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# SENTINEL

Electro-optic automatic FOD detection system

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TR-01P-2014



## SENTINEL System Foreign Object Debris (FOD) Detection Performance Evaluation Trial - June



November 2014

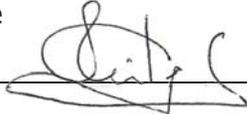
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## EXECUTIVE SUMMARY

PHAROVISION conducted a trial of the SENTINEL ground-based electro-optic automatic bird detection system in mid June 2014 at an Israel Defense Force Air Base with the objective to evaluate the system's detection performance, as well its functionalities, in order to demonstrate its ability to be used as an effective foreign object debris (FOD) detection system in airport environments. The experiment results clearly demonstrate that the SENTINEL in its baseline configuration can be used to automatically detect most foreign objects in airport surfaces. The detection range of the SENTINEL system enables the system to be used as ground based electro-optic FOD system during day and night operations. The system can also meet the FAA requirements described in its Advisory Circular FAA N° 150/5220-24 in terms of location accuracy, continuous inspection of runways, and response time, essential for such types of systems operating in airport environs. It was shown that the system is capable of detecting small 3 cm x 3 cm FOD targets at a distance of 800 meters with small temperature differences between the object and background ( $\Delta T \geq 2^{\circ}\text{C}$ ). The trial demonstrated the advantages of having both visible (video CCD) and infrared (infrared) imagery of the tarmac surfaces since there are cases in which the system showed better detection of FOD targets with the visual camera than with the thermal camera (e.g. the detection of small metal foreign objects at small thermal differences ( $\Delta T \geq 2^{\circ}\text{C}$ ) or the detection of asphalt foreign objects at high tarmac temperatures).

It is inferred from this experiment that the fulfillment of all the FAA requirements is technically attainable using the current system configuration with modifications, and an entire runway surface (along with adjoining taxiway surfaces within the same range) can be achieved utilizing more than one SENTINEL sensor head, with optimized spacing between each system, and preferably using high performance thermal (IR) and CCD video cameras (like the "Long-Range" sensor heads of Pharovision's portfolio) with spatial resolution to enable FOD identification. To effectively scan the full length of a typical runway, the system should be composed of 2 to 4 SENTINEL sensor heads, preferably integrating the sensor data into a single composite image. To be competitive with a dedicated FOD system in this case the sensors should not be located more than approximately 400 meters from the runway surface (if using the same sensor specifications as the baseline system). Considering the cost of an individual sensor head, the SENTINEL system could be a cost-effective solution as a FOD-detection system in airports and even a complete substitute of for other FOD detection systems currently on the market and, depending on the chosen sensor specifications and system architecture, it can surpass the performance level of detection of such systems. If uninterrupted scanning is required, an extra pair of IR and CCD cameras could be added to baseline configuration of the system in order to allow the identification task to be carried out separately while maintaining the continuous scan of airport surfaces.

The recommendations of this trial will enable to configure a future trial where a hardware configuration and system architecture will be used in order to fully cover the totality of an runway surface, in order to demonstrate that the system can detect and identify the full range of FOD targets listed in FAA AC N° 150/5220-24 at the required minimum ranges.

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## **1. BACKGROUND**

The PHAROVISION SENTINEL bird detection system has been designed primarily to automatically detect individual birds and flocks of birds, day or night, using a ground-based infrared and electro-optical scanning payload and advanced proprietary image-processing algorithms. This capability allows the SENTINEL system to support two critical efforts: the monitoring of bird movements in support of wildlife management programs and the surveillance of airspace to identify potential threats to the safe operation of aircraft through the mitigation of the risk of bird strikes within the Control Tower Region (CTR) of the airport.

In addition to the bird detection capability, SENTINEL's ability to detect foreign object debris (FOD) on airport surfaces, namely on runways or taxiways, have drawn a great deal of interest by potential users including a large number of airport operators. Upon initial review, the benefit of the SENTINEL system as a FOD-detection system in comparison with dedicated FOD detection systems is twofold: (1) it can be used for multiple functions – from bird detection to mitigate the risk of bird strikes with aircraft, through security roles, to FOD detection on the runways and other tarmac surfaces, and; (2) the overall cost of multiple SENTINEL systems is considerably lower than any singular dedicated FOD system. This means that the SENTINEL can be a cost-effective solution as FOD-detection system in the airports and even a complete substitute of such systems, provided that it can achieve the same detection performance level of such systems. The system had demonstrated in the past its general capability to detect FOD on the runways but no formal tests or trials had been conducted to assess its performance detection of typical FOD targets like those delineated in the FAA AC N° 150/5220-24 (related to the requirements of minimum performance of FOD-detection systems).

