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FogEye UV Sensor System Evaluation: Phase II Report

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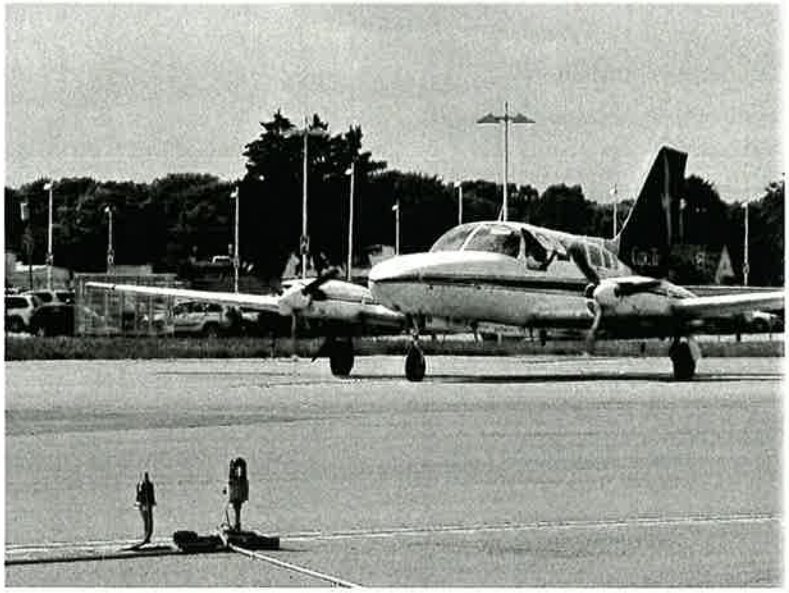

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TABLE OF CONTENTS

PREFACE

FogEye technology employs radiation in the solar-blind region of the ultraviolet spectrum to operate sensors and systems that have favorable atmospheric characteristics during all aviation weather conditions. Congress requested the FAA to evaluate the feasibility of applying FogEye technology to aviation-related problems. The FAA's Office of Surface Technology Assessment (AND-520) assumed responsibility for this investigation and requested the support of the Volpe Center.

The FogEye Sensors that were evaluated were provided by Norris Electro Optical Systems Corp.

This evaluation has thus far extended over a two-year period, 2002 and 2003, in response to Congressional Directives for each of the two years. The first year involved evaluation of the characteristics of FogEye technology and assessment of application of the technology as a sensor that would aid in runway incursion prevention. The technology was embodied in Demonstration Models that were statically evaluated at the Volpe Weather Test Facility at Otis Air National Guard Base (OANGB). Operation of these sensors was quantitatively observed during dense fog, rain and bright sunlight conditions. The sensors were also employed to detect the surface movement of F-15 aircraft at OANGB. The evaluations were successful. A Volpe Transportation Center report concluded "These test results indicate the basic characteristics of ultraviolet (UV) technology are favorable. The conclusions thus far are that the technology has considerable merit and therefore the FogEye assessments should continue as planned, to determine the most attractive and effective weather applications"[1]. These 2002 results led to the 2003 operational evaluations that are discussed herein.

This evaluation could not have been successfully completed without the cooperation and help of the Rhode Island Airport Corporation. Specifically, Mr. Alan Andrade, Deputy Airfield Operations Manager, who interfaced our test activities with flight operations. Special thanks also go to Mike Thorsted, Reginald Harrison, and Eldon Ziegler of Norris Electro Optical Systems Corp for their support at Providence International Airport and the Volpe Center Weather Test Facility.

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[1] Clark, K.L., Burnham, D.C. and Jacobs, L.; FogEye UV Sensor System Evaluation: Phase I Report; Report No. DOT-VNTSC-FAA-02-04; September 2002.

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) and the commercial aviation industry seek to develop and evaluate technologies that have the potential to reduce runway incursions and improve safety of airport operations during all visibility conditions. Reliable and cost effective detection of aircraft movement along taxiways and runways is a fundamental and essential requirement for preventing runway incursions. FogEye technology offers the potential to accomplish this capability. It operates in the solar blind portion of the UV region and is therefore free of natural background noise, thereby enabling operation during extremes of fog, rain or bright sunlight.

This report documents the operational performance of Prototype FogEye Transmitter-Receiver sensors for detecting the presence of aircraft and other vehicles at Providence, Rhode Island, International Airport (PVD) during Phase II of the 2003 evaluation period. The Prototype units consist of operationally configured Transmitter-Receiver pairs. The Transmitter units are mounted integral with runway edge lights. The Transmitter radiates a beam to a Receiver unit that is located directly across a taxiway. The Receiver is also integral with an existing runway edge light. Two Transmitter-Receiver pairs are located along a taxiway in the hold short area. One of the Receivers is designated the ”master”. It contains a microprocessor that registers detections from both Receivers. The microprocessor reports, in real time, characteristics of aircraft movement within a particular hold short area. These reports are provided in RS 232 serial port format. This hardware embodiment and capability of FogEye technology is known as Safety Sentry.

Following approval from the FAA New England Region and the Rhode Island Airport Commission (RIAC), Safety Sensor was deployed at two sites at PVD from September 1, 2003 to November 30, 2003. The first site was the hold short area of taxiway Alpha; the second site was the hold short area of taxiway Tango. Two sets of Transmitter-Receiver pairs were installed at each site at the location of existing taxiway lights. A Riegl laser ranger and an imaging camera were positioned at both sites as sensor performance evaluation aids. The camera was triggered to operate when the laser ranger detected the presence of an object. The digital Safety Sentry aircraft movement messages were transmitted over hard wire to a RS 232 modem. The modem analog signal output and the laser and camera data were simultaneously and continuously recorded with a Digital Acquisition System (DAS).

Installation and setup of the system on the airport backbone using individual addressed servers had to be abandoned due to interface problems. An alternative method of operation required a change in PVD Standard Operation Procedures (SOP) in the area of power. PVD secures their taxiway lights during daylight hours. The Safety Sentry requires power during day light hours for the UV source and UV receiver. In order to proceed with testing RIAC approved the SOP change and the taxiway lights were powered 24 –hours per day. No other installation problems were noted.

Recorded performance data indicated Safety Sentry detected aircraft presence with a probability of 0.994 based on 4074 events and 23 misses. Analysis of the firmware performance indicates that incorporation of some minor change is likely to improve Safety Sentry system probability of detection to approximate 1.00.

Supportability data, including reliability, maintainability and MTBF were concurrently collected over a three-month period, for a total of 3,800 hours of operation. No repairs were required during this period. The system operated maintenance free, without failure. PVD experience indicates the mean time to replace an individual unit is 15 minutes. A Transmitter or Receiver unit is considered a Line Replaceable Unit.

These favorable aircraft detection results and the supportability history, in an operational commercial airport environment, substantiate a recommendation that the Safety Sentry sensor be integrated into runway incursion prevention systems currently under development at selected intersections as an aircraft presence detection sensor.

