PROCEDURES FOR FOD DETECTION SYSTEM PERFORMANCE ASSESSMENTS: ELECTRO-OPTICAL FOD DETECTION SYSTEM

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PRESENTED FOR THE
2010 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Atlantic City, New Jersey, USA

April 2010

INTRODUCTION

As part of a comprehensive performance assessment of Foreign Object Debris (FOD) detection systems at civil airports, assessments of an electro-optical, intelligent vision system was conducted by the Center of Excellence for Airport Technology (CEAT). The performance assessments of FOD detection technologies were designed to provide a rich data resource that could assess the performance of both individual sensors and combined sensor systems. Targets included a variety of items, some with known detection characteristics, such as radar cross sectional area (RCS) for radar-based sensors and color and surface condition for electro-optical systems. Targets also had different shapes and sizes and were made of different materials to provide target characteristics that would challenge detection systems. Assessment campaigns were scheduled over a 12-month period with the intent of testing under varied weather conditions. The electro-optical FOD detection system that was the subject of this assessment was the *iFerret*™ FOD detection system developed by Stratech Systems, Ltd.

The overall goals of testing any FOD sensor are:

1. calibrating the FOD detection system with items of known detection characteristics and confirm sensor operation for each test campaign, providing information on system reliability and robustness;

2. determining detection performance for FOD items with different hazard potentials, considering distance from the sensor and orientation to the sensor;

3. assessing system detection of FOD items placed randomly in blind testing, providing a test of the typical detection needs of airports.

Electro-optical sensors operate in the visible spectrum using high resolution video cameras and advanced computer processing to detect FOD on airport surfaces. The *iFerret*™ system utilizes multiple sensors along the runway positioned at roughly 1000 ft (300 m) intervals. The sensor consists of an image capture system that utilizes high quality optics with zoom capabilities that are networked to a processing system and system control console.

There are nearly limitless possibilities of sizes, shapes and materials that can comprise FOD, and each one of these properties constitute a crucial variable that can influence detection. For vision-based systems, critical variables include lighting and contrast of the target with backgrounds. The intelligent vision capabilities of the *iFerret*™ system support use under daylight, changing lighting conditions, and with very low levels of ambient lighting in the dark. Other factors, such as rainfall, can affect visibility and will influence sensor capabilities.

In the performance assessment of the *iFerret*™ FOD detection system, test procedures were developed that considered:

- background color and characteristics
- target color, including surface conditions that could affect visibility
- target height above the runway
- ambient lighting, including sun angle and rapid changes in lighting at dawn and dusk

- the effects of weather on the lighting and detection environment.

The performance assessment of the *iFerret*™ FOD Detection System was conducted at Chicago's O'Hare International Airport (ORD) and at Singapore's Changi International Airport (SIN). The testing at ORD utilized two sensors located on a single tower. Position of the tower allowed surveillance of Runway 27R and an adjacent taxiway MM. The SIN installation provided full system coverage for two runways with 12 sensors located along each runway. The performance assessment was initiated in May 2009 at SIN and continues at ORD.

SENSOR-SPECIFIC ASSESSMENT ISSUES

Each sensor type used in the CEAT performance assessment program presents different challenges when defining technical capabilities. For example, radar-based sensors operate based on target reflectivity to radio frequencies, so light levels are not critical to target detection. The target acquisition capabilities of vision-based electro-optical sensors are dependent on lighting and factors such as sun angle that differentially illuminate targets with complex shapes or targets that create shadows that enhance detectability. Because vision-based systems require consideration factors such as target color, background color, and lighting, the assessment procedures for the iFerret™ FOD Detection System were developed considering color, lighting, and sensor location that defines aspect-specific detection capabilities.

Color and Surface Condition

The contrast between an object and its background will influence visual detection. This contrast can be created by color differences or differences in surface conditions that influence light reflectivity. An object with a color and texture similar to that of the surface (background) will exhibit low contrast and be more difficult to detect. In the CEAT performance assessments, a set of calibration targets were selected to address color issues. Although an infinite number of colors are possible, we felt color influences could be captured by using white, grey, and black targets. The standard targets selected by CEAT for visual systems were machined from solid PVC tubes that provided non-reflective targets that were 1.5 in (3.8 cm) in diameter and 1.25 in (3.1 cm) in height. In addition to these cylindrical targets, CEAT adopted a standard target type proposed by Stratech Systems, Ltd. This target was a common golf ball painted with white, grey, and black paint. A flat paint, rather than a reflective paint, was used.

