DOT/FAA/AR-11/13

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Performance Assessment of an Electro-Optical-Based Foreign Object Debris Detection System

March 2012

Final Report

U.S. Department of Transportation
Federal Aviation Administration

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-11/13		

4. Title and Subtitle	5. Report Date
PERFORMANCE ASSESSMENT OF AN ELECTRO-OPTICAL-BASED FOREIGN OBJECT DEBRIS DETECTION SYSTEM	March 2012
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Edwin E. Herricks*, Peter Lazar III*, Elizabeth Woodworth*, and James Patterson, Jr.**	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
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12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration William J. Hughes Technical Center Aviation Research Division Airport Technology Branch Atlantic City International Airport, NJ 08405	Final Report
	14. Sponsoring Agency Code AAS-100

15. Supplementary Notes

The Federal Aviation Administration Airport and Aircraft Safety R&D Division COTR was James Patterson.

16. Abstract

In 2008, the Federal Aviation Administration (FAA) Airport Technology Research and Development Team conducted a performance assessment of the iFerret™, electro-optical, foreign object debris (FOD) detection system. This assessment included the system's capability to detect objects of various shapes, sizes, and materials at all locations on the runway surface. The system's capability to detect FOD during both nighttime and daytime conditions, in periods of sun, rain, mist, fog, and snow was also assessed.

A comprehensive performance assessment of the technology was demonstrated at the Chicago O'Hare International Airport (ORD). Installation of iFerret sensors was completed at ORD in late 2008, and extensive data collection was conducted from June 2009 through July 2010. These were supplemented by an assessment of an iFerret installation at Singapore's Changi International Airport in May 2009. At the conclusion of the data collection process, the FAA had sufficient data to conclude the performance assessment. The iFerret FOD detection system was able to detect objects of various shapes, sizes, and materials on runway surfaces, taxiways, and aprons and was able to perform satisfactorily in nighttime, daytime, sun, rain, mist, fog, and snow conditions, as required by FAA Advisory Circular 150/5220-24, "Airport Foreign Object Debris (FOD) Detection Equipment."

17. Key Words	18. Distribution Statement
Foreign object debris, Radar, Performance Assessment, Optical sensors, Intelligent vision, O'Hare, Airport FOD detection	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	41	

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LIST OF ACRONYMS

AC	Advisory Circular
AOA	Airport operations area
CEAT	Center of Excellence for Airport Technology
FAA	Federal Aviation Administration
FOD	Foreign object debris
GPS	Global positioning system
GUI	Graphical user interface
ORD	O'Hare International Airport
SIN	Singapore's Changi International Airport
UI	User interface

EXECUTIVE SUMMARY

In fiscal year 2008, the Federal Aviation Administration (FAA) Airport Technology Research and Development Team initiated research to conduct a performance assessment of the iFerret™ electro-optical foreign object debris (FOD) detection system. Following a preliminary demonstration in April 2007 at Singapore's Changi International Airport (SIN), the University of Illinois Center of Excellence for Airport Technology (CEAT) submitted documentation to seek approval for installation at Chicago O'Hare International Airport (ORD) in September 2007.

Installation of the iFerret at ORD was completed in late 2008. Installation and preliminary testing continued in 2009. The performance assessment program was implemented in May 2009 with a testing schedule intended to evaluate detection performance under typical airport operational conditions and under different environmental conditions. An additional program was also implemented in May 2009 at SIN. As part of the FAA Airport Safety Technology Research and Development program, research teams from the CEAT developed the performance assessment protocol and implemented test procedures appropriate to the technology and the specific airport setting.

This report reviews the performance assessment of the iFerret. Performance requirements are based on FAA Advisory Circular (AC) 150/5220-24, "Airport Foreign Object Debris (FOD) Detection Equipment," which details parameters for a FOD detection system's basic functions, detection performance, and system output.

The iFerret system performed according to the manufacturer's specifications and met performance requirements identified in AC 150/5220-24. For basic functions, the iFerret FOD detection system

- provided surveillance in the aircraft operations area (AOA) as specified by the airport.
- detected and located single and multiple FOD items on the AOA.
- provided an alert to the user when FOD was detected.
- operated in conjunction with, and did not interfere with, airport and aircraft communication, navigation, and surveillance systems.
- operated in conjunction with, and without interference from, normal airport and aircraft operations.
- provided a data record of detected FOD, allowing for equipment calibration and maintenance and for analysis of the FOD event.

In the area of detection performance, the iFerret FOD detection system

- met requirements for location accuracy.
- met requirements for inspection frequency.
- provided surveillance of an entire runway.
- met specifications for clear weather, dry pavement conditions with a standard target detection rate of 94%.
- met specifications for the detection of FOD objects with 100% detection of the objects in a 100-ft by 100-ft rectangle with items placed no more than 10 ft apart.
- provided alerts of FOD presence on the runway and provided location information to facilitate removal.

For system output, CEAT testing revealed that the iFerret detection system

- provided a digital data record of operations that included an alert time and date and the location of the FOD object.
- provided digital data that could be presented in a number of formats.
- provided digital data suitable for management and that can meet the needs of multiple airports.

1. INTRODUCTION.

As part of the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development Program, the University of Illinois Center of Excellence for Airport Technology (CEAT) has been supporting the research and development activities at the FAA William J. Hughes Technical Center for more than 10 years. In 2004, the FAA initiated research to assess foreign object debris (FOD) detection systems. The system that is the subject of this assessment is the iFerret™, an electro-optical FOD detection system. In April and July 2007, CEAT conducted a preliminary assessment of the FOD iFerret at Singapore's Changi Airport (SIN). Based on the positive findings from the preliminary assessment, CEAT and the FAA developed plans to install the iFerret at the Chicago O'Hare International Airport (ORD) in Chicago, Illinois. Installation of the iFerret was completed at ORD in late 2008. A performance assessment program was implemented in late 2008 with a test schedule intended to evaluate detection performance under typical airport operational conditions and under different environmental conditions. In addition to ORD, performance assessments were also conducted at SIN. Test campaigns at both airports were conducted in May 2009 and July 2010. The CEAT research team developed performance assessment protocols and implemented test procedures appropriate to the technology and the specific airport setting.

2. OBJECTIVE.

The overall objective of the assessment was to determine the performance of the iFerret and to develop requirements and standards for FOD detection technologies. With publication of Advisory Circular (AC) 150/5220-24 [1], performance requirements were identified by the FAA. This report describes the performance of the iFerret and considers if the assessment data is relevant to the requirements described in the AC for electro-optical-based systems.

3. PERFORMANCE REQUIREMENTS FOR FOD DETECTION SYSTEMS.

In September 2009, the FAA published AC 150/5220-24. This AC established specifications, as shown in table 1, for a range of FOD detection technologies, including:

- an electro-optical system, such as the iFerret
- a radar-based FOD detection system
- an electro-optical and radar-based hybrid system
- a mobile, radar-based system

The requirements in AC 150/5220-24 for an electro-optical-based system are used in this report as a focus of the performance assessment of the iFerret and provide the performance criteria to which the technology should be evaluated to demonstrate compliance with the AC. The FOD items used in the tests were selected based on sensor characteristics conforming to the AC requirements for this technology.

Table 1. AC 150/5220-24 Performance Requirements

AC Category	AC Performance Requirements for FOD Detection Systems
Basic Functions	Equipment must perform the following functions: 1. Provide surveillance in the airport operations area as specified by the airport. 2. Detect and locate single and multiple FOD items on the airport operations area. 3. Provide an alert to the user when FOD has been detected. 4. Operate in conjunction with, and not interfere with, airport and aircraft communication, navigation, and surveillance systems. 5. Operate in conjunction with, and without interference from, normal airport and aircraft operations (e.g., aircraft and vehicle movements). 6. Provide a data record of the detected FOD, allowing for equipment calibration and maintenance, and analysis of the FOD event.
Detection Performance: Object Detection	Systems must be able to detect the following objects (mobile systems must provide this performance at a minimum speed of 20 mph (30 km/h)): 1. An unpainted metal cylinder measuring 1.2 in. (3.1 cm) high and 1.5 in. (3.8 cm) in diameter 2. A white, gray, or black sphere measuring 1.7 in. (4.3 cm) in diameter (i.e., a standard size golf ball) 3. 90% of the following objects when placed within a 100- by 100-ft (30- by 30-m) square in the desired coverage area. One item from each category must be included in the group, and each item must measure no more than 4 in. (10 cm) in any dimension, unless otherwise specified: • a chunk of asphalt or concrete • any portion of a runway light fixture (in-pavement or edge light) • an adjustable crescent wrench up to 8 in. (20 cm) long • a deep socket at least 2 in. (5 cm) in length • a piece of rubber from an aircraft tire • a distorted metal strip up to 8 in. (20 cm) in length • a fuel cap (aircraft or automotive) • a lug nut • a hydraulic line (from aircraft or ground support equipment) up to 8 in. (20 cm) in length • a white PVC pipe 2 in. (5 cm) in diameter 4. Any two of the objects above, located no more than 10 ft (3 m) apart from each other, identified as separate objects.