In order to do a complete assessment of a FOD-detection system capability to operate in the airport environment and in accordance with FAA guidance and recommended specifications for procurement of such systems by airport operators, a final overall assessment should be carried out in order to evaluate not only the system's ability to detect typical FOD objects in terms of material, shape and sizes, but also the system's ability to conduct automated, continuous search of tarmac surfaces and detection of typical FOD, day and night in all type of weather conditions, on runways and other aircraft movement areas.

## **1. INTRODUCTION**

The author conducted a trial in controlled conditions at an Israel Defense Force airbase in the central coastal region of Israel in mid June 2014 in order to evaluate the performance of the SENTINEL system operating as a stationary electro-optical FOD-detection system in the typical airport environment. For that purpose an SENTINEL system (in its baseline configuration) consisting of one

sensor unit (consisting of a thermal camera, CCD video camera and a laser range finder – see specifications in annex A) was installed at the base of an air traffic control tower and on a tower located near runway surfaces.

The trial objective consisted not only in performing an assessment of the system's ability to automatically detect and identify typical FOD objects at several ranges but also in the assessment of the system's compliance with general minimum requirements delineated FAA AC N° 150/5220-24. Furthermore, the results of this trial can be used in the future to modify the SENTINEL system baseline configuration (infrared detector specification, addition of sensor heads in the complete architecture of the system, and number and spacing of sensor units).

The FAA requires that a stationary electro-optical detection system must be able to detect a 0.80 in. (2.0 cm) object target, at ranges of up to 985 ft (300. m) using only ambient lighting. The sensors must be located 490 ft (150 m) or more from the runway centerline. Generally, five to eight sensors are required per runway, depending on airport requirements and runway specifications.

Specifically the SENTINEL was tested in order to assess its ability to perform the following baseline minimal requirements in the above-mentioned FAA AC:

a. Basic Functions.

- (1) Provide surveillance in the aircraft operating area (AOA) as specified by the airport.
- (2) Detect and locate single and multiple FOD items on the AOA.
- (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 detected FOD, allowing for equipment calibration and maintenance, and for analysis of the FOD event.

b. Detection Performance.

(1) Object Detection. FOD detection systems must be able to detect the following objects:

- (a) Two, unpainted, aluminum squares each measuring 3 cm by 3 cm and 10 cm by 10cm,
- (b) Two rubber squares each measuring 3 cm by 3 cm and 10 by 10 cm,
- (c) Two asphalt squares each measuring 3 cm by 3 cm and 10 by 10 cm.
- (d) Any two of the objects above, located no more than 10 ft (3 m) apart from each other, identified as separate objects.

(2) Location Accuracy. FOD detection systems must provide location information for a detected object that is within 5.0 m of the actual FOD object location

(3) Inspection Frequency

(a) Continuous Detection System. The systems 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.

(4) Detection Response Time. FOD detection systems must have the capability to provide rapid detection of a FOD occurrence in the area being scanned.

(a) For continuously operating FOD detection systems that are designed to provide between-movement alerts, the system must provide inspection of runway surfaces between aircraft movements.

(b) 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.

(5) Surveillance Area. The airport operator will specify the desired surveillance (detection) area in the AOA 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 lesser importance, with a decreasing level of priority from other paved movement areas down to non-paved, non-movement 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.

(6) Performance in Weather. FOD-detection systems must demonstrate the detection performance under both clear and inclement weather conditions. Under clear weather conditions, the pavement of the AOA is expected to be dry, while under inclement weather conditions the pavement will be wet with rain, snow, or mixed precipitation.

(a) Detect objects under rainfall or snow conditions (e.g. having a specific intensity, duration, and frequency) for a two-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.

(b) FOD-detection systems must have site-specific performance specifications that include:

(i) performance during clear weather conditions;

(ii) performance during inclement weather conditions; and

(iii) provide the user with the amount of time required for the system to recover after a rain or snow storm, that is, to return the performance capabilities of clear weather conditions after adverse weather conditions subside. In this case, the end of adverse weather conditions will be defined as when precipitation of rain or snow ends.

(c) Lighting conditions. All systems must demonstrate detection performance during daylight, nighttime, and dawn/dusk operations.

(7) Alerts and Alarms. FOD-detection systems must be able to alert the system operator to the presence of FOD in scanned areas. The alert must provide airport management with enough information to assess the severity of the hazard in order to determine if immediate object removal is necessary.

(a) 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:

(i) one per day as averaged over any 90-day period, for FOD-detection systems with visual detection capabilities, or

(ii) three per day as averaged over any 90-day period, for FOD detection systems without visual detection capabilities. Note: Wildlife may move, or small items may be blown away, before airport operators using these detection systems have a chance to investigate FOD alerts.

