LOOP TECHNOLOGY (LOT) AS AN ALTERNATIVE SURFACE SURVEILLANCE SYSTEM

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Abstract

This paper provides an overview and preliminary results for demonstration of a prototype distributed loop-based system called LOT. This paper contains only the understanding and views of the authors and is not intended to reflect the official position of the FAA. The FAA completed the first phase of a prototype system installation in 1997 at Long Beach Airport (LGB) in California. This prototype applies inductive loops, a mature technology, to the airport surface surveillance application. The project also involves a technology transfer of neural network signal processing technology from Department of Defense to form a non-cooperative surface movement sensor system. LOT has the potential to be used in a standalone mode or as a supplemental sensor input to an Airport Surface Detection Equipment (ASDE) radar surface surveillance system.

Introduction

Most automation efforts to date have rightly concentrated on surface safety and incursion problems at higher level airports, where traffic is more dense and complex. The Airport Surface Detection Equipment-3 (ASDE-3) has been implemented to provide surface surveillance at these higher level airports. However, an alternative surveillance system is needed to address airports where ASDE-type equipment will not be installed or the monitoring requirement is too localized to warrant an ASDE-type system. The system employed should offer more flexibility in application (i.e., limited application vs. full airport), be scalable, and allow for incremental implementation to reduce or manage the cost. A non-cooperative surveillance system is preferred, as no new aircraft equipage is required to provide surveillance.

The FAA is evaluating LOT for its surface surveillance application. The project is currently comprised of two phases – a technical assessment and an operational assessment. The first phase, conducted in 1997, investigated the technical feasibility and performance of a distributed inductive loop-based system to provide surface surveillance. Evaluations were performed LGB in California and at Hyde Field in Maryland. LOT demonstrated the capability to detect aircraft and ground vehicles when they taxi over an inductive loop. LOT goes one step beyond the typical highway loop implementation by using the inductive signature to classify the aircraft or ground vehicle. Detection and classification information is used to track traffic in the airport loop coverage area. The second phase began in 1998, and the LOT system installed at LGB received enhancements of an approach radar interface, safety logic and a ground controller display. Evaluations are planned for late 1998.

While LOT can provide full runway/taxiway coverage, a more cost-effective implementation is a limited system installation that addresses the immediate and localized safety needs of the airport. Figure 1 illustrates four LOT applications, which are further discussed in the following sections. The flexibility exists to install inductive loops to support any one or combination of these applications at any location(s) on the airport.

