Effective Non-invasive Runway Monitoring System Development Using Dual Sensor Devices

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Abstract. At airports, the runways are always troubled by the presence of ice, water, cracks, foreign objects, etc. To avoid such problems the runway is supposed to be monitored regularly. To monitor the runways a large number of techniques are available such as runway inspection mobile vans. These techniques are largely human dependent and need interruptions in the runway's operations for inspection. In this position paper, we suggest an alternative way to monitor the runway. This method is non-invasive in nature with the involvement of Light Detection and Ranging (LIDAR) sensors. In the methodology, we describe the schemes of labelling the data obtained from LIDAR using MARWIS sensors fitted in a mobile van. We describe the entire system and the underlying technology involved in developing the system. The proposed system has the potential of developing an efficient runway monitoring system because the LIDAR technology has proved its efficiency in several terrestrial mapping and monitoring systems.

Keywords: Runway monitoring · LIDAR · Machine learning

1 Introduction

Runways, taxiways, and aprons are some essential entities on all airports, and they need to be maintained well for the safety of the carriers and the passengers. On all airports, foreign objects, ice or water films, and structural defects (e.g., cracks) are the factors that impose a potential threat to the carriers. Due to such types of threats, the runways, taxiways, and the aprons are to be monitored regularly. Generally, the foreign objects found over taxiways and runways [24] can lead to accidents like that of Air France Flight 4590 on 25^{th} July 2000, where due to the foreign object debris (FOD) an airplane crashed into a hotel killing 113 persons [3]. Amongst the foreign objects found at Airports 60% are metallic and 18% are of rubber materials, respectively [9]. Besides this, the aviation industry

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has lost around 3.5 B€ just because of the problem caused by foreign objects [6]. Some radar-based systems can be used to detect foreign objects on the runways using millimeter-wave imaging [5,13,23]. These methods are non-invasive but interfere with current installations of the airport and therefore require special permission. Besides interference, the system is expensive and requires special training for installation and maintenance, and may not be suitable for mid-sized or small airports. Another non-invasive foreign object detection system uses the technology from the visual domain, where the videos and images were taken at different time intervals for foreign object detection [2,17]. Another method used Convolutional Neural Networks to build an automated system for region-based object detection using data obtained from the cameras mounted on a runway scanning vehicle [1].

Structural integrity is the other issue at airports that also leads to problems, including accidents because any flaw on the taxiway or runway impacts the aircraft's taxiing and landing (or take-off) [14]. An interesting work used robot mounted Ground Penetrating Radar and camera to detect cracks on the runway [7]. For non-invasive structural flaw detection on runways, a large number of methods were developed to identify cracks on the track using computer vision [15,19]. Ice and thin film of water are other problems that lead to the critical situation at airports especially during landing and take-off of the aircraft. Several sensor-based techniques exist that can be used to detect ice formation on the runways using microwaves [4] and capacitance [21] measurement of the surface.

The existing runway monitoring for the aforementioned problems is mostly invasive, therefore requires a lot of time to scan the tracks and eventually interrupts the operations at the airport. Ice formation, waterlogging and structural deformations are persistent problems and one scan a day is sufficient. However, the foreign objects require regular monitoring of the runway, and invasive methods cannot be used for this purpose. In this paper, we are suggesting a system that can monitor the entire runway in a non-invasive manner. The proposed system exploits the LIDAR technology to perform the real-time scanning of the runway. We describe several technologies that will be used to develop the proposed system. While describing these technologies we also justify: how the system can detect all the three types of anomalies found at the airports; how monitoring is possible in real-time; and how anomalies can be geo-referenced to determine their locations. The article is organized as follows. Section 2 describes some existing systems that are used to monitor the runways. Section 3 details the technologies necessary to build the proposed system. In Sect. 4 we describe the entire system for non-invasive runway monitoring along with the development information. We end this article in Sect. 5 with conclusions and directions to system development.

2 Related Runway Monitoring Systems

In this section, we provide information about some existing systems that are suitable for structural deformations on the runway, or identification of foreign objects, or water thickness on the tracks.

2.1 Monitoring Systems for Structural Deformations

The structural deformations are found everywhere at airports, but they become a security risk when encountered by airplanes, especially, on runways.