The selection of these standard target types recognized that drab-colored and rough- or matte-textured objects will decrease the possibility of detection because these characteristics are often shared with a paved airport surface. Asphalt, concrete, and rubber are common FOD items that may actually originate from the runway. Conversely, bright and vivid colors and glossy or smooth textured objects are more readily detected by a visual system because the additional reflectivity enhances the likelihood of detection under variable lighting conditions.

One of the more challenging aspects of the performance assessment procedures is relocation and retrieval of experimental FOD items placed on a functional runway. This is particularly true for night-time testing where lighting is limited. CEAT developed specific procedures for vision-based systems. It was not possible to use reflective paints because these paints would improve overall detectability. CEAT used a UV paint that added a dull surface of neutral color to experimental FOD items. Upon illumination with a portable UV light, these paints fluoresced, enabling easy location of FOD items. In the CEAT performance assessments, objects with a range of colors were used in the performance and blind testing procedures.

Lighting

Illumination of sufficient intensity to produce a contrast between the target and background is essential for vision-based sensors. The *iFerret*™ FOD Detection System intelligent vision capabilities were developed to overcome lighting restrictions, but lighting is still a critical issue in assessing detection performance. For this reason, testing was planned for daylight and night-time periods. Testing was also scheduled at dawn and at dusk, when changing lighting conditions were expected to challenge detection capabilities. In addition to light intensity, the angle of the light on the object is an important consideration. Different illumination angles can produce different reflections and shadows from FOD items.

Night-time detection is an obvious challenge to vision-based sensors, which can compensate for the lack of light using active or passive techniques. Active sensors project light from a source that illuminates targets using wavelengths invisible to the human eye, such as infrared. Passive sensors amplify ambient light and process images to support target identification under low lighting conditions. The *iFerret*™ FOD Detection System used passive processes and allowed selection of targets that were appropriate for visible wavelengths. This required that the visibility of targets was not enhanced by reflective paint for night time use. In the CEAT performance assessments, test campaigns were scheduled to provide different seasonal sun angle and lighting conditions, dawn and dusk testing, and daylight and night-time testing.

Aspect

The basis of detection is a contrast with background conditions. This is true for radar as well as vision-based sensors. Of particular importance to vision-based sensors is the shape characteristics of the target that are captured in the system image. Depending on the angle of view, the same target may appear to have different shapes. To address this issue, standard targets were spheres that provided a uniform shape when viewed at different angles. CEAT also used cylinders as a means of connecting *iFerret*™ performance assessments with other assessments conducted in the program.

In addition to shape, aspect is also determined by the shape of an object and how high the object projects above the surface on which it rests. CEAT considers aspect ratio an important factor in target characterization. An important metric in aspect ratio determination is the ratio of the length of the long axis to width and height. A long object, presented with long axis perpendicular to the sensor, will be more easily detected than the same object at an end view. Height above the surface is also important. A relatively large, flat object that does not project above the runway surface will be more difficult to detect than a small object that projects above the runway surface. In the CEAT performance assessments, objects with a range of aspect ratios were used in the performance and blind testing procedures.

Weather

A factor not under the control of the assessment design was weather. At the outset of the assessment design process, weather was considered and was addressed through overall scheduling and by inclusion of opportunistic testing. In all performance assessments, testing was scheduled to include seasonal weather conditions by planning a minimum of one year for the assessment duration. As testing progressed, weather conditions during past tests were reviewed and efforts were made to plan future testing to obtain needed weather differences. A particular problem was winter weather and the objective of testing that included snow. For these tests, efforts were made to be present during snow events so that assessments could be executed.