Table 1. AC 150/5220-24 Performance Requirements (Continued)

AC Category	AC Performance Requirements for FOD Detection Systems
Detection Performance: Location Accuracy	Systems must provide location information for a detected object that is within 16 ft (5.0 m) of the actual FOD object location. Note: This standard is based on the average accuracy of hand-held GPS devices, which most airport operators use when retrieving detected FOD. Airport operators using nonvisual detection systems, who require greater location accuracy, can procure optional components that enable the system to have visual detection capabilities.
Detection Performance: Inspection Frequency	For continuous detection systems—The system must provide continuous operation from fixed sensors to allow for the continuous inspection of runway surfaces during flight operations. The duration of flight operations is dependent on the airport and specified by the user. For mobile detection systems—The system must provide a mobile operations capability to enhance mandated airport safety self-inspections (per AC 150/5200-18 [2]). The frequency of inspections is dependent on the airport and specified by the user.
Detection Performance: Detection Response Time	Systems must have the capability to provide rapid detection of a FOD occurrence in the area being scanned. For continuously operating FOD detection systems designed to provide between-movement alerts—The system must provide inspection of runway surfaces between aircraft movements. For other continuously operating FOD detection systems—The system must provide inspection updates as specified by the airport, generally within 4 minutes of a FOD occurrence.
Detection Performance: Surveillance Area	The airport operator will specify the desired surveillance (detection) area in the airport operations area requiring FOD detection. This area is generally based on the airport's FOD management plan. The primary area of coverage is the runway; certain portions of the runway may be specified by the airport operator if full coverage is not feasible. Other areas are of less importance, with a decreasing level of priority from other paved movement areas down to nonpaved, nonmovement areas. The manufacturer of a FOD detection system must notify the airport operator of any locations within the specified surveillance area where detection would not be possible.

Table 1. AC 150/5220-24 Performance Requirements (Continued)

AC Category	AC Performance Requirements for FOD Detection Systems
Detection Performance: Performance in Weather	Systems must demonstrate detection performance under clear and inclement weather conditions. Under clear weather conditions, the pavement of the airport operations area is expected to be dry; under inclement weather conditions, the pavement will be wet with rain, snow, or mixed precipitation. 1. Objects must be detected under rain or snow conditions (e.g., having a specific intensity, duration, and frequency) for a 2-year category of storm in the local region, as specified in CLIM 20, Climatology of the United States No. 20 [3]). More stringent requirements may be specified by the user. 2. Systems must have site-specific performance specifications that include: • performance during clear weather conditions. • performance during inclement weather conditions. • amount of time required for the system to recover after a rain or snow storm (e.g., to return to clear-weather performance capabilities after adverse weather conditions subside, defined as when precipitation of rain or snow ends.) All systems must demonstrate detection performance during daylight, nighttime, and dawn/dusk operations.
System Performance: Alerts and Alarms	Systems must be able to alert the system operator to the presence of FOD in scanned areas, providing airport management with enough information to assess the severity of the hazard to determine if immediate object removal is necessary. • False alarms (an alert causing the airport operator to take action to remove a FOD object that does not exist) should be minimized and must not exceed: – For systems with visual detection capabilities, one per day as averaged over any 90-day period. – For systems without visual detection capabilities, three per day as averaged over any 90-day period. Note: Some small items may be moved by wildlife or blown away before airport operators have a chance to investigate FOD alerts.

Table 1. AC 150/5220-24 Performance Requirements (Continued)

AC Category	AC Performance Requirements for FOD Detection Systems
System Output: Detection Data	All systems must automatically provide a data record on detected FOD. 1. Records must contain: • alert time and date • location of FOD object 2. Capturing the following information is recommended, but not required: • Description of FOD detected or retrieved (e.g., size, name, type, serial number) • Time and date of FOD retrieval • Time and date of disposition of alert • Name of personnel detecting/investigating FOD item • Image of the FOD object retrieved (if available) • Chain of custody information
System Output: Data Presentation	FOD detection data can be provided in a coordinate scheme, on maps of the airport, in an operator's console, or broadcast to mobile units. The selection of information options will be specified by the airport, consistent with airport systems operations.
System Output: Data Management	Data collected in the FOD detection process should be digitally recorded. Data systems should have the capability to retain the data for at least 2 years after the detection event.

GPS = Global positioning system
PVC = Polyvinyl chloride

4. iFERRET CHARACTERISTICS AND SPECIFICATIONS.

The iFerret is based on optical/video sensors mounted in a scanner unit located on a tower as much as 500 ft (175 m) from the surface to be scanned. The sensor is a video camera with optical-zoom capability supported by image-processing software. The iFerret provides continuous surveillance of scanned surfaces with multiple sensors providing surveillance along the length of the runway, figure 1. The iFerret is designed to sweep along the length of the runway with each sensor covering approximately 1100 ft (330 m) of the runway surface, figure 2. The iFerret surveillance capabilities include more than runways. Depending on installation objectives, iFerret sensors also operate on taxiways, aprons, and in ramp areas. In runway surveillance applications, the iFerret provides scanning intervals at as little as 70 seconds. The iFerret provides a high-resolution image of FOD on airport surfaces and high-speed detection of FOD.

Figure 1. iFerret Sensors Located at ORD Between Runway 27L and Taxiway MM

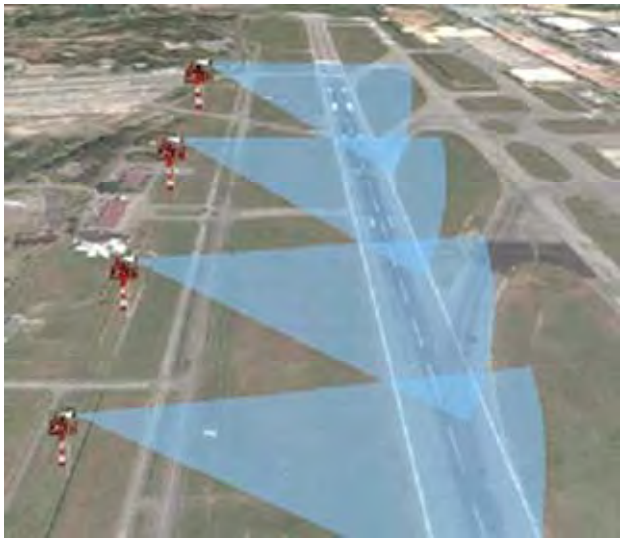

Figure 2. Typical iFerret Installation Illustrating how Multiple Sensors Operate to Provide Surveillance Along the Length of a Runway

The iFerret sensor is passive, using only ambient lighting, and is capable of detecting small FOD items under all lighting conditions. The system uses the manufacturer's proprietary image-processing software, which interprets the data provided by the system's cameras. When FOD is detected, the iFerret operator receives an audio and visual alert. With an alert, the iFerret's user interface (UI) supports operator analysis of the target to confirm the presence of FOD and support hazard assessment. The UI information includes the location of the FOD and a video

image of the target. Sensor zoom capabilities provide detailed images of the items producing the alert. The primary performance criterion for the iFerret is detection of a 1.7-in. (4.3-cm) spherical target on the runway.

5. iFERRET INSTALLATION AT ORD AND SIN.