1. INTRODUCTION

1.1 Background

Fog and inclement weather produce accidents and hinder airport operations because of reduced visibility. Fog also promotes accidents by means of "aerial perspective," a visual effect which causes people to misjudge distance. People automatically perceive objects which are low contrast and indistinct as being further away. We learn this because of an environmental regularity: light from distant objects, such as mountains far away, must pass through more air molecules and becomes more scattered. Distant objects are then less indistinct and fainter. The pilot approaching the stopped aircraft will judge it to be further away than it really is and therefore underestimate the time and distance needed to stop.[2]

FogEye (Safety Sentry) is a commercial name for solar-blind ultraviolet technology used to penetrate fog. The technology can be applied to circumstances requiring navigation or surveillance during low visibility conditions. Evaluation of FogEye devices packaged in taxiway light configurations was performed in a two-phase effort. The objective of Phase-I[3] was to evaluate the form, fit, and functionality of the sensor, and revalidate the repackaged system maintained solar blind characteristics. Phase II examined the operational performance capabilities of FogEye at a commercial airport during normal operations.

The FogEye emitter/sensor pairs are intended to autonomously detect the proximate presence of aircraft on taxiways. Individual sensors or combinations thereof can function as triggers for indications of presence of aircraft or vehicles. The goal of Phase II is to demonstrate that the FogEye emitter/sensor can be used to reliably detect aircraft and vehicular traffic in fog and under bright daylight conditions.

The FogEye technology was initially evaluated during 2002 at the Volpe Weather Test Facility (WTF) at Otis Air National Guard Base (OANGB) during all types of weather. The evaluations were a success. They were performed with Demonstration Model hardware. Additional evaluations, under actual airport operational conditions, were recommended. The hardware was then reconfigured as a form and fit Prototype that conformed to the airport operational environment. It was subsequently retested at the WTF during Phase I of 2003. The favorable performance characteristics exhibited during 2002 were found to be retained. Deployment and evaluation in an airport operational environment was therefore merited.

1.2 Test Objective and Methodology

The primary objective of the FogEye Evaluation Program is to determine whether coupled ultra-violet sources and detectors may provide enhancements to safety on the airport surface. The results of this effort will be used to complete the evaluation of the basic concepts of FogEye and assist in the design of future operational applications.

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[2] Visual Expert Human Factors, "Weather and Accidents: Rain & Fog", Marc Green, 2003

[3] Clark, K. L., Burnham, D. C., Jacobs, L., and Soares, M., FogEye Sensor Evaluation: Phase I Report," Report No. DOT-VNTSC-FAA-03-08, Volpe National Transportation Systems Center, Cambridge, MA

The evaluation examined the sensors repackaged as taxiway lights and configured on two taxiways on Providence International Airport (PVD). With the assistance of Rhode Island Airport Commission (RIAC) and FAA two sites were selected on the airfield that was deemed high traffic areas.

2. TEST CONFIGURATIONS

2.1 Test Sites

In Phase II, four FogEye Sensor pairs were installed at two sites on PVD. The two sites are circled in red below. (Figure 1) Two sensor pairs were installed on taxiway Alpha and two sensor pairs were installed on taxiway Tango. Figure 2 depicts a pair next to standard taxiway lights at taxiway Tango.