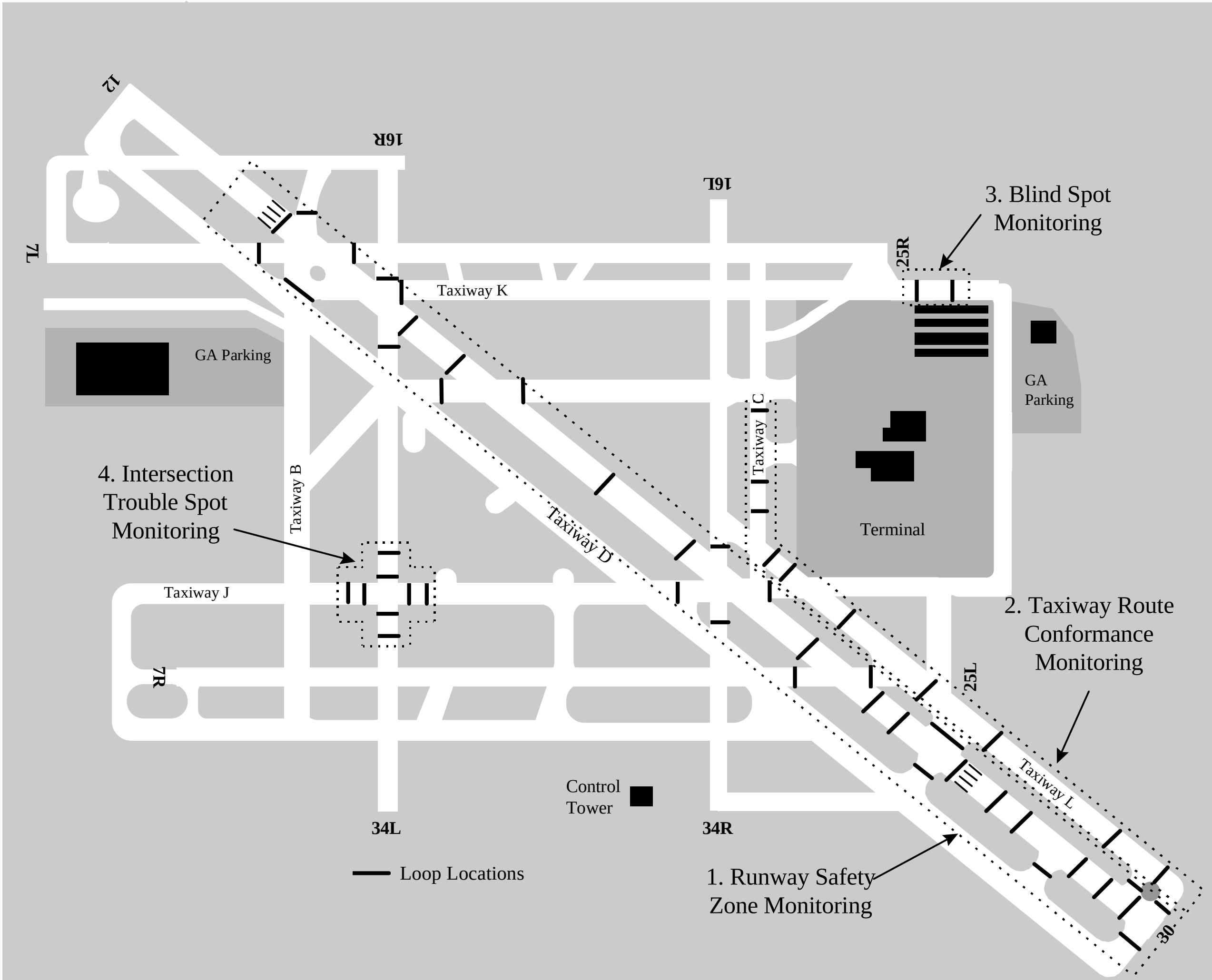

Figure 1. LOT Conceptual Applications

Operational Concept

Air traffic controllers can use LOT to aid in minimizing the risk of incursion incidents and improve situational awareness. In addition to providing an operational display of surface traffic where loops are installed, LOT can provide the following capabilities (See Figure 1): (1) runway safety zone violation, (2) standard taxi route conformance monitoring, (3) blind spot monitoring, and (4) monitoring of troublesome intersections. The system will be used by local and ground controllers to augment visual observations of aircraft and vehicle movement, and may be used by the controllers under the following conditions:

- Visibility is less than the most distant point in the active movement area where loops are installed.
- Traffic is operating in blind spots with respect to the tower.
- Verification of position of aircraft or vehicles at specific update points is needed.
- In the controller’s judgment, the systems used will assist in the performance of their duties at any time.
- There are system-generated aural and visual indications of violation of runway threshold or an unsafe condition on runway.
- There are system-generated aural and visual indications of non-conformance with standard taxi route operation.

The LOT-derived position and identification information will be used to assist the controllers with the following activities:

- Formulating clearances and control instructions to aircraft on the movement area.
- Determining when the runway is clear of aircraft and vehicles prior to a landing or departure.
- Positioning aircraft and vehicles.
- Determining the exact location of aircraft, or their relationships to other aircraft on the movement area.
- Monitoring compliance with control instructions.
- Confirming pilot-reported positions.
- Providing directional taxi information (excluding heading) on pilot request.
- Identifying the weight class of aircraft to assist in maintaining proper departure separation standards.
- Determining when an aircraft has lifted off or touched down.

