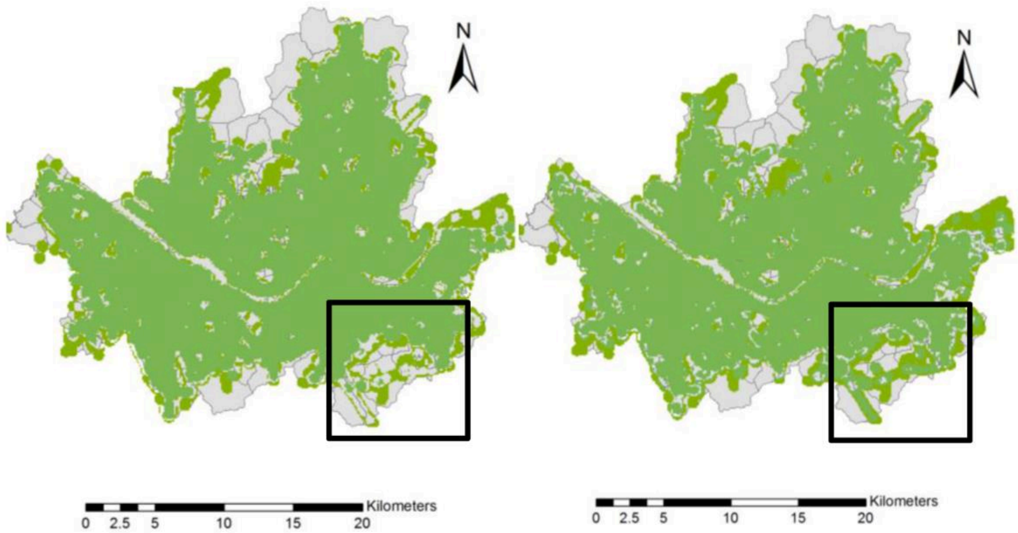
For dynamic service area analysis, over 5,000 taxis operating in Seoul area was used to create dynamic service area of taxis. Due to large number of operating taxis, most of the Seoul area was fully covered as ‘serviceable area’ within 10 minutes threshold with exception of Gangnam area where traffic flow is generally higher than rest of Seoul.



(a) (b)

Figure 6. Dynamic Service Area Map for Taxis (a) 08:00~08:30; (b) 08:30~09:00

By implementing the suggested method of data-driven service area analysis and dynamic service area analysis, new insights and implementation towards both public and private sectors could be achieved. In terms of publics sectors, public facilities such as fire stations and emergency medical centers can re-calculate their service area at different time of day, resulting in more accurate service area analysis. Dynamic service area analysis could be implemented to police vehicles which patrols around the designated area to ensure safety of the public. By using the suggested method, each patrol car can recognize their own ‘moving service area’ and use the visualization tools to optimize the patrol routes with other patrol cars. This could lead to global optimization where less patrol cars are required to achieve high security level for public. For the private sectors, autonomous vehicles can implement dynamic service area analysis to recognize its ‘cover area’. Rising autonomous car-sharing market could use this technique to guide and control the routes of vacant vehicles, ensuring high coverage of designated area to improve serviceability.

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UAS-Based Airport Maintenance Inspections: Lessons Learned from Pilot Study Implementation

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ABSTRACT

Unmanned aircraft systems (UAS) can be used to collect visual assets such as 2D geo-referenced and infrared images. These 2D images can be converted into 3D point clouds through the UAS photogrammetry process. Such point clouds can then be utilized to detect obstructions around airports. This research describes the process of data collection, using UAS at airports to analyze point cloud data and document the potential implications of UAS-based airport inspections. Two field tests were conducted and three different UAS platforms were deployed. The Point Cloud Library (PCL) was employed to detect and measure trees around runways. The main contribution of this study is the provision of an overview of how UAS and visual assets can be used for airport inspections, in order to improve work efficiency and reduce human error.

INTRODUCTION

Airports require periodic maintenance to ensure the safe operation of air traffic during takeoff, landing, and taxi procedures, as well as of adequate condition of related facilities during airport operations. State aviation agencies and Departments of Transportation (DOTs) are entrusted with managing the airport inspection process. Inspectors usually drive to an airport facility or runway to inspect the situation, assessing aspects such as general pavement conditions, obstructions to approach paths, and design issues (i.e., markings and signs) around the runway (Irizarry et al. 2017; Temme and Trempler 2017). Visual inspection also involves manual equipment such as rangefinders, inclinometers, and measuring wheels employed to assess a runway’s design components, the heights of nearby trees, and approach angles (Irizarry et al. 2017). However, this method is limited to inspectors’ direct view of what can be seen at ground level and requires a significant number of manhours.

