A New Multilateration System for Ground Surveillance

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Abstract

In the vicinity of buildings and aircraft in airports, conventional multilateration systems sometimes have difficulties in positioning precisely due to reflected signals, so-called multipath. To overcome this problem, ENRI has invented a new multilateration system for ground surveillance, named as Optically ConnecTed PAssive Surveillance System (OCTPASS). OCTPASS uses the same techniques as conventional multilateration systems. For instance, OCTPASS computes target's positions with Time Differences Of Arrival (TDOA) between ground stations. The major difference from conventional systems is that OCTPASS ground stations directly transmit RF signals to the main processor through Radio On Fiber (ROF) devices and optical fiber cables. This feature enables OCTPASS to position targets with high accuracy under multipath environments.

In 2004, to evaluate the performance of OCTPASS, we developed a test system for 1090MHz Mode S signal and conducted tests in an airport. In this paper, we first introduce the test system. Then we show the results of tests. The results show that OCTPASS is capable of positioning targets with high accuracy under multipath environments.

1. Introduction

To improve safety and efficiency of airports, Advanced Surface Movement Guidance and Control System (A-SMGCS) has been developed in several countries. A-SMGCS is an integrated system of surveillance, routing, guidance and control functions [1]. Since the latter three functions heavily depend on the surveillance function, to obtain accurate and reliable surveillance information is one of the most important topics in the development of A-SMGCS.

The Mode S multilateration system, which uses 1090MHz Mode S signals to determine aircraft's positions, is one of the major surveillance sensors in A-SMGCS since it has capabilities to provide its user for aircraft identification information. It has been deploying in several airports in the U.S. and the EU region. The positioning accuracy of the system is approximately 6m (1σ) [2][3].

In the vicinity of buildings and aircraft in airports, radio positioning systems have difficulties in positioning precisely due to reflected signals, so-called multipath. The multilateration system also can't avoid this problem. Under multipath environment, the shape of multipath-contaminated signals is different from that of the original signal. It is difficult for the systems not only to determine accurate Time Of Arrival (TOA) from signals but also to detect the presence of signals. In Japan, many building and hangers are placed in airports because of the limit of space. Multipath is a severe problem for us.

A solution of multipath is to deploy extra stations around multipath-rich areas in order to increase the probability of receiving uncontaminated signals. However, extra stations increase the costs and complexity of systems.

To solve this problem, ENRI has invented a new multilateration system for ground surveillance, named as Optically ConnecTed PAssive Surveillance System (OCTPASS). Basically OCTPASS uses the same techniques as conventional multilateration systems to compute target's positions. For instance, it uses Time Differences of Arrival (TDOA) between ground stations. The major difference from conventional systems is that OCTPASS ground stations directly transmit Radio Frequency (RF) signals to the main processor through Radio On Fiber (ROF) devices and optical fiber cables. This new device enables OCTPASS to position targets with high accuracy under multipath environment. In 2004, to evaluate the performance of OCTPASS, we developed a test system for 1090MHz Mode S signal and conducted tests in an airport.

In this paper, we introduce OCTPASS and show the results of tests. In section II, we first give a brief description of OCTPASS. In section III, we explain the OCTPASS test system and test site where the tests were conducted. Then, in section IV, we show the results of tests. In final section, we make a conclusion.

2. OCTPASS

OCTPASS uses the same techniques as conventional multilateration systems. The principle of positioning is based on the technique in the hyperbolic navigation. Multiple ground stations surround a surveying area and acquire signals from targets in the area. The ground stations derive TOA from the acquired signals. Then, subtracting TOA at a station from TOA at other stations, the system obtains TDOAs between stations. Then the system computes the position of a target with TDOAs.

The major difference from conventional systems is that OCTPASS ground stations directly transmit RF signals to the main processor through ROF devices and optical fiber cables. ROF enables long-distance RF signal transmission by changing RF signals to optical signals. ROF devices are used in various kinds of radio systems. However, there was no ROF application for multilateration. OCTPASS is the first multilateration system with ROF devices.

There are three advantages to use ROF devices.

Accurate TOA Detection   In order to obtain accurate TOA,   conventional multilateration systems need to possess accurate clocks or to synchronize an outer time source occasionally in each station. On the other hand, OCTPASS does not need accurate time in each station since TOA detection process is implemented only in a main processor in a station. Since OCTPASS uses a single time source, accurate TOAs are available.