LOT Overview

System Architecture

The LOT system uses Commercial-Off-The-Shelf (COTS) inductive loop technology and a computer workstation to provide surface surveillance and surface traffic safety processing for aircraft and ground vehicles operating on runways and taxiways where inductive loops are installed. The LOT system consists of the following major elements:

Surveillance Subsystem

The surveillance subsystem forms the heart of a loop-based surveillance system. It consists of the sensor (loop wire), detection component and tracking component. This subsystem provides track reports to the safety subsystem for display and processing by the safety logic.

Inductive Loops

Inductive loops provide the sensing element for the Loop Detection Component (LDC). They can be located over the whole runway/taxiway surface or in strategic locations (i.e., troublesome intersections, blind spots). Inductive loops are implemented on the airport surface in rectangular saw cuts, which span most of the width of the runway and/or taxiway to be monitored (see Figure 2). In the demonstration system installed at LGB, the taxiway loops are 10'x65' and the runway loops are 10'x150'. The loops are spaced to achieve a nominal update rate of once every four seconds at typical taxi speeds. A loop consists of three turns of encapsulated stranded wire, which is laid down in a saw-cut groove. A backer rod is installed in two-foot sections spaced two inches apart on top of the loop wire. The saw cut is then covered with epoxy sealant to ensure against water seepage and prevent cracking of the surface where installed. A key factor in the overall performance of inductive loops is the quality of the installation and keeping the loop wires from moving.

Loop Detection Component (LDC)

Each inductive loop has an associated LDC. The LDC is located within the controller cabinet, which is usually within 500 - 1000 ft. of the loop itself. Each loop is connected to the LDC via a lead-in cable. In the LGB installation, each controller cabinet houses up to four LDCs. The LDC provides detection of aircraft and ground vehicles. The LDC also extracts signatures and performs classification and single loop velocity estimates.

The LDC drives a current through the loop wire at the loop resonant frequency and the current creates an electromagnetic field around the loop wire. The loops are laid out such that the shortest side or length is normal to the direction of movement of the aircraft or vehicle across the loop. The metallic structure of the aircraft/vehicle cuts (see Figure 3) through the electromagnetic field and sets up eddy currents, which tend to lower the inductance of the loop in proportion to the aircraft underside surface area and height above the loop [Ref. 1]. As the aircraft/vehicle continues to move over the loop, the result is a varying inductance change, which produces a shape-based signal “signature” or pattern output (see Figure 4).

