whole area was aerially mapped to assist in redesigning the uncontrolled intersection.

Task 3.5: Building Mapping

UT Arlington conducted the data collection of an L-shaped building within the TxDOT maintenance office area located at 1900-2098 Proform Rd, Seguin, TX 78155 (Location Coordinates: 29° 35' 29.6304" N, 97° 59' 54.2364" W). The purpose of this data collection is to provide the input into a 3D building modeling task that will be performed by TxDOT.

CHAPTER 3 ANALYSIS OF INDIVIDUAL TASKS

All of the data collected was analyzed and provided to the respective TxDOT SMEs participating in the inspections. The procedures and other details were provided to the project committee. A brief overview of those details is as follows.

Task 3.1: Houston Fred Hartman Bridge Inspection

The Fred Hartman Bridge in Houston has two spans that serve the north-and-south-bound traffic. An aerial inspection of the pylons was planned with traffic control. There are four lanes of traffic in both directions on each side of the bridge, and traffic control included the closure of one lane of traffic on each side during the inspections. However, due to scheduling problems resulting from a barge collision with a nearby bridge, this inspection did not occur.

Task 3.2: Tower Inspections

Communication Towers

Tower inspections conducted at Kaufman, Corsicana, Fairview, and Lubbock provided the TxDOT SMEs with quick insights into the condition of the towers. Some of the salient findings during the tower inspection included the identification of the presence of lightning antenna tips, a wrongly oriented dish, disconnected cables, broken antennas, and rusted areas, as shown in Figures 1 and 2. The images taken in-level with the tower features were also useful in identifying the relative elevations of the different features mounted on the tower.

