LiDAR Based Remote Sensing System for Foreign Object Debris Detection (FODD)

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***Abstract*—Foreign object debris (FOD) on runway pose potential hazard to safety of the aircraft. This hazard can lead from minor incident to fatal accident. A successful foreign object detection (FOD) can be attained with effective Safety Management System (SMS). According to aviation authorities FAA (Federal Aviation Authority) and National Aeronautics and Space Administration's (NASA) guidelines, a safety and security protocol for debris detection and elimination must be followed to control foreign object debris related damages. The SMS programme need 24/7 surveillance of debris sensitive areas to detect and eliminate them in any weather condition. This article presents a study of proposed method for foreign object detection and alert system based on hardware such as (LiDAR, Microprocessor) and software to locate debris location for elimination. In lab conditions experimental work proved suitability of proposed method to detect location (coordinate) debris of various sizes and activate alarm to generate alert for airport SMS staff member.**

***Index Terms*— Debris Detection, Remote Sensing, FODD, LiDAR, Safety Management System.**

I. INTRODUCTION

Aviation industry is considered as backbone of many economies around the world. This sector including commercial and non-commercial flights alone contribute billions of US dollars to the world's economy [1]. The processes involved to keep this sector running needs high level of safety and security, because a small error or ignorance in safety can easily lead to a fatal accident. The commercial airline safety has enhanced significantly since the industry's emergence, which has a history of over a century. Although, fatal accident rate for airlines in advanced countries have dropped to the level where it is now being considered as a safest mode of transportation. However, it is quite evident that safety performance across all segments, all countries and regions of the world is non consistent. The poorer safety records for developing countries continues to be a persistent conclusion in aviation safety research [2]. The results from a survey revealed importance of aviation safety culture for overall airline performance and highlights specific areas that still needs deliberation for improvement [3].

The manufactures and operators related to aviation received a high quality, intensive training due to the nature of their job. Employees in aviation industry also follow several strict procedures to meet high levels of safety, yet many accidents or incidents are reported every year.

There can be many reasons for aircraft accidents or incident such as human error, equipment failure, material failure, technical problems, internal object damage, foreign object ingestion, bird strike, weather and pilot error, etc. [4]. Several investigations into these accidents highlighted the ingestion of foreign object into propulsion systems was the reason that paved its way towards a major occurrence. Federal aviation administration's (FAA) research into technologies for the development of detection systems and recommendations from different other efforts of effective foreign object debris control techniques need further emphasize its importance for aviation [5, 6].

As highlighted above, foreign object debris is one of the main reasons that could lead to serious consequences [7]. These objects could be loose objects, small debris, wildlife, and even stray humans [6]. TABLE I summarize different possible types of foreign object debris. In aviation FOD has two connotations:

- Foreign Object Debris,
- Foreign Object Damage.

TABLE I
FOD (debris) Types and sources [8]

FOD types	Sources
Personnel	Caused by inappropriate housekeeping and poor working behavior.
Infrastructure	Pavements, lights, and signs
Materials	Paint chips, rubber joint, asphalt and concrete chunks
Environment	Ice, snow, and wildlife
Operating Equipment	Ground Handling vehicles and construction equipment
Aircraft parts	Tire fragments, trapdoors, oil stick, and fuel cap
Fasteners	Washers, bolts, and nuts
Flight Line Items	Luggage tags, personnel badges, cans

Foreign debris leads to damage which results not only in financial loss but also pose serious potential threats to human lives. Therefore, the accidents and incidents caused by Foreign

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Object Debris are called Foreign Object Damage [8]. Debris removal from designated areas is essential for damage prevention, in accordance with the National Aeronautics and Space Administration's (NASA) guidelines, sensitive areas should consider factors including the probability and consequences as presented in Fig 1 [9]. Fig 2 provides the percentage of FOD (debris) item locations in different areas of operating surfaces [10]. All National Aviation Authorities follow their own routines to ensure clean aircraft operating surfaces to prevent ingestion of such objects during flight operations.