The iFerret installation at ORD consisted of two sensor units, mounted on a single tower, scanning a portion of Runway 27L and a portion of Taxiway MM, figure 3. The installation scanned approximately 275 ft (84 m) of Runway 27 L and a 185-ft (56-m) section of Taxiway MM. In addition to the installation at ORD, CEAT was able to conduct a performance assessment of the iFerret installation at SIN. The combination of airport assessments allowed single-sensor testing at ORD and iFerret testing at SIN, where it was possible to assess multiple sensor integration when targets are placed beyond the expected detection range of a single sensor. At SIN, the sensors were located to provide a single-sensor scan of 1100 ft (330 m) between runway edge lines. A total of 12 sensors were installed along the 12,000-ft (4,000-m) total length of the two primary runways at SIN.

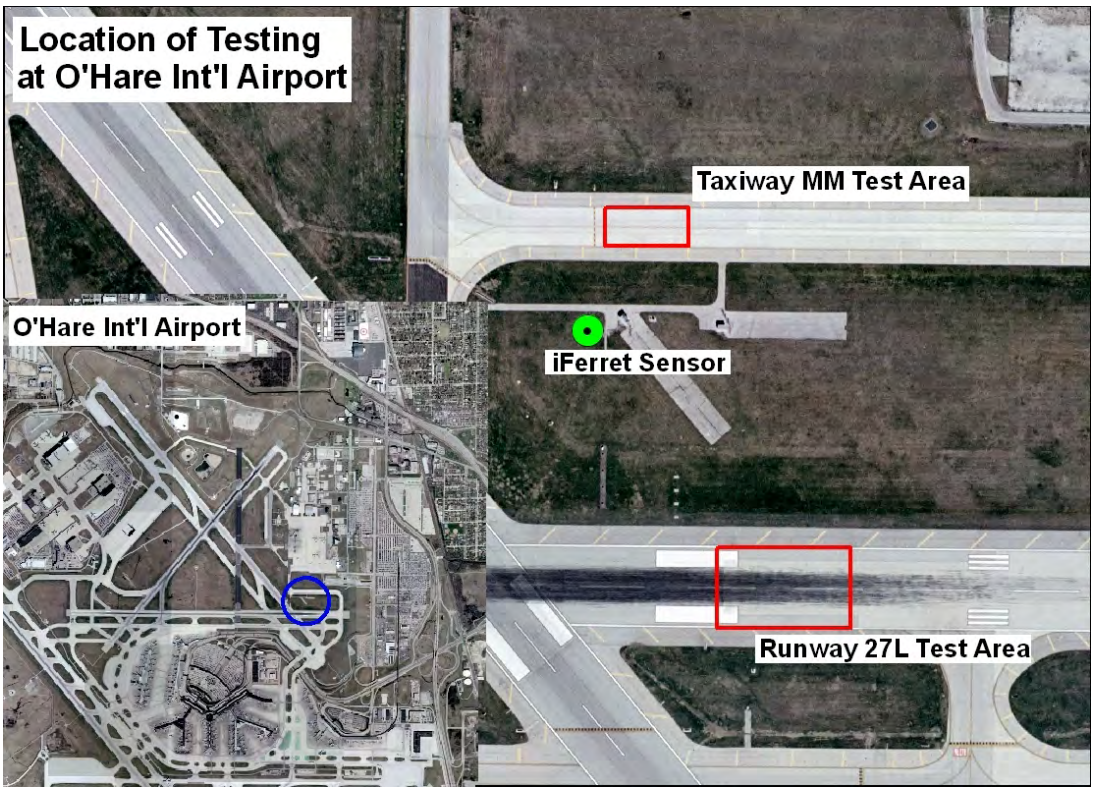

Figure 3. Composite Images Showing iFerret Installation at ORD

6. iFERRET ASSESSMENT PROTOCOLS.

6.1 THE FOD TEST ITEMS.

To meet the performance requirements of AC 150-5220-24, as shown in table 1, a performance assessment was conducted of the system's ability to detect an unpainted metal cylinder

measuring 1.2 in. (3.1 cm) high and 1.5 in. (3.8 cm) in diameter, and white, grey, or black spheres measuring 1.7 in. (4.3 cm) in diameter (i.e., a standard size golf ball). As part of the long-term test program, AC 150/5220-24 requires that a set of FOD items that are technology-specific items be selected to challenge the system's performance. The FOD items used in this portion of the performance assessment are called standard targets. CEAT confirmed that the standard targets selected for the iFerret system performance assessment conformed to the specifications provided in the AC. The standard target was a painted sphere (golf ball) measuring 1.7 in. (4.3 cm) in diameter. An array of standard targets consisted of a group of three spheres on a line, with a black, a grey, and a white sphere placed at 1.5 ft (0.5 m) intervals, as shown in figure 4. The different colored spheres were used to evaluate the contrast between the runway and the target and provided a visual challenge for the system under different lighting conditions. In all the tests, detections were scored based on identification of each of the individual targets on the line, not the array of three. This is considered a conservative approach to detection because it might be expected that detection of a single object, located near another object, would support removal of both objects.

Figure 4. Standard Targets Used to Assess the iFerret

6.2 RUNWAY AND TAXIWAY TEST LOCATIONS.

The ORD assessment procedures were designed to test sensor performance, so all targets were placed within an expected single-sensor coverage area. The SIN assessment was designed to assess system performance; therefore, targets were placed in the area scanned by a single sensor, and additional targets were placed a minimum of 30 ft (10 m) from the expected single-sensor scanning zone to assess system redundancy and sensor integration. In the assessments at ORD and SIN, the iFerret was operated in an engineering mode so that full information on detected items was retained and could be used in the detection analysis.

Testing at ORD was conducted on Runway 27L, with a nominal test rectangle dimension of 275 ft (82 m) long by 150 ft (48 m) wide (figure 5) and Taxiway MM, with a nominal test rectangle dimension of 185 ft (56 m) long by 35 ft (10 m) wide (figure 6). Targets were placed on marked locations on a detection grid for Runway 27 L (figure 7) and Taxiway MM (figure 8).

The distance to target locations varied from approximately 175 ft (53 m) for the location nearest the sensor to 715 ft (218 m) for the corner locations at the greatest distance from the sensor (figure 8).

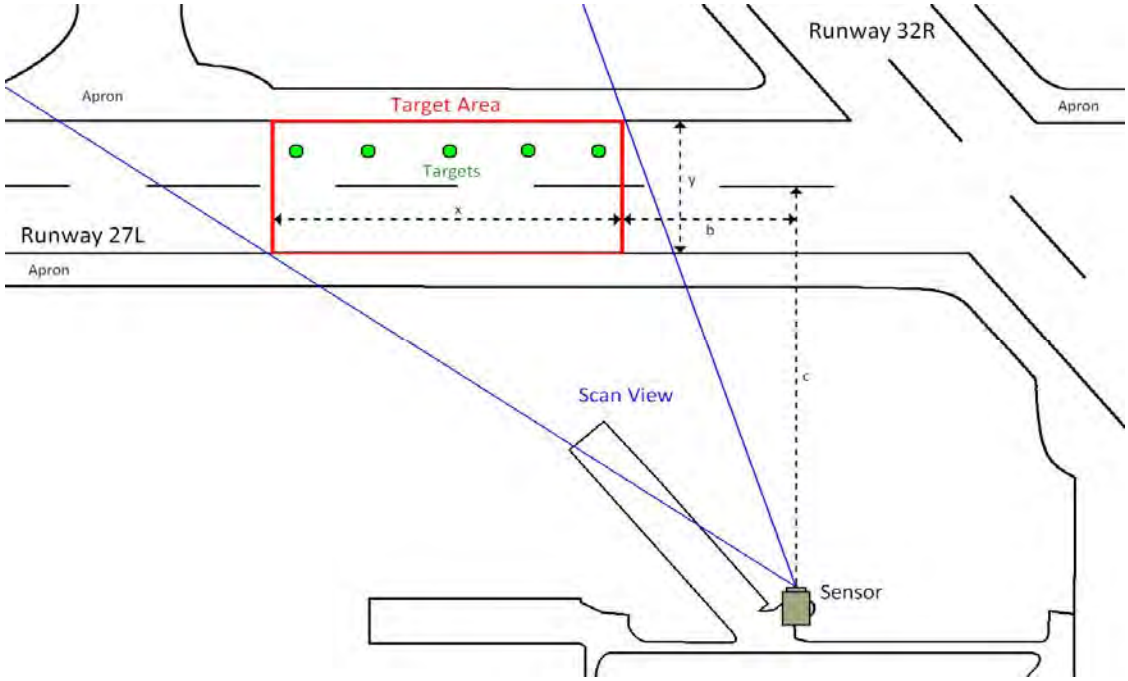

Figure 5. Location of Sensor for Runway 27L at ORD Showing the Test Rectangle Where the Targets Were Located