## **2. THE EXPERIMENT**

In order to access the FOD detection performance capability of the SENTINEL system, the following FOD objects were used as targets that met and exceeded the FAA-mandated requirements:

(a) Target type A - Two, unpainted, aluminum squares each measuring 3 cm by 3 cm and 10 cm by 10cm,

(b) Target type B -Two rubber squares each measuring 3 cm by 3 cm and 10 by 10 cm,

(c) Target type C –Two asphalt squares each measuring 3 cm by 3 cm and 10 cm by 10 cm,

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

(e) Target type D – A metallic screw 3 cm by 1,5 cm.

The temperatures of the tarmac and targets were measured for each run during the trial. Meteorological data (air temperature, relative humidity) were collected by the airbase meteorological station. The tarmac and target temperatures was measured using a calibrated APPA 90 Series II Multimeter.

Verification of the detection of objects was conducted at slant ranges of 800m and 1500m.

Measurements were conducted using dry and wet tarmac conditions. For that purpose the tarmac surfaces were pre-wet with water.



In some of the trial runs, the targets were heated to different temperatures using boiled water in order to get required temperature differences between the FOD experiment targets and the background (tarmac).

During each run the SENTINEL system was operated in "search mode" using first the IR camera and then the CCD video camera in order to evaluate the system's capability to automatically detect the experiment targets. During each run, after target detection, the system was set to "observation mode", zooming in on the detected targets alternatively with the IR camera and CCD video camera in order to confirm the classification of targets as FOD and to identify the targets.

The precise object target location on the runway was obtained using the "Multi-Spider" display with GIS (Geographic Information System) overlay where the detected targets are superimposed on the airfield map. The coordinate position of latitude, longitude, distance and azimuth (from the sensor head) are automatically displayed on the system.

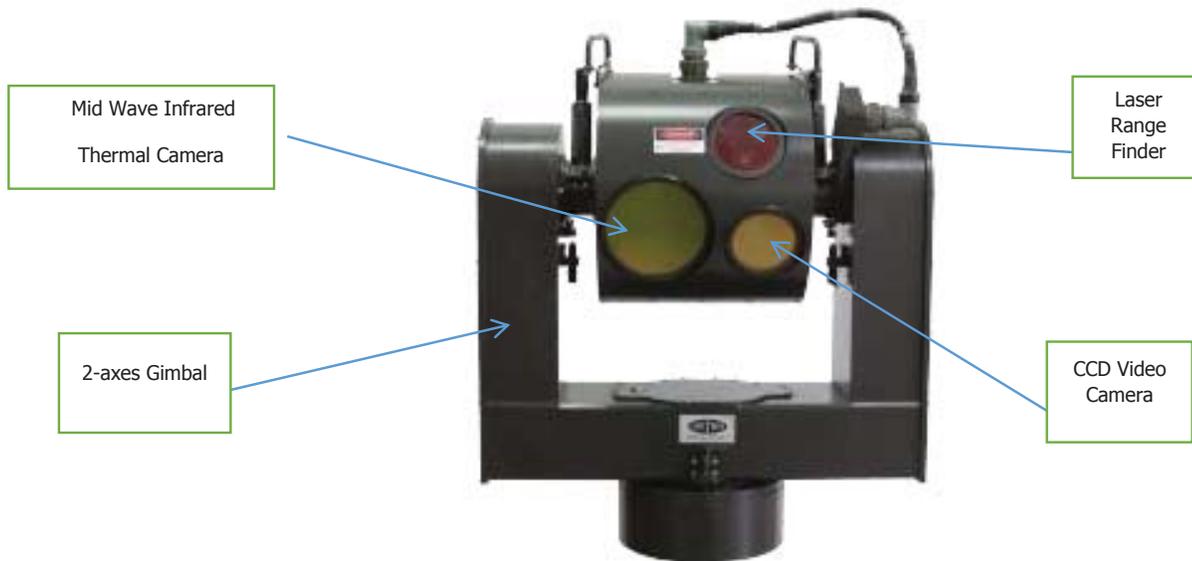


Figure 1. System Sensor Head

**System parameters*****Camera parameters***

The INTERCEPTOR EO/IR sensor subsystem configuration used during the experiment corresponded to the INTERCEPTOR baseline configuration as follows:

- A MWIR camera (FLIR)
  - 640X512 pixel detector, with 15 micron pitch
  - 2.2° - 27° continuous optical zoom lens
  - NTSC standard video in Observation mode~
  - Camera aperture:
  - Detector material:
  - Lens material:
- A daylight camera
  - 1/3" color detector
  - 0.9° - 13° continuous optical zoom lens
  - NTSC standard video
  - Camera aperture:

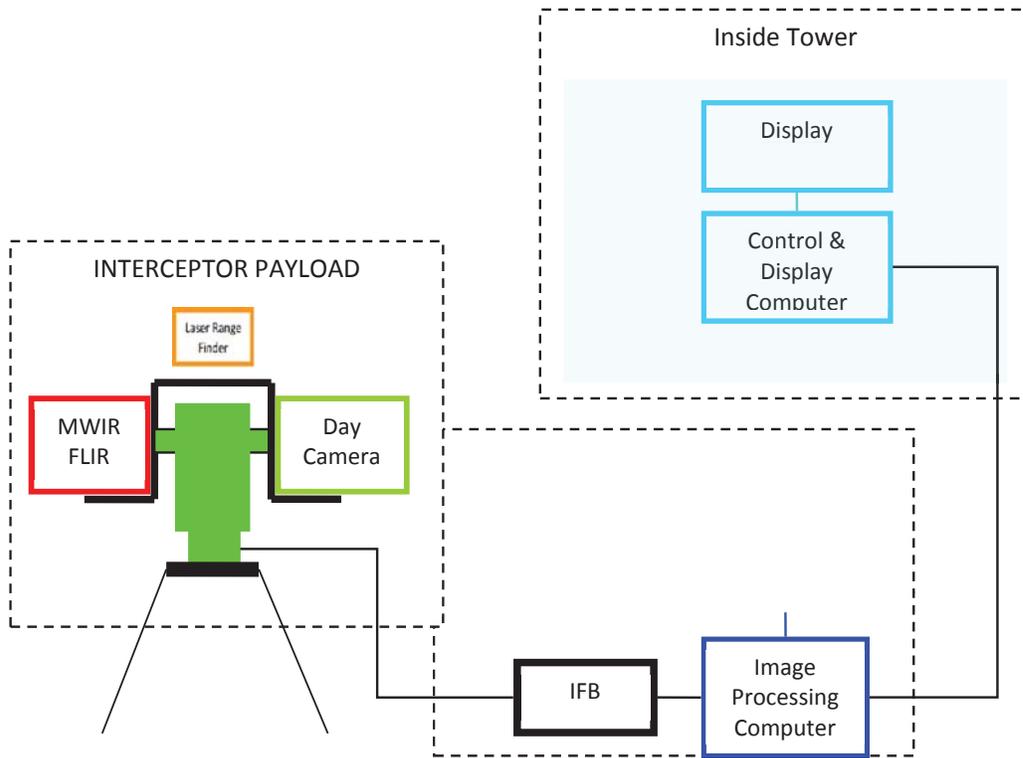


Figure 2. System block diagram

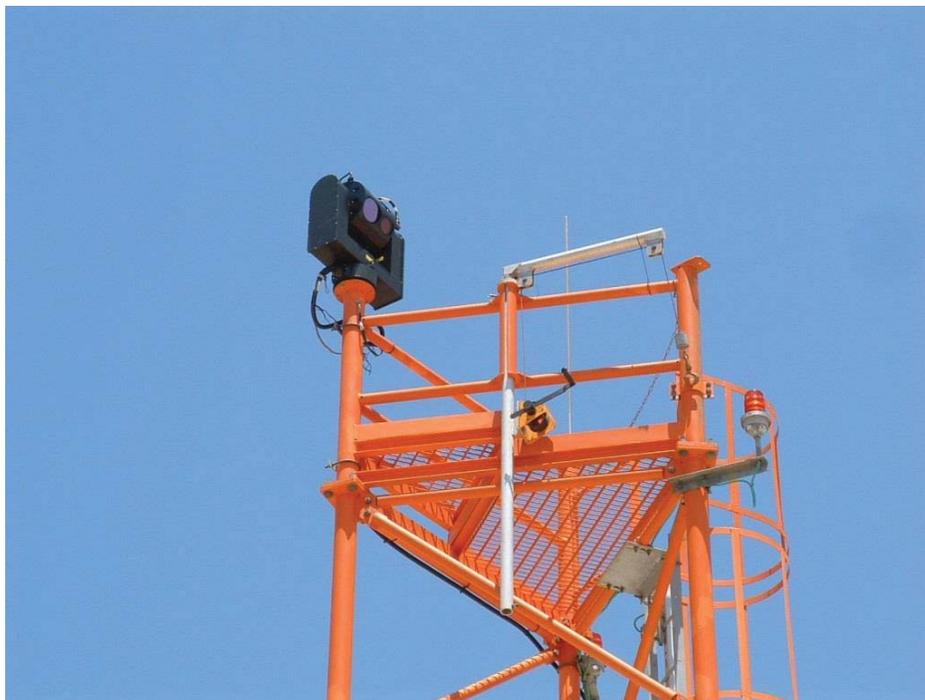


Figure 3. Installation of the SENTINEL on a mast during the trial

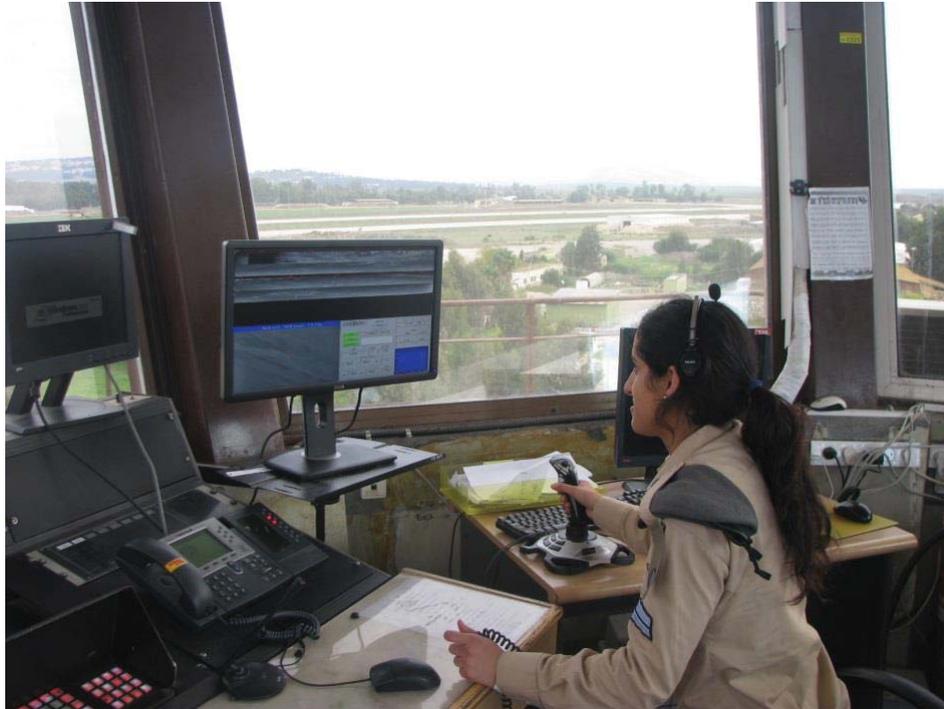


Figure 4. Control and display unit of the SENTINEL system in the ATC tower.



Figure 5. A calibrated APPA 90 Series II Multimeter was used to measure the target object and tarmac temperatures