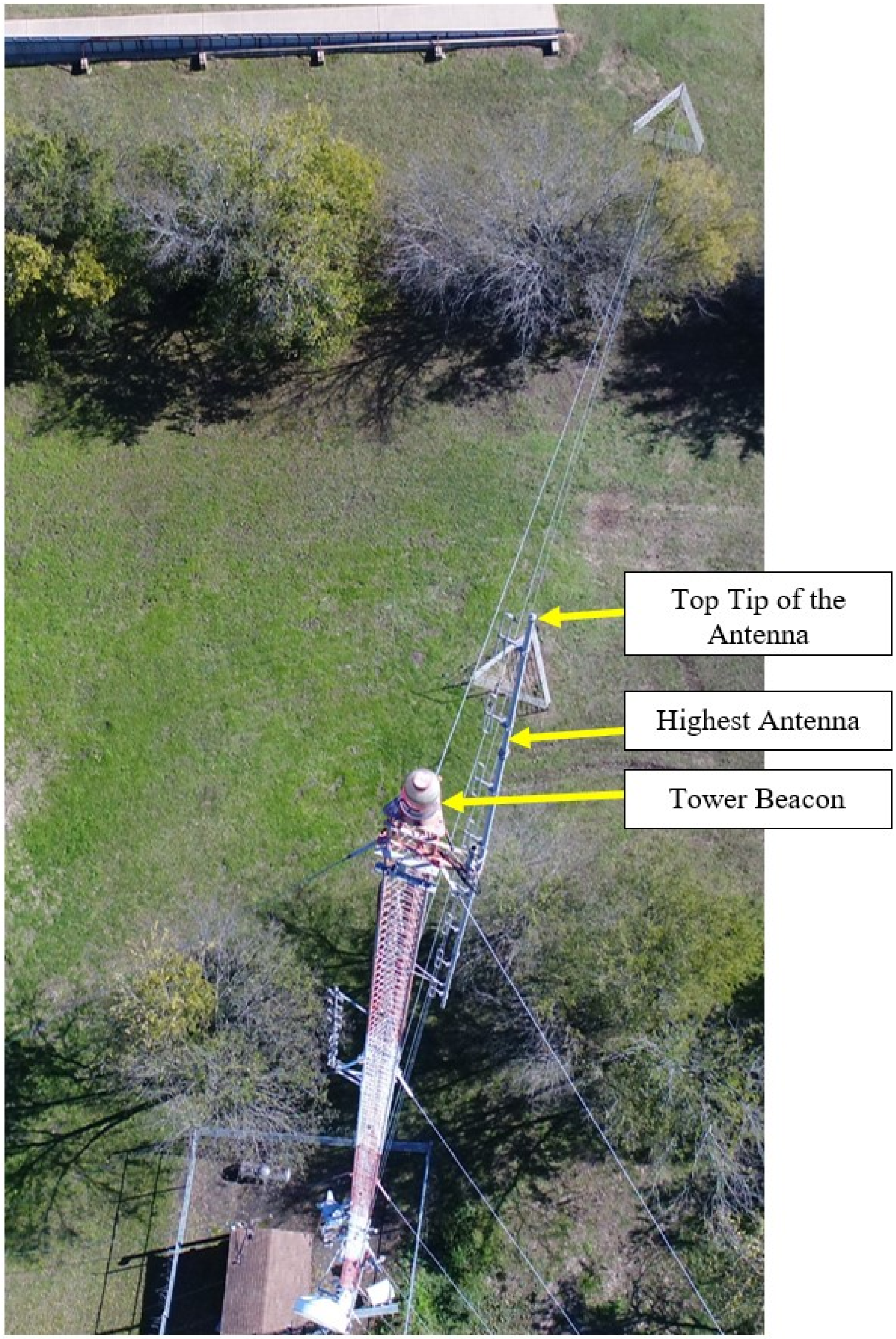

Figure 1. Inspection of the top of the highest antenna and beacon on the west face of the Kaufman tower