Unmanned aircraft systems (UAS) can provide a different and more effective view for visual inspection and data-driven decision-making for inspection programs, as well as facilitate significant cost and time savings (Gillins et al. 2016; Irizarry and Bastos-Costa 2016; Kim et al. 2016a). A UAS-based topography will reduce the workhours required to inspect airports and increase the accuracy of the necessary measurements (Irizarry et al. 2017). According to Irizarry (2017), UAS can be integrated into the airport inspection procedure to review and assess runway pavement conditions and obstructions around airports. In addition, UAS photogrammetry can generate a 3D model based on the 2D images collected around points of interest (Kim et al. 2016b; Rodriguez-Gonzalvez et al. 2014). In this sense, the goal of this study is to demonstrate the lessons learned from two field tests at active airport facilities, including the Federal Aviation Administration (FAA) regulations for safe operation at airports. An overview of the visual data collection and analysis process is also provided. It is expected that the lessons learned from this pilot study will provide a better understanding of how different types of visual assets can be used for infrastructure maintenance programs, particularly airport runway inspections and obstruction evaluations.

AIRPORT MAINTENANCE AND INSPECTION

Airport maintenance primarily consists of runway inspections and investigations of nearby obstructions. Runway inspection involves verifying the adequacy of runway markings and signs, determining the heights of nearby trees (i.e., the tree line), and confirming the condition of runway pavement (Irizarry et al. 2017). Currently, runway pavement inspections require maintenance personnel to drive along the runway several times a day to search for loose objects, debris, cracks, roughness, and general surface damage (Absolon et al. 2015; Temme and Trempler 2017). The International Civil Aviation Organization (ICAO) provides standards and procedures for preventive maintenance, particularly of paved areas. Maintenance procedures involve eliminating any loose objects and debris that might cause damage to aircraft, as well as performing friction tests (International Civil Aviation Organization 2013). Because a runway's surface deteriorates over time due to traffic and weather, inspections must be carried out on a regular basis. While visual inspections must occur at least four times a day, runway friction levels are usually tested more often during adverse weather conditions (i.e., slippery and icy conditions) than in dry seasons (Temme and Trempler 2017).

Successful UAS applications in a variety of construction and built environments, such as progress checks (Lin et al. 2015), safety inspections (Irizarry et al. 2012; de Melo et al. 2017), and surveying (Siebert and Teizer 2014), suggest that airport runaway inspections could also benefit from adopting UAS technology. However, very few attempts have been made to use UAS in this fashion. To assess its usefulness, UAS-based runway inspections could be carried out and the collected data compared to existing reference data, such as previous pictures of runways (Temme and Trempler 2017). A few DOTs (e.g., the Georgia DOT, or GDOT) across the United States have begun to explore UAS for airport maintenance and inspection (Irizarry et al. 2017).

The aviation department of GDOT's intermodal division, for instance, is responsible for inspecting airport runway pavement conditions, assessing the general conditions around the airport and its runways, and monitoring the construction progress of airport facilities. Inspectors and managers in GDOT's aviation department regularly drive on airport runways and taxiways to perform visual inspections. This task often requires the use of special equipment such as rangefinders, inclinometers, and measuring wheels. The time required to inspect a runway depends on the size of the airport. GDOT's aviation department frequently hires external inspectors to assist internal personnel in runway pavement inspections. All data collected is processed and reported to the airport manager, who compares it to the data from the previous inspection, and requests corrective measures as needed.

FAA PART 107 UAS REGULATION

In the United States, the FAA provides regulations for using UASs in commercial applications. These regulations are found in the Code of Federal Regulations, Title 14, Part 107 – Small Unmanned Aircraft Systems. To fly under the FAA's UAS rule within the U.S. National Airspace System (NAS), an operator must earn a Remote Pilot Certificate from the FAA, register the UAS as a "non-modeler," and follow all Part 107 rules, including obtaining prior approval of the operation or a Section 333 Exemption. Companies using in-house personnel to operate UASs require a Section 333 Exemption granted by the FAA (Federal Aviation Administration 2016; Tatum and Liu 2017). In addition to observing Part 107 rules, an operator must also comply with state UAS regulations. In general, regulations concerning UAS flights at or around airports are more restrictive and prohibit the use of UASs within a certain distance of critical airport facilities, if prior permission has not been obtained. A summary of PART 107 is described below (Federal Aviation Administration 2016):