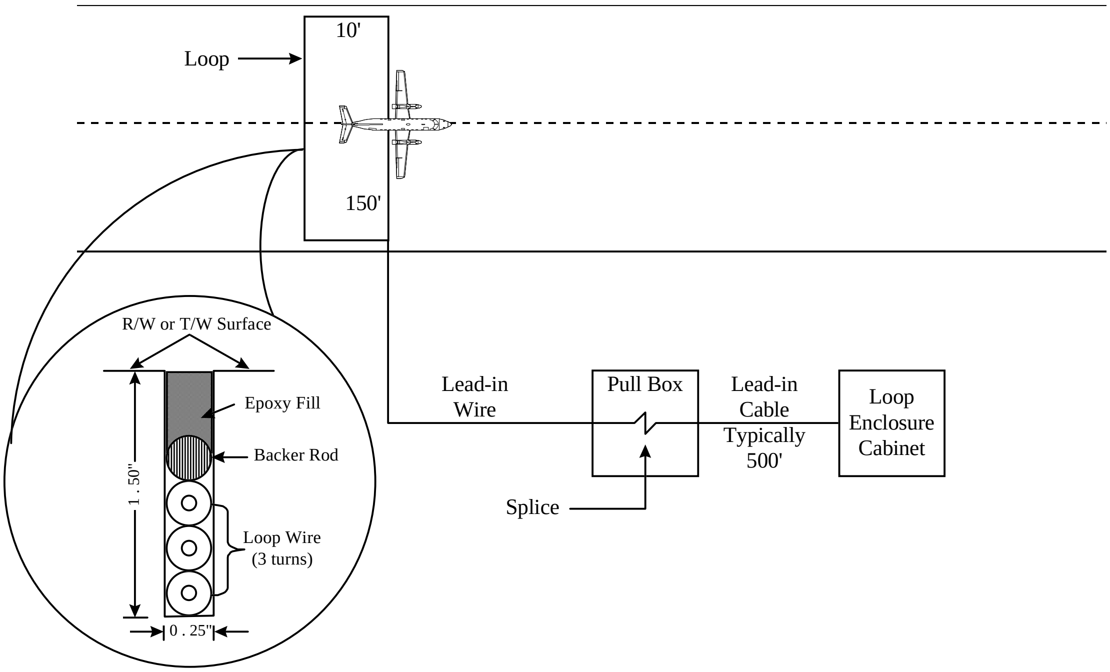

Figure 2. Physical Layout of Loop System Airfield Components with Loop Wire Cutaway View

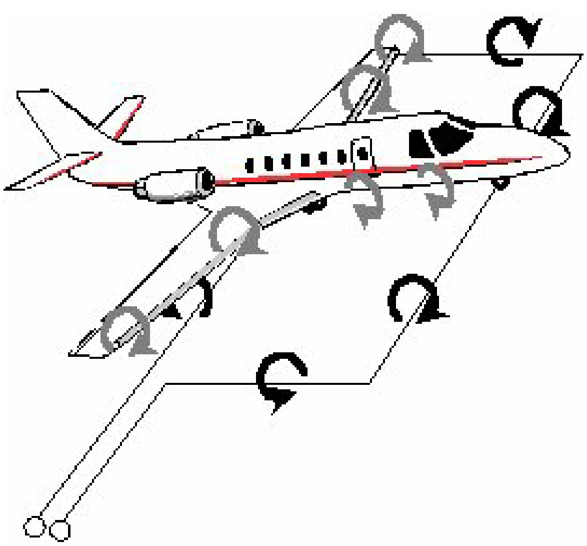

Figure 3. Aircraft Cutting Loop Flux Lines

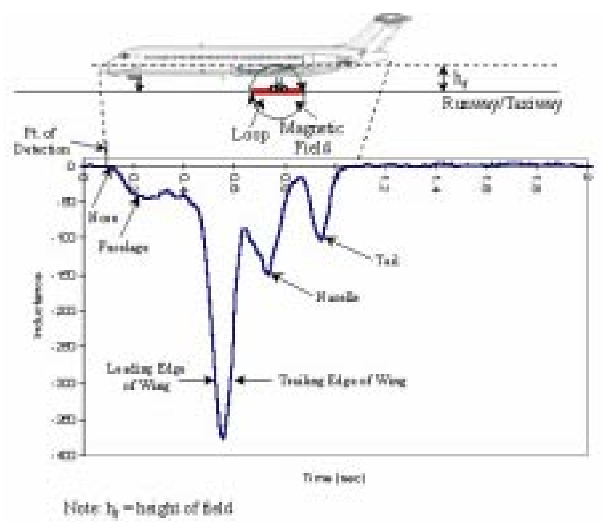

Figure 4. Signature of a DC-9 2 Dimensional Model

This signature is unique for each aircraft type. When the time-varying signal exceeds the loop detector detection threshold, detection is declared. The detection will not be dropped until the signal drops below the threshold and remains there for a parameter-determined length of time. Small ground vehicles can also exhibit a distinguishing signature (double hump), which can be discriminated from aircraft signatures (see Figure 5).