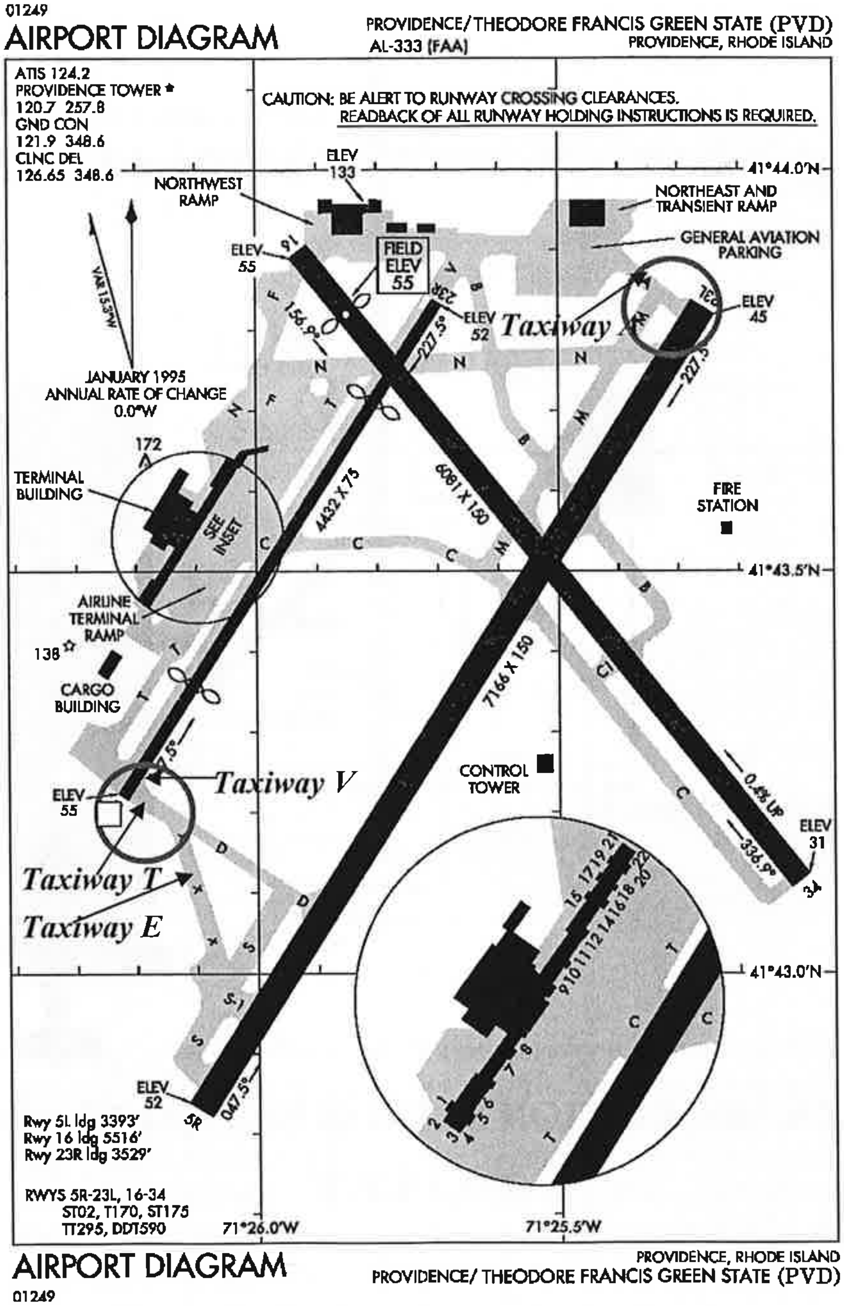


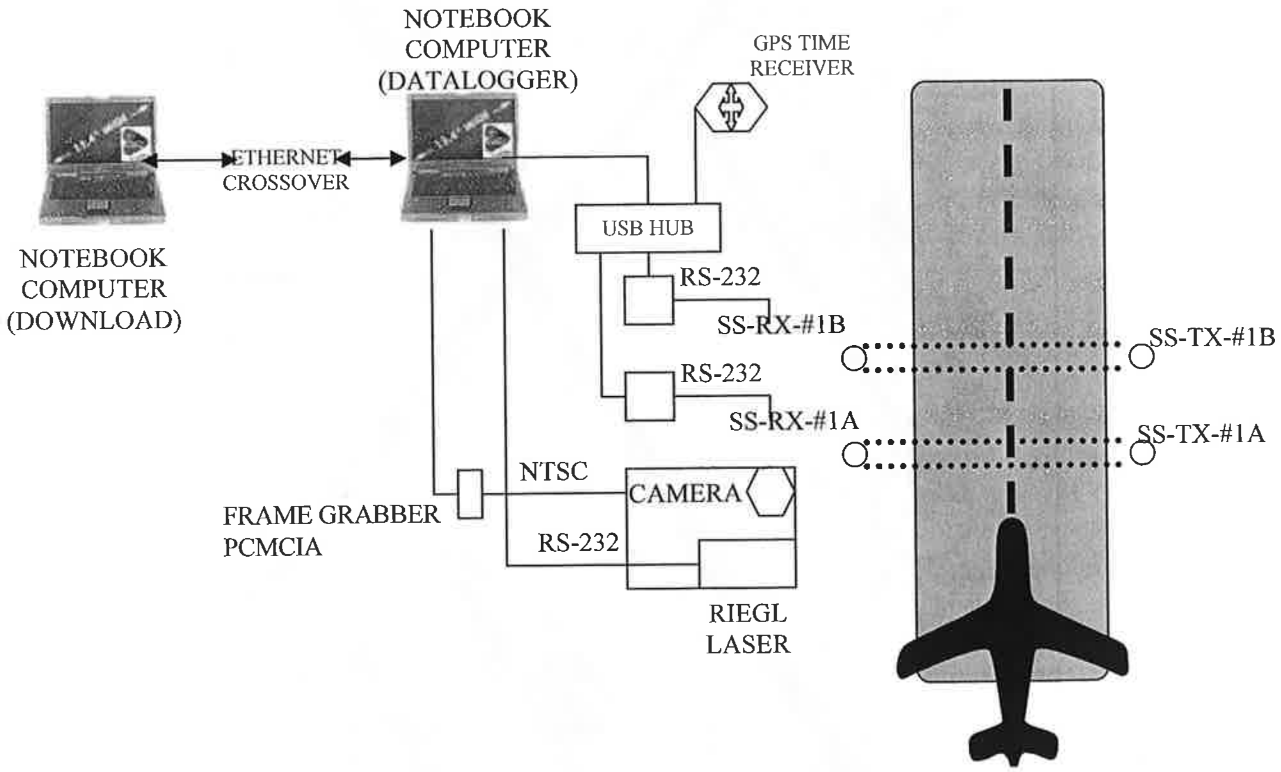
Figure 1 – FogEye Sensor Test Sites at Providence International Airport (PVD)

The entire system consists of the following components as shown in the table below:

Hardware	Taxiway Alpha	Taxiway Tango
FogEye Pair	2	2
Reigl Laser Range Finder	1	1
Video Imaging Camera	1	1
Laptop Computer (DAS)	1	1

2.2 System Setup

There are 2 FogEye pairs, 1 Laser, 1 Video Camera and a Laptop Computer located at each taxiway. The interconnections for the entire system are shown below in Figure 2. A schematic of the taxiway T is depicted in Figure 3.



FOGEYE DATA ACQUISTION SENSOR NETWORK ARCHITECTURE

FIGURE 2

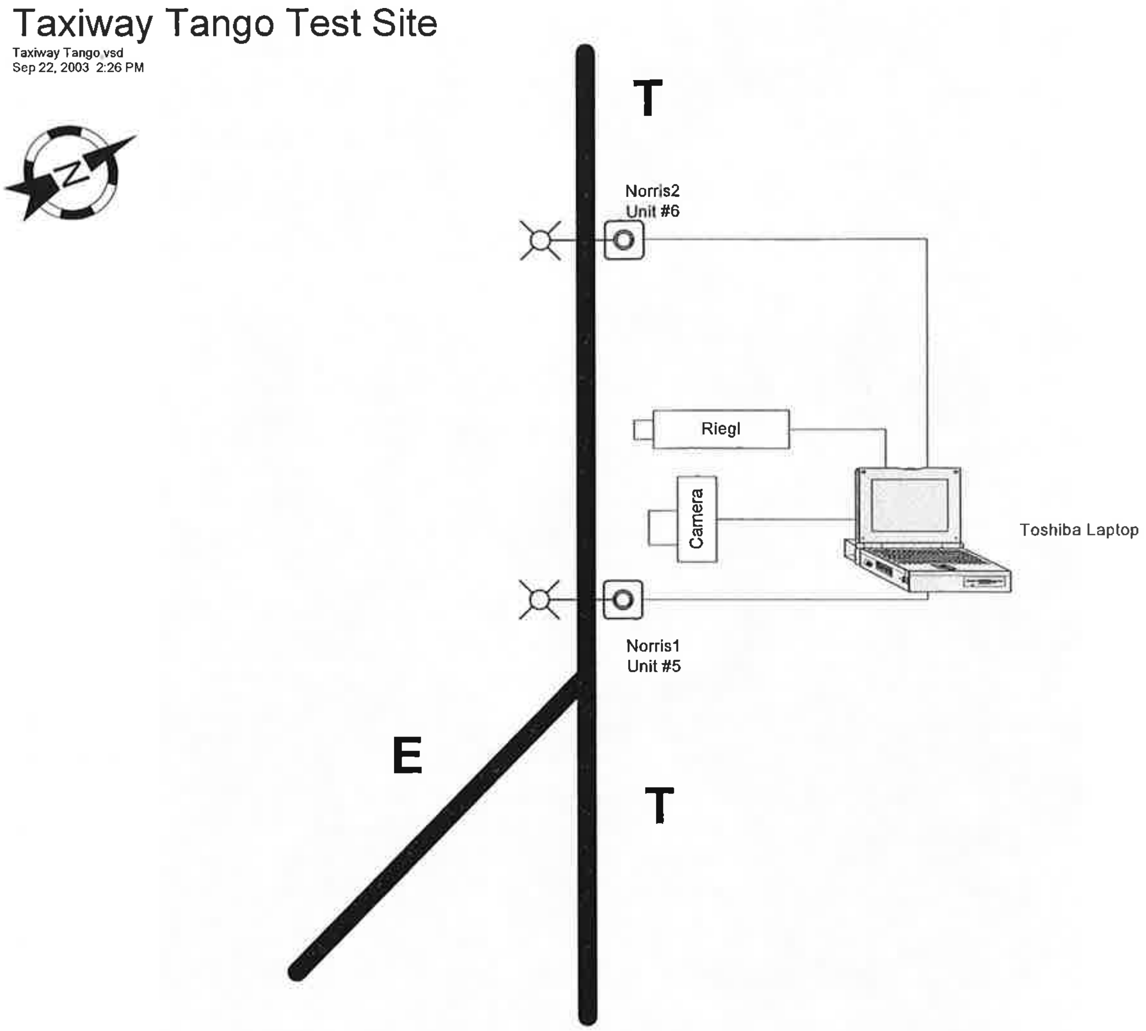


Figure 3

The two pairs for taxiway T were installed between the east side of taxiway V and the diagonal that breaks off from taxiway T and extend south to taxiway E. The second pair was installed on taxiway A between the west side of runway 23L and taxiway M. Power and communication to and from these sensors was supplied by a dedicated series lighting loop on the wig-way light series loop. Access to the loop for the taxiway T location will be via the wigwag wiring can (L-867 light base) at the intersection of taxiway T with runway 5R. Access to the loop at the taxiway A location will be via the wigwag light can at the intersection of taxiway A with runway 23L. Note that in each case a wire from the can splices, in series, at four light locations, and then returns uninterrupted, by the same route, back to the original wigwag can. A view of taxiway T is depicted in Figure 4.