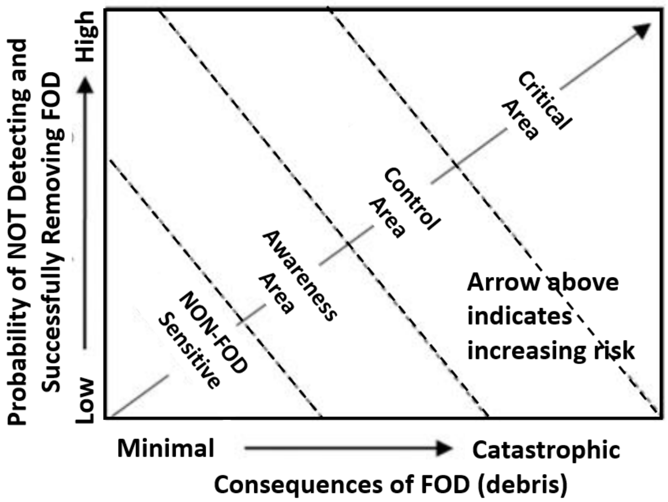

Fig 1: Probability and consequence for sensitive area [9]

There are numerous accidents or incident reported in past that are caused by the foreign object debris, but one of the worst examples is the Air France flight 4590. Accident occurred on 25th July 2000 at Charles de Gaulle International Airport causing lives of nine crew members and hundred passengers on board. Whereas, one seriously injured, and four lives were lost on ground. The investigations lead that five minutes before unfortunate flight, a strip of titanium fell from Continental Airline DC-10 flight departing to New York was the reason of accident that shattered one tire of the Concorde. A large chunk of tire struck the aircraft's wing, rupturing fuel tank and initiating fire in the wing. This fire on wing caused a loss of stability control of the aircraft. The titanium strip could not be detected before flight because the runway inspection was not completed, which should have been done before the flight as a preparation [11]. The strip not only claimed over a hundred unfortunate lives but also had major financial impact. Since this tragedy, the debris threat on runways has been focused on keeping the aircraft maneuvering areas clean and safe. Therefore, international aviation agencies and organizations outlined several methods for FOD detection [12].

Nowadays, the manual foreign object detection drills are practiced on many airports and military air force bases. Based on the FAA and he International Civil Aviation Organization (ICAO), "the airline personnel, when feasible, should join the airport staff in daily, daylight inspection of aircraft maneuvering areas for removal of FOD" (debris) [13]. To control the FOD (debris) in the civil or military airports, ICAO published procedures are to be followed that are divided into four sections:

- Training
- Inspection
- Maintenance
- Coordination

Ground personnel drill to detect and debris pick up maybe possible on non-civilian airports but manual inspection on commercial airports is extremely difficult because runways are in continuous use [14]. This invokes the need of remote sensing methods to detect debris on runway and send alert to security and safety team for removal and prevention of serious consequences.

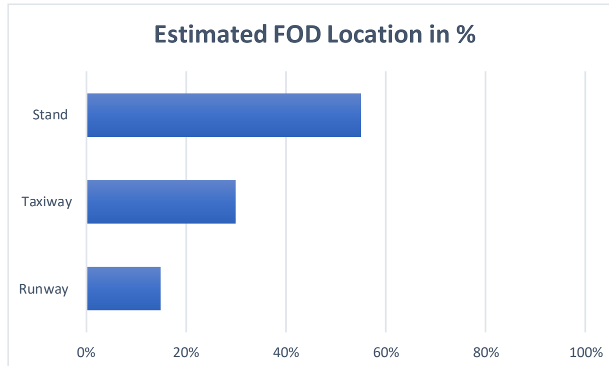

Fig 2: Foreign object debris possible location area [10]

In recent years foreign object detection is getting attention from many researchers. Aviation history has revealed that the debris on runway may cause a high loss, which is as high as 3 to 4 billion US dollar per annum [11]. Hitherto, many researchers developed robust detection methods, some of them are based on remote sensing by using (millimeter wave radar, optical cameras, laser range finder, photoelectric encoder, data fusion device and LiDAR based autonomous vehicle) while others use high definition video surveillance to locate and report debris [6, 7, 14-18]. However, until now a perfect and cost effective system is yet to be developed which can timely detect very small foreign objects such as socket or wrench on runway surface [19]. Another major challenge with autonomous systems is to tackle false alarm issue in the presence of birds and other small creatures as insects. By considering the existing problem a foreign object detection and alert system based on LiDAR technology has been proposed and reported in this article. LiDAR stands for Light detection and ranging uses laser beamed method to detect object and calculate its location by reflecting object. The proposed prototype for debris detection system is a combination of hardware such as (LiDAR and microprocessor) and software (Data acquisition and application of logical decision-making algorithm). Acquired results exhibited the accuracy of FOD (Debris) detection to reduce the risk of unwanted circumstances through use of cost effective and state-of-the-art technology.