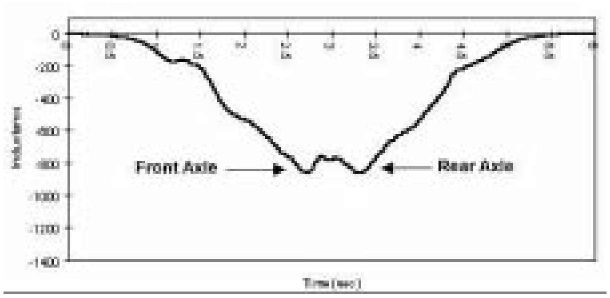

Figure 5. The Distinguishing Double-Hump Signature of a Small Ground Vehicle

Tracking Component (TC)

The TC is a computer workstation that performs loop-to-loop correlation and tracking function position, velocity, and heading based upon kinematics. It also performs data handoff between arrival surveillance data and the loop data from the airport surface.

Safety Subsystem

The safety subsystem provides for processing of track reports from the surveillance subsystem by the safety logic for detection of runway occupancy and runway safety zone violation.

Controller Display

The display provides the controller with a situational display of traffic movement in the inductive loop coverage area(s). Aural and visual indications are provided in the event that there is a violation detected by the safety logic (e.g., violation of runway safety zone, entry into blind spot area, etc.).

Neural Network Classification

The demonstration prototype LOT installed at LGB has a neural network classifier associated with each loop detector component. Although a certain amount of information and tracking can be done from detection alone, classification by neural network processing forms the essence for a loop-based surface system and its ability to track aircraft and vehicles. Classification provides information, which can be used to help accurately correlate a detection update with an established track.

As mentioned under *Loop Detection Component*, each aircraft type produces a unique signature. An aircraft's unique signature is based on its distinguishing characteristics or "features" (e.g., location of nose wheel engine placement, shape of wing, etc.). Just as the controller has been trained to recognize different aircraft type by visual observation of certain features, a properly trained neural network classifier can achieve similar results by emulating a similar process. An air traffic controller is trained by his supervisor to recognize and classify different aircraft types by visual observation of their features. Being able to identify the type of aircraft gives the controller much more information about the flight characteristics of that aircraft.

The neural network is trained, Figure 6, to the population set of aircraft and vehicle signatures appearing at the airport. Development of the signature training set requires collecting aircraft and ground vehicle signatures or patterns and visually truthing them by type. Once this training is completed, subsequent signature inputs for which it has been trained can be classified with high confidence. Presently, we are only attempting to classify three major classes: aircraft, ground vehicle, and unknown. The aircraft class is subdivided into the sub-classes of small (representing GA type aircraft), large (representing air carrier type aircraft), and heavy (representing the larger air carrier type aircraft). Planned enhancements to the neural network classifier may enable classification of many aircraft down to the specific type (e.g., B737, MD-11, DC-9, etc.). Preliminary testing indicates that an enhanced classification capability may enable the system to perform velocity estimates with surveillance from a single loop.

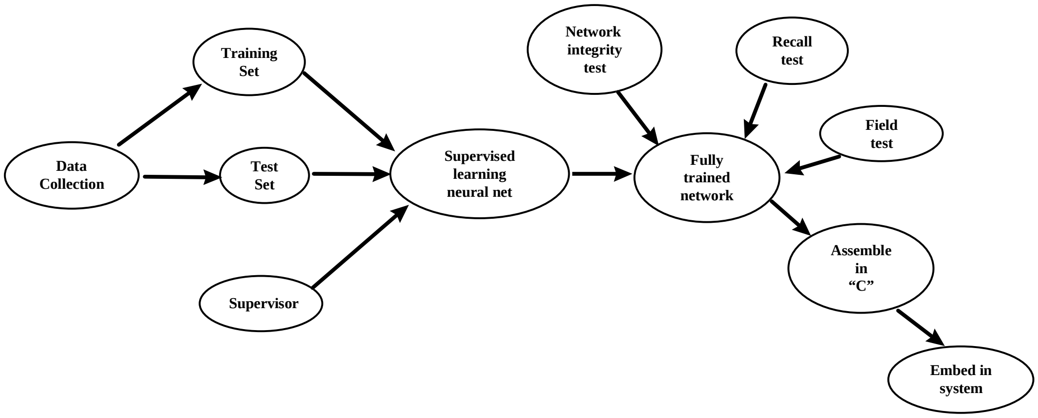

Figure 6. Neural Network Training Process

Preliminary LOT Evaluation Results

LOT evaluations [Ref. 4, 5, 6] were performed at Hyde Field and LGB. RTCA defines guidelines and recommended requirements for surface movement sensors [Ref. 7]. A qualitative assessment with respect to key RTCA-recommended requirements (in italics) is provided below. Future testing will better quantify performance results.

