CAIT-UTC-NC49

Utilizing Unmanned Aircraft Systems for Infrastructure Management

FINAL REPORT
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Submitted by:

Michael O'Connell
Research Engineer

Rutgers University Center for Advanced Infrastructure and Transportation
100 Brett Road, Piscataway NJ 08854

External Project Manager Patrick
Szary, Rutgers University

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16. Abstract
The field of Unmanned Aerial Systems (UAS) research has been shown to have many applications in the transportation infrastructure industry. Nationally, there has been a trend to incorporate UAS in infrastructure management activities such as bridge and roadway inspections. The objective of this study was to evaluate the effectiveness of utilizing UAS to inspect, inventory, and monitor interchange assets along the New Jersey roadway network. The team used the video and photographic data collected from the UAS to perform preliminary inspections on multiple components of the interchange including: signage, roadway markings, barrier island, and asphalt condition.

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1 DESCRIPTION OF THE PROBLEM

Roadway interchanges contain an array of transportation safety assets, all of which require regular maintenance and inspection to ensure each element is performing as intended. A single interchange could possess a variety of transportation safety assets including: signage, roadway striping, guiderails, roadway/median barriers, and pavement markings. It is currently up to the individual transportation agency to develop a maintenance and inspection schedule to ensure roadway assets are compliant with the Federal Highway Association standards outlined in the Manual on Uniform Traffic Control Devices (MUTCD). Regarding signage, the MUTCD provides the following guidance:

> *01. Maintenance activities should consider proper position, cleanliness, legibility, and daytime and nighttime visibility (see Section 2A.09). Damaged or deteriorated signs, gates, or object markers should be replaced.*
>
> *02. To assure adequate maintenance, a schedule for inspecting (both day and night), cleaning, and replacing signs, gates, and object markers should be established. Employees of highway, law enforcement, and other public agencies whose duties require that they travel on the roadways should be encouraged to report any damaged, deteriorated, or obscured signs, gates, or object markers at the first opportunity.*
>
> *03. Steps should be taken to see that weeds, trees, shrubbery, and construction, maintenance, and utility materials and equipment do not obscure the face of any sign or object marker.*
>
> *04. A regular schedule of replacement of lighting elements for illuminated signs should be maintained.*

(FHWA MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES, 2009 EDITION) [1]

Transportation agencies utilize both informal and formal methods of asset inventorying and inspection. Informal methods include: training staff to identify deficiencies in an asset's ability to perform, receiving notifications from police patrols or citizens regarding missing or damaged assets. Formal methods of inventorying and inspection include training maintenance staff on how to look for deficiencies, developing a maintenance and inspection schedule, develop inspection procedures for identifying defects, provide maintenance technicians with necessary equipment to perform on-the-spot repairs, develop systems of work orders for larger repairs and replacements, and develop a record keeping system for asset management [2].

Current asset management and inventorying methods often involve relying on agency staff to manually collect photos and data through field inspections. Field inspections may require the field team to perform multiple activities while in the presence of traffic. These activities could include crossing the roadway to access various traffic management assets, and collecting photos or other data while on the shoulder of the roadway. Performing these activities may put the inspection team at risk for injury due to oncoming traffic, or from geological features of the location (ex: rocks, steep hills, etc). In some situations, it may be beneficial to perform preliminary inspections and inventorying of roadway assets via Unmanned Aircraft System (UAS). Incorporating UAS into these operations may allow for field technicians to perform their inspection and inventorying duties at a safer distance from the roadway. It may also reduce the amount of physical movement the operator must do to access the asset, potentially reducing the probability of an injury due to environmental features. In addition to safety concerns, incorporating UAS technologies into inventorying activities may provide a unique viewing perspective of the asset not available through ground-based photographs.

2 APPROACH

This study will aim to assess if unmanned aircraft systems (UAS) could be a potential infrastructure management tool for inventorying and monitoring transportation safety assets. The field of Unmanned Aircraft Systems has been shown to have many applications in the transportation infrastructure industry. Nationally, there has been a trend to incorporate UAS for infrastructure management activities including:

- Bridge Inspection
- High Mast Inspection
- Incident Management
- Traffic Monitoring
- Surveying

The objective of this study is to provide groundwork investigation into the potential of utilizing a UAS for asset management along the New Jersey roadway network. The team will use the video and photographic data collected from the UAS to perform preliminary inspections on multiple components of an interchange including:

- Signage
- Pavement Markings
- Striping
- Medians/Barriers
- Asphalt Conditions

To accomplish this task, the team will acquire a UAS capable of collecting high resolution images and video. The selected UAS should have a long enough flight time and battery life to collect images of the various assets to minimize take-off and landing activities – as these activities may pose the most risk and distraction to drivers along the roadway, as well as the flight crew. In addition to the asset imagery collection flights, the flight crew will also collect aerial imagery which will be processed into 3-Dimensional model of the interchange. The team will study the imagery collected and model processed to identify potential asset defects including asphalt cracking, eroded striping, and other damages, as well as identify potential limitations to utilizing a UAS for such activities.

3 METHODOLOGY

3.1 FAA Pilots License

As a flying aircraft, all outdoor UAS operations fall under the jurisdiction of the Federal Aviation Association (FAA). The FAA governs all activity within the national airspace, and has adopted rules and regulations to promote the safe incorporation of UAS into airspace. The FAA currently designates UAS operations into two categories: Commercial/Government use, and Recreational use. The FAA provides rules and guidelines depending on the designation of the flight. In the case of this study, all flight activities fell under Commercial/Government use.