For vision-based systems, it is expected that weather will influence detection. Cloud cover can create a variety of lighting conditions. Uniformly overcast skies may cause a more-or-less constant decrease in available sunlight. However, partially cloudy conditions, where clouds are continuously moving across the sun, create rapidly fluctuating levels of light. At night, clouds will reflect the light created by airport infrastructure and create a brighter ambient environment. Greater cloud cover increases the amount of reflection. Conditions are clearly different on an overcast night than on a clear night and are expected to influence detections.

Precipitation can influence detections. Falling rain and snow may limit visibility, and blowing snow can continue to hamper visibility following a snowfall. In addition to changing visibility, precipitation may alter background conditions. Rainfall can darkened the color of runway surfaces. Standing water left after heavy rainfall may be interpreted as a FOD item or may influence lighting and the reflectivity of FOD items. Paved surfaces rarely dry uniformly, creating changing background conditions that challenge system detection capabilities. Weather has the potential to create dynamic background conditions where constantly shifting light and dark areas of contrast influence detection. Snowfall adds additional complexities for a visual sensor. Snow may cover the runway surface and may cover FOD items. Snow removal operations clear runways, but such operations also produce FOD in the form of debris from snow removal equipment and FOD in the form of snow and ice on or near the runway. Considering vision-based sensors, snow fall and snow removal will create a new background conditions quickly and may also produce FOD items. There is also the possibility of snow accumulating on the sensor and obscuring its view of the target surface.

In the CEAT performance assessments, portable weather stations were deployed and local weather records were obtained and archived for each assessment campaign.

IFERRET™ FOD DETECTION SYSTEM PERFORMANCE ASSESSMENTS

CEAT assessed the Stratech *iFerret™* FOD detection system at ORD and SIN. The assessment at ORD used runway and taxiway sensors, and the assessment at SIN provided an opportunity for system assessment.

The installation at ORD involved two sensors mounted on a single tower (Figure 1) with one sensor monitoring a 600 ft (200 m) length of runway 27L and the other sensor monitoring a 300 ft (100 m) length of taxiway MM, Figure 2. The ORD installation was the primary assessment location for the *iFerret*™ system with test campaigns scheduled for approximately one year, beginning in June 2006.

Figure 1. Sensor Installation at ORD.