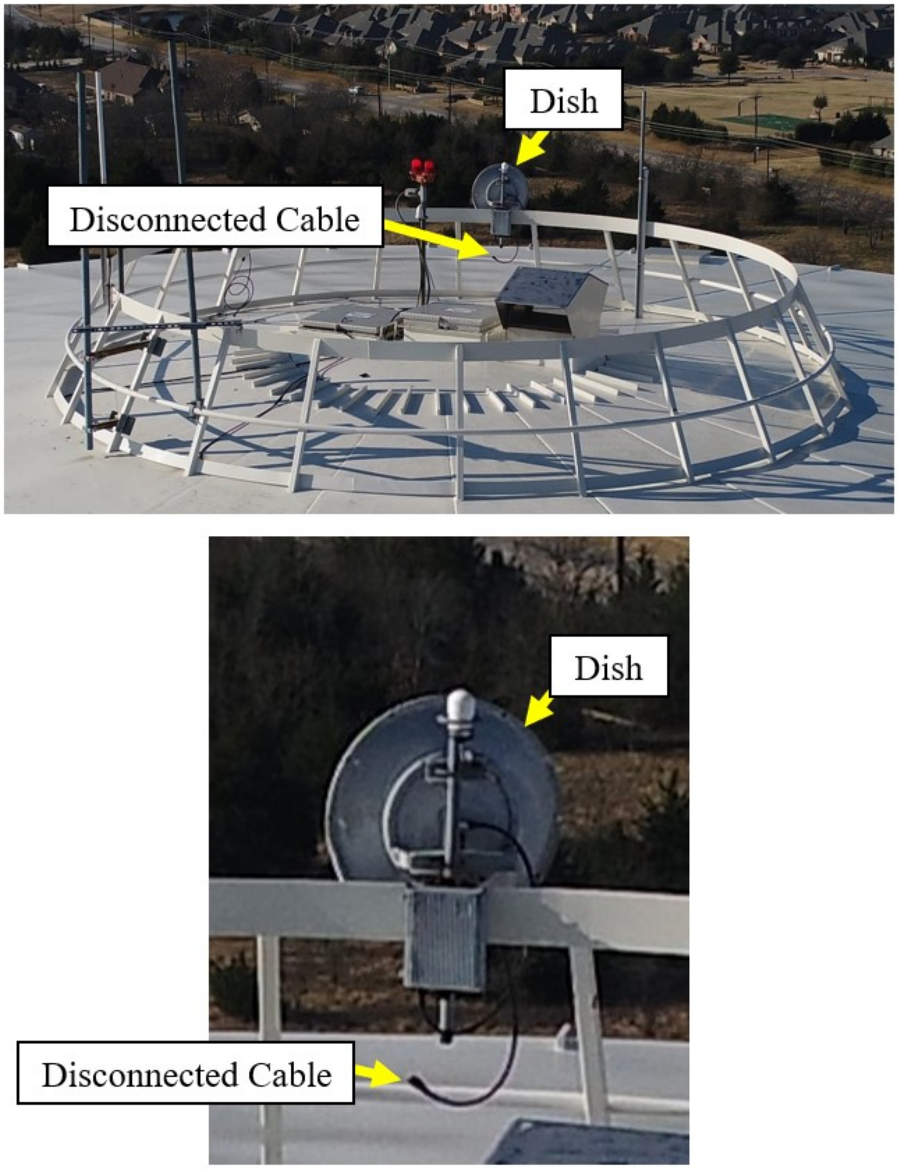

Figure 2: Detection of a disconnected cable of a dish antenna at the Fairview tower

High Mast Tower

The high mast tower is approximately 150 feet tall, with a lighting assembly held by a pulley system. The lighting assembly was comprised of twelve lights of varying intensities, facing different directions, and three beacons mounted on rods. The inspection was conducted to identify the reason for the faulty movement of the lighting assembly while the pulley was being operated. Before operating the pulley system, the TxDOT SME wanted to inspect the condition of the pulley and the presence of cotter pins at the three connections holding the lighting assembly. The inspection was broken down into two phases. In the first, a flight operation was performed before the operation of the pulley, as shown in Figure 3; in the second, a flight operation was performed during the operation of the pulley, as shown in Figure 4.