The FAA requires all UAS operators who operate a UAS for commercial or government use become a certified drone pilot and receive a Small Unmanned Aircraft Systems (sUAS) pilot's license. For first time UAS pilots, the requirements to become a UAS certified pilot are:

- Be at least 16 years old
- Read, write, and understand English
- Be in physical and mental condition to safely fly a drone
- Pass the initial aeronautical knowledge exam

SOURCE: HTTPS://WWW.FAA.GOV/UAS/COMMERCIAL_OPERATORS/BECOME_A_DRONE_PILOT/ [2]

The aeronautical knowledge exam is a comprehensive written exam with questions detailing a multitude of subjects that relate to the safe operation of a UAS. The exam contains questions to test a prospective pilot's knowledge in such areas as: aviation weather, ability to read and decipher sectional charts, airspace classifications, knowledge of airport diagrams and runway patterns, ground crew roles, operational requirements, UAS maintenance and inspection, ground crew roles, and other key factors. Once a pilot has passed the aeronautical knowledge exam, they will be eligible to receive their Remote Pilot Certificate to operate UAS for commercial and government use. This certificate is valid for two years, after which the certificate holder must pass a recurrent knowledge test.

3.2 Equipment

In order to collect aerial imagery for both the production of the 3-dimensional model, and the visual inspection photos, the research team opted to use the DJI Phantom 4 UAS. This specific unit was selected for several reasons. First, the unit's smaller footprint of 13.77 inches diagonally makes this a portable unit that a field crew could include as part of their equipment. It's lower cost of ~$1,400 means that this unit could be replaced in the case of an incident in which the unit is damaged or lost. It is equipped with a 12.4 Megapixel camera with a field of view of 94°, and can take UHD video at 4096x2160 (4k). This unit is equipped with an obstacle sensing system, which can assist in avoiding in-air collisions with objects such as trees, overhead lighting, or powerlines. Additionally, it runs off a lithium-ion polymer battery, with flight times of approximately 20-25 minutes. This of flight time would allow the operators for this study to collect sufficient imagery of the interchange assets within one launch and landing cycle.

Figure 1: DJI Phantom 4

Table 1: DJI Phantom 4 Specs

DJI PHANTOM 4 SPECIFICATIONS	
Cost	~$1,400
Size	13.77" diagonally
Weight	3lbs
Camera (Photos)	12.4M Effective Pixels
Camera (Video)	Up to 4096x2160
Field of View	94°
Operating Temperature	14° F – 103°F
Flight Time	~20-25 minutes

3.3 FAA Regulations

As previously stated, the FAA has jurisdiction over all aircraft operating within the national airspace. This includes both manned and unmanned aircraft such as drones. It is therefore imperative that the UAS pilot-in-command of the operation have a thorough understanding of the current rules and regulations the FAA has placed on UAS operation. These regulations help ensure the safety of both the UAS flight crew, as well as the safety of any manned aircraft that may also be operating in the area. It is the responsibility of the Pilot-in-Command of the operation to ensure that all in-flight procedures and activities follow FAA mandate. Furthermore, the FAA has the authority to fine and prosecute any UAS pilot who breaks any of the laws relating to UAS operation in the national airspace.

On August 29, 2016 the 14 CFR Part 107 regulations went into effect. These regulations established enforceable rules that UAS operators must abide by in order to maintain FAA compliance throughout their flight operations. Several of these regulations would directly have an impact on how flight procedures for this study were to take place. The regulations that would directly impact this flight are as follows:

§ 107.39 Operation over human beings.

> *No person may operate a small unmanned aircraft over a human being unless that human being is:*
>
> *(a) Directly participating in the operation of the small unmanned aircraft;*
>
> *or*
>
> *(b) Located under a covered structure or inside a stationary vehicle that can provide reasonable protection from a falling small unmanned aircraft.*

This regulation would restrict certain flight patterns above the roadway. As the regulation clearly states an individual must be within a “stationary” vehicle, flying over moving traffic would therefore be in violation of this law. Therefore the UAS flight crew would need to ensure that the UAS does not fly over any nonparticipant vehicular traffic by:

- Ensuring the roadway is clear of traffic before UAS flies over

- Develop a flight pattern that minimizing the amount of times the UAS must cross the roadway

§ 107.41 Operation in certain airspace.

> *No person may operate a small unmanned aircraft in Class B, Class C, or Class D airspace or within the lateral boundaries of the surface area of Class E airspace designated for an airport unless that person has prior authorization from Air Traffic Control (ATC).*

From this regulation, the UAS research team would need to ensure that the airspace for the asset inspection operations take place in Class G airspace in order to obtain the most flexibility in terms of operations. The research team would need to view the sectional charts as well as supplemental airspace resources such as airmap.com and B4UFly application to ensure they were allowed to operate in the airspace above the roadway interchange.

§ 107.31 Visual line of sight aircraft operation.

> *(a) With vision that is unaided by any device other than corrective lenses, the remote pilot in command, the visual observer (if one is used), and the person manipulating the flight control of the small unmanned aircraft system must be able to see the unmanned aircraft throughout the entire flight in order to:*
>
> > *(1) Know the unmanned aircraft's location;*
> > *(2) Determine the unmanned aircraft's attitude, altitude, and direction of flight;*
> > *(3) Observe the airspace for other air traffic or hazards; and*
> > *(4) Determine that the unmanned aircraft does not endanger the life or property of another.*
>
> *(b) Throughout the entire flight of the small unmanned aircraft, the ability described in paragraph (a) of this section must be exercised by either:*

(1) The remote pilot in command and the person manipulating the flight controls of the small unmanned aircraft system; or

(2) A visual observer.