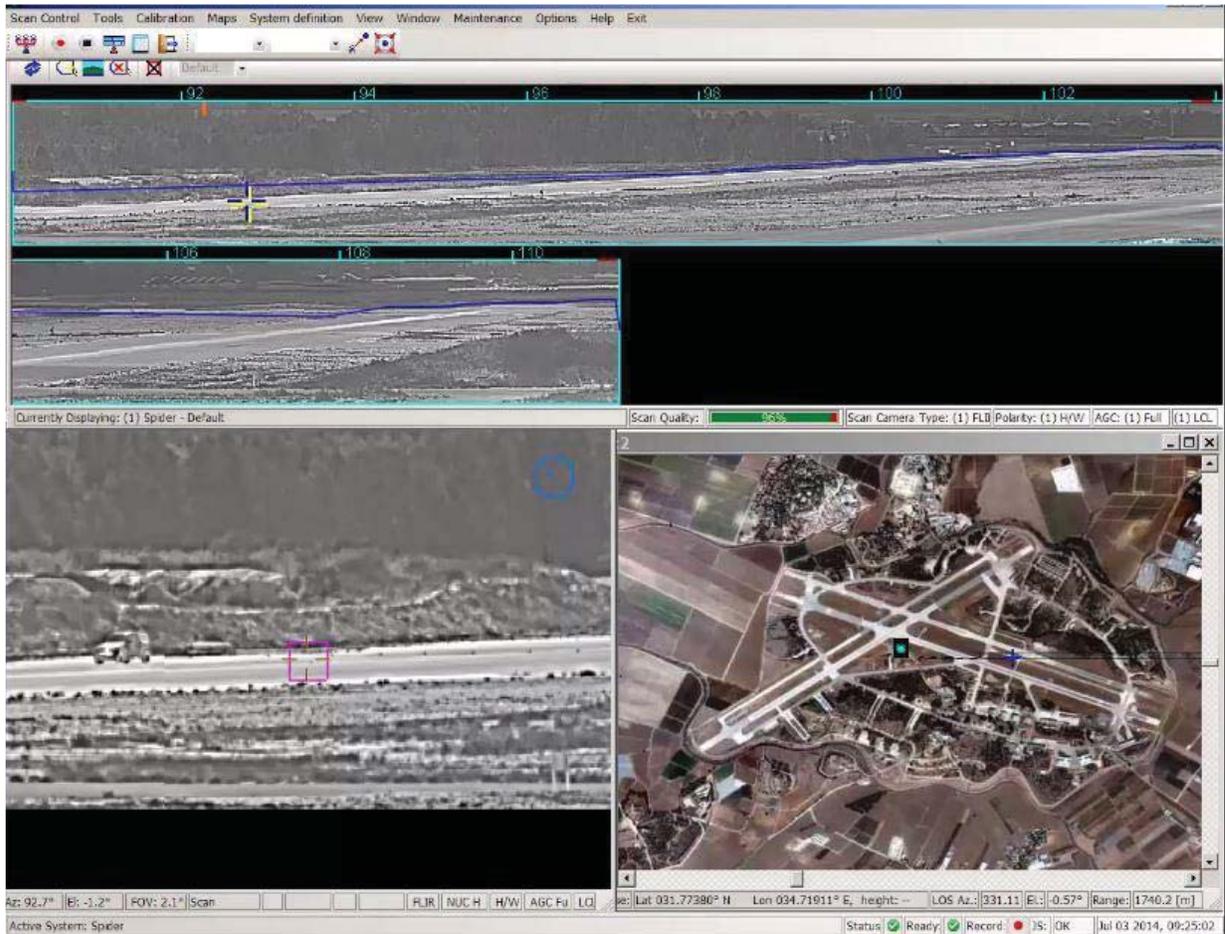


Figure 5. Capture of the SENTINEL display during one of the trial runs - A FOD test target of 10 cm x 10 cm was automatically detected at reading of: Azimuth=331.11°, Elevation = -0.57°, and Range=1740.2 meters. The detected target (blue cross) can be seen on both the GIS display in the lower-right corner with the geographical coordinates (longitude and latitude) of the FOD test target, as well as the real-time visual scan (pink box) in the lower left display. System location is denoted by a light blue square on the GIS display.