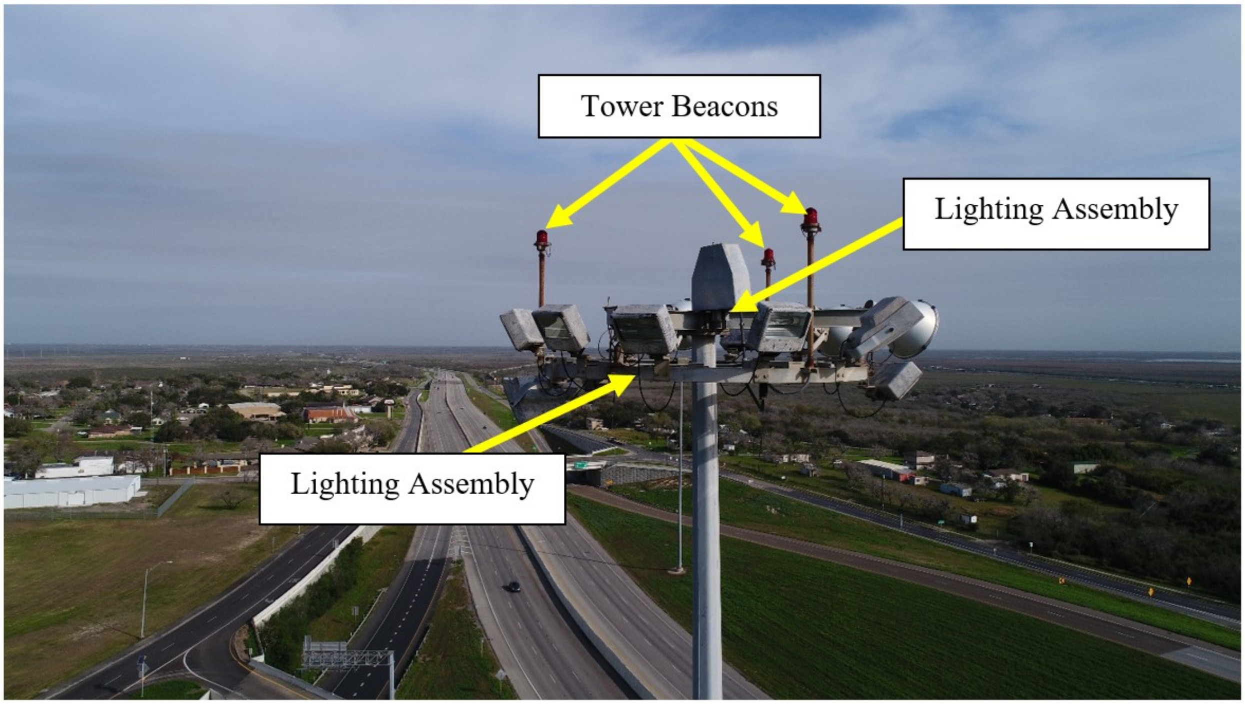

Figure 3. Inspection of the lighting assembly and pulley system from south of the high mast tower before the pulley operation

The visuals of the first flight assured the TxDOT personnel that cotter pins were holding the lighting assembly in place. Hence, the SME decided to perform the aerial inspection while the pulley was being operated to lower the lighting assembly.

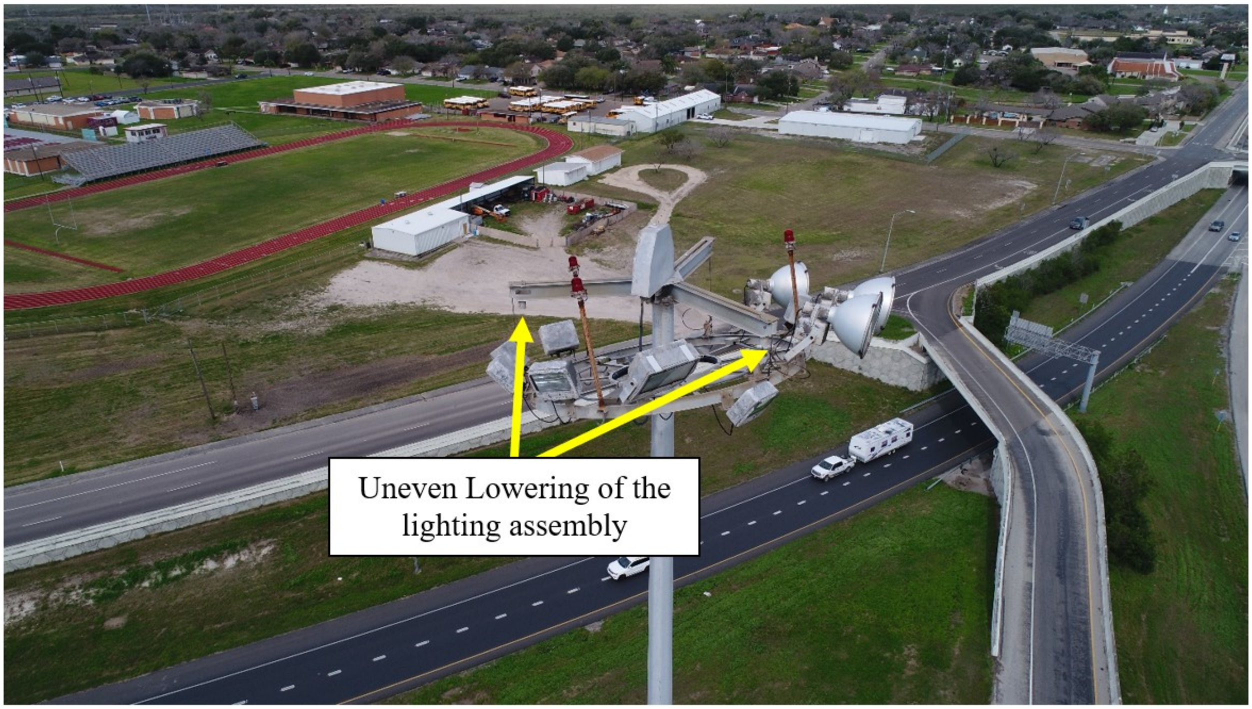

Figure 4. Inspecting the inclined lighting assembly while operating the pulley

At the end of the inspection, the following salient features were identified. Cotter pins of the pulley leg connections were secured in place, enabling the TxDOT personnel to operate the pulley system safely. The beacon rods were rusted, but all of the cable connections were found to be secured in place. The southeast leg of the pulley was causing the uneven lowering of the lighting assembly.