This regulation requires either the pilot-in-command or the visual observer to have a clear line-of-sight view to the UAS at all times. This regulation could potentially limit the location at which the UAS flight would take place. Locations with significant overhead foliage may not provide adequate viewing angles in which to maintain line-of-sight to the UAS during the full operation.

3.4 Location

Prior to identifying a location to hold the UAS flights, the research team identified three primary criteria that would allow the team to collect useful photogrammetry data of assets while facilitating the coordination of flight activities. These considerations included: airspace classification, property ownership, and available infrastructure assets.

The FAA has several classifications for controlled airspace: Class A, B, C, D, and E. Operating a UAS in any of these airspaces will generally require a waiver from the FAA as well as coordination with the Air Traffic Control at the controlled airspace's airport.

In an effort to provide the most flexibility in flight operations, the research team decided to identify locations for the UAS flights in uncontrolled Class G airspace. Class G airspace does not have the same waiver and coordination with ATC requirements as the other controlled airspace, and would provide the most flexibility for flight times, patterns, and coordination.

In addition to airspace concerns, the team also took property rights and ownership into consideration when selecting a location for the UAS flights. While the FAA has jurisdiction over the UAS in-air activities, public and private property owners may still place restrictions of operating a UAS from their property. Identifying a location either within, or adjacent to University owned property would allow researchers greater flexibility in flight coordination, eliminating the need for additional permissions and/or permits from landowners.

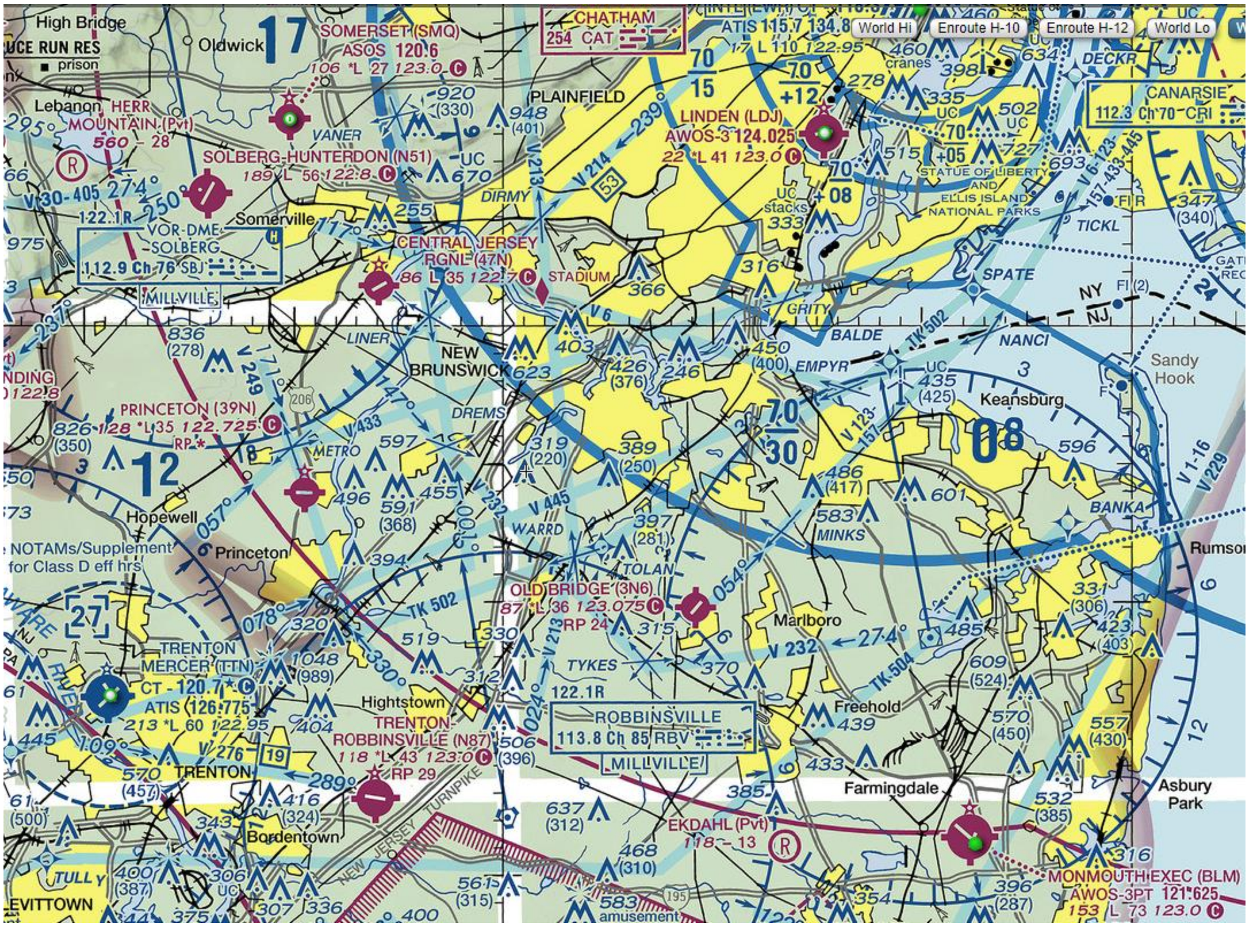

Figure 2: Sectional Chart of New Jersey Airspace

3.5 Infrastructure Assets

In an effort to test the capabilities of both the UAS and the modeling software on a variety of transportation safety assets, the team identified locations that would have multiple asset types including:

- Signage
- Striping
- Guide Rails
- Barriers
- Pavement Markings

A location which includes all of these features would allow the team to test the modeling software on assets of various shapes and sizes, as well as collect multi-asset imagery data.