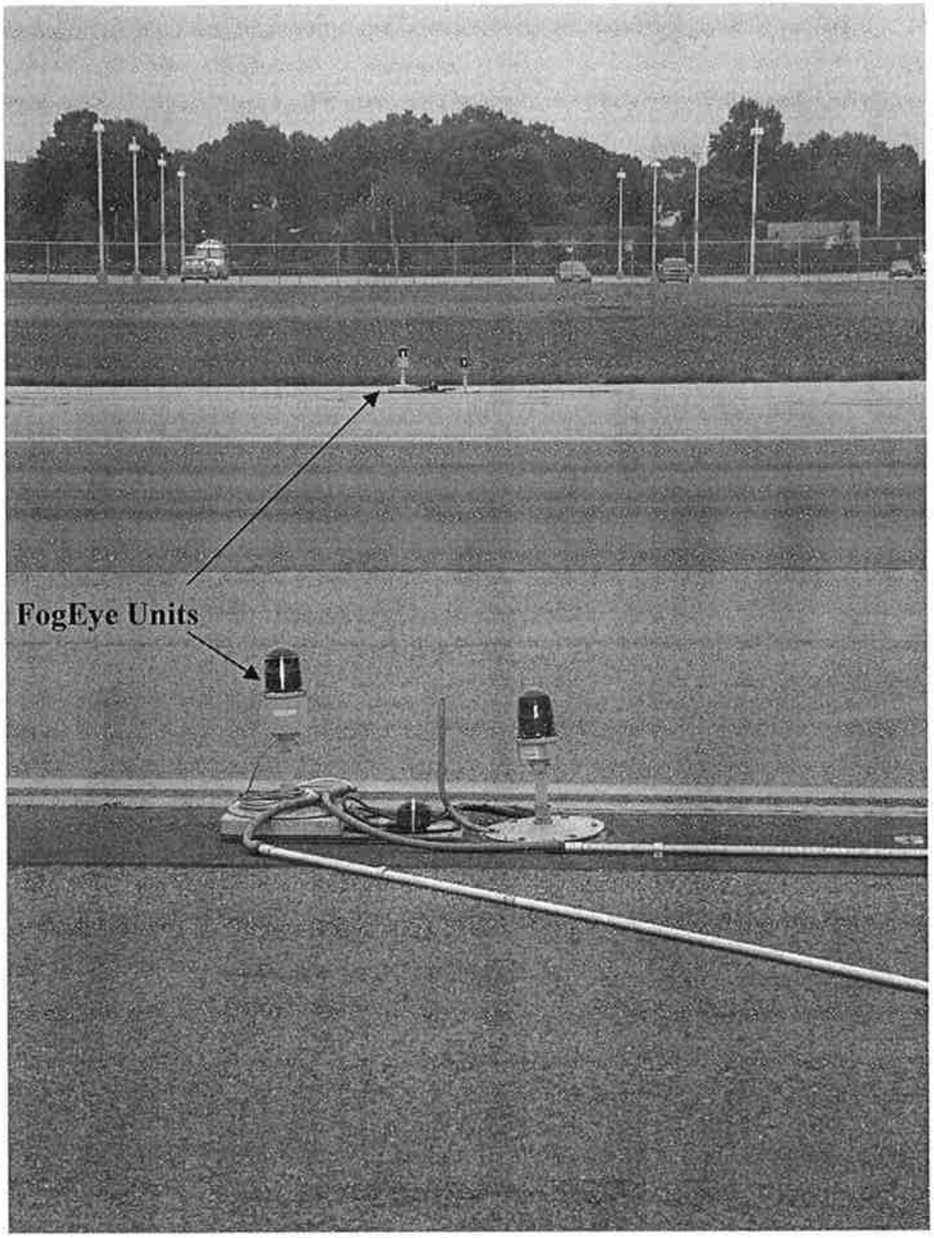


Figure 4 – Taxiway T

2.3 System Description

A Safety Sentry System reports the presence or departure of aircraft or vehicles along a designated movement area. It also reports other relevant aircraft movement characteristics and the health status of its sensors.

Each Safety Sentry System consists of two Transmitter and Receiver pairs. Each pair are located at opposite boundaries of a movement area through which an aircraft or vehicle travels. A Transmitter unit is mounted integral with an existing taxiway edge light. It radiates a beam to a Receiver unit that is located directly across the taxiway. The Receiver is also integral with an existing taxiway edge light. The beam transverses along one of the movement area boundaries. A second Transmitter –

Receiver pair is similarly located at the opposing movement area boundary. Both the Transmitter and Receiver pairs are in the form of hockey pucks. These cylindrical modules are inserted between the flanged base of an edge light fixture and the fixture's lamp and globe that mount to the base. They are powered by the existing constant current edge light power line. Installation is accomplished by simply inserting a "hockey puck" into an existing edge light fixture or replacing an existing fixture with one that includes a previously inserted Transmitter-Receiver module. Power and signal connections are made if appropriate, within the edge light can. The Receiver also has an integrated RF link that is capable of transmitting system messages in an RS232 serial format.

The characteristics and deployment of the beam are such that the nose wheels and the main landing gear wheels of aircraft individually intercept the passage of the beam. These beam interruptions are detected and measured by the Receiver and processed to describe an aircraft's movement characteristics. The Receiver of one of the pair is designated a "slave"; the Receiver of the second pair functions as a "master". The slave simply reports beam interruptions to the master. The master employs a microprocessor to register the slave inputs in addition to its own detections of beam interruptions. The sequence and period of the interceptions are processed to provide: aircraft presence, aircraft departure, aircraft direction, and aircraft velocity. The processor is also capable of providing additional information such as aircraft type.

The information is structured in an RS232 format and transmitted to remote locations where the data is decoded and made available in the form of discretes for activation of annunciators, inputs to safety logic, or for use in displays. The transmission means is either via radio frequency carrier modulation or hard wire. Both capabilities are resident in the master Receiver. In either case appropriate receptors are provided at the remote receiving end to translate the information into parallel, discrete, TTL signal formats, e.g., 5 VDC indicates aircraft absent and 0 VDC indicates aircraft present; these signals can be used directly to activate a flashing PAPI.

In addition, sensor analog signals are provided for sensor performance or "health monitoring" purposes. These signals also serve as an aid that allows for beam interrupt threshold level adjustments, and time constant variations for background and detection signal gain control.

For this airport operational evaluation the master Receiver communicates over hard wire in a RS 232 format with a Data Acquisition system (DAS). The DAS reads the messages from the serial port, unpacks and displays the message contents and, optionally, writes the message contents to log files. Taxiway A Configuration is shown in Figure 5.