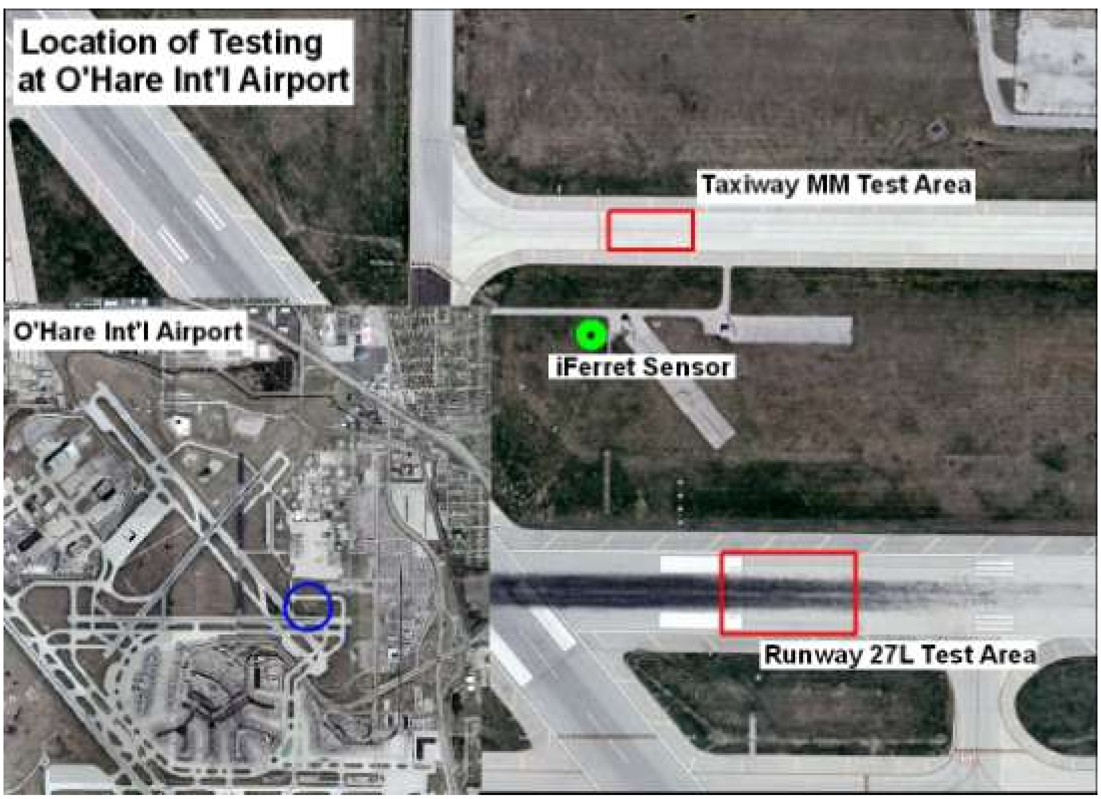

Figure 2. Testing Locations for the *iFerret*™ FOD Detection System at ORD.

At SIN, CEAT took advantage of a airport installation of the *iFerret*™ system on the parallel runways at SIN, 02L/20R and 02C/20C. A total of 12 sensors were installed along the length of each of the runways. A typical tower with an *iFerret*™ sensor is illustrated in Figure 3. A single sensor monitored the full width and a 300 m length of the runway. The performance assessment at SIN was conducted with the assistance of the Civil Aviation Authority of Singapore. The assessment stressed system-based and detection redundancy capabilities.

Figure 3. A Sensor at SIN.

Calibration Testing

Calibration testing and was conducted at both ORD and SIN. In all calibration tests white, grey and black spheres were used, Figure 4. In addition to these spheres, white, grey, and black cylinders were used in some locations, Figure 5.

Figure 4. Set of White, Grey and Black Spheres Used in Calibration Testing.

Figure 5. Set of White, Grey and Black Cylinders Used in Calibration Testing.

For each sensor a rectangular test area was defined and marked. A single target placement consisted of a white, grey, and black sphere placed in line with a spacing of 1.5 ft (0.5m). Figures 6 and 7 provide examples of target placement at ORD. Because of taxiway size limitations, the test area on Taxiway MM was reduced and there was a corresponding reduction in the number of targets placed in the rectangle.

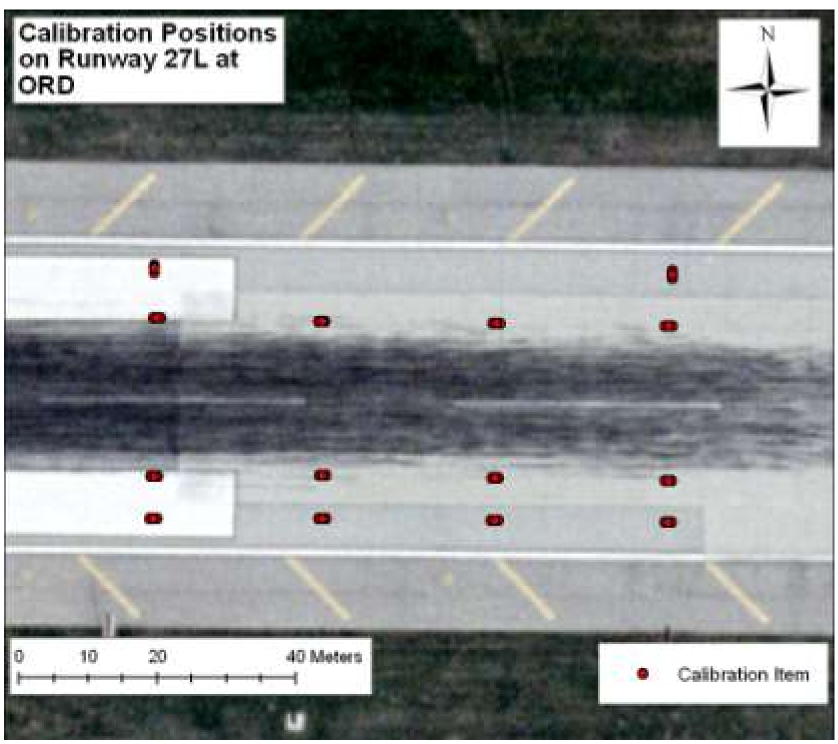

Figure 6. Calibration Target Placements on Runway 27L at ORD.