3.6 Location Identification

With airspace, property ownership, and available infrastructure assets in mind, the research team performed a cursory review of potential locations to hold the UAS flights. After reviewing several potential on-campus locations, the team determined that the interchange leading from US 1 to College Farm Road in New Brunswick, NJ would fit all of the conditions for the UAS operations.

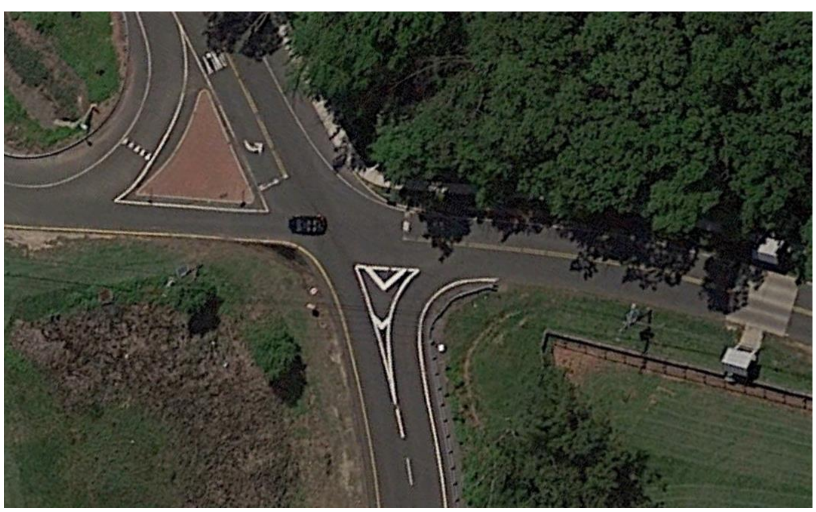

Figure 3: Route 1 & College Farm Road (Google Earth)

The interchange is located at 40°28'12.42"N, 74°26'3.70"W, is approximately 15.5 Nautical Miles (NM) from Morristown Class D airspace, and 16.85 NM from Trenton Mercer Class D airspace. Although these two airspaces reach from surface level to 2,700ft, they were well outside of the operating radius from the proposed flight activities. Additionally, this location does fall within the horizontal bounds of New York Class B airspace, however, the controlled Class B airspace because at 3,000 feet and goes up to 7,000 feet. The flight operations would fall well below these altitudes, and would therefore not interfere with the controlled airspace.