Task 3.3: Tyler Planimetric and Topographic Mapping

The Tyler intersection has heavy traffic with complicated airspace due to the presence of overhead utility lines, guy wires, wooden utility poles, and large metal utility poles. Before the mapping, it was necessary to secure permission, from the owners of the adjacent properties, to take off and land from outside TxDOT's right of way. Aerial imagery data collected at the Tyler intersection was used to create the orthomosaic as shown in Figure 5.

Figure 5. Orthomosaic of the Tyler intersection generated from the aerial images

Task 3.4: Seguin Intersection Mapping

The Seguin intersection is located near a residential area, and traffic control was provided during the data collection as a precautionary measure. An aerial data collection was conducted to capture the intersection legs and the area where the proposed roundabout would be constructed. The images were used to build a dense point cloud and a mesh model. The mesh model was used to generate a digital elevation model (DEM) and an orthomosaic (Figures 6 and 7).

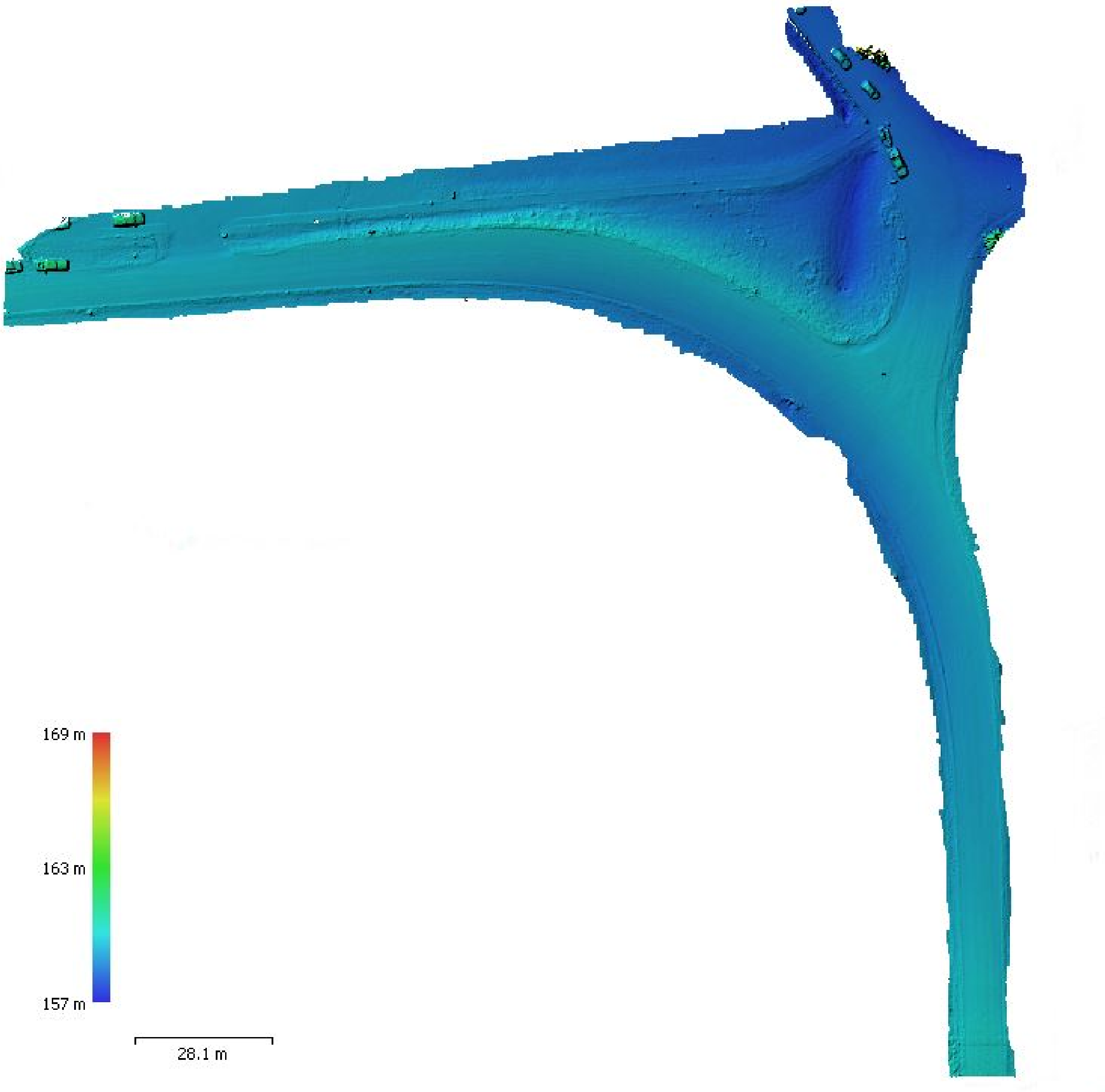

Figure 6. Digital Elevation Model (DEM) of the Seguin intersection area

Figure 7. Orthomosaic of the Seguin intersection area developed from the aerial images

Task 3.5: Seguin Building Mapping

Aerial imagery of an L-shaped building located at the TxDOT Seguin maintenance facility was collected using UAS mounted with an optical camera. The camera was inclined at an angle to better capture the vertical faces of the building, in addition to the nadir images. The data was used to create a point cloud, mesh model, and orthomosaic (Figure 8). TxDOT will use the data to create a 3D building model of the structure.