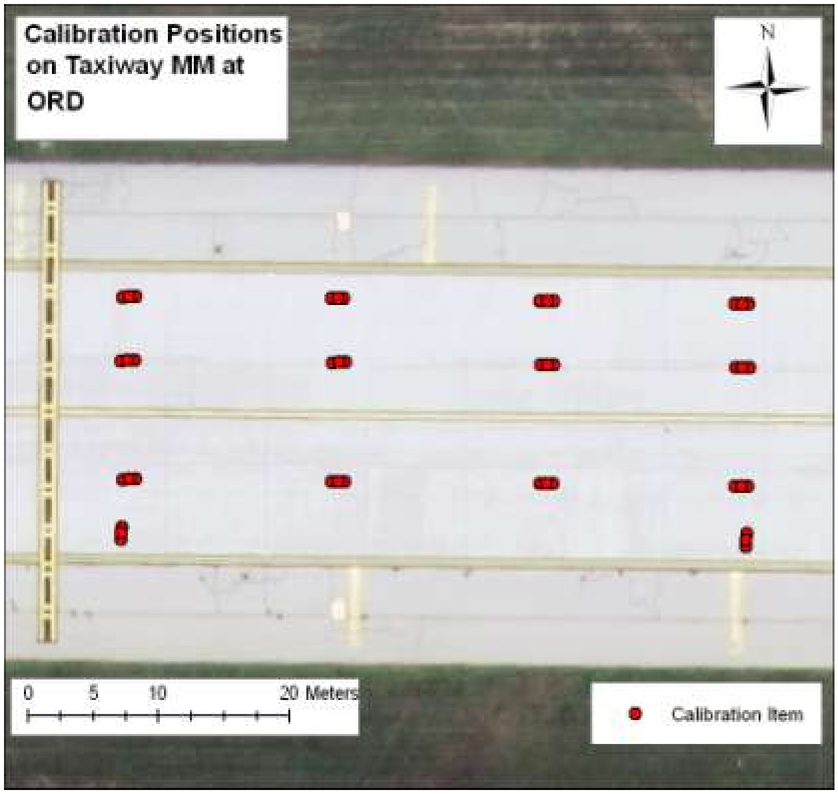

Figure 7. Calibration Target Placements on Taxiway MM at ORD.

Positions were marked using ultraviolet paint that dries transparently and is nearly invisible unless an ultraviolet flashlight is used. Calibration tests were performed at the beginning of each test campaign, and calibration targets were also used in performance testing to provide detection references. Calibration testing provides the assessment not only with a means of establishing a baseline for sensor functionality, but also provides a method of analyzing the relationship between object characteristics and the airport environment.

Calibration testing was conducted at SIN using similar targets and consistent test procedures that were adapted to multiple sensor assessment. Because sensors provide redundant detection for targets located outside of the test rectangle, the system testing included placement of calibration targets outside of the sensor rectangle, but in the view of an adjacent sensor. Target locations in relation to sensors are provided in Figure 8.