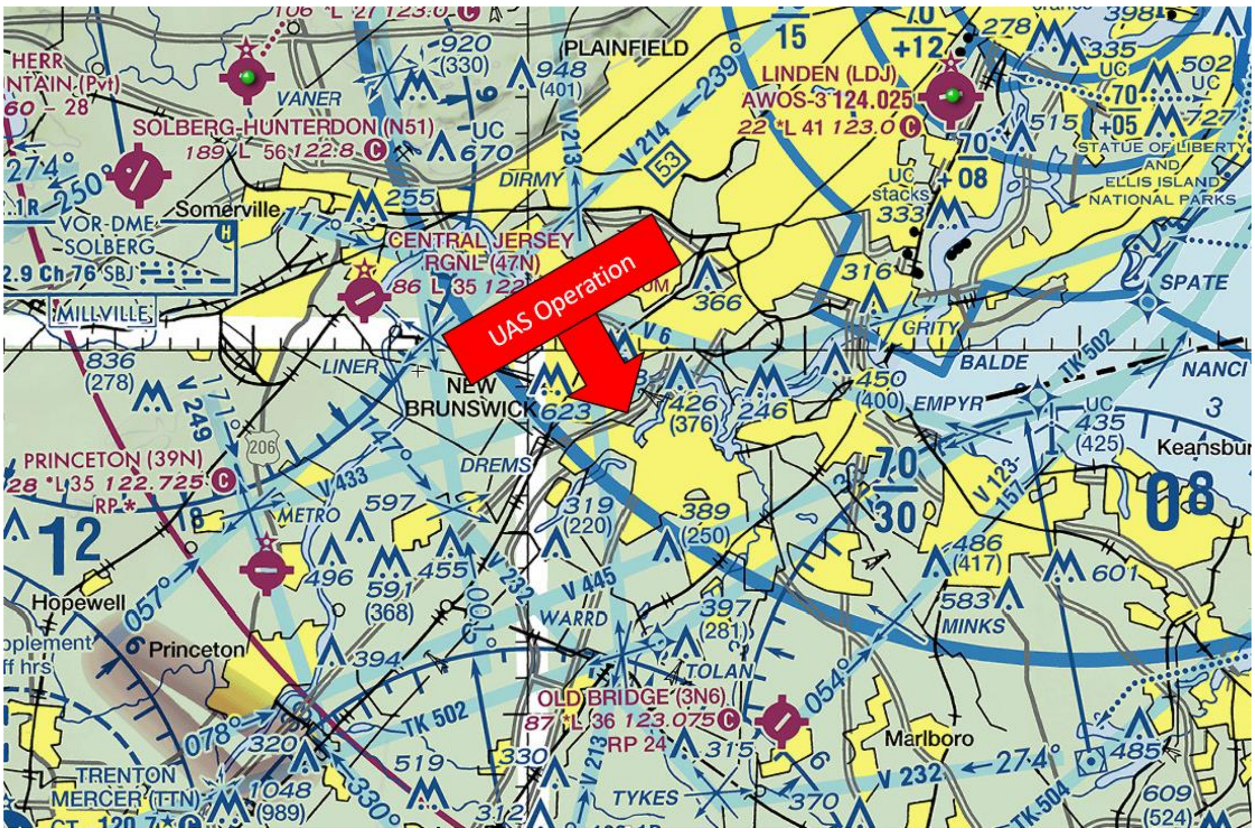

Figure 4: Proposed UAS Operational Location

Additionally, this location is directly adjacent to a Rutgers University own field from which the UAS operations could take place. This location would give the UAS pilot and air crew a location to perform launch and landing activities a safe distance away from the roadway.

From reviewing the Google Street and Aerial views of this location, the researchers were able to identify several infrastructure assets to collect photographic data from. These assets include:

- (3) Stop Signs
- (2) Yield Signs
- (2) Do Not Enter Signs
- (1) One Way Sign
- (2) Roadway Directional Signs
- (1) U-Turn Sign
- Roadway Striping
- Roadway Markings (Stop Bars, Yield Bars, Left Turn)
- Guide Rail
- Barrier Island

Figure 5: Street View of Interchange (Google Earth)

3.7 Pix4D Modeling Software

For this project, we used the Pix4DMapper as our modeling software to develop the 3-dimentional model of the interchange. Pix4D is a modeling software that relies on multi-ray photogrammetry data to produce 3-dimensional models. The software develops these models through photographs taken via UAS (or other camera sources), and uses the overlap of the images and with the respective location the image was taken to produce a 3-dimensional model of the image. From these multiple overlapping images, Pix4D can calculate the relative distances between objects in three dimensions.

The level of accuracy for models developed with Pix4D are influenced by a Ground Sampling Distance (GSD) equation. The GSD is the distance between two consecutive pixel centers measured from the ground. Larger values of GSD result in lower spatial resolution, and a less accurate model with less available detail. Lower GSD values result in greater spatial resolution and more detailed model [4]. For Pix4D, Ground Sampling Distance is a function of:

- Altitude(meters)
- Camera Focal Length (mm)
- Pixel Size (microns)

The formula to estimate GSD for a Pix4D project from a given UAS image capture flight is as follows:

$$Altitude = GSD \times \frac{Focal\ Length}{Pixel\ Size} \times 10$$

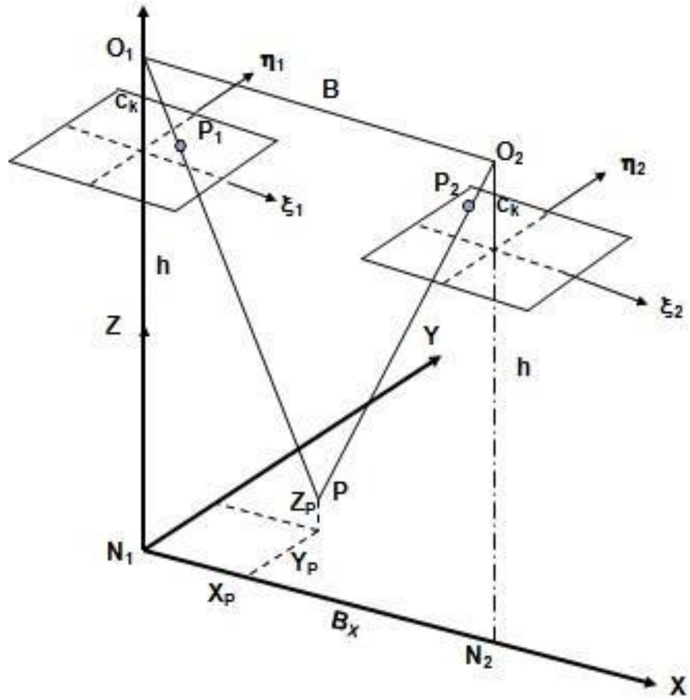

Figure 6: Principle of Photogrammetry (Pix4D Presentation)