Improved TOA Detection   Multilateration systems need at least three TOA to determine two-dimensional position. The system fails to position the target unless unable to acquire three TOAs. However, under multipath environment, ground stations have difficulties in detecting the presence of signals. According to a field test [4], the probability of the signal detection in an airport is 75-83%. The probability of the signal detection under multipath environment such as in aprons and spots is much lower than that in runways and taxiways. Consequently, to obtain a certain level of detection probability, the system needs to prepare extra ground stations or to improve signal detector in each stations.

OCTPASS main station observes all RF signals from stations. Once it finds a Mode S signal in RF signal from one station, the system acquires RF signals from all stations. Then, the system starts to detect TOA of a signal in the acquired RF signal waves. Some TOA detection techniques do not care for the contents of signal. Even if the system is not able to obtain data in signals correctly, TOAs of signals are available from the contaminated signals. OCTPASS detects signals with an assistance of simultaneously acquired signals at multiple stations. Therefore, OCTPASS obtains the TOA's with higher probability.

Compact ground station   The ground station becomes compact and simple because stations do not need to possess the complex processing units such as the signal detector, a precise clock , TOA detector or message decoder. The substations only need to condition RF signal by using a band pass filter (BPF), preamplifier and other simple devices, and to transform RF signals into optical signals by using a ROF transmitter.

3. Test System and Site

To evaluate the performance of OCTPASS, we have developed a test system. In 2004, we conducted tests in Sendai Airport. Sendai Airport with a 3000m runway and a 2000m runway is one of the middle size airports in Japan. In this section, we introduce the components of the test system and the test site where the tests were conducted. An overview of the test system is shown in Figure 1.

Target vehicle   A Mode S transponder is set on a vehicle to play a role of an aircraft. The transponder broadcasts a Mode S squitter signal with DF11 format every second. The Mode S antenna is placed on the roof of the vehicle. The antenna height is approximately 2.2 meters.

The vehicle equips a GPS receiver. The GPS receiver measures a position of the vehicle every 2 seconds. Simultaneously, another GPS receiver at a known fixed position measures position data for kinematic GPS (K-GPS) process. K-GPS is a precision positioning with carrier phase measurements and with the aid of measurements at a known base station position. After the tests, accurate vehicle positions are available. Specifications of Mode S transponder and GPS receivers are listed in Table I-(2) and (3).

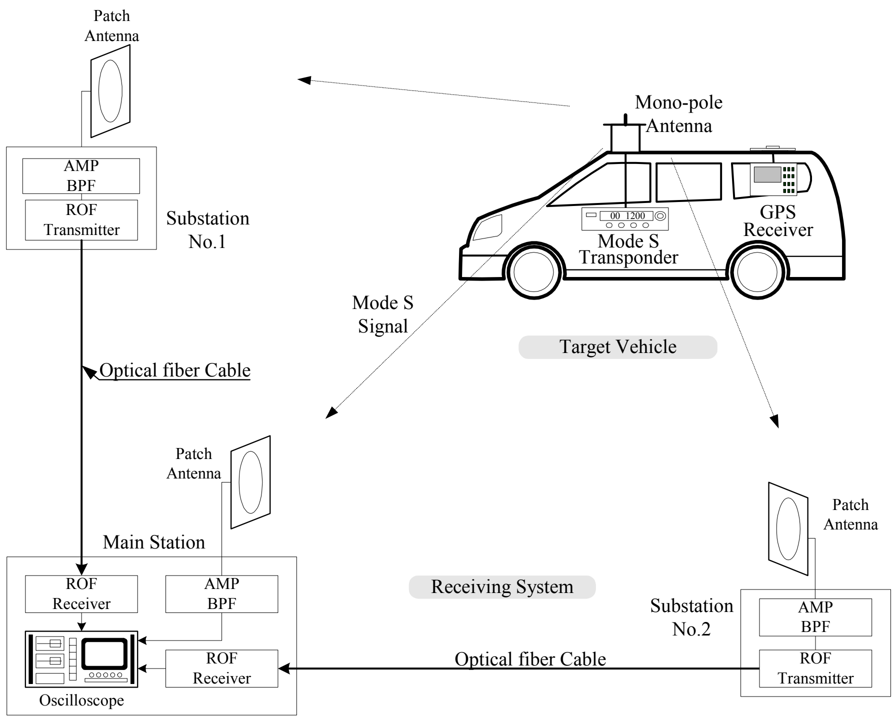

Figure 1   OCTPASS test system

TABLE I

(1) SPECIFICATIONS OF MODE S TRANSPONDER

Transponder	Bendix King KT70
Carrier Frequency	1090MHz
Modulation	Pulse Position Modulation
Antenna	Omni-Directional λ/4 Monopole Antenna
Transmit Power	200W (minimum)