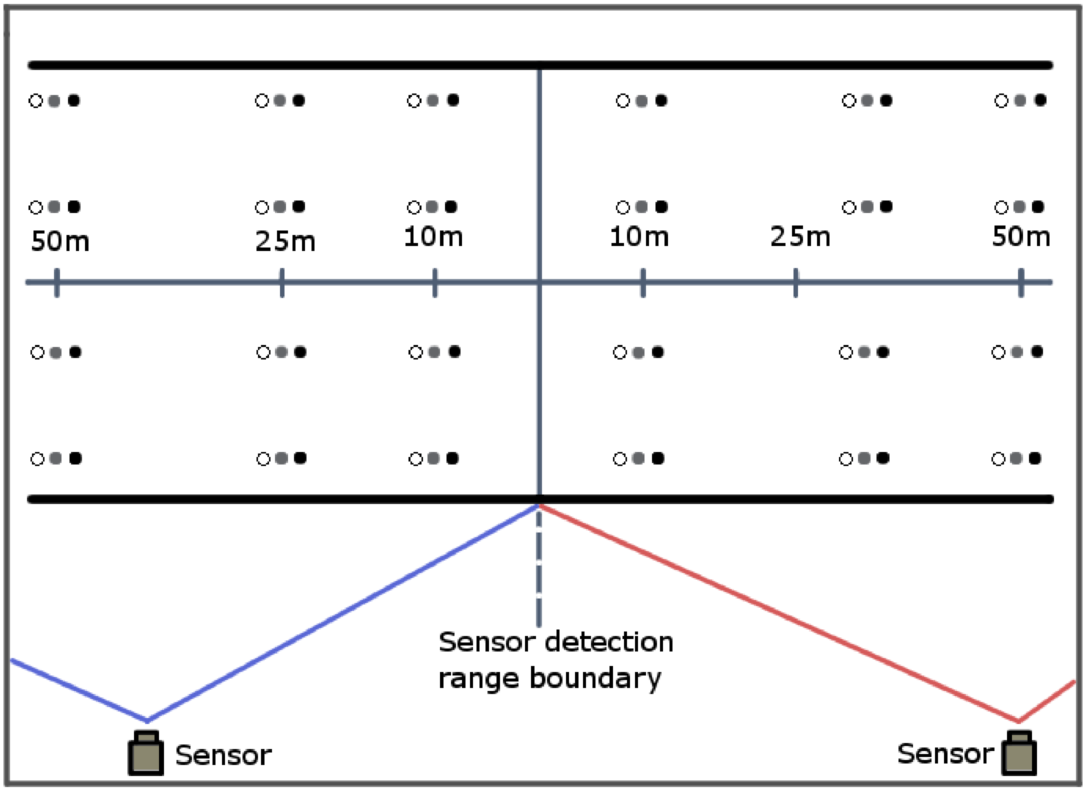

Figure 8. Target Location at SIN.

Performance Testing

Performance testing uses a standard set of actual FOD items. For the *iFerret*™ assessment at ORD and SIN, identical items were placed at five locations in two lines in the detection rectangle, Figures 9 and 10. Because angles of the items varied by position, the rotation of long-axis items was limited to two positions: long axis parallel to the runway and long axis perpendicular to the runway. A typical performance testing campaign placed items in positions marked by UV paint, first with the long axis parallel to the runway and then, after a detection period, the items were rotated 90 degrees for a second detection opportunity.

As seen in Table 1, the performance test items provided a range of sizes, aspect rations, and colors.

Table 1.
Standard FOD Items Used in Performance Assessments.

FOD Item[a]	Expected Hazard	Frequency of Occurrence
1. Small Piece of Concrete	High	Common
2. Standard Lug Nut from Service Vehicle	High	Common
3. Roller Bearing	High	Common
4. Chunk of Rubber	Low	Common
5. Mechanics Wrench	High	Common
6. Fuel Cap	High	Common
7. Cotter Key	Moderate	Common
8. Plastic Bottle/Bottle cap	Low	Common
9. Strapping Material	Moderate	Common
10. Expansion Joint Material	Low	Common
11. Construction Material–Galvanized Nails or Sheetrock Screws	Moderate	Based on Construction Activity
12. Runway Infrastructure Part–Piece of Runway Light or Signage	High	Uncommon
13. Small Fasteners	Moderate	Common
14. Metal Strip	High	Uncommon
15. Fiberglass Door	Moderate	Common
16. Asphalt Chunk	High	Common

[a]Items were selected based on consultation with James Stephan of Delta Airlines based on his studies of FOD items common on runways.