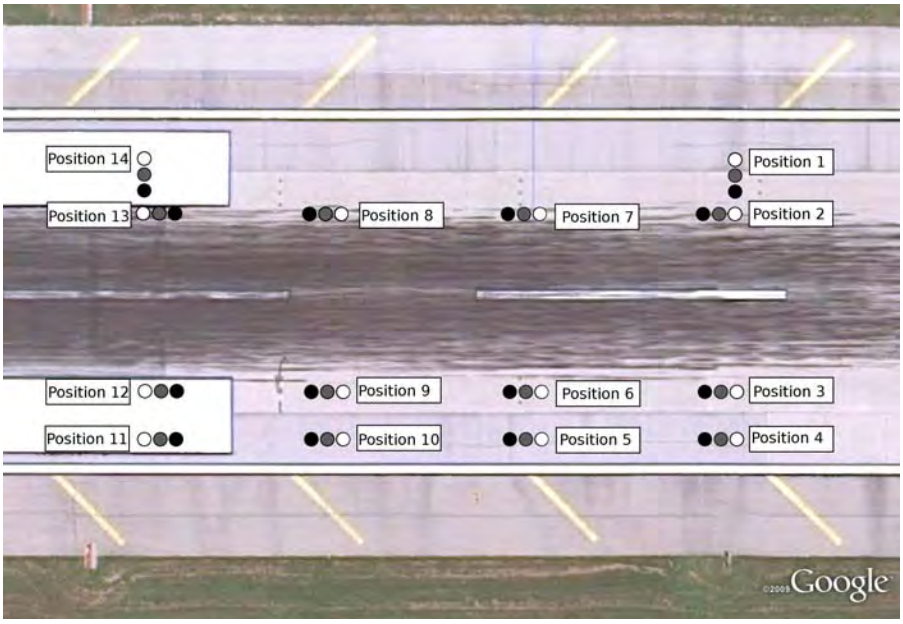

Figure 6. Target Locations in the Test Area on Runway 27L at ORD

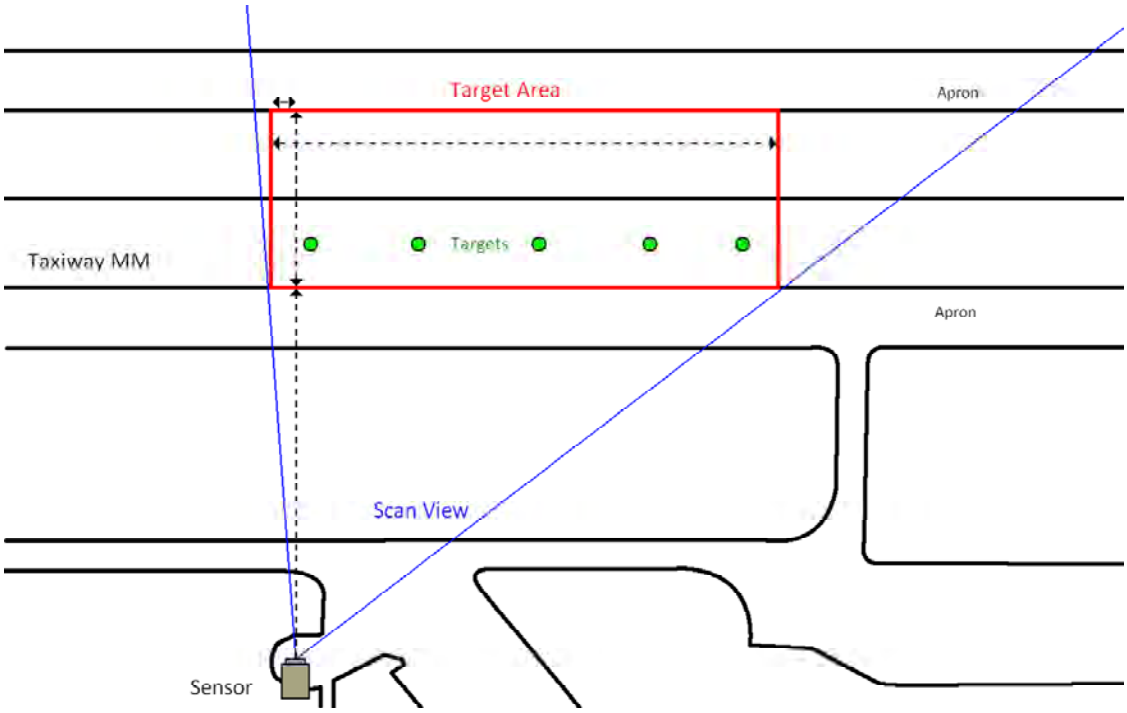

Figure 7. Location of Sensor for Taxiway MM at ORD Showing the Test Rectangle Where the Targets Were Located

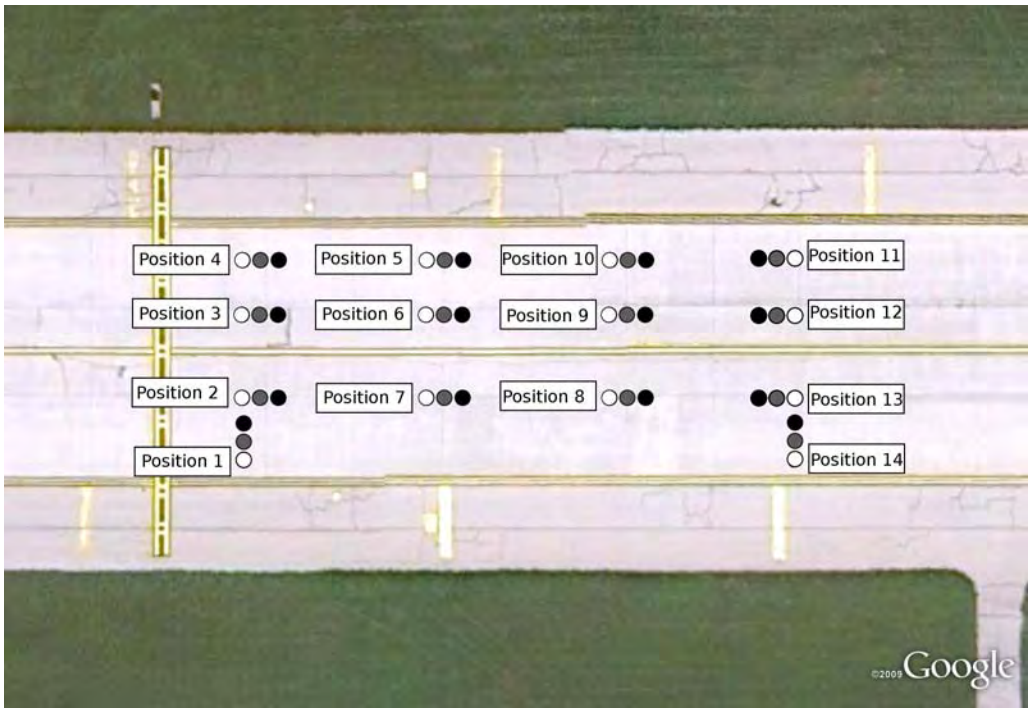

Figure 8. Target Locations on Taxiway MM at ORD

At SIN, the test rectangle was 1100 ft (330 m) long and 197 ft (60 m) wide with minimum and maximum distances of 673 ft (205 m) and 997 ft (300 m), respectively. In this rectangle, a 10-by-4 position grid was established, with positions marked 100 ft (30 m) apart along the length of the runway (figure 9). At each position along the length of the runway, four positions across the width of the runway were also marked. Thus, the grid had 10 "columns" of 4 locations for a total of 40 target locations.