Probability of Detection > .9995

Detection performance testing with ground vehicles and a small aircraft was performed. A range of speeds up to 60 mph was tested. Loop crossing points from the centerline out to the runway or taxiway edge were tested, and various angles of crossing were tried. Test results indicate that there is a high probability of detection when the detector is set to provide sufficient sensitivity. During initial testing, missed detections were experienced for slow moving ground vehicles and small aircraft. However, using a detector set to provide improved sensitivity resolved the problem.

False Detection Reports < 1 per 8 hours

Erroneous detections were not experienced during any of the testing. The loops, being wires, act as antennas, yet all noise was well below the threshold of detection, thus having no impact on detector performance. Ground vehicles driven over the lead-in wire in the grass areas did not cause false detections. It was found that aircraft could be detected before entering a loop, if the detector sensitivity is set too high. Failure to set the sensitivity at the proper setting could potentially result in a false detection of a hold line crossing.

Coverage of Runway and Taxiway Centerlines where Surveillance is Required

Surveillance for the full width of the runway or taxiway was demonstrated. This provides the capability to detect ground vehicles, which sometimes travel along the edges of taxiways and runways. Reliable coverage is provided in regions where the loops are installed, thus demonstrating the capability to provide localized surveillance to address trouble spots. Accordingly, using a localized approach allows LOT to be implemented in a cost-effective manner. System scalability will be demonstrated in Phase II with the addition of more loops to expand the LOT coverage area.

Position Accuracy Within ±7.5 Meters

LOT determines position based on initial detection of an aircraft or ground vehicle. Ideally, this detection occurs as soon as the aircraft enters the loop just over the hold line. Initial detection occurs when the inductance measured by the detector exceeds a detection threshold. Detection typically occurs soon after the aircraft's nose or ground vehicle's front bumper crosses the wires at the loop entry point. Preliminary indications are that the ±7.5 meters can be achieved. Testing with small aircraft and ground vehicles results in accuracy performance better than ±2 meters.

Position Reported Within One Second of Passage Through Sensing Area

LOT provides an indication of detection prior to the aircraft transversal of the loop or sensor area, thus exceeding the requirement. A demanding application for latency is safety zone violation detection. Detection should occur soon after the aircraft proceeds from a stop at the hold line and the nose enters the runway safety zone. Initial testing has shown that detection will occur within four seconds for aircraft. This time is expected to improve to less than two seconds when the detector is re-configured for improved sensitivity in Phase II.

Classification to Four Weight Classes - Probability of Correct Classification > .9

Testing has been performed to demonstrate classification by aircraft type (e.g., B-737, MD-80) as opposed to weight class (i.e., heavy, large, small). Classification by type is a more demanding application. Figure 7 provides sample signatures. Both the heavy and large aircraft tend to have a peak inductance change associated with the wings. The level segment in front of the peak is associated with the fuselage. The gently sloping segment after the peak is associated with the fuselage and the tail. Unlike the large and heavy aircraft, small aircraft signatures tend not have a level segment in front of the peak associated with the wing. However, in many cases a segment associated with the small aircraft tail is identifiable. Large ground vehicles will give a single peak with no identifiable leading or trailing segments. Small ground vehicles will give a double peak signature. Initial testing indicates that many large and heavy aircraft can be classified by type. However, small aircraft classification by type may be difficult. The small aircraft signatures tend to be similar to each other, thus making it difficult to discriminate. However, small aircraft signatures are distinct from signatures of other aircraft classes. LOT can differentiate between ground vehicles and aircraft. While aircraft type information is desirable, it is not essential for an operational system. The goal for the LOT project is to classify traffic in one of the following categories: heavy aircraft, large aircraft, small aircraft, and ground vehicles. Neural network logic has been modified to perform classification by category as opposed to type. Classification performance testing will be performed in Phase II.