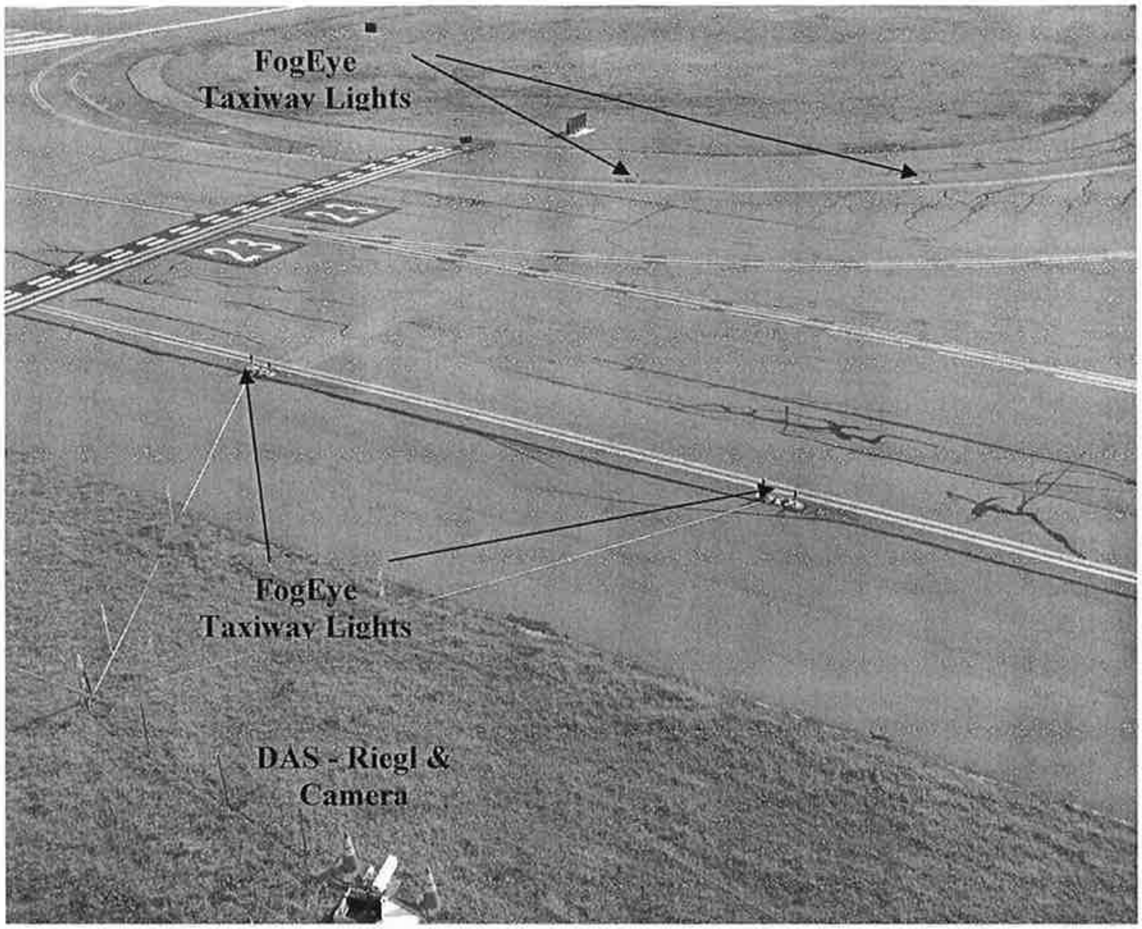


Figure 5 – Taxiway A

2.4 Data Acquisition Equipment

Two Riegl laser range finders were used to independently detect aircraft in the region monitored by the FogEye sensor pairs. A height suitable for both GA and airline aircraft was selected. The Volpe data acquisition system is designed to accept serial messages and apply time tag. The clock synchronization signals are sent out by the Volpe data acquisition system to the FogEye sensors. The DAS is shown below in Figure 6.

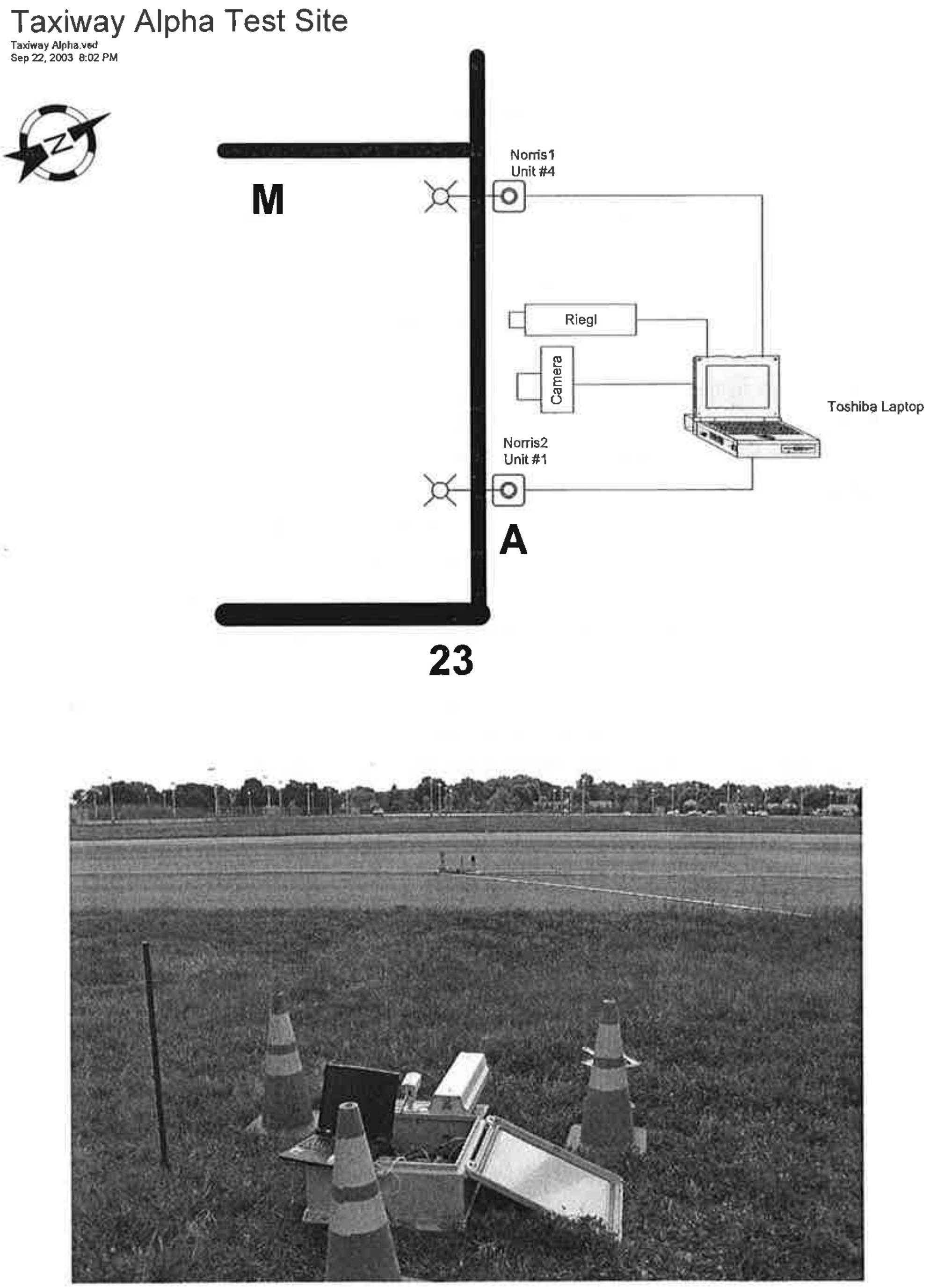


Figure 6 – Data Acquisition System

2.5 Operation and Digital Interface

All four FogEye sensors tested had an interface suitable for integrating into a ground surveillance system. Algorithms were developed to provide logic to detect aircraft with wheels that straddle a sensor. The basic information provided by the sensor is the presence or absence of beam blockage. System messages are of two types: beam blocked at time hh:mm:ss:ttt (with ttt as fine a resolution as msec) and beam unblocked at time hh:mm:ss:ttt. The Volpe data acquisition system was designed to accept serial messages and apply time tag with a timing accuracy of ± 0.5 seconds. GPS datum provided time synchronization.