- An aircraft must be operated at an altitude of no more than 400 feet above ground level;
- The weight of the aircraft must be less than 55 pounds, including all payloads;
- The aircraft may not be operated at a speed exceeding 87 knots (100 miles per hour);
- If the aircraft loses communications or the GPS signal, it must return to a predetermined location within the private or controlled-access property;
- The pilot in command (PIC) must abort the flight in the event of unpredicted obstacles or emergencies;
- The aircraft should not fly directly over people;
- UAS operators may coordinate with the airport administration and obtain permission to fly if the airport facilities are located within five miles of the UAS flight area; and
- UAS operations require visual observer(s) to keep track of the aircraft during flight (i.e., it must stay within visual line-of-sight) to avoid unforeseen circumstances and accidents. Some of these rules are subject to waiver.

RESEARCH METHODOLOGY

This study consists of three main steps to demonstrate a field test-based method: 1) 2D image collection using UAS at an airport; 2) UAS photogrammetry to generate a 3D point-cloud model based on the 2D images; and 3) PCL-based measurement and analysis. To collect the 2D images, two field tests in Georgia were conducted in 2017 as a part of two different and active airport maintenance projects. Figure 1 shows the overall method of this study. A detailed field-testing protocol was developed to collect the data during the field tests.

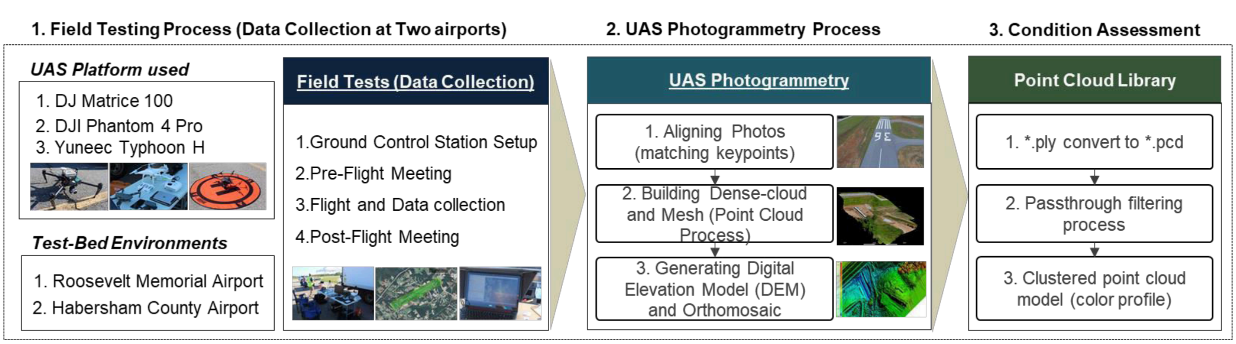


Figure 1. Overall Process of the Study

Three off-the-shelf UAS platforms (i.e., a DJI Matrice 100, Yuneec Typhoon H, and Phantom 4 Professional) were deployed to collect 2D and infrared images. During the first field test at the Roosevelt Memorial Airport in Georgia, the DJI Matrice 100 and Yuneec Typhoon H were deployed, and 143 2D images and 29 infrared images were collected. At the second test, which was conducted at the Habersham County Airport in Georgia, the DJI Phantom 4 Professional collected a total of 101 geo-referenced images, while 29 infrared images were collected by the Yuneec Typhoon H. Table 1 shows the results of the collection of visual assets for the field tests. These platforms are capable of flying over the point of interest for up to 25 ~ 30 minutes, capturing images based on 12.4 effective megapixel sensors and recording 4K videos during flight. During the field tests, a ground control station (GCS) was established to control and command all of the UAS operations. During the pre-flight meeting, a PIC and other related personnel, including the DOT and airport coordinators, discussed the development of the flight mission to capture the 2D images. The collected geo-referenced images were processed to generate point cloud data through photogrammetry. The point cloud data were then exported as Stanford PLY data (*.ply) and converted into PCL data (*.pcd). The PCL is capable of identifying potential obstacles around the runway by using a passthrough filter.