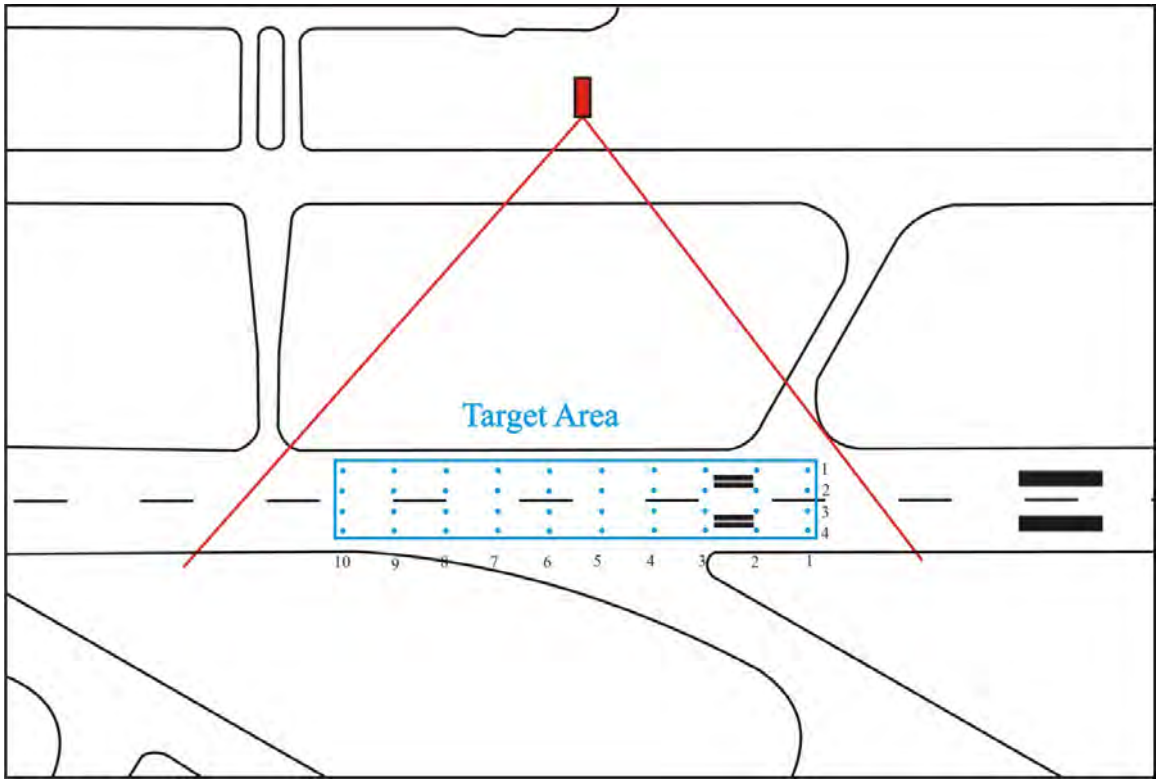

Figure 9. Runway Test Locations at SIN Based on Using a Single Sensor With Target Placement Testing Adjacent Sensors

6.3 PERFORMANCE ASSESSMENT METHODS.

Final assessment procedures were developed to accommodate the specific capabilities of the iFerret.

6.3.1 Targets.

Targets conformed to AC 150/5220-24 specifications and were approved by Stratech as appropriate for the sensor technology. The performance assessment procedure developed by CEAT used the same target type for all assessments. When testing was conducted periodically over several months, a calibration/intercalibration result was achieved that provided assurance of the system's functioning.

6.3.2 Test Methods.

Test procedures were standardized for all performance assessment test campaigns. The sensor made a clear-field scan and then stopped. Targets were then placed as discussed previously, and the iFerret scan was initiated, which requires the movement of the sensor (pan) across an area of the runway. At ORD, the length of the area scanned was 275 ft (82 m), and at SIN, the length of the area scanned was 1100 ft (330 m). Although the iFerret was operated in an engineering mode, normal operation was used during the performance assessments, in that target presence was reported, but the scan continued. After a scan or an alert, the sensor could be positioned to verify object characteristics.

6.3.3 Location Accuracy.

AC 150/5220-24 contains specifications for FOD detection system location accuracy. To assess location accuracy, each target position was surveyed using a Leica Geosystems RX 1250 SmartRover and differential global positioning system (GPS), with an accuracy of millimeters in the X/Y plane. Each location was then compared to the latitude and longitude provided by the iFerret for each target.

7. iFERRET PERFORMANCE ASSESSMENT RESULTS AND DISCUSSION.

7.1 SUMMARY OF STANDARD TARGET DETECTION.

The test results for the iFerret standard target detections under dry pavement conditions for all test campaigns are presented in tables 2 and 3.

Table 2. Summary of Detection of all Standard Targets at ORD

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	400	388	97
Gray	400	363	91
White	400	377	94
Total	1200	1128	94

Table 3. Summary of Detection of all Standard Targets at SIN

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	397	385	97
Gray	398	369	92.7
White	399	399	100
Total	1194	1153	96.6

7.2 TARGET DETECTION DETAILS.

Because runway and taxiway locations were serviced by different sensors with different ranges-to-targets and different test conditions (daytime and nighttime testing), tables 4 and 5 show standard target detection by target color and runway or taxiway at ORD.

Table 4. Detection of Standard Targets by Color on Runway 27L

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	140	132	94
Gray	140	120	86
White	140	120	86
Total	420	372	89

Table 5. Detection of Standard Targets by Color on Taxiway MM

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	260	256	98
Gray	260	243	93
White	260	257	99
Total	780	756	97

Because range-to-target may be important in target detection, tables 6 and 7 show the detection results for all test campaigns by test location on the runway and taxiway. Note, these tables contain data from night and dawn runway tests.

Table 6. Detection of Standard Targets by Position on Runway 27L

Position	Number of Targets	Number of Detections	Percentage of Detections
1	42	37	88
2	42	37	88
4	42	38	90
5	42	34	81
7	42	36	86
8	42	38	90
10	42	37	88
11	42	37	88
13	42	40	95
14	42	38	90
Total	420	372	89

Table 7. Detection of Standard Targets by Position on Taxiway MM

Position	Number of Targets	Number of Detections	Percentage of Detections
1	78	78	100
2	78	77	99
4	78	75	96
5	78	73	94
7	78	78	100
8	78	78	100
10	78	75	96
11	78	71	91
13	78	77	99
14	78	74	95
Total	780	756	97

Various lighting conditions can have an influence on the detection capability of electro-optical FOD detection systems due to the changes in contrast that the system must process. The standard targets that were selected for assessing the iFerret provided a range in the level of contrast the targets had with the pavement, the background, weather conditions, and varying lighting conditions, including shadowing at different times of day. The assessment was designed to create challenges for the iFerret, including testing the system in daylight, at night, and during dawn and dusk when lighting conditions changed the most. The test results for this part of the assessment are shown by target color and by target position in tables 8 through 14.

Table 8. Daytime Detection of Standard Targets by Color on Taxiway MM

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	90	90	100
Gray	90	90	100
White	90	90	100
Total	270	270	100

Table 9. Daytime Detection of Standard Targets by Location on Taxiway MM

Position	Number of Targets	Number of Detections	Percentage of Detections
1	27	27	100
2	27	27	100
4	27	27	100
5	27	27	100
7	27	27	100
8	27	27	100
10	27	27	100
11	27	27	100
13	27	27	100
14	27	27	100
Total	270	270	100

Table 10. Nighttime Detection of Standard Targets by Color for ORD Runway and Taxiway Locations

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	220	208	95
Gray	220	183	83
White	220	200	91
Total	660	591	90

Table 11. Nighttime Detection of Standard Targets by Color on Runway 27L

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	120	112	93
Gray	120	100	83
White	120	101	84
Total	360	313	87

Table 12. Nighttime Detection of Standard Targets by Color on Taxiway MM

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	100	96	96
Gray	100	83	83
White	100	99	99
Total	300	278	93

Table 13. Nighttime Detection of Standard Targets by Position on Runway 27L

Position	Number of Targets	Number of Detections	Percentage of Detections
1	36	31	86
2	36	31	86
4	36	32	89
5	36	28	78
7	36	30	83
8	36	32	89
10	36	31	86
11	36	31	86
13	36	34	94
14	36	33	92
Total	360	313	87

Table 14. Nighttime Detection of Standard Targets by Position on Taxiway MM

Position	Number of Targets	Number of Detections	Percentage of Detections
1	30	30	100
2	30	30	100
4	30	27	90
5	30	25	83
7	30	30	100
8	30	30	100
10	30	27	90
11	30	23	77
13	30	30	100
14	30	26	87
Total	300	278	93

The changing light conditions of dawn and dusk present particular challenges to electro-optical systems and were the focus of specific testing. Table 15 summarizes the near-dawn tests for both runway and taxiway locations. Tables 16 and 17 show detections by target color for near-dawn tests on Runway 27L and Taxiway MM.