Safety Sentry was originally intended to be installed and operated with an existing Runway Guard Light power and control system that was installed and operated by Siemens Airfield Solutions at PVD. The Siemens BRITE system was to control power to Safety Sentry and also provide communication massages. An excessive work load at Siemens precluded their ability to incorporate necessary software changes that would have provided this capability in a timely manner. An alternative method of operation involved powering Safety Sentry directly from the existing taxiway power lines. However, Safety Sentry operation was required 24 hours a day and the taxiway lights were powered only from dawn to dusk. To accommodate this Safety Sentry 24 hour requirement, RIAC approved a change in their standard operating procedures to allow for 24 hour power to the affected taxiway power lines. Communication of the Safety Sentry messages was transmitted directly over hard wire to the DAS rather than through the hard wire of the Siemens hard wire carrier. The power line carrier capability will be provided at a later data. A RF means to communicate the messages has been implemented and successfully demonstrated at the contractors facility. Time did not permit its operational evaluation at PVD as part of this Phase II effort. The Safety Sentry system was configured to provide presence detection, direction, velocity, and classification of aircraft and vehicles. However, the Phase II evaluation concentrated only on presence detection.

2.6 Safety Sentry Characteristics

2.6.1 Characteristics Table

The Safety Sentry description is set forth in paragraph 2.3. Electro optical characteristics of the Transmitter and Receiver pairs that constitute the sensors for Safety Sentry are described in Table 1.

Table 1. Safety Sentry Characteristics

Transmitter	
Wavelength	254 nanometers
Beam Width	12^0 half width, half power
Prime Power	6.6 amp, 60 Hz, 3 watts
Receiver	
Wavelength	254 nanometers
Sensitivity	3×10^8 amp./watts
Field of View	1.5^0
Dynamic Range	3×10^5
UV/Visible Isolation	$>10^6$
Prime Power	6.6 amps, 60 Hz, 1.5 watts

2.6.2 Interface Diagram

An Interface Block Diagram is provided in Figure 7. The output messages of the Safety Sentry Master Receiver are provided in the Runway Edge Light Can as a serial port on a DB9S 9 pin connector. The signal format is RS 232, with pin 2 being the output, pin 5 being ground, and pin 3 being an RS 232 input to the Receiver. The RS 232 Modem shown at the remote location on the diagram is the same as the local Modem board housed in the Master Receiver. In this instance, the remote Modem serves as an Interface Controller. It is firmware programmable such that any of the signals shown under the Sensor Message Content can be provided as an isolated discrete in TTL format; +5 VDC as a high signal and 0 VDC as a low signal. It therefore can be located at a flashing PAPI or other annuniciator and the signal used to trigger the annunciator.

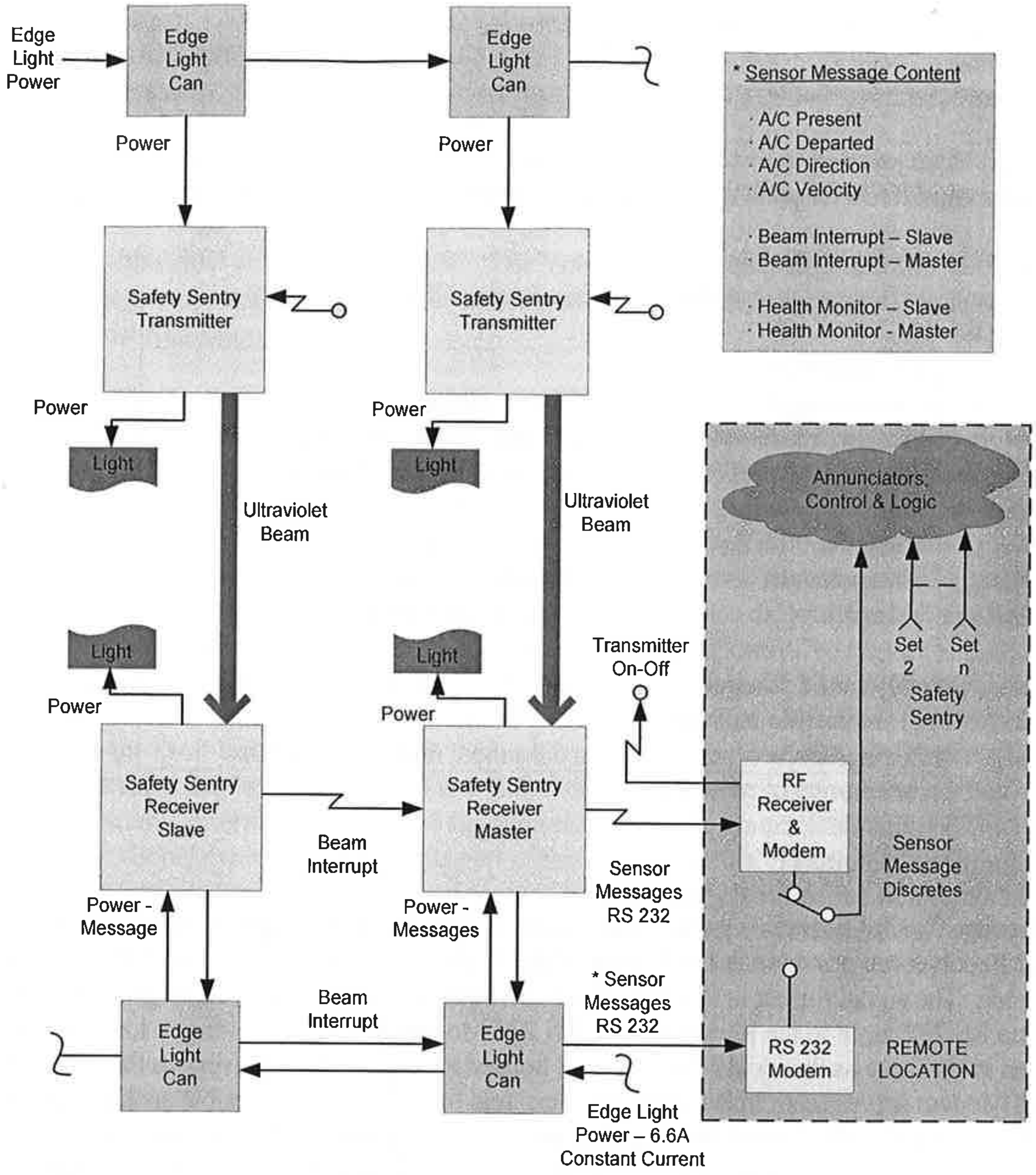


Figure 7 – Safety Sentry Interface Block Diagram

3. DATA ANALYSIS

3.1 Performance Evaluation

In evaluating the performance of the FogEye emitter/sensor pairs the analysis used aircraft/vehicle pictures recorded by the DAS to verify an event occurred. Using time tags these events were compared to events the FogEye system recorded. Data taken the DAS and the FogEye system were reconstructed in time sequence in order to determine the reliability and consistency of the FogEye system. Three months worth of testing data from the PVD airport at Alpha and Tango taxiway were analyzed picture by picture to be precise. A total of approximately 5,000 (to be updated) cases of arrivals or departures from each taxiway were analyzed.