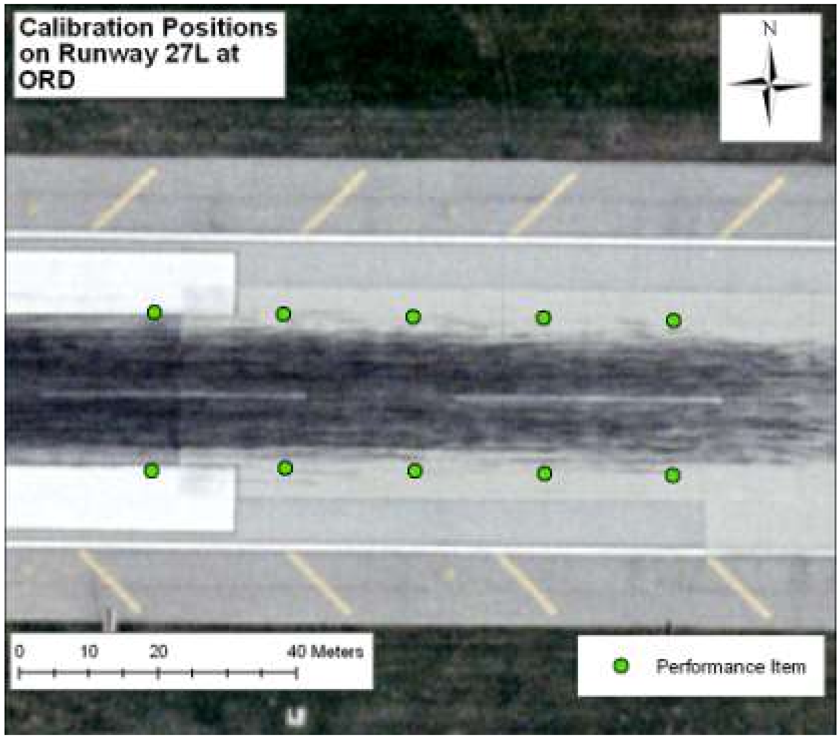

Figure 9. Performance Target Placements on Runway 27L At ORD.

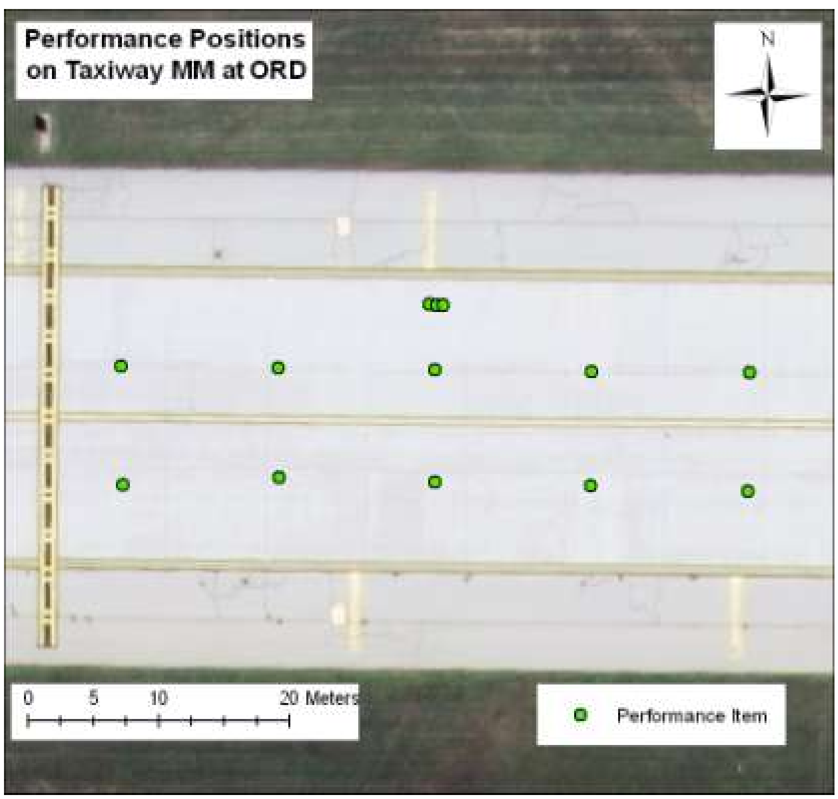

Figure 10. Performance Target Placements on Taxiway MM at ORD.