1 **RIS Hi-PAV**:
It is a road and runway assessment system that uses ground penetrating radar (GPR) to perform the survey of several road conditions (such as detecting cavities, and cracks) [8]. RIS Hi-PAV can scan the entire runways at a high speed (e.g. 260 Km/hr) using a single antenna. This system can be used to verify and test new roads. This system comes with a semi-automatic road sub-surface detection software (GRED 3D) that makes it easy to use and take little survey and processing time. This system is non-invasive but needs to use a mobile van to scan the entire runway and therefore interrupts the operations at the airports.

2 **Roadscanners**
The Roadscanner is a non-invasive system that comes with an entire package of runway monitoring, mapping, diagnostic, and inspection [18]. The Roadscanner runway system has three components: first, the Road Doctor Survey Van mounted with technologies (e.g., GPR and LIDAR) to scan the path on the airport wherever the Van goes; second, the Road Doctor Software that processes the data obtained from the Van; third, the team of expert consultants that interprets the processed data. This system is suitable for surface monitoring, sub-surface monitoring, quality control, maintenance optimization, and underground mapping. Though the system is very advanced, it does not perform the real-time monitoring of the entire runway and needs human supervision to carry out anomaly detection such as structural deformations.

2.2 Monitoring System for Foreign Objects

As described in the introduction, the foreign objects are very critical, especially when they are found on the runways of airports. In this section, we describe systems that are well-reputed in detecting FODs on runways.

1 **iFerret^{TM}**
iFerret^{TM} is an intelligent vision-based runway foreign object detection system. It is capable of real-time, automated foreign object detection, identification, and pin-point foreign object's location; recording, and post-event analysis; full visual assessment from ATC/Ground Ops Control [10]. With the software and Electro-Optic Sensors, iFerret automatically detects, locates, classifies, and records foreign objects at commercial airports and military airbases. The system uses color (i.e., green, yellow, and red) coding to classify the type of foreign object and its associated threat (i.e., no, medium, and high threat, respectively). The system is very effective, but it's difficult to train this system to identify the same object as foreign objects at a different light intensity. The system also has problems identifying small foreign objects having the same color as the floor.

2 **Tarsier**
The Tarsier system is an automatic runway FOD detection system, which uses millimeter-wave (MMW) radars to scan the runway surfaces continuously [20]. The radar performance is not affected by dust or heatwaves and pinpoints debris location in a precise range and bearing. Being non-invasive, this system provides foreign object detection also in low light conditions like shadow, darkness, rain, and fog. The system is capable of detecting foreign objects such as metal, plastic, rubber, glass, and organic matter. The status information is relayed to airport operators through a graphical display. Live video feeds from powerful MIL-SPEC day and night camera systems are automatically cued to allow object verification before someone is sent to remove debris. A high-resolution night camera combined with a near infra-red illumination tuned to the lens system far exceeds any competing night vision system. An event log records the data for historical analysis.

3 Background

3.1 LIDAR Technology for Terrestrial Scanning

The Light Detection and Ranging (LIDAR)is a methodology where a distance (range) of an object is calculated by projecting a laser beam on the object and sensing its reflection on a sensor. The variation in the time of reflected beam and changes in its wavelengths are used to build a 3-D image of the target object. Mostly, the range is determined using two techniques; first, using the phase of the beam; second, using the pulse of the beam. In this article, we focus on the ground-based terrestrial sensors and describe them with respect to the proposal. The importance of LIDAR for this proposal is based upon its non-invasive nature of scanning terrestrial surfaces. There are LIDAR systems that can achieve an accuracy of 5mm and cover a range of 800 m [11], therefore it is extremely suitable for detecting cracks, ice, water, and foreign objects on the airport runways.

The data produced by LIDAR is a set of data points in 3-D space, commonly known as Point Clouds. Figure 1 shows an example of a torus represented by a point cloud. Point clouds have been used for many purposes, such as 3-D CAD model for manufactured parts, and their quality inspection, etc. In our proposal, the point cloud is produced by scanning the airport's runway using the terrestrial LIDAR sensor. The RIEGL VZ-400i [11] (see Fig. 2) is one of the possible candidate LIDAR sensor that can be used in our proposed system. This device is used for: Forensic and Crash Scene Investigations, architecture surveying and facade measurements, surveying and monitoring, etc. RIEGL VZ-400i can scan a view of $100° \times 360°$ in a range up to 800 m with an accuracy of 5 mm. The data acquisition speed is 500,000 measurements/sec with real-time geo-referencing simultaneously.