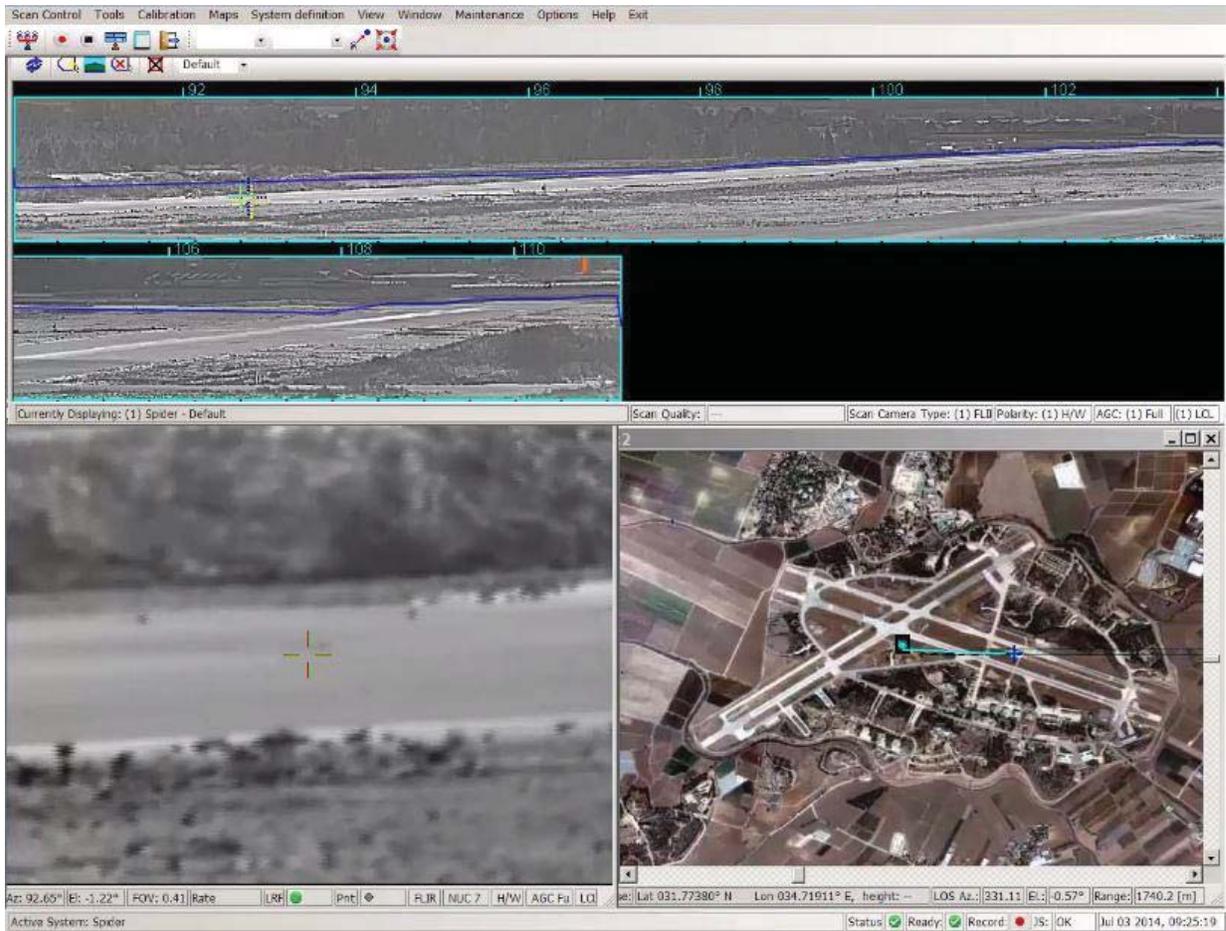


Figure 6. Capture of the SENTINEL display. Zoomed view of the FOD test target shown in Figure 2.1 to confirm the detected foreign object. The system was unable to identify the target at that range.

### 3. RESULTS AND CONCLUSIONS

The results of the trial are shown in Table 1.

In "search mode", the system was able to consistently and automatically detect 10 cm x 10 cm object targets at a distance of 800 meters. The system would automatically present and highlight with a green box, the foreign object target detected during the automated runway scan. For the smaller targets (3 cm x 3 cm) the detection was carried out by the system operator. The detection of the object targets was confirmed by zooming in on the target by switching the system to "observation mode".

The system showed a negligible false alarm rate.

From the trial runs, the following conclusions regarding the SENTINEL detection performance in its baseline configuration can be drawn:

- (1) The SENTINEL is able to detect small foreign object targets (3cm x 3cm) of different materials types that typically constitute FOD at a distance of 800 meters provided that temperature difference between the foreign object and background is at least 2°C ( $\Delta T \geq 2^\circ\text{C}$ )
- (2) The SENTINEL is capable to automatically detect small targets (10 cm x 10 cm) of different materials types that typically constitute FOD at a distance of 800 meters.
- (3) The use of the visual CCD camera can be advantageous in place of the infrared camera to detect small metal foreign objects at small thermal differences ( $\Delta T \geq 2^\circ\text{C}$ ) or in the detection of asphalt foreign objects at high tarmac temperatures.
- (4) The infrared sensor had difficulties in detecting asphalt objects against hot tarmac background, even at high temperature differences.

The experiment results clearly demonstrate that the SENTINEL system in its baseline configuration can be used as to automatically detect most foreign objects on airport surfaces. In its current configuration, with a single sensor head, the long detection range of the SENTINEL system enables the system to be used as ground-based electro-optic system to automatically detect FOD in all weather conditions, day and night, within acceptable ranges from the sensor head. Also the trial showed that the system, without any modification, is capable of meeting the FAA requirements described in its Advisory Circular FAA N° 150/5220-24 in terms of location, accuracy, continuous inspection of runways, and response time that are requirements for such type of a system in airports.

It is inferred from this experiment that the fulfillment of all the recommended FAA requirements for a single runway surface is technically attainable using a system configuration with more than one

SENTINEL sensor head, with an optimized spacing between them, and preferably using higher performance thermal (IR) and CCD video cameras with spatial resolution to enable FOD identification. To effectively scan the full length of a typical runway, the system would likely be composed of 2 to 4 SENTINEL sensor heads, preferably integrating the sensor data into a single composite image. To be competitive with current dedicated FOD systems, the sensors should not be more than approximately 400 meters from the runway surface (if using the same sensor specifications as the baseline system). Due to the constraints of the operating environment and local conditions, target detection was only accomplished at 800 meters. Though the system was able to automatically detect the larger targets (10 cm x 10 cm) at this range, it was unable to automatically detect the smaller objects (3 cm x 3 cm). Though the system was capable of manually detecting the targets at this range (through user interaction), it can be inferred that the system should be capable of automatically detecting all targets (including the smaller sized targets – 3 cm x 3 cm) at the recommended range of 400 meters. Even at this much smaller range, integration of 3 to 5 sensor heads would sufficiently cover a typical runway surface (3000 meters).



INTERCEPTOR FOD detection performance trials - Israel July 2014

Table 1.