A complete performance test placed two item types in a single sensor scan. Items with a long axis were rotated for the second scan; then the items were removed and new items were placed for another scan sequence. A characteristic of the *iFerret*™ sensor was the need for a clear field scan before each item placement. The final testing sequence involved an initial clear field scan, placing items, a detection scan, items removal and clear field scan, item placement at new rotation, item removal, and an initial clear field scan to repeat the process for two new items. Data was recorded during target scans, including the target items placed, start time of scan, general weather conditions and the solar radiation reading from the solar meter.

Blind Testing

Blind testing uses actual FOD items randomly placed in a detection rectangle to assess detection performance in a simulated operational environment. Challenging the ability to detect a highly diverse and unpredictable set of items is critical to the functionality of a FOD detection system and a necessary addition to the performance assessment. CEAT has developed a collection of actual FOD items. These items are numbered and general characteristics are recorded (e.g. color, length, width, height, composition, etc.) In the blind testing portion of the *iFerret*™ assessment at ORD and SIN, 30 items were randomly selected from the collection. The detection rectangle was divided into a grid with items in each placement randomly assigned a position in the grid, Figure 10. Sections within the grid were general and not exclusive, so several items could be placed within one section and many sections would not contain any items. Each item was placed at a random orientation, and its position was recorded onto a handheld GPS device. Time, general weather conditions and a solar reading were recorded during each placement scan. Ten of the thirty items were randomly placed on the runway and standard scanning was initiated.

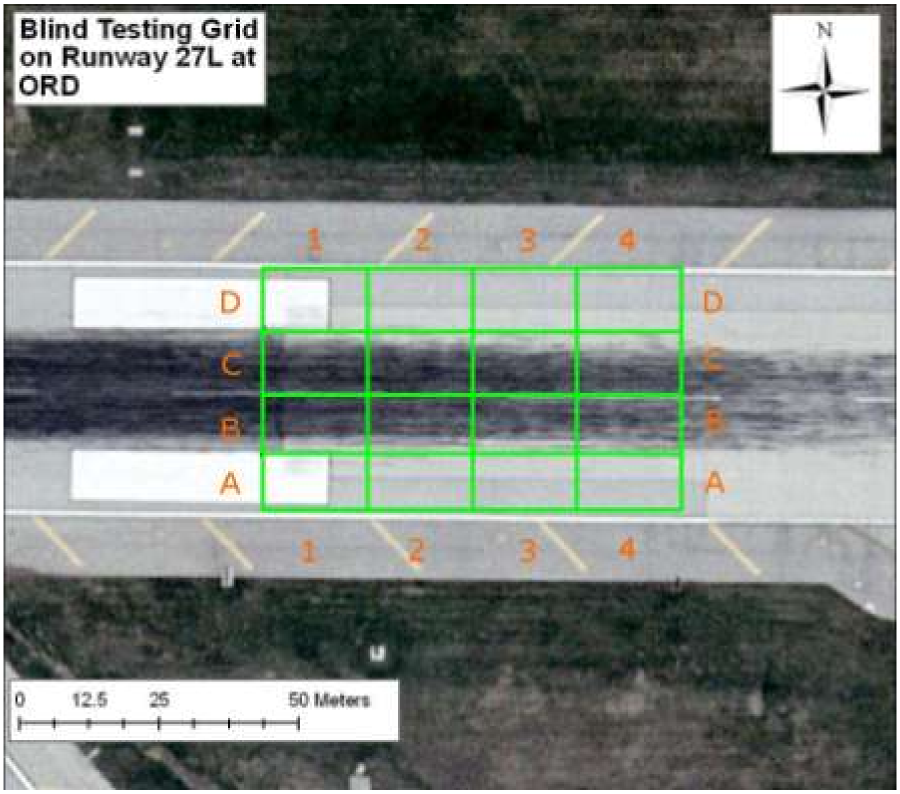

Figure 10. Blind Testing Grid for Runway 27L at ORD.

SUMMARY

As part of a comprehensive performance assessment of FOD detection systems at civil airports, the performance assessment of the *iFerret*™ FOD detection system was initiated in May 2009 at SIN and in June 2009 at ORD. The performance assessment continues.