The data was captured by the DAS second by second and then summarized into events. Data from three devices: 1 Riegl system and 2 units of FE (FE1, FE2), were reconstructed in time sequence to compare among them and determine whether there is any mismatches on detecting an aircraft present. Each event of detecting an object is categorized into one of the following possible categories:

- **Ok**: all 3 devices detected the aircraft or vehicle
- **N1 miss**: FE1 failed the detection but FE2 detected when the Riegl picture showed an aircraft
- **N2 miss**: FE2 failed the detection but FE1 detected when the Riegl picture showed an aircraft
- **Miss by both FEs**: no detection by both FE1 and FE2 and detected by Riegl
- **No Riegl**: detected by both FE1 and FE2 and no detection by the Riegl
- **N1 single**: detected by FE1 only and no detection by Riegl
- **N2 single**: detected by FE2 only and no detection by Riegl
- **Fault positives**: when the Riegl's picture showed empty of aircraft and FE had a detection
    - N1 fault positive: only FE1 had a detection on empty picture case
    - N2 fault positive: only FE2 had a detection on empty picture case
    - Both N1, N2 fault positive: both FE1 and FE2 had a detection on empty picture case

3.2 Analysis method applied:

- **At least one detection per aircraft**: at least 1 detection is required for the same aircraft, even if multiple pictures were taken by the Riegl.
- **Extended duration of detections**: looking at the reconstructed events, it shows that FE tends to extending the detection duration from one aircraft to the next, thus, hard to tell when the first aircraft has left and another aircraft has arrived. However, as long as the extended duration covered the whole duration of aircraft presence, it is acceptable even though at the expense of runway capacity.
- **Reasonable elapse time allowed**: due to the location of the 3 devices on taxiway, speed of aircraft, and direction of aircraft traveling, a reasonable elapse time is considered while examining the data..

- **Double checking for detection accuracy**: due to the software complexity in determining whether there is a detection of aircraft or a bird flying by, both the event summary and detailed gated records were checked to ensure the accuracy of this analysis and duly treating the performance of the FE.
- **Validated by the Riegl's picture**: a detection has to be validated by the Riegl's picture for any existence of fog, aircraft or vehicle presence. Description of Recorded Data

3.3 Description of Recorded Data

A typical recorded data set is shown in Figure 8. Figure A shows an aircraft as it moves between the two Safety Sentry sensors at the Tango taxiway hold short area. Figure 8 (B - bottom) shows the analog signal outputs of the Safety Sentry Slave Receiver at the Tango taxiway. The green signal is the detector AGC level. The red and blue signal is the output of the detector. The same signal description applies to Figure 8 (B - top) for the Safety Sentry Master Receiver. In chronological sequence, the Riegl Range Finder detects the presence of an object in its field of view. The range finder is the white object on the right side of Figure 8 (A). Detection of an object triggers the imaging camera. The camera records an image of the aircraft as shown. As the aircraft moves from left to right its nose wheel initially interrupts the slave beam. This beam interruption is followed by a main gear interruption of the same slave beam. Shortly thereafter the aircraft nose wheel interrupts the master beam (Figure 8 (B - top)). This interruption is immediately followed by an interruption of the same master beam by the main landing gear. In both cases the red segment of the detector signal indicates the "presence of an aircraft" has been declared. The blue signal indicates a declaration that "the aircraft has departed the hold short area", and the sensor is awaiting approach of the next aircraft.

Both Figure 8 (B - top and bottom) are tagged at hour 14, minute 28, and second 50. Both of the figures therefore begin at the 50 second mark, continue through the minute 28 and then progress into minute 29, second 0. The time sequence can be seen to evolve as follows:

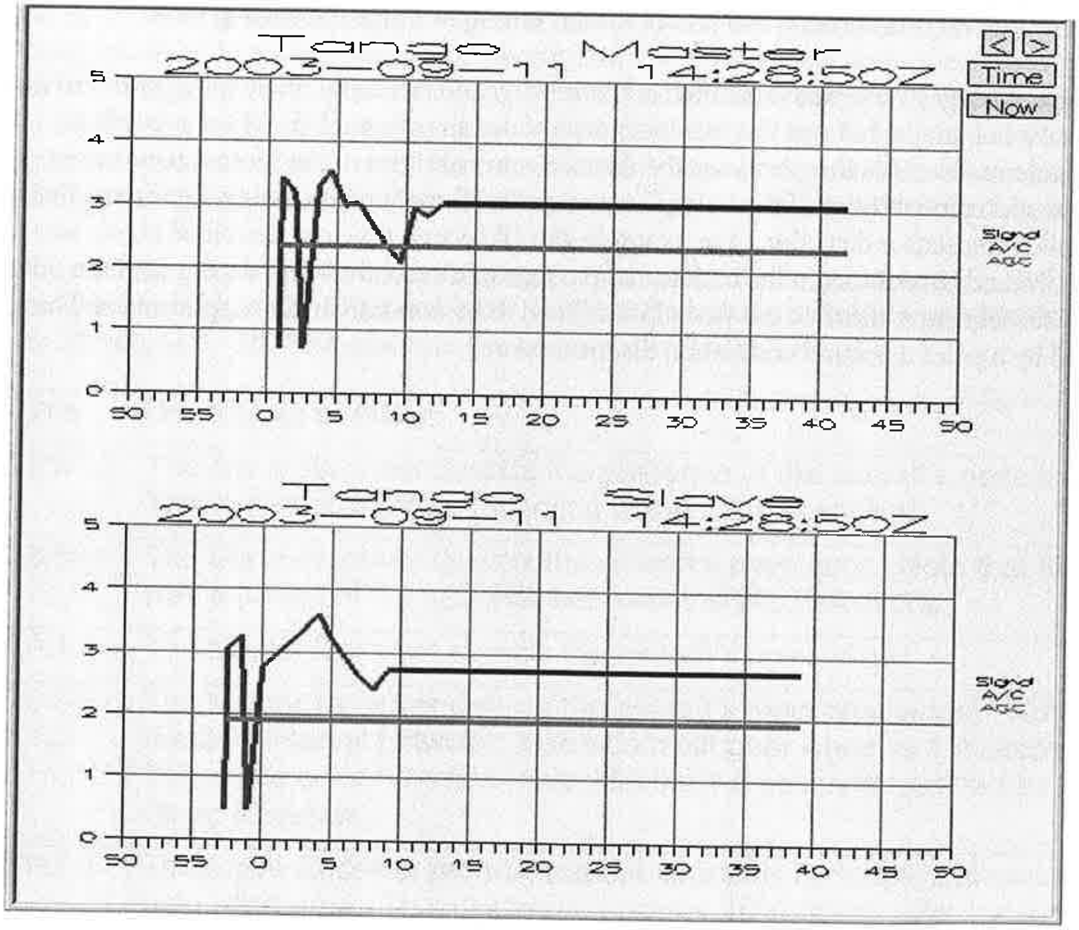
Time	Description of Action
28:57.2	The Slave Receiver detects the presence of the aircraft's nose wheel. This detection triggers recording of the data as shown.
28:59.0	The Slave Receiver detects the aircraft's main gear. Note that there was a period of 1.8 seconds between the two detections.
29:1.1	The Master Receiver detects the aircraft's nose wheel.
29:3.0	The Master Receiver detects the aircraft's main gear wheel. Note that the time interval between nose and main gear wheel is 1.9 seconds. This value compares favorably with the 1.8 seconds reported by the Slave Receiver.
29:9.0	The Slave Receiver reports that the aircraft is no longer present in the hold short area. This declaration occurs 10 seconds after the main gear was detected. This is an adjustable time out period that allows for movement of an aircraft in a curved hold short area. In this instance, the point detection capability of the beam could potentially detect the same main gear twice as the left and right gear moves through the

	beam at different time intervals. Such was not the case here. Further, this time out period is long. It will be reduced.
29:39.0	After approximately 40 seconds the system ceases to record. It will be reactivated when the slave or master detects a beam interruption.