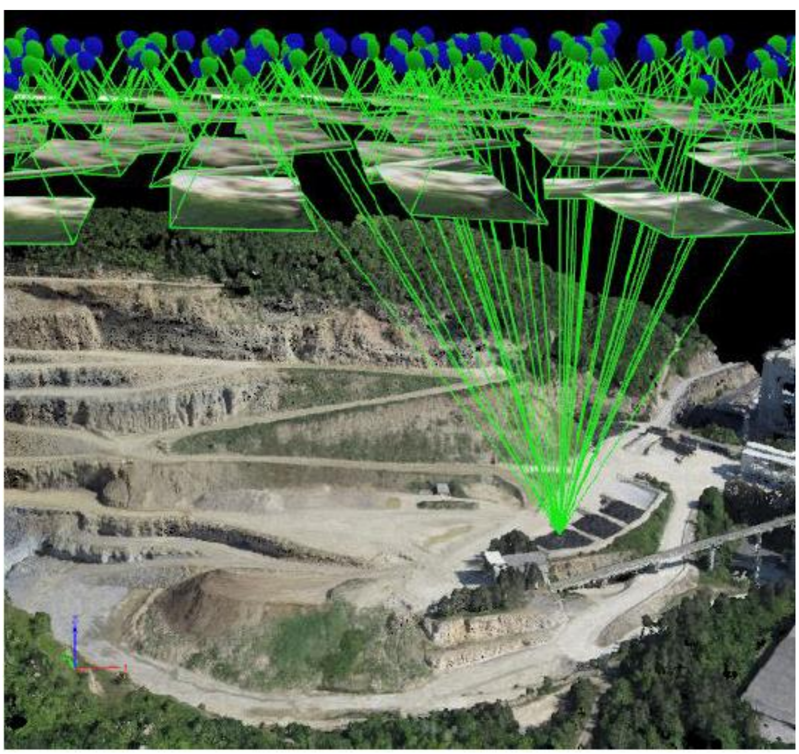

Figure 7: Pix4D Aerial Photo Overlap (Pix4D Presentation)

In addition to GSD, the amount of overlap between photos will have an effect on the level of detail and noise within a model. For general cases of mapping a location, Pix4D recommends using either a grid pattern or double grid pattern. Pix4D recommends at least 75% frontal overlap with the photos and 60% side overlap for the single grid flight pattern. They also recommend to extend at least one flight line beyond the area you are interested in mapping. For double grid patterns, it is recommended to achieve 85% front overlap and 70% side overlap. A third type of flight plan, a circular pattern, can be used for building reconstruction and object modeling. With this flight pattern, the camera will be angled down while the UAS will flies around the building or object. In the case of tall buildings and structures, it is recommended to perform this flight pattern at multiple heights and angles. Additionally, the model collects data of the overlapping points by taking pictures every 5 to 10 degrees throughout its flight plan. [5]

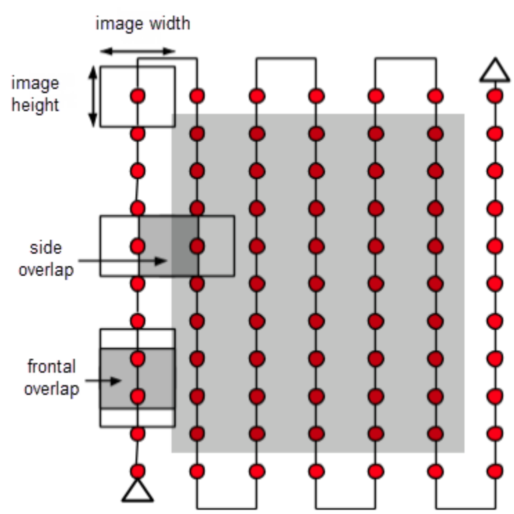

Figure 8: Single Grid Flight Plan [5]

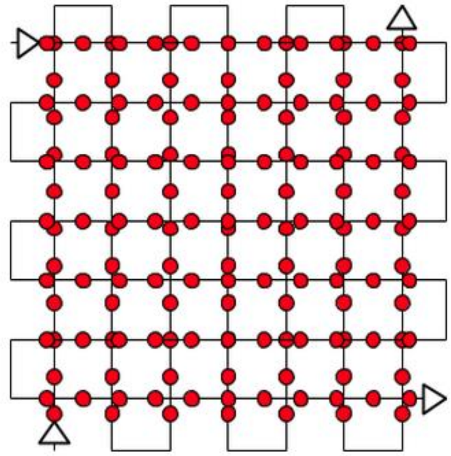

Figure 9: Double Grid Flight Plan [5]

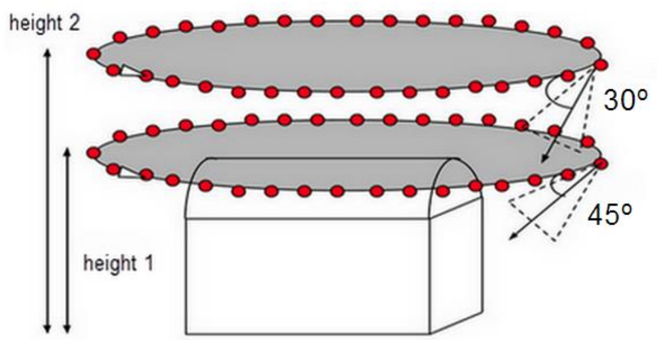

Figure 10: Circular Flight Plan [5]

3.8 Flight Planning

Prior to performing flight operations, a flight plan was developed to detail the concept of operations prior to the flight, establish emergency procedures, identify roles, and assess operational risk. Launch and landing operations would be held adjacent to the field on the northern section of the interchange. In addition to the launch and landing site, three areas were identified as potential emergency landing locations should there be a need to land the aircraft immediately. Flight altitudes would vary depending on the objects identified, however a maximum altitude threshold of 250 feet was set as a precaution. The UAS would fly within the operational area to collect imagery of the various assets within the interchange. Additionally, to remain compliant with FAA Regulation § 107.39 "Operation over human beings," the pilot and visual observer would ensure that there was no active traffic along the roadway prior to any UAS crossings.