II. Method

The schematic diagram of the proposed prototype is presented in Fig 3. A table size (122cm in length and 60cm in width) prototype was designed with LiDAR and microprocessor installed. Airport conditions were simulated by drawing runway. The viewing zone for LiDAR scanning was chosen 0.5m in radius. The main objective of this proposed method is to proof the concept for a low-cost method for FODs (debris) detection on aircraft operating surfaces. LiDAR continuously scans the surface to detect debris. When a debris is located, the item's coordinate location is sent to the operator by using software and an alarm is activated to acquire the operator's attention.

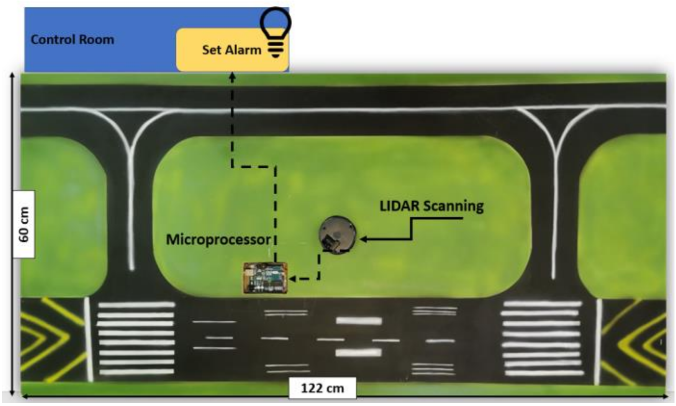

Fig 3: Schematic of prototype for Foreign object detection

Flowchart in Fig 4 summarizes the operations involved in foreign object debris detection. The proposed prototype comprises various components to detect debris such as LiDAR (Type 2 Delta), microprocessor (Arduino UNO) and airport runway simulation. Subsequent section further provides the details of each component used in the prototype.

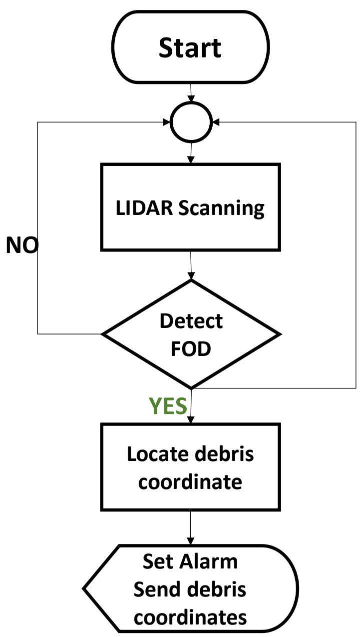

Fig 4: Flow diagram for method FOD detection

A. LiDAR

LiDAR is state of the art remote sensing technology which uses laser light pulses for objects detection like radar. It uses a much shorter range and wavelength than the radar (tens to hundreds of meters) [9]. It is 360-degree omnidirectional scanner that can sample (2 to 5) ks/s (kilo samples / second) at 6.2 Hz rotational speed. It provides reliable high quality and identifies the object's location (with coordinates) up to 120 m away from it with centimeter accuracy (distance depends on types of LiDAR).

LiDAR uses the laser triangulation principle to measure the coordinates of object. To measure the distance of traveling the photon of the light to and from any object can be computed by using equation 1.

$$Distance = \frac{Light\ speed \times Time\ of\ flight}{2} \quad (1)$$

There are two types of measurements in the LiDAR like horizontal displacement (XY plane) and vertical displacement (Z's direction) as illustrated in Fig 5 and Fig 6 [20]. Equation 2 explains the relation of horizontal range (hor_{scale}) between a neighbor range r_{nb} and the reference range r_{ref} [20].

$$hor_{scale} = \frac{r_{nbhor}}{r_{ref}} = \frac{\sin(\alpha_{ref} - \alpha_{\prod})}{\sin(\alpha_{nb} - \alpha_{\prod})} \quad (2)$$

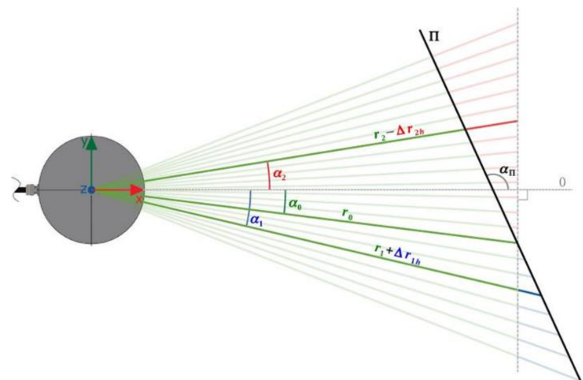

Fig 5: LiDAR horizontal Measurement [20]