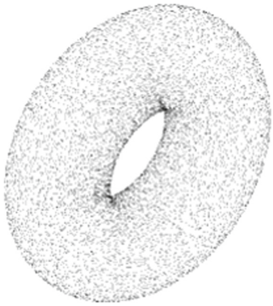

Fig. 1. Example point cloud representation of a Torus [16]

Geo-referencing is one of the important characteristics of the proposed system. Through geo-referencing, we intend to locate the anomaly on the runway. Preventive or curative actions are to be taken at the location of the anomaly, based upon the severity of the anomaly. The integrated GNSS receiver and high accuracy and precision of ranging of RIEGL VZ-400i enable near accurate geo-localization of the anomaly. The RIEGL VZ-400i provides real-time data flow through dual processing platforms; the first processing system performs system operations and waveform processing, and simultaneous acquisition of scan and image data; the second system provides onboard registration, geo-referencing, and analysis. The RIEGL VZ-400i also comes with a 3G/4G LTE modem, Wi-Fi, and Ethernet ports, therefore, enables its remote operations.

Fig. 2. LIDAR RIEGL VZ-400i [11]

3.2 MARWIS for Terrestrial Scanning via Vehicle

Mobile Advanced Road Weather Information Sensor (MARWIS) is a non-invasive anomaly detection system for road and runways [12]. MARWIS is a kind of mobile weather station that performs real-time detection of several road's and runway's critical parameters such as temperature, friction, etc. At runways, the

Fig. 3. MARWIS sensor assembly [12]

problems caused by waterlogging and ice formation can lead to disastrous situations. Besides this, the road conditions such as temperature, relative humidity, friction, etc., also add to the problem with runways. MARWIS is a solution to address the aforestated problematic road conditions at runways. MARWIS aids in classifying road conditions like dry, moist, wet, icy, snow, slush, chemically wet. It also calculates the road surface temperature, ambient temperature, water film height (up to 6 mm), dew point temperature, ice percentage, and friction. The data collected from MARWIS will be helpful in developing the proposed system as we can use these classification produced by MARWIS to label LIDAR data (Fig. 3).

3.3 XTraN^{TM} for Vehicle Monitoring

XTraN is a solution for efficiently managing fleets and teams. The system provides several functionalities such as fleet scheduling, achieving energy efficiency in vehicle-usage, etc. XTraN has an on-board processing unit [22] designed to record event in a vehicle. XTraN also provides various interfaces to a vehicle's sensors and enables sensor data collection for vehicle monitoring and fleet management related optimizations. XTraN's on-board processing unit can be easily installed on the majority of vehicles. XTraN on-board unit has a GNSS module that has an accuracy of 25 cm, an integrated UHF radio link (license-free band), and several communication ports (including RS-232, RS-485, 1-wire, USB, and CAN). XTraN on-board unit communicates with the main system by interfacing GPRS to one of its communication ports (Fig. 4).

The XTraN on-board unit also has digital I/Os and analog inputs that can be used to interface with some additional sensors, if required to complement the main source of data. Another advantage of this solution is that it accepts a wide voltage range (between 10-36V), with a typical consumption of 120mA, which makes it directly pluggable to the car battery without additional components. We intend to utilize the XTraN on-board unit and interface it with MARWIS to collect data related to the runway, and further utilize this data for labeling the LIDAR data.

Fig. 4. XTraN's on-board processing unit for monitoring vehicle [22]

4 Proposed System

In this section, we describe the proposed system and its functions. First, we detail the components of the system. Secondly, we discuss the possible field arrangement of the sensors at the runway and scenarios to collect the data.

4.1 Component of Runway Monitoring System

There are four major components of the proposed system; Sensors; Data Storage; Artificial Intelligence (AI) and Machine Learning (ML) Stack; User interface. Figure 5 shows the complete architecture of the proposed system.