Table 15. Detections by Target Color for Near-Dawn Tests for Both Runway and Taxiway Locations at ORD

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	59	58	98
Gray	60	57	95
White	60	59	98
Total	179	174	97

Table 16. Detections by Target Color for Near-Dawn Tests on Runway 27L

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	19	19	100
Gray	20	20	100
White	20	19	95
Total	59	58	98

Table 17. Detections by Target Color for Near-Dawn Tests on Taxiway MM

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	40	39	98
Gray	40	37	93
White	40	40	100
Total	120	116	97

A series of tests was conducted at ORD at dusk on Taxiway MM. Table 18 summarizes the test results.

Table 18. Detections by Target Color for Dusk Tests on Taxiway MM

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	80	79	99
Gray	80	78	98
White	80	78	98
Total	240	235	98

7.3 LOCATION ACCURACY.

During the location accuracy tests, the iFerret FOD detection system reported and recorded the location of the target that it detected. The accuracy of the system was calculated by finding the difference between the system's reported detection location for a target and the surveyed location of the target, as measured with CEAT's portable differential GPS unit. This test was conducted

during three test campaigns. The results of the location accuracy tests are shown in table 19, including the maximum and minimum differences between the iFerret's reported location and the differential GPS surveyed location and the average differences during each of the test campaigns. The average difference between the surveyed location and the location reported by the iFerret was 0.82 ft (0.25 m). The maximum difference between the surveyed location and the location reported by the iFerret was 1.56 ft (0.48 m). The minimum difference between the surveyed location and the reported location was 0.33 ft (0.1 m).

Table 19. Location Accuracy Based on Comparing Surveyed Location and Position Reported by the iFerret System

Test	Maximum (ft)	Minimum (ft)	Average (ft)
1	1.10	0.37	0.77
2	1.35	0.35	0.82
3	1.56	0.33	0.87

7.4 DETECTION UNDER VARIABLE WEATHER CONDITIONS.

The performance assessment program at ORD was planned over approximately 1 year so that assessments could be made under different environmental and weather conditions. The test campaign schedule was coordinated with the operations department at ORD to provide CEAT with the opportunity to use a closed runway for the test campaigns. If the runway was available during the test campaign, CEAT would use the runway. In the event the runway was not available, CEAT would use taxiway MM for the test. At ORD, using the taxiway offered more flexibility due to lesser traffic and longer time periods of accessibility. All test scheduling was made with the expectation that adverse or inclement weather would occur during one or more of the scheduled test periods. In addition to the scheduled test campaigns, CEAT also implemented special test campaigns that were scheduled with just a few day's notice based on weather forecasts for unique weather opportunities. This allowed performance assessment data to be collected during wet pavement (rain) and snow- and ice-covered pavement conditions. By the end of the performance assessment of the iFerret, wet pavement conditions were assessed for both runway and taxiway locations, while snow/ice conditions were only assessed on the taxiway. Tables 20 through 22 provide detection information during wet pavement (rain) and ice- and snow-covered pavement conditions.

Table 20. Detections in Inclement Weather at ORD

Pavement Condition	Number of Placements	Number of Detections	Percentage of Detections
Wet	162	134	83
Snow and ice	192	184	96

Table 21. Detections by Target Color Under Wet Pavement (Rain) Conditions at ORD

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	54	46	85
Gray	54	44	81
White	54	44	81
Total	162	134	83

Table 22. Detections by Target Color With Pavement Contaminated on Snow- and Ice-Covered Pavement at ORD

Target Color	Number of Targets	Number of Detections	Percentage of Detections
Black	64	64	100
Gray	64	64	100
White	64	56	88
Total	192	184	96

8. iFERRET DETECTION OF STANDARD FOD ITEMS AS REQUIRED BY AC 150/5220-24.

The specifications and criteria provided in AC 150/5220-24 include the requirement that the manufacturer of a FOD detection system demonstrate detection performance with targets that simulate actual FOD items. As specified in the AC, the FOD detection system should detect 90% of the following group of objects when placed within a 100- by 100-ft (30- by 30-m) square in the desired coverage area. (Note: one item from each category must be included in the group, and each item must measure no more than 4 in. (10 cm) in height, width, or length unless otherwise specified.):

- A chunk of asphalt or concrete
- Any portion of a runway light fixture (in-pavement or edge light)
- An adjustable crescent wrench up to 8 in. (20 cm) in length
- A deep socket at least 2 in. (5 cm) in length
- A piece of rubber from an aircraft tire
- A distorted metal strip up to 8 in. (20 cm) in length
- A fuel cap (aircraft or automotive)
- A lug nut

- An hydraulic line (from aircraft or ground support equipment) up to 8 in. (20 cm) in length)

- A white PVC pipe 2 in. (5 cm) in diameter

- Any two of the objects above, located no more than 10 ft (3 m) apart from each other, identified as separate objects

The manufacturer selected a group of targets and provided them to CEAT for testing, as shown in figure 10. As part of this assessment, CEAT observed the placement of these items in a rectangle approximately 100 by 100 ft (30 by 30 m). The iFerret demonstrated that it was able to detect 100% of the FOD items. CEAT also also confirmed that the FOD items were placed no more than 10 ft (3 m) from each other and confirmed that these items were detected.

Figure 10. Items Selected to Meet AC Detection Requirements

9. iFERRET ASSESSMENT BASED ON AC 150/5220-24 REQUIREMENTS.

The CEAT performance assessment of the iFerret detection system at ORD was based on the specifications and criteria provided in AC 150/5220-24. The AC lists specifications for basic functions, detection performance, and system output. From data collected during the performance assessment, table 23 shows iFerret performance as it relates to AC 150/5220-24, and sections 9.1 through 9.3 provide a narrative analysis of the iFerret's conformance to the AC performance specifications.

Table 23. Summary of iFerret Performance Related to AC 150/5220-24 Requirements

AC Category and Performance Requirement	CEAT Findings
Basic Functions	
1. Provide surveillance in the airport operations area as specified by the airport.	Met the AC specification for a detection zone that included an entire runway, although only a portion of Runway 27L was covered by the iFerret.
2. Detect and locate single and multiple FOD items on the airport operations area.	Detected and located single and multiple FOD items in detection zones.
3. Provide an alert to the user when FOD has been detected.	Provided visible and audible alerts.
4. Operate in conjunction with, and not interfere with, airport and aircraft communication, navigation, and surveillance systems.	In operation from June 2009 through July 2010; no interference was reported.
5. Operate in conjunction with, and without interference from, normal airport and aircraft operations (e.g., aircraft and vehicle movements).	In operation from June 2009 through July 2010, no interference was reported.
6. Provide a data record of detected FOD, allowing for equipment calibration and maintenance, and for analysis of the FOD event.	A full data record for the period of operation was provided; equipment was calibrated and maintained, and multiple FOD events were recorded.
Detection Performance: Object Detection	
1. An unpainted metal cylinder measuring 1.2 in. (3.1 cm) high and 1.5 in. (3.8 cm) in diameter.	Detected this target.
2. A white, gray, or black sphere measuring 1.7 in. (4.3 cm) in diameter (i.e., a standard size golf ball).	Detected standard targets with these dimensions.