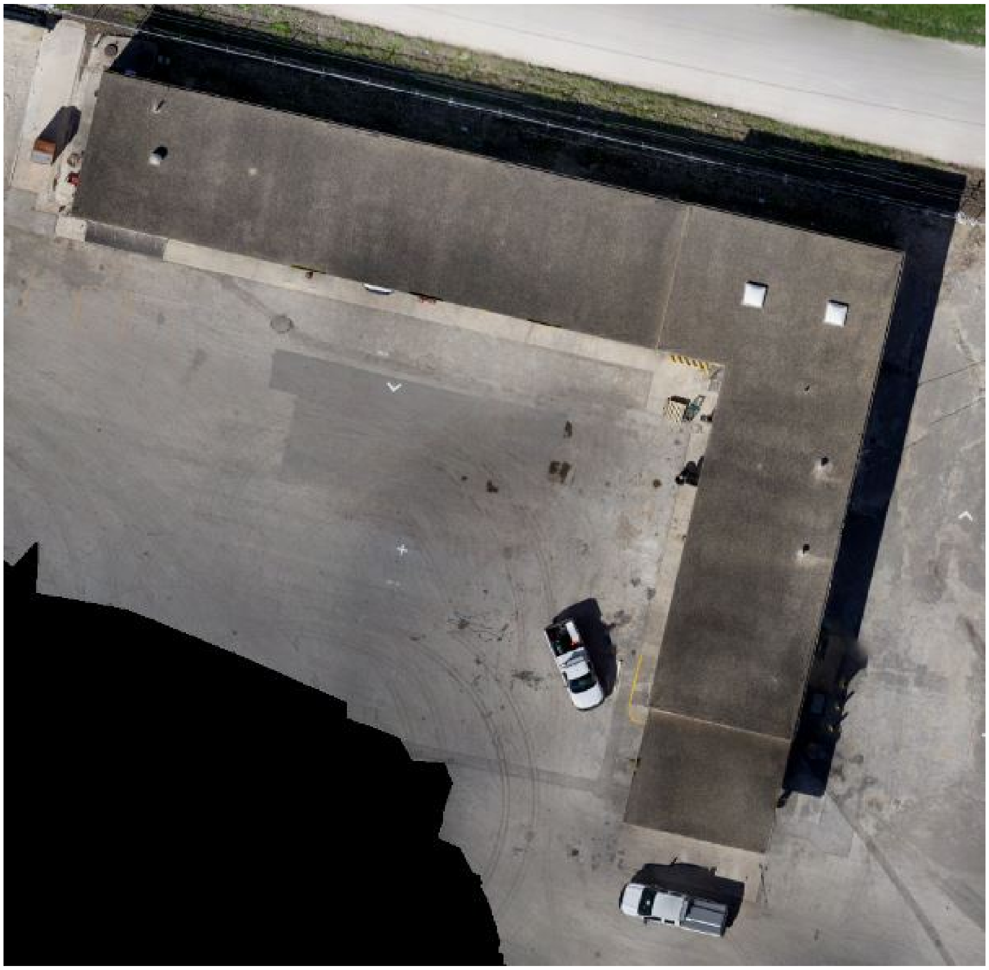

Figure 8. Orthomosaic of the building area developed from the aerial images

CHAPTER 4 SUMMARY OF INSPECTION TASKS

The following table presents a comparison of the traditional data collection (compiled predominantly from discussions with SMEs) and UAS data collection methods for various inspection and mapping missions. The data collection, time, and cost details provided under traditional inspection for planimetric and topographic mapping are based on laser surveys. The data collection, time, and cost details provided under intersection mapping task are based on traditional surveying techniques.

Table 1. Comparison between traditional and UAS inspections

Mission Task	Traditional Inspection and Mapping				UAS Inspection and Mapping			
	Crew	*Data Collection*	*Processing Time*	*Cost*	*Crew*	*Data Collection*	*Processing Time*	*Cost*
Tower Inspection	Two	Three - six hours	One hour	$2,500 - $4,000	Two	One - Two hours	One - Two hours	$2,000 - $2,500
Planimetric and Topographic Mapping	Two - Three	Three Days	Two Days	$17,000 - $19,000	Two	Two - Three hours	Ten - Twelve hours	$6,000 - $7,000
Intersection Mapping	Two - Three	Three Days	Two Days	$8000 - $10,000	Two	Two - Three hours	Ten - Twelve hours	$5,000 - $7,500
Building Mapping	NA	NA	NA	NA	Two	One hour	Five - Eight hours	$4,000 - $4,500
High Mast Tower Inspection	Two	One - Two hours	One hour	$800 - $1,000	Two	Half - One hour	One - Two hours	$1,000 - $1,500

After the vendor performed the planimetric and topographic mapping using UAS, TxDOT did manned aircraft mapping at the same intersection. As per the email communication with TxDOT RTI, the manned aircraft mapping was found to be less expensive in terms of labor rates, travel costs and others as the manned aircraft mapping costs were around $1,425 less than the UAS costs. It was also reported that intersection mapping accuracy was the same for both UAS and manned aircraft technologies.

The above information indicates the economic benefits of the UAS studies over the traditional practices for some of the applications provided in Table 1. Aerial tower inspections using a UAS were key in identifying the condition of the tower elements and planning for repairing or replacing the faulty elements. The aerial high mast tower inspection using a UAS demonstrated safety to the inspection personnel who were unsure of the condition of the pulley until after the initial UAS inspection. Depending on conditions, some planimetric and topographic mapping may be accomplished more efficiently using a manned aircraft mission. Intersection mapping using a UAS was useful in providing existing conditions of the intersection for planning any improvements. Building mapping using a UAS demonstrated a quick inspection of structures and the feasibility to assist in building modeling.

One of the major advantages identified from most of these tasks is that they can be performed quickly and safely using UAS. The limitations are that the UAS data collection is influenced by inclement conditions and complicated airspace. It was observed that some applications may not be cost effective compared to manned aircraft missions.

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