Table 1. Result of Field Testing

Field Test		Used Platform	Collected Data	Amount of Data
1	Roosevelt Memorial Airport	DJI Matrice 100	2D geo-referenced images	143 photos
		Yuneec Typhoon H	Infrared images	29 photos
2	Habersham County Airport	DJI Phantom 4 Pro	2D geo-referenced images	101 photos
		Yuneec Typhoon H	Infrared images	29 photos

DATA ANALYSIS AND FINDINGS

After the field tests, the 2D still images were organized to observe and assess the general conditions of the pavement and markings (see Figure 2). This process could also be used to identify possible obstructions on the runway and around the airport, but without any dimensional information because still images cannot provide measurements of depicted components. This study explored the potential uses of UAS for the airport inspection process. This section describes how the 2D images collected can be converted to raw point clouds through the photogrammetry process, as well as how such point cloud data can be processed to measure potential obstructions around runways. In this study, Agisoft PhotoScan and the PCL were utilized to process the point cloud data. PhotoScan, like photogrammetry software, can provide simple steps for users to follow to generate point clouds (Agisoft 2016). The PCL is a standalone, large-scale, open-source code for 2D and 3D images and point-cloud processing, available for free for commercial and research use (Rusu and Cousins 2011).

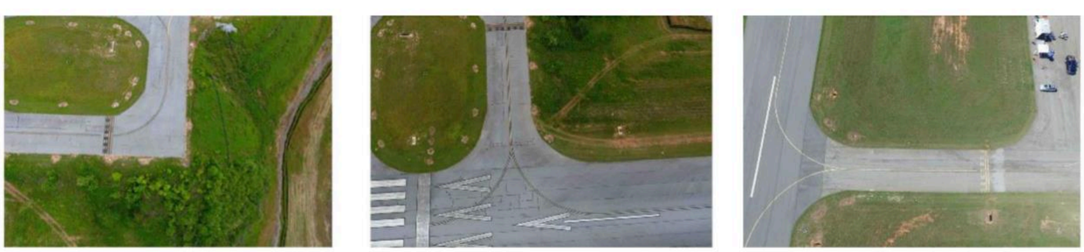
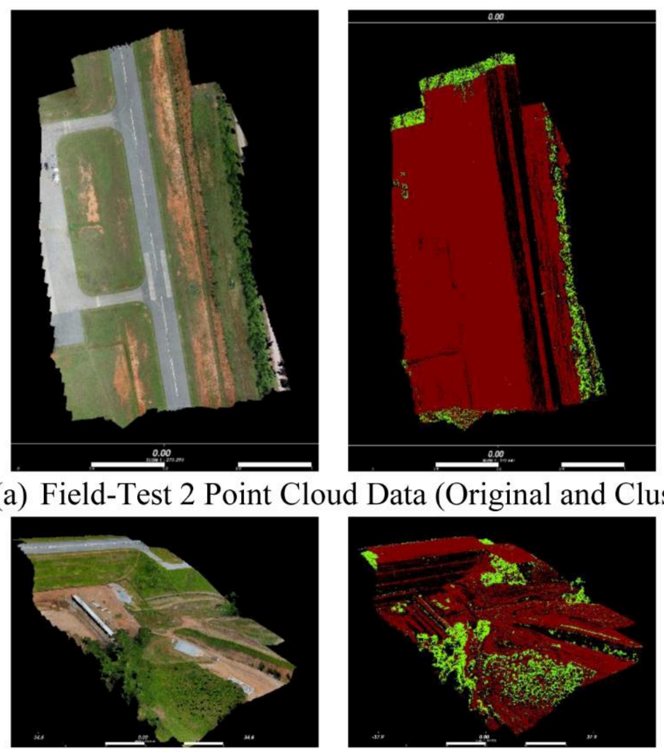


Figure 2. 2D Still Images of the Airport: Overview of Condition

The collected 2D images were aligned to compute the camera positions and find match points in each photo. The image alignment process generated a total of 60,252 tie points and 76,317 points on each image set. The aligned photos allowed for the building and visualization of dense point clouds, and the construction of a mesh model texture; the result was a 3D mesh model produced by the software. Two raw point cloud datasets from the two field tests were exported to Standard PLY files (*.ply). Those files were then converted into a *.pcd file, which was utilized in the PCL environment. Since this study did not focus on real-time applications, the quality of performance was more important than the computing process time. Therefore, it was not necessary to conduct a voxel filtering procedure to reduce the number of points (i.e., down-sampling) in the dataset. In addition, this study did not remove statistical outliers from the dataset, since the photogrammetry software already engaged in outlier removal. The dataset of a point cloud typically includes coordinates (x, y, and z-coordinates), RGB, and normal values for each point. Based on the normal values given, a model can represent a surface model and a measure of the curvature obtained between the eigenvalues of a surface patch. Among the normal vectors, normal z-values closer to 1 represent the ground, while those closer to 0 indicate vertical columns on the ground. Based on this thresholding, in the current research the trees, as obstructions surrounding the airport, could be segmented and detected. Figure 3 depicts a comparison of the original and post-processed (i.e., segmented and clustered) point clouds produced by the passthrough filtering process. Extracted points showed color profiles; for example, green represented potential elevated obstructions (e.g., trees or plants) that might hinder the safety of airplane operations. Red points indicated the ground.