While equation 3 represents the vertical relation between reference range and neighbor range [20].

$$ver_{scale} = \frac{r_{nbver}}{r_{ref}} = \frac{\sin(\omega_{ref} - \omega_{\prod})}{\sin(\omega_{nb} - \omega_{\prod})} \quad (3)$$

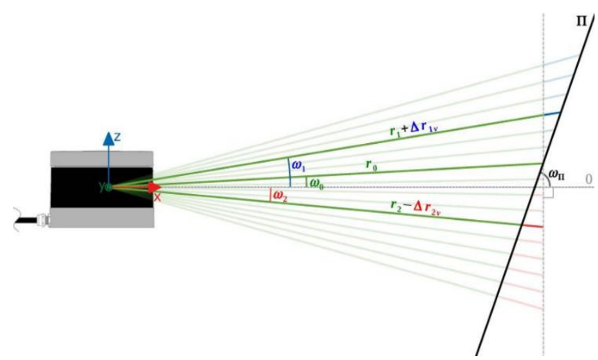

Fig 6: LiDAR vertical measurement[20]

By combining the horizontal and vertical relations, the neighbor range that expected will be [20].

$$r_{nb} = hor_{scale} \cdot ver_{scale} \cdot r_{ref} \quad (4)$$

Azevedo et al. also explained angular detection of object in detail by comparing between any point and its neighbor. If the cluster that the neighbor belongs to is suitable to have approximation into a plane $\prod$, $\omega_{\prod}$, and $\alpha_{\prod}$ are calculated based on its normal. Otherwise, it is assumed that $\omega_{\prod} = \frac{\pi}{2}$

(perpendicular to XY), and $\alpha_{\prod} = \frac{\alpha_{ref}+\pi}{2}$ (orthogonal to the beam of reference). The angular value of the object constrained by the interval $\omega_{\prod}, \alpha_{\prod} \in [0, \pi]$[20].

B. Arduino (Micro-Processor)

Arduino microcontroller is an open source electronic component that allows to use of hardware and software to meet required objective. The microprocessor board used in the commissioning of this prototype has 14 digital input/output pins. 6 of them are used as a PWM (Pulse-Width-Modulation) output, and 6 are analogue inputs.

C. Software design

A software was designed and developed in the C++ programing platform which contains data acquisition from LiDAR. It applies logical decision making in case of foreign object detection, obtains item coordinates and displays this information to the operator.

III. Prototype Performance Evaluation

After the fabrication of the prototype, experimental testing was carried out for different types of FOD in Lab environment. Fig 7 shows schematic of the testing facility. In lab condition, LiDAR has shown ability to scan any item in 4 m radius. The viewing zone of LiDAR is dependent on choice of LiDAR for example, model Delta 2 LiDAR has eight meters diameter [21], whereas model YDLIDAR-X4 has 10 meters diameter [9]. The viewing zone for proposed method to detect foreign object is in between 0.13 m to 8 m and it can scan 2.5 million points per second.

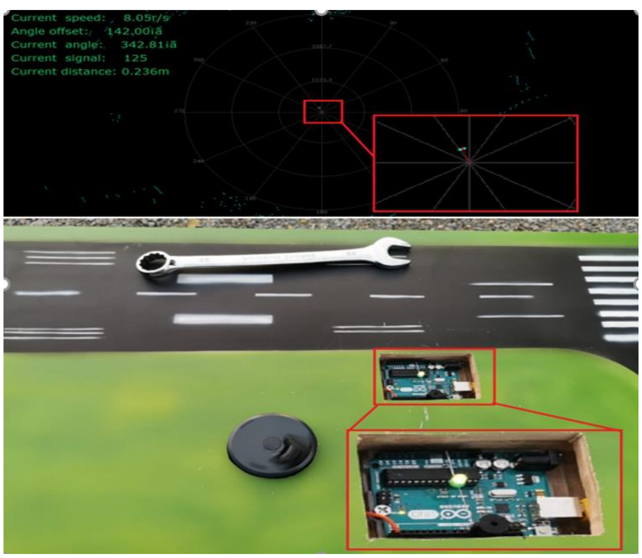

Fig 7: FODD System Testing

The purpose of using various sizes of FOD (debris) is to evaluate prototype's detection ability of various sizes (TABLE II provides the details of selected item for testing) and location with its coordinates. In this program of testing, selection of items was based on personnel practical experience. Only those items which could usually be found on aircraft operating surfaces were used for testing the system. The dimensions of the smallest object were (18.6×0.7×0.8) cm, whereas the largest object was (20.5×12.5×4.7) cm.