Table 23. Summary of iFerret Performance Related to AC 150/5220-24 Requirements (Continued)

AC Category and Performance Requirement	CEAT Findings
Detection Performance: Object Detection (continued)	
3. Detect 90% of the following group of objects when placed within a 100- by 100-ft (30- by 30-m) square in the desired coverage area. One item from each category must be included in the group, and each item must measure no larger than 4 in. (10 cm) in any dimension unless otherwise specified: • A chunk of asphalt or concrete • Any portion of a runway light fixture (in-pavement or edge light) • An adjustable crescent wrench up to 8 in. (20 cm) long • A deep socket at least 2 in. (5 cm) in length • A piece of rubber from an aircraft tire • A distorted metal strip up to 8 in. (20 cm) in length • Fuel cap (aircraft or automotive) • Lug nut • Hydraulic line (from aircraft or ground-support equipment) up to 8 in. (20 cm) in length • White PVC pipe 2 in. (5 cm) in diameter	Detected 100% of the objects in the tests observed by CEAT.
4. Any two of the objects above, located no more than 10 ft (3 m) apart from each other, identified as separate objects.	Met the AC specification.
Detection Performance: Location Accuracy	
Systems must provide location information for a detected object that is within 16 ft (5.0 m) of the actual FOD object location.	Provided average location accuracy of approximately 0.82 ft (0.25 m) with a maximum difference of approximately 1.56 ft (0.48 m). Met AC requirement for average accuracy.

Table 23. Summary of iFerret Performance Related to AC 150/5220-24 Requirements (Continued)

AC Category and Performance Requirement	CEAT Findings
Detection Performance: Inspection Frequency	
Continuous Detection Systems. The system must provide continuous operation from fixed sensors to allow for the continuous inspection of runway surfaces during flight operations. The duration of flight operations is dependent on the airport and specified by the user. Mobile Detection Systems. The system must provide a mobile operations capability to enhance mandated airport safety self-inspections (per AC 150/5200-18). The frequency of inspections is dependent on the airport and specified by the user.	Met the AC specification.
Detection Performance: Detection Response Time	
Continuously operating FOD detection systems designed to provide between movement alerts: The system must provide inspection of runway surfaces between aircraft movements.	Scan time as little as 70 seconds met the AC requirement for typical aircraft movement activity.
Other continuously operating FOD detection systems. The system must provide inspection updates as specified by the airport, generally within 4 minutes of a FOD occurrence.	Met the AC requirement for 4-minute scan time.
Detection Performance: Surveillance Area	
The primary area of coverage is the runway; certain portions of the runway may be specified by the airport operator if full coverage is not feasible.	Manufacturer provided runway coverage, meeting the AC requirement.
Other areas are of lesser importance, with a decreasing level of priority from other paved movement areas down to nonpaved, nonmovement areas.	Manufacturer also demonstrated effectiveness for taxiway surveillance.
The manufacturer of a FOD detection system must notify the airport operator of any locations within the specified surveillance area where detection would not be possible.	No areas without detection were identified.

Table 23. Summary of iFerret Performance Related to AC 150/5220-24 Requirements (Continued)

AC Category and Performance Requirement	CEAT Findings
Detection Performance: Performance in Weather	
1. Detect objects under rain or snow conditions (e.g., having a specific intensity, duration, and frequency) for a 2-year category of storm in the local region as specified in CLIM 20, Climatology of the United States No. 20. More stringent requirements may be specified by the user.	Tests were conducted under rain and snow conditions, but the tests did not produce results for specific frequency events.
2. Systems must have site-specific performance specifications that include:	
• performance during clear weather conditions	Met the requirements for clear weather conditions.
• performance during inclement weather conditions	Tests were conducted on wet pavement during a rain event and on snow/ice covered pavement with no appreciable reduction of detection capability.
• amount of time required for the system to recover after a rain or snow storm (e.g., to return to clear-weather performance capabilities after adverse weather conditions subside, defined as when precipitation of rain or snow ends.	System was tested after snowfall and runway clearance; the system performed during snowfall conditions.
3. All systems must demonstrate detection performance during daylight, nighttime, and dawn and dusk operations.	System performance under lighting conditions was variable with best performance in daylight and at dawn and dusk.

Table 23. Summary of iFerret Performance Related to AC 150/5220-24 Requirements (Continued)

AC Category and Performance Requirement	CEAT Findings
Detection Performance: Alerts and Alarms	
False alarms (an alert causing the airport operator to take action to remove a FOD object that does not exist) should be minimized and must not exceed: • For systems with visual detection capabilities: one per day as averaged over any 90-day period • For systems without visual detection capabilities: three per day as averaged over any 90-day period. Note, some small items may be moved by wildlife or blown away before airport operators have a chance to investigate FOD alerts.	Assessment did not incorporate operational analysis to determine conformance to specification.
System Output: Data Detection	
1. Records must contain: • Alert time and date • Location of FOD object 2. Capturing the following information is recommended, but not required: • Description of FOD detected or retrieved (e.g., size, name, type, serial number) • Time and date of FOD retrieval • Time and date of disposition of alert • Name of personnel detecting or investigating FOD item • Image of the FOD object retrieved (if available) • Chain of custody information	Met the AC specification.
System Output: Data Presentation	
FOD detection data can be provided in a coordinate scheme, on maps of the airport, in an operator's console, or broadcast to mobile units. The selection of information options will be specified by the airport, consistent with airport systems operations.	Met the AC specification.
System Output: Data Management	
Data collected in the FOD detection process should be digitally recorded. Data systems should have the capability to retain the data for at least 2 years after the detection event.	Met the AC specification.

9.1 BASIC FUNCTIONS.

9.1.1 Provide Surveillance in the Airport Operations Area as Specified by the Airport.

The iFerret was installed at ORD and provided continuous surveillance of a portion of Runway 27L and Taxiway MM. The iFerret was also installed at SIN, providing surveillance of SIN's two primary runways. This surveillance met the airport requirements for this technology demonstration.

9.1.2 Detect and Locate Single and Multiple FOD Items on the Airport Operations Area.

The iFerret was able to consistently locate single and multiple FOD items on the airport operations area under a variety of test conditions during the approximately 1-year performance assessment conducted by CEAT.

9.1.3 Provide an Alert to the User When FOD has Been Detected.

The iFerret provided visual and audible alerts of detected FOD to the central console. At SIN, this console was located in the air traffic control tower.

9.1.4 Operate in Conjunction With, and not Interfere With, Airport and Aircraft Communication, Navigation, and Surveillance Systems.

Operation of the iFerret occurred with no interference to aircraft communication, navigation, or surveillance technologies. Through the normal 7460 application process, radio frequency issues were reviewed and installation and operation of the iFerret followed normal approval processes of the FAA and the Federal Communications Commission. Because iFerret is a passive surveillance technology, the only radio frequency issue was wireless connectivity.

9.1.5 Operate in Conjunction With, and Without Interference From, Normal Airport and Aircraft Operations.

The iFerret was operated during the performance assessment without interference from normal airport and aircraft operations. Detection algorithms in the system differentiated between stationary and moving targets, and no false alarms were associated with vehicles or aircraft.

9.1.6 Provide a Data Record of Detected FOD, Allowing for Equipment Calibration and Maintenance, and for Analysis of the FOD Event.

The iFerret provided a digital record of calibration, any maintenance activity, and all FOD alerts associated with detections on Runway 27L and Taxiway MM at ORD. In addition, the system at SIN could retain video records for each sensor.

9.2 DETECTION PERFORMANCE.

9.2.1 Object Detection.

The iFerret detected an unpainted metal cylinder and white, gray, and black spheres approximately 1.7 in. (4.3 cm) in diameter (i.e., a standard size golf ball). The iFerret was also able to consistently detect white, gray, and black cylinders that measured 1.2 in. (3.1 cm) high and 1.5 in. (3.8 cm) in diameter. The detection rate for all targets during the performance assessment was 94%. The detection rate was slightly lower at night and on wet pavement. The detection performance was 97% or better under variable lighting conditions (dawn and dusk).