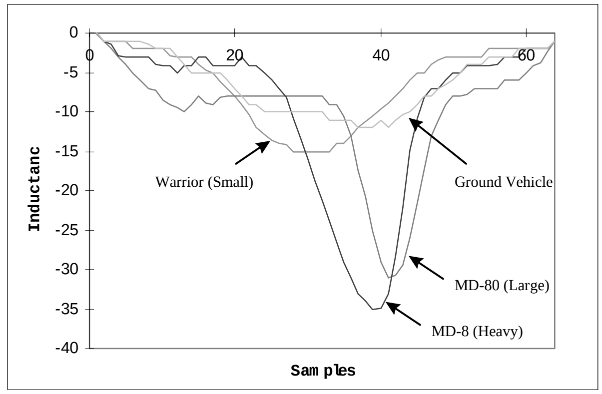

Figure 7. Aircraft and Ground Vehicle Signatures

Provide Velocity Measured for Speeds up to 20 Meters per Second

Velocity was measured for speeds up to 50 meters/sec. The primary means for estimating velocity is the two-loop method. An estimate of velocity is performed each time that an aircraft crosses any two consecutive loops. The speed is calculated using time between loop pairs and distance traveled equal to the separation between loops. Typical loop separations are 300 to 500 feet. Heading is determined from the loop crossing sequence. A second method for estimating velocity is the single-loop method, which is applied for taxi scenarios (e.g., aircraft stops between loops then moves again) where the two-loop method can not be used. Distance traveled equals aircraft length, and time equals single loop crossing time. Aircraft length is obtained via a database lookup, which is performed upon classification.

Velocity Accuracy Within ±2 Meters per Second for Velocities Exceeding 5 Meters per Second

Velocity is estimated using either the single-loop method or the two-loop method. The single-loop method has demonstrated velocity accuracy performance better than 5 meters/sec. for small aircraft. However, accurate classification to aircraft type is critical to achieving a high degree of accuracy. An assessment of the two-loop method has not been performed. Two factors that influence the accuracy of the two-loop method are variability in point of detection and vehicle dynamics. Vehicle dynamics will have the biggest influence on accuracy. For instance, an aircraft that changes acceleration between loops will introduce errors in the velocity estimate.

Indicated Direction is Correct Within ±89 Degrees

Reliable direction determination was demonstrated. The system determines direction of travel when an aircraft crosses two consecutive loops. The heading is assumed to be parallel to the pavement centerline in the direction of travel. Classification information is used to confirm that any two consecutive crossings are from the same aircraft. Taxiing with frequent stops is common for many airports. The system maintains knowledge of an aircraft's presence in the zone between loops, which is used to determine direction when the aircraft crosses the next loop. Testing was performed to determine if a single loop could be used to provide direction determination. Several loop shapes were tried, but single-loop direction determination was not demonstrated.

Conclusions

The initial evaluations have demonstrated that LOT can provide reliable aircraft and ground vehicle detection. Airport surface surveillance requires large loop sizes which places demands on detector sensitivity performance. Sufficient sensitivity is required to ensure reliable detection and classification. Initial indications are that the system can achieve the RTCA recommended requirements. The overall viability of LOT as an alternative airport surface surveillance will be demonstrated in Phase II. In particular, classification and detection of runway safety zone violations will be demonstrated. System performance will be evaluated against RTCA and International Civil Aviation Organization (ICAO) Advanced Surface Movement Guidance and Control Systems draft requirements [Ref. 8].

Acknowledgements

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