Upon detection of item, developed method immediately initiates audio/visual alertness through an alarm and light to get operator's attention. Fig 7 explains the viewing zone and its successful detection of foreign object and its position with an accuracy of ±1%, such as angle of laser light reflection and the distance between the FOD (debris) and LiDAR.

TABLE II
List of FODs (debris), their dimension and detection

Item	Dimension (cm)	Distance (m)	Detected
Piece of Carton	20.5×12.5×4.7	0.22 m	Yes
Plastic bag	14×10.3×0.7	0.46 m	Yes
Bottle of water	16×4.5×5.5	0.32 m	Yes
Pencil	18.6×0.7×0.8	0.23 m	Yes
Screwdriver 1	11.5×2×2.4	0.40 m	Yes
Screwdriver 2	24.6×2×2.2	0.37 m	Yes
Spanner	25.5×4.5×2.4	0.27 m	Yes
Rock (stone)	9.4×5.6×3.6	0.38 m	Yes

TABLE II tabulates several items successfully detected by the proposed and detection system. These items were not only of different sizes but were placed at a different distance from the sensor to effectively evaluate the prototype's capability.

Different items were placed between the range of 0.22 meters to 0.46 meters away from sensor, the response time of item detection was 3 to 4 seconds. Presented results prove that the proposed FOD (debris) detection method can detect the angle of reflected foreign objects on runway within the parameter of 360-degree and measure distance of object from sensor. The obtained information from proposed method further processed by using software to activate an alarm and get attention from safety management staff. Results presented in TABLE II reveals that proposed designed prototype has advantages for detecting FODs with medium, large, and not too small sizes.

IV. Discussion

Presence of foreign object debris on critical areas of airport can cause damage from minor incident to a fatal accident which can be controlled by a timely detection and removal approach. On commercial airports the detection of FOD is only possible by using a remote sensing method. Existing approved systems for debris detection are either costly, in some cases depend on weather conditions, needs trained human resources, or interrupt airport operations for surveillance purpose [22].

A low cost, 360° degree omnidirectional LiDAR-based remote sensing system proposed and reported in this paper shows success for detection of FOD, activates alarm and sends coordinates information for debris to SMS promptly. TABLE II explains that the proposed system can detect various items of different sizes, provides 24/7 surveillance without interrupting airport operations and is less affected by weather conditions in comparison to other approved method for detection of FOD.

Previously, it has been reported that LiDAR-based remote sensing method faced challenges in detection of very small debris item such as a socket and wrench but with the help of the proposed system in this article it can successfully detect these kind of debris without applying further complex processing

[19]. To our knowledge this innovative proposal by authors is the first study which uses omnidirectional LiDAR for 360° scanning facility along with microprocessor for detection of FOD. Although, the proposed debris detection system proved its suitability for successful detection any item on runway however, it can be a part of largest automated system to minimize the risk of hazard significantly.

Proof of concept as demonstrated through working prototype of the proposed system is a way forward towards development of a cost effective and robust debris detection system. An innovative approach used in the proposal makes it attractive for implementation and employment with ease. However, the only constraint of system is its optimized installation to cover the complete spectrum of the sensitive areas for significant reduction or elimination of potential hazard to operating aircraft.

V. Conclusion and Future Direction

There are several accidents and incidents caused by FODs, in aircraft maneuvering areas such as runways, taxiways, and aprons, should be protected from any FOD that can be a potential risk to the aircraft. Traditional methods like sweeping, magnetic bars, and rumble strips, etc. or using modern methods as using millimeter-wave radar or LiDAR for FOD detecting which reduce the manual burden on manpower. A prototype designed and developed (by combining different hardware including LiDAR and microprocessor and software) is reported in this article.

Evaluation of developed method has shown promising results that uses shorter range and wavelength as compared to RADAR with high resolution. Proposed and developed scheme also makes the system economical by reducing technological burden. Although, designed and developed autonomous foreign object debris detection system has met all the project objectives. However, authors intend to continue the work on design improvements for development of a robust, economical and easily deployable debris detection system which can significantly reduce potential hazard on flight safety and meets aviation expectations. As an initial follow up work, the developed method is to be integrated with an algorithm in order to handle false alarm generated due to birds, other wildlife on runway or landing and taking off aircraft.

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