This performance assessment included the use of objects (specified by AC 150/5220-24 and provided by the manufacturer) for testing in a 100- by 100-ft (30- by 30-m) square. In the AC-specified object test, 100% of the objects were detected. The performance assessment did verify detection of multiple objects when placed within a 100- by 100-ft (30- by 30-m) square in the desired coverage area. The performance assessment also confirmed detection of two objects located no more than 10 ft (3 m) from each other and confirmed identification as separate objects.

9.2.2 Location Accuracy.

The iFerret provided location information that, when compared to location acquired from a hand-held GPS, exceeded AC 150/5220-24 requirements. The average difference between the surveyed location and the location reported by the iFerret system was 0.82 ft (0.25 m). The maximum difference between the surveyed location and the location reported by the iFerret was 1.56 ft (0.48 m). The minimum difference between the surveyed location and the reported location was 0.33 ft (0.1 m). CEAT was able to confirm that the iFerret system's location accuracy performance met the AC 150/5220-24 requirement that the detected object be within 16 ft (5.0 m) of the actual FOD object location.

9.2.3 Inspection Frequency.

The iFerret installed at ORD provided continuous detection of the target runway for the period defined by the performance assessment. This operation met the AC 150/5220-24 specification for continuous operation, and the system provided continuous inspection of a portion of Runway 27L and Taxiway MM during flight operations.

9.2.4 Detection Response Time.

The iFerret is designed to provide between movement alerts to FOD presence. During the performance assessments, detection of FOD items was generally completed within 70 seconds, although scan times varied. The iFerret provides between movement detection of FOD items.

9.2.5 Surveillance Area.

The iFerret provided partial coverage of Runway 27L and Taxiway MM at ORD.

9.2.6 Performance in Weather.

The iFerret was assessed during dry pavement, wet pavement, and snow and ice conditions. One nighttime test on Runway 27L was completed in a steady rain, and several test campaigns were completed with wet pavement and with snow and ice present on the pavement.

The iFerret met AC 150/5220-24 performance specifications for clear weather, dry pavement conditions with a 94% detection rate for a standard target.

The iFerret operated during inclement weather, and detections were verified during rain and snow conditions.

9.2.7 Alerts and Alarms.

The iFerret provided alerts of FOD presence on the runway, video images of the detected items, and location information to facilitate removal.

The CEAT performance assessment was designed to place known objects on airport surfaces and determine detection performance. No false alarm data were developed in this assessment.

9.3 SYSTEM OUTPUT.

9.3.1 Detection Data.

The iFerret provides a digital data record of operations that included an alert time and date, the location of the FOD object, and video images of the object.

9.3.2 Data Presentation.

The iFerret provides video and digital data that could be presented in a number of formats. The basic graphical user interface (GUI) provides a real-time video image of the scanned surfaces, supplemented by a line drawing of the runway infrastructure. In addition to specific locations of detected FOD contained in the digital record, the GUI provides a visual representation of the FOD location. At SIN, the iFerret kept records of all operations that were archived and retrieved for review.

9.3.3 Data Management.

The iFerret provides digital data that are suitable for data management and can meet the needs of many airports.

10. OPERATIONAL ANALYSIS.

During this performance assessment, CEAT was not able to conduct an analysis of the system's operational performance at ORD due to the systems remote location and the absence of a control module that would allow ORD operations personnel to use the system in their day-to-day activities. CEAT was able, however, to conduct an analysis of the system's operational

performance with the Changi Airport Group (CAG) at the iFerret installation in Singapore. This system was commissioned in June of 2009 and remained operational throughout the remainder of the CEAT performance assessment at ORD.

Chapter 6 of AC 150/5210-24 [4] provides airports with information on the importance of collecting data and conducting analysis on the types of FOD found at their airport. The iFerret data management software application provides the user with an easy to use interface that supports data collection, data analysis, and support for a FOD reporting system. While conducting the performance assessments, CEAT was able to briefly evaluate the iFerret's data management tool and provide the following observations.

- The iFerret system integrates sensor input from the hardware into its proprietary software application to provide a complete summary of the system operation and detection activity. iFerret's typical FOD inspection report is a result of data that is integrated within and is capable of reporting all user-defined parameters that the airport operator is interested in viewing, including images of the detected FOD items. Access to the reporting function is available from any monitoring console by simply logging into the system via an iFerret administration application.

- In the report generation function of the iFerret system, the user is asked to select search options that can filter the type of data generated by their inquiries. Search options include start and end dates, time periods, runway or tower, and the FOD status: suspected, nuisance, confirmed, or retrieved. Reports can be generated that provide:

  – runway and sensor tower location of detected FOD object.

  – date and time of FOD detection, confirmation, and retrieval.

  – current status of FOD alert (e.g., detected, confirmed, retrieved).

  – description of FOD retrieved (category, size, and color).

  – location of FOD object referenced to airport coordinate.

  – an image of the FOD object detection.

  – possible source of FOD object.

  – date and time of recovery team acknowledgement and alert clearance time (from a hand-held device).

  – an image of the FOD object taken onsite (from a hand-held device).

  – video playback and export of FOD event for postanalysis.

  – graphical plot of FOD occurrence versus time and runway zone.

A typical GUI screen from a generated report is provided in figure 11.

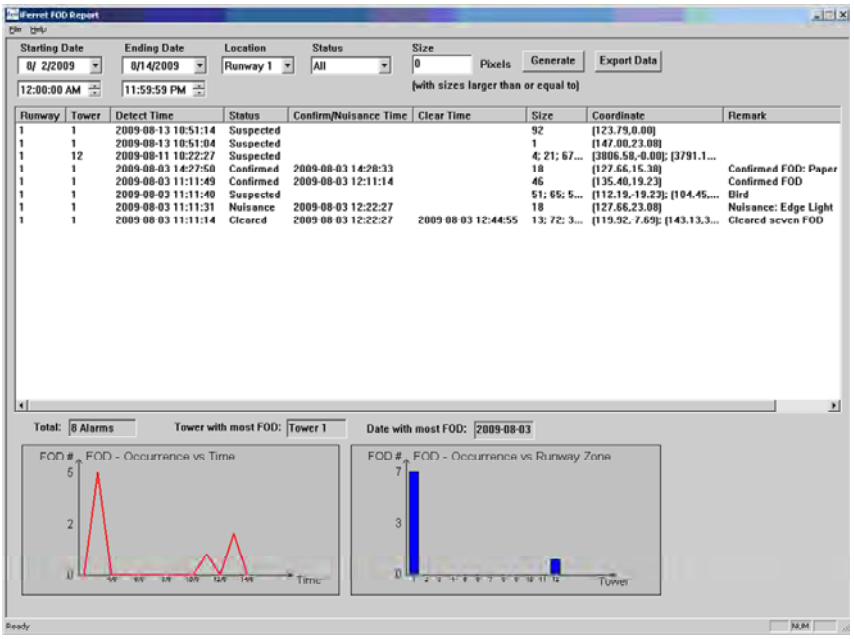

Figure 11. Screenshot of the iFerret Reporting Function

The iFerret records all images collected by system sensors. From the GUI, users can access still images taken from each sensor and video records that can be used in forensic analysis, training, and system improvement.

11. SUMMARY.

The iFerret FOD detection system was assessed at ORD and SIN by the Center of Excellence for Airport Technology. A performance assessment, consisting of calibration and intercalibration tests, performance tests, blind tests, and an operational evaluation was performed at ORD in June 2009 and completed in July 2010. In this performance assessment, test campaigns were completed under different weather conditions. The iFerret performed according to the manufacturer specifications and met performance requirements identified in Advisory Circular 150/5220-24, "Airport Foreign Debris (FOD) Detection Equipment." A performance assessment was also performed in May 2009 at SIN. Since June 2009, the iFerret has remained operational on SIN's two primary runways.

12. REFERENCES.

1. FAA AC 150/5220-24, "Airport Foreign Object Debris (FOD) Detection Equipment," September 30, 2009.

2. FAA AC 150/5200-18, "Airport Safety Self-Inspection," April 23, 2004.

3. National Climatic Data Center, “Climatology of the United States No. 20 (CLIM20),” U.S. Department of Commerce, 1971-2000. http://www.ncdc.noaa.gov/oa/documentlibrary/pdf/eis/clim20eis.pdf

4. AC 150-5210-24, “Foreign Object Debris (FOD) Management,” September 30, 2010.