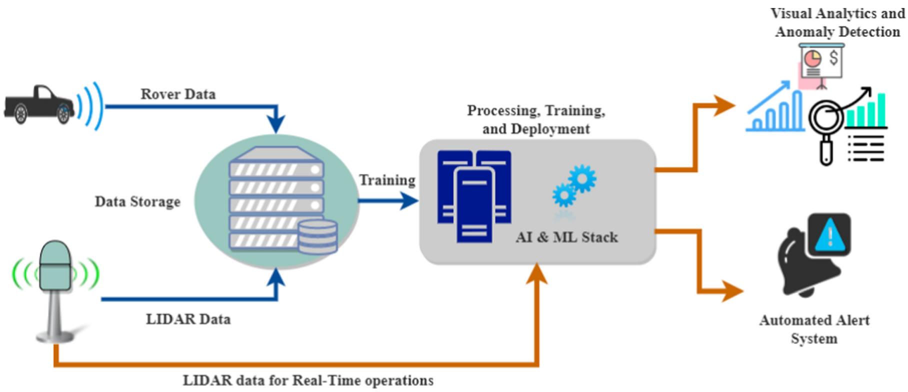

Fig. 5. Architecture of the runway monitoring system

1 **Sensors:** In the proposed system, we suggest using two types of sensors. LIDAR is the prime sensor of the system because it can 3-D scan the entire runway in a non-invasive manner (see Sect. 3.1 for LIDAR's description). The data sensed from LIDAR is utilized in two ways; saved in storage developing

ML models; and relayed to AI and ML stack for real-time operations (classification, visualization, etc.). MARWIS sensor is the second sensing device we propose to use in this system. MARWIS can be attached to the XTraN's on-board processing unit of the Rover to scan the runway for anomalies such as water film, ice, etc. (see Sects. 3.1 and 3.3 for the description of XTraN and MARWIS). Data from the Rover is also saved into the data storage that can be used to label the LIDAR data.

2 **Data Storage:** Data Storage (Lake) is created, to save the data obtained from the two sensor devices. The data from LIDAR sensors is converted in standard LAS format and stored as .las file in the data storage. The data obtained from the Rover can be stored in a database and saving various parameters captured (or calculated) by it. For every capture event, the time and GPS location of the rover is saved. This GPS location and time will help label the LIDAR data.

3 **AI and ML Stack:** There are three main purposes of this stack; data processing; modeling; and model deployment. In data processing, a stack of python scripting language along with libraries like Scikit-Learn, pandas Open3d, etc., can be used to process the data obtained from the rover and LIDAR, and label the LIDAR data. In modeling, a stack of python along with TensorFlow and Keras can be used to perform the classification operation by using the Convolutional Neural Network (CNNs). In modeling, we also perform tasks like clustering for unsupervised machine learning operations and use visualization libraries like the matplotlib, and seaborn for displaying the results. In model deployment, we pickle the learned model and deploy it to provide the classification in real-time. Besides python, the AI and ML stack also consist of the opensource tool CloudCompare to perform the data analysis and ML operations. We also intend to crop small images from the point cloud near to the georeference provided by the Rover data and use it to label the object in the point cloud.

4 **User Interface:** The system will have two types of interfaces; an automated alert system; and visual analytics and anomaly detection. The automated alert system is a dashboard that provides the output of the runway scan in real-time along with the anomalies identified by the system and their location. This system can help generate an automated alert based upon the severity of anomaly identified by the system. The second interface is also a dashboard but with a visual aid for example displaying the point cloud with several clusters in the cloud. This interface is also helpful to identify the unknown anomalies (via human interpretations) which are not identified during the training process.

As displayed in Fig. 5 we first store the data from the two runway scanning sources. The point cloud data from LIDAR is labeled using the geolocations of anomalies determined by the MARWIS sensor of the Rover. After processing and labeling the data, we train a CNN for the labeled point cloud data. Once the training completes and the model is validated, it is deployed to the real-time alert system. The visual analytics can also be performed by plotting the identified clusters.