(a) Field-Test 2 Point Cloud Data (Original and Clusted)

(b) Field-Test 2 3D Point Cloud Data (Original and Clusted)

Figure 3. Raw Point Cloud (left) and Potential Obstructions Filtered (right)

Based on the x, y, and z-coordinates of the trees, the information about the mean values of the tree heights and the trees' locations could be identified in the model. In the first field test, the z-coordinate value among the points representing the trees was computed as 214.88; in contrast, the z-coordinate value of the ground was 202.15. By abstracting these values, the height of the tallest tree near the airport was calculated at approximately 12.73 meters. Based on the results of a manual inspection conducted in 2016, the height of the trees at the end of the runway was documented at 15.5 meters. This information was then incorporated into the airport maintenance manual to document the report. Along with detecting existing obstructions surrounding the airport and cracks and holes in the runways, another advantage of post-processing using the PCL is the ability to measure meaningful distances, numbers, and locations. This provides more accurate data beyond existing manual measurement tools, because it reduces human error.

This study documents how infrared images can be utilized to assess the conditions of runway markings such as the centerline and threshold, as well as the operational conditions of the lights and beacons surrounding runways (as shown in Figure 4). This process facilitates the comparison of still and infrared images by inspectors. Different colors in the infrared images indicate the degree of temperature, which helps in assessing the condition of the design components in the picture. Green and blue colors indicate lower temperatures than do yellow and red. The threshold and centerline on a runway are comprised of white painted lines that reflect UV energy. The difference in color between the gross areas and beacons indicate if they are operating normally, because the temperature of the light (appearing green) is higher than in the gross areas (which appear blue). Thus, infrared images provide a broad overview of the design component conditions that can be used by airport inspectors.

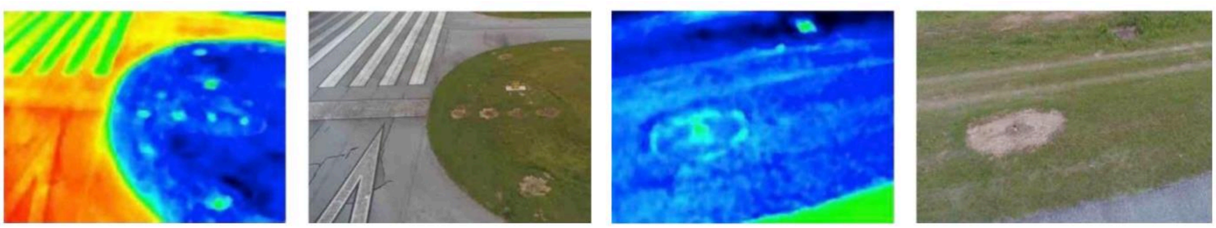


Figure 4. Infrared Image-based Assessment (Runway Components and Lights/Beacons)

CONCLUSION

This study documented the potential of implementing UAS-integrated airport inspections, and the implications of employing visual assets such as still images, point cloud models, and infrared photography. In 2017, two field tests were conducted at different airports in Georgia. Three different UAS platforms were used to collect the 2D and infrared images at the test-bed environments. After the field tests, 3D point cloud models were built via a UAS photogrammetry process. This post-processing generated a standard PLY format (*.ply) point cloud model, which was converted into the point cloud data format (*.pcd) compatible with the PCL. As a result of the data analysis, the following implications were documented. 1) UAS-based 2D still images can provide an overview of the logistics information of airports and runways. 2) UAS-based point cloud data can provide detailed information regarding obstructions around runways (e.g., trees and berm). 3) The detection and measurement of cracks on a runway require a greater number of point clouds, which in turn demand more geo-referenced images and a closer view in the pictures (i.e., the UAS should fly at a lower level. 4) Infrared images can provide the current condition of airport light and beacon operations, as well as runway threshold conditions. This pilot study contributes to a better understanding of how UAS and the visual assets they produce can be used in the airport inspection process. Further studies should evaluate the performance of UAS-based inspections by comparing the results with those of the manual inspection method. In addition, PCL-based crack and obstruction detection and conditions assessments should be conducted and analyzed to determine any further implications and the final outcomes of this study.

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