Range [m]	Run #	Target A (metal) 10x10 cm				Target B (rubber) 10x10 cm				Target C (asphalt) 10x10 cm				Screw 3X1.5 cm			
		ΔT [°C]	3x3 cm C	ccd detect IR detect	ΔT [°C]	3x3 cm C	ccd detect IR detect	ΔT [°C]	3x3 cm C	ccd detect IR detect	ΔT [°C]	3x3 cm C	ccd detect IR detect				
1500 m	1	12	1,0	N													
	2				6	0,5	Y	Y	8	0,7	Y	Y	6	0,5	Y	Y	
800 m	3	-10	-0,5	N					-4	-0,1	Y	Y	-17	-0,4	N		
	4				-8	-0,2	Y	Y									
	5	-6	-0,2	Y					-4	-0,1	Y	Y	-6	-0,2	Y		
	6	-8	-0,4	Y					-10	-0,5	Y	Y	-8	-0,4	Y		
	7	-2	-0,1	N					-3	-0,2	N	N	0		N		
	8				-2	-0,1	Y	Y					-2	-0,1	N		
	9	10	2,0	N					9	1,8	Y	Y	9	1,8	Y	Y	
	10				10	2,0	Y	Y									
	11	-2	-0,1	N					-4	-0,1	Y	Y	-4	-0,1	Y		
	12				-2	-0,1	Y	Y					-4	-0,1	Y	Y	
	13				-2	-0,1	Y	Y					-4	-0,1	Y	Y	
	14	-2	-0,1	N					-4	-0,1	N	N	-4	-0,1	N		

Table 2. SENTINEL compliance with FAA AC N° 150/5220-24		
	Yes/No	Observations
Basic Function		
Basic Functions.	Yes	Pre-programmed surveillance areas can be pre-defined and user modified
(1) Provide surveillance in the AOA as specified by the airport.	Yes	
(2) Detect and locate single and multiple FOD items on the AOA.	Yes	
(3) Provide an alert to the user when FOD has been detected.	Yes*	
(4) Operate in conjunction with, and not interfere with, airport and aircraft communication, navigation, and surveillance systems.	Yes	
(5) Operate in conjunction with, and without interference from, normal airport and aircraft operations (e.g., aircraft and vehicle movements).	Yes	
(6) Provide a data record of detected FOD, allowing for equipment calibration and maintenance, and for analysis of the FOD event.	Yes	
b. Detection Performance.		
(1) (a) Two, unpainted, aluminum squares each measuring 3 cm by 3 cm and 10 cm by 10cm,	Yes*	At 800 meters, only the 10X10 cm object targets were detected automatically. The smaller objects were manually detected. At 400 meter range, the system should be capable of detecting the smaller objects.
(1) (b) Two rubber squares each measuring 3 cm by 3 cm and 10 by 10 cm,	Yes*	
(c) Two asphalt squares each measuring 3 cm by 3 cm and 10 by 10 cm.	Yes*	
(d) Any two of the objects above, located no more than 10 ft (3 m) apart from each	N/A	This test was not able to be completed during this test and should be conducted at a future date.



other, identified as separate objects.		
(2) Location Accuracy. FOD detection systems must provide location information for a detected object that is within 5.0 m of the actual FOD object location	Yes	Strongly advised the system to have the "Multi-Spider" display with GIS overlay.
(3) Inspection Frequency		
(a) Continuous Detection System.	Yes*	The system is either in continuous scan mode or track/identification mode. Once a target is detected and if the operator wishes to confirm the classification as FOD with one of the cameras, the system halts the scanning during that period.
(4) Detection Response Time. FOD detection systems must have the capability to provide rapid detection of a FOD occurrence in the area being scanned.		
(a) For continuously operating FOD detection systems that are designed to provide between-movement alerts, the system must provide inspection of runway surfaces between aircraft movements.	Yes*	The response time depends of the pre-programmed sectors the system is assigned to scan. For a typical runway, the system takes about 18 seconds to scan upon initiation if the system is only operated for that purpose (2 sweeps are necessary in order to detect changes of the scene). This time is halved between all subsequent scans.
(b) 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.	Yes	

#### **4. RECOMMENDATIONS**

The trial results clearly showed the benefit of having the SENTINEL system in its current baseline configuration employed to detect foreign object debris on airport surfaces. Moreover, this trial provided an important insight in to how the system architecture and configuration can potentially be adjusted or modified for the system to meet all the requirements recommended by FAA for an electro-optic FOD-detection system.

Future trials must test the system performance under adverse conditions (e.g. rain, snow, etc.) where a degradation of the detection range can be expected due to a decrease in atmospheric transmission or signal-to-noise ratio degradation.