(2) SPECIFICATIONS OF GPS RECEIVERS

Reference/Rover Receiver	Trimble 4000SSi
Positioning Rate	0.5Hz
GPS Data Analyzing Software	Trimble GPS Survey
Observing Bands	L1/L2

(3)SPECIFICATIONS OF OCTPASS

Antenna		Patch Antenna
ROF Device		Fiber Span AC231T/R-2.5
Data Acquisition Device		Tektronix TDS 5104
Sampling Frequency		625MHz
Data Processing Frequency		156.25MHz
Optical Fiber Cable	Wave Length	1.3μm
	Mode	Single
	Main and Sub1	Approx. 1300m
	Main and Sub2	Approx 650m

OCTPASS Test System OCTPASS test system is composed of three stations. Three ground stations are classified into one main station and two substations. The main station is composed of an antenna, a preamplifier, a BPF, two ROF receivers and a digital oscilloscope with a personal computer. The RF signals received by the main antenna are not transmitted through ROF devices. Each substation is composed of an antenna, a preamplifier, a BPF, and a ROF transmitter. The oscilloscope acquires all observing RF signal waves when a signal with a certain magnitude is observed. The acquired signals are stored into a storage device in the PC. After tests, we analyze the acquired signals and compute the two dimensional positions of the target vehicle. Specifications of the system are listed in Table I-(3). The tests were conducted at night after the airport was closed. There was no other target that transmits Mode S signals on the ground. However, we sometimes observed signals from aircraft passing over the airport.

TOA Detection Technique

To determine TOA of signals, we apply the Delay Attenuate and Compare Technique (DAC) technique. This technique is originally used in Precision Distance Management Equipment (DME/P), a subset of the Microwave Landing System (MLS) [5]. The technique compares a delayed version of the pulse to an attenuated version of the same pulse. TOA is declared when the delay signal level exceeds the attenuated signal level. We have adopted the DAC to the positioning system that uses 1030MHz signal [6]. We clarified that the DAC is durable to multipath and applicable to 1030MHz systems. Since 1090MHz signals have a structure similar to 1030MHz signals, we choose this TOA detection technique.

Test site

To evaluate the performance under multipath environment, we choose the north side of the terminal buildings as the test site. This area has most congested and complicated layout in the airport. There are many structures which produce multipath signals, such as the tower, passenger boarding bridges, boarding vehicles and aircraft in parking spots. During tests, seven aircraft were in the parking spot (A320 in spot 4, B767 in spot 5, MD81 in spot 6, B737 in spot 7,Fokker-50 in spot 8, CRJ200 in spot 10, B737 in spot12). A view of the terminal building is shown in Figure 4.

The layouts of the stations are shown in Figure 2 by triangle mark. The stations surround the runway, taxiways, aprons, parking spots and border-side roads. Positions of the stations in WGS-84 and in the East-North-Up (ENU) are listed in Table II. We use the ENU coordinate frame in analysis. The WGS84 positions in GPS data are transformed to the ENU [7]. The antenna height is 4.14 meters in main station, 1.87 meters in substation No.1 and 1.67 meters in substation No.2.

The distance between the main and the substation No.1 is 530 meters and the main-No.2 distance is 760 meters. The optical fiber length between the main and the substation No.1 is approximately 650 meters and the main- No.2 length is approximately 1300 meters.

We assess positioning errors caused by a layout of substations by computing the Horizontal Dilution Of Precision (HDOP). HDOP is shown in Figure 3 by contour plot. In general, the system observing area is to be an area where the HDOP is low. Because, the bigger the HDOP become, the more inaccurate the positioning results become. For example, the FAA draft specification [8] requires that multilateration system should have 6.0m accuracy in the areas where the HDOP is 1.5 or less. In our analysis, we do not care for HDOP. The worst HDOP is approximately 7.5 at the west end of the apron.