Figure 11: Operational Area & Emergency Landing Locations

When reviewing the site, the team identified several objects that may pose a hazard to flight operations. Potential hazards to flight operations included:

- Powerlines
- Trees
- Potential RF interference from high tension towers

The Remote-Pilot-in-Command (RPIC) determined that this area would still be safe to perform flight operations, so long as precautionary measure were taken place to minimize the risk from these hazards. The RPIC would make sure to maintain an altitude well above the trees and powerlines when in their vicinity, so as to avoid an in-air collision. Additionally, should radio interference occur as a result of the nearby high tension towers, flight operations would be cancelled for this location and a new location will be identified.

During the flight planning phase, the team assessed the flight pattern options to develop the 3-dimensional model of the interchange. Ideally, to develop a 3-dimensional model with the highest level of detain, a double or single grid pattern would have been used to collect the most overlapping images. However, this method would require a longer flight time, consisting of multiple crossings of the roadway. Performing a large amount of roadway crossings along the active roadway could result in additional traffic control devices needed to prevent the UAS from flying over a motor vehicle. In an effort to reduce the amount of times the UAS would fly over the roadway, the team decided to perform a circular flight pattern traditionally used for object modeling. This flight plan would all the team to collect overlapping images of the intersection, while limiting the amount of times the UAS would fly over the road. Additionally, a minimum height of 210 feet was determined in an effort to reduce potential distraction to drivers on the adjacent roadway. Based on the GSD calculations provided by Pix4D, and the focal length and pixel size of the Phantom 4's FC330_3.6 camera, our estimated GSD becomes:

$$210 = GSD \times \frac{3.61}{1.57937} \times 10$$

$$GSD = \frac{1}{210} \times \frac{1.57937}{3.61} \times \frac{1}{10} = 2.8$$

Our GSD of 2.8cm represents that one pixel of the image represents linearly 2.8cm on the ground.

3.9 Flight Operations

On the day of the flight, the flight team confirmed that aviation weather conditions were suitable for a safe and compliant flight. As per part (c) and (d) of the FAA's 14 CFR Part §107.51 "Operating limitations for small unmanned aircraft," no less than 3 statute miles of visibility is required for UAS operations, and the UAS must remain 500 feet below clouds. To verify that the weather conditions met this standard, the team used https://www.aviationweather.gov to observe the visibility and cloud ceiling, and confirm they met the FAA regulations to conduct a UAS flight. In addition to weather concerns, the team checked for any Temporary Flight Restrictions (TFRs) or Notices to Airmen (NOTAMs) from https://tfr.faa.gov, which would have restricted flight operations in the area.

For the first flight operation, the UAS was launched from the launch and landing zone, and was manually flown to an operating altitude of 20'. From there, the UAS was flow to the various infrastructure assets to collect photographic images. Altitude was adjusted to collect images of the assets from various heights, with a maximum altitude of 150'. Images collected of the signage, striping, roadway markings, and guide rails were given a preliminary review to visually identify defects.

The second operation would be to collect photogrammetry data to produce the 3-dimensional model using Pix4D. To develop this flight pattern, the team would use the Pix4D Capture software. Pix4D capture allows the pilot to map out a designated altitude and flight pattern prior to launch of the UAS. The UAS will then follow this pre-planned flight pattern autonomously, and collect images at designated intervals. As identified in the flight planning phase, the Pilot in Command plotted a circular pattern around the interchange to collect data on the assets. This pattern was chosen to reduce the amount of times the UAS would cross over the roadway, so as to minimize the possibility of the UAS flying over a nonparticipant in a moving vehicle. The following parameters were used for this flight:

- Altitude: 210 feet
- Camera Angle: 74°
- Capture Angle: 10°
- Flight Time: 1 minute 54 seconds
- Path Length: 580ft
- Total Images: 34

The photogrammetry data and asset imagery photos were stored on the UAS via an on-board micro SD card. The photos were transferred to a computer running Pix4D software so that the photogrammetry images could be processed into a 3-dimensional model. The asset photos were also transferred for a closer review.

Figure 12: Circular Flight Pattern for 3-Dimentional Model Data

4 FINDINGS

4.1 Aerial Imagery

The images of the interchange assets were given an initial review to visually identify defects. From the aerial imagery, it was possible to identify multiple cracks in the pavement as shown in Figure 13 and Figure 14.

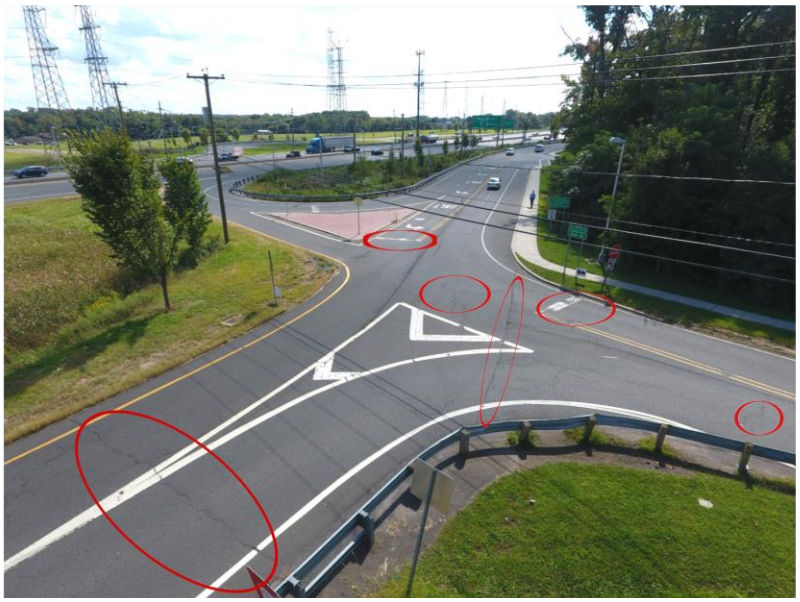

Figure 13: Asphalt Cracking

Figure 14: Asphalt Cracking Cont.