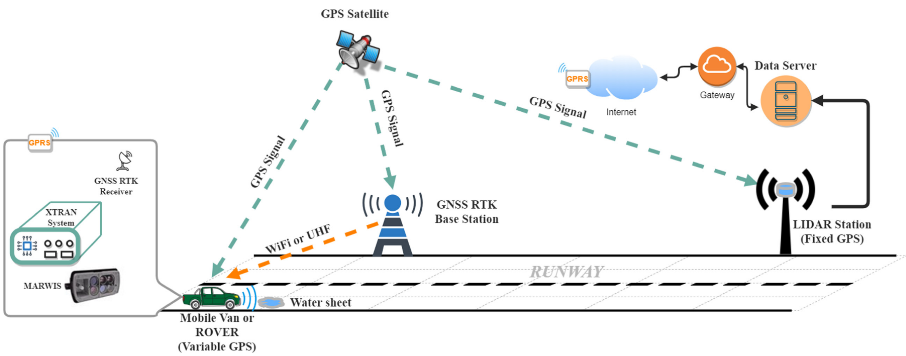

Fig. 6. Field view of the runway monitoring system

Figure 6 shows a field view of sensor deployment and data collection strategy on the runway. The Rover is mounted with the MARWIS and GNSS sensors. The LIDAR sensor is mounted over a pole with an integrated GNSS receiver. Both LIDAR and Rover send the sensed data to the data store via Ethernet and GPRS respectively. In the whole system, the data collection is the most crucial part because we need to send the Rover on the runway which interrupts the aviation service. Following are two data collection schemes that can be efficient:

1 **Data Collection Scheme 1**
In this scheme, the LIDAR data is collected first. This collected point cloud data can be used as a reference and can be used to compare (using Cloud-Compare software) with other point clouds collected at different times. The geolocation of the anomalies identified by point cloud comparisons can be used by Rover to scan those locations and further label the anomaly. This scheme has the advantage that anomalies are identified in advance and Rovers can be sent to the runway to the specific locations on the runway. This also can save time needed to interrupt the runway for scanning.

2 **Data Collection Scheme 2**
The labeling process takes place at the end of the data collection process. In this scheme, the LIDAR and Rover perform the runway scan simultaneously. This scheme has the advantage of identifying a large number of anomalies because the Rover scans the whole runway before coming back to the base.

4.2 Discussion

Due to the involvement of the laser-based scanning method, the proposed system can monitor the airport's runway in a non-invasive manner. The technologies we mentioned in this proposal are well proven for their domain and we intend to integrate them into a runway monitoring system. There are some issues we anticipate to encounter while developing the proposed system:

1 **Point Cloud Data Processing**
In this system, the laser signals will be processed into the point cloud by the in-built software to the LIDAR (i.e., REIGL VZ-400i device). However, the real challenge lies in the processing of the generated point cloud because the point cloud obtained from the terrestrial scan of the runway will be huge.
2 **Labeling Foreign Objects**
The list of foreign objects, whether living or non-living, is endless. It is practically impossible to label all foreign objects that are found on the runway because they vary from location to location.
3 **Size and Severity of Foreign Objects**
The LIDAR device suggested in this system can scan objects as small as 5 mm and we can also determine and label several small objects using the Rover. However, there are a lot of foreign objects (e.g. metal ball bearings, etc.) that are not recognized by MARWIS and they can be equally dangerous for the aircraft and the bigger objects. Labeling such kind of objects will also be a challenging task.

5 Conclusion

Air travel is considered the safest mode of transport. This achievement of the aviation industry is a result of highly efficient airport management. This management also includes the constant monitoring of the airport's assets, where the vigilance at runways, taxiways, and aprons are of high priority. Any problems occurring on these assets lead to delays in flights, increase costs, and in the worst-case results in accidents. In this article, we focused on three problems at the airports which are related to structural integrity, foreign objects, and water or ice. We surveyed several methods that solve either of the aforementioned problems, individually. Besides the methodologies, we also describe four runway monitoring technologies that are state of the art in the detection of foreign objects and structural deformation at the runways and taxiways.

Among the methods and technology reviewed for this work, some take a lot of time to scan the runways, therefore, interrupt the functioning of the airport. Some methods perform real-time monitoring operations but are dependent on human interventions to identify the objects and their exact location. In this article, we provide guidelines to develop a system that can monitor the airport's assets in real-time and in a non-invasive manner. The proposed system consists of LIDAR for non-invasive scanning of the airport's assets. The System also has MARWIS sensors mounted connected to the XTraN on-board processor of a mobile rover. We describe all components of the proposed system and its underlying technologies. We also explain two data collection schemes to label the LIDAR data based upon the location and category of anomaly sensed by the rover. The use of mature technologies of the proposed system has the potential to efficiently monitor the airport's assets in real-time and in a non-invasive manner. We also discuss some issues that are to be addressed before developing the system.

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