These analog signals provide clear insight into the interaction of the sensor detectors and the Safety Sentry firmware processing. They also provide a an indication of the health of the Safety Sentry sensors. Note that the Slave Receiver must maintain an AGC level of two to realize a Receiver non-detection level of 2.8 for the slave. Note further that the master requires an AGC level of 2.3 to maintain a master receiver non-detection level of 3. These comparisons are consistent in that a higher AGC level produces a higher detector gain and hence a higher output signal as shown. These signals also provide criteria for adjusting the threshold level for signal detection. In the case of the Master Receiver shown, the detection threshold was adjusted to trip at 38% of the nominal Receiver signal level. For the 3 volt level shown, the threshold is 1.1 volts. Nose wheel and gain gear detection discretes would therefore be clearly declared in this instance. The over shoot and under shoot shown following main gear detection is due to a non-optimum setting of a signal damping filter.

Aircraft/vehicle passages were analyzed, both automatically and manually, in the process of arriving at the test results in paragraph 4 and the conclusions provided in paragraph 5. These recordings played a key role in discriminating between the detection probabilities of the sensors themselves versus the detection probabilities of the Safety Sentry system firmware processing algorithms that are introduced following sensor detection. For example, the 10 second time out described above was too long in some instances, resulting in the undetected passage of a second aircraft during the time out period. As a consequence, the time out period was found to be non-universally applicable and has been replaced by a point detection correlation discriminator.

(A) Aircraft Passing Hold Short Area



(B - top) Data From Master Receiver at Tango Taxiway
(B - bottom) Data From Sensor Receiver at Tango Taxiway

Figure 8

3.4 Raw Data

	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT
Sept.Totals	**Alpha**	865	10
Sept.Totals	**Tango**		

	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT
Oct.Totals	**Alpha**	1992	12
Oct.Totals	**Tango**		

	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT
Nov.Totals	**Alpha**	684	1
Nov.Totals	**Tango**	188	0

Known Fog Events	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT
Oct.Totals	**Alpha**	264	0
Nov.Totals	**Alpha**	81	0

Weather	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT
Fog		345	0
Non-Fog		3739	23

3.5 Probability of Detecting Presence of Aircraft/Vehicle

3.5.1 During Fog Conditions

Number of misses/number of events = $1 - P_{fog}/P_{fog}$

Where: $(1 - P_{fog})$ = probability of failing to detect an aircraft during fog

P_{fog} = probability of successful detection during fog
$(1 - P_{fog})$ = probability of failure to detect during fog

$0/345 = 1 - P_{fog}/P_{fog}$

$P_{fog} = 1.0000$

There were no missed detection for 100% of the time during fog

3.5.2 During Clear Conditions

$23/3729 = 1 - P_{clear}/P_{clear}$

$P_{clear} = 0.9938$

There were no missed detections for 99.38% of the time during clear conditions

3.5.1 During Fog and Clear Conditions

$23/4074 = 1 - P_{\text{all conditions}}/P_{\text{all conditions}}$

$P_{\text{all conditions}} = 0.9944$

There were no missed detections for 99.44% of the time during all conditions

Note: *Test data for September and October at Taxiway Tango was irregular due to power fluctuations and failures at that site and removed from the analysis.*

4. Test Results

4.1 Aircraft/Vehicle Delectability

Data collected from the test period is summarized in the Tables below.

	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT	PROB. OF DETECTION
Sept.Totals	**Alpha**	865	10	0.9884
Sept.Totals	**Tango**	**See Note*	*	*

	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT	PROB. OF DETECTION
Oct.Totals	**Alpha**	1992	12	0.9940
Oct.Totals	**Tango**	**See Note*	*	*

	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT	PROB. OF DETECTION
Nov.Totals	**Alpha**	688	1	0.9985
Nov.Totals	**Tango**	188	0	1.000

Fog Events	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT	PROB. OF DETECTION
Oct.Totals	**Alpha**	264	0	1.0000
Nov.Totals	**Alpha**	81	0	1.0000

	TAXIWAY	AC/VEHICLES	FOGEYE FAIL TO DETECT	PROB. OF DETECTION
Fog		345	0	1.0000
Non-Fog		3729	23	0.9938
Total		4074	23	0.9944

Note: Test data for September and October at Taxiway Tango was irregular due to power fluctuations and failures at that site and removed from the analysis.

4.2 Operational Availability

For continuous use systems, operational availability shall be designated Ao and shall be determined as the ratio of system "uptime" to system "uptime plus downtime."

$$\boxed{\frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}}}$$

Availability was 100 percent when the taxiway power was set at level three, the highest of three settings. The FogEye system power supply has been modified to accept levels one and two.

4.3 Supportability

4.3.1 Reliability.

During initial FogEye installations a power supply failure was caused by a power line over voltage spike of 26 volts. The power supply and subsequent power supplies have been modified to protect against high voltage surges. Thereafter no failures of any type were noted during 3,800 hours of operation.

4.3.2 Maintainability

Based on over 3,800 hours of operation without need to repair, this system is deemed virtually maintenance free. PVD indicates the Mean Time To Replace individual Receiver or Transmitter units is 15 minutes. A Transmitter or Receiver module is a line replaceable unit.

5. CONCLUSIONS

5.1 Conclusion:

The overall probability of aircraft/vehicle detection for Safety Sentry was determined to be 0.9944, based on 4074 events and 23 system misses.

The performance and supportability data were recorded for Safety Sentry hardware that was physically and functionally compatible with an operational commercial airport environment.

Safety Sentry, for these operational evaluations, consisted of two Receiver-Transmitter pairs with integral firmware processing that reported aircraft presence within a detection zone. Two Safety Sentry sets were evaluated. They provided effective and accurate aircraft/vehicle presence detection for passages through the detection zone at taxi speeds from stop and go, to free flow. The aircraft types ranged from General Aviation to large commercial narrow body aircraft. Safety Sentry provides a typical maximum detection zone in the direction of traffic flow (up/down taxiway) of 250 feet. The zone detection size in the transverse taxiway direction is at least 300 feet. The Safety Sentry detection zone can be selected which covers the entire lane width including some or all of the shoulders.

At the hardware level, individual Receiver-Transmitter FogEye pairs detected aircraft presence with a detection probability of 1.00. These pairs functioned as "point" sensors, detecting nose and landing gear wheels as an aircraft passed through the opposing boundaries of a detection zone, in the traffic flow direction.

The difference between direct aircraft detection probability of individual Transmitter-Receiver FogEye pairs and the aircraft detection probability of the Safety Sentry system was due to a detection time-out discriminator employed by the Safety Sentry firmware. Use of a more universally applicable point detection correlation discriminator can be expected to improve the Safety Sentry system probability of aircraft/vehicle detection to approximate 100%.

Supportability data was collected over a three month period, for a total of 3,800 hours of operation. The system operated maintenance free. There were no failures. The Mean Time to Replace was determined to be 15 minutes.

These favorable aircraft detection results and the supportability history, at an operational commercial airport, substantiate a recommendation that Safety Sentry be integrated into runway incursion prevention systems currently under development at selected intersections as an aircraft presence detection sensor.