Further degradation of both line striping, asphalt markings, and stop bar could be observed from the Southwest approach to the interchange. Imagery of signage was also collected and review, revealing cracking on the face of the Wrong Way signage on the northeast side. Photos of the guiderail adjacent to the Route 1 exit ramp and College Farm Road revealed a missing connection between the guiderail and wooden post.

Figure 15: Marking Degradation

Figure 16: Signage Defects

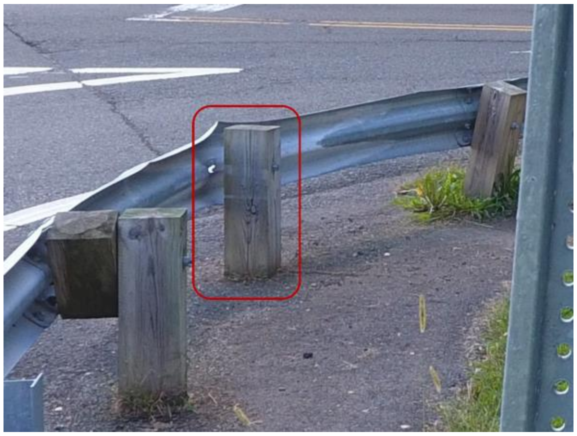

Figure 17: Guiderail Missing Connection

4.2 Pix4D Model

The 34 aerial images of the interchange collected via UAS flight were uploaded and processed through Pix4D modeling software. The processed images were used as input to generate a Ray Cloud comprised of automatically generated Tie Points. The tie points were generated via the software by identifying and overlapping similar objects and features from multiple source photos. Based on the output report, the calculated Average Ground Sampling Distance (GSD) for this project was about 3.03cm

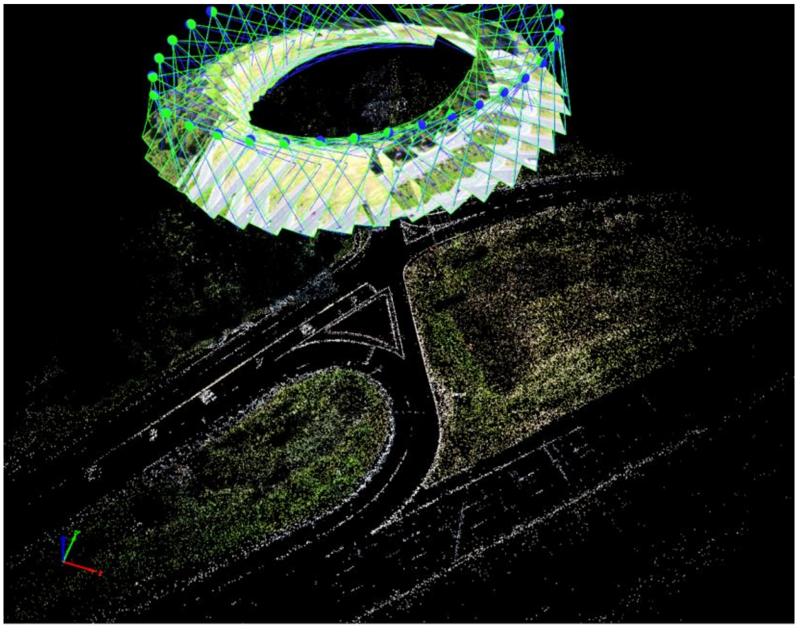

Figure 18: Ray Cloud Produced from Overlapping Photos

Figure 19: Rendering of Interchange

The team observed that the Pix4D model was able to capture several features of the interchange including the striping, pavement markings, stop bars, and some asphalt cracking. However, closer inspection revealed that the model was unable to reproduce the signage assets. This could be a result of the signage being too narrow in dimensions for the software to reliably replicate it via photogrammetry data. In addition to the missing signage, a closer view of the roadway shows “noise” in the data, as the asphalt is not shown to be flat and smooth in the model. Discussions with a Pix4D representative revealed that at this time, Pix4D still has issues reliably modeling dark, homogeneous textures. Additionally, as the roadway was active at the time, “ghosted” images of vehicles along the roadway can be seen in the model.

Figure 20: Missing Signage and Noise

5 CONCLUSIONS

This preliminary study into utilizing unmanned aircraft systems for asset management applications provided some useful insight into how a UAS could be incorporated as a tool for asset management applications. The study showed that the UAS was able to collect useful data regarding the various assets within the interchange including the signage, striping, pavement markings, guide rails, and asphalt conditions. Defects in several of the assets could be identified via the mounted camera on board the UAS. Additionally, this study showed that a 3-dimensional model could be developed via photogrammetry data, using a one-pass circular flight plan. While the researchers were able to develop a model of the interchange using Pix4D software, the software was unable to reproduce signage, and moderate "noise" was observed in the asphalt.

6 RECOMMENDATIONS

There does appear to be potential to incorporate unmanned aircraft systems into asset management applications. Further research could be conducted into driver distraction on the adjacent roadways to determine what effect, if any, do roadside UAS operations have on driver reaction. Additionally, further research into optimal altitudes and flight patterns should conducted to enhance data collection and potentially develop a more accurate model.

REFERENCES

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