To clarify the difference of positioning accuracy in part of the test site, we divide the test site into three areas (Area 1, 2

TABLE II LOCATIONS OF ANTENNAS

	WGS-84			ENU[m]			Distance From the Main Station[m]
	Latitude East(deg)	Longitude North(deg)	Altitude [m]	X	Y	Z	
Main Station	38.13930331	140.93291347	47.135	1059.31	263.09	4.05	--
Substation No.1	38.14405191	140.93227353	44.582	1003.10	790.60	1.82	530.50
Substation No.2	38.14298386	140.92556019	44.274	416.81	671.51	1.67	760.70
The Origin of the ENU	38.1393057	140.93288900	42.231	0	0	0	--

We set the origin of the ENU at the center of Runway A

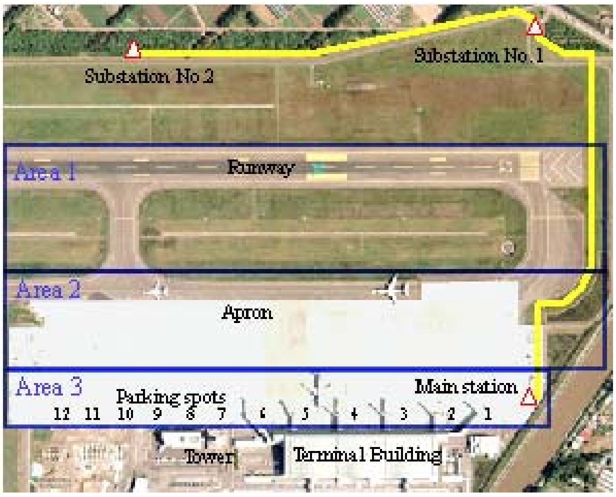

Figure 2 A view of the test site

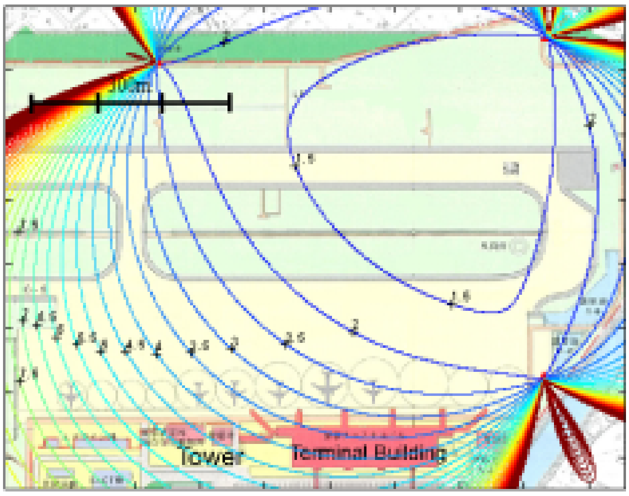

Figure 3 HDOP in the test site

Figure 4 A view of Sendai Airport Terminal building

and 3). The areas are shown in Figure 2 by the rectangular box. Area 1 is the north side of the terminal building and on the runway and taxiways. Area 2 is the north side of the terminal building and on the apron. The area is more than 80 meters away from the terminal building.

Area 3 is in the parking spots and adjacent to the building including the road under the passenger bordering bridges. The area is less than 80 meters away from the terminal building.

Many multipath signals are observed in the test site. The characteristic of multipath is different in each area. The further the target is away from the building, the longer the multipath delay becomes. The shorter the multipath delay becomes, the more difficult the system eliminates the multipath errors.

4 Results of Tests

In this section, we present results of measurements of a standing target at a known fixed point and a moving target on the airport surface.

Measurements of a Standing Target at a Known Fixed Point

To eliminate optical transmission delays from TDOAs, we observe the vehicle standing at a known fixed point. We choose the point at which the HDOP is low and no severe multipath is observed. The point in the airport is marked by a X marker in Figure 2.

Results of measurements at the fixed point are shown in Figure 5. The red cross marker is the true fixed position. Blue dots are the OCTPASS positions. 2RMS errors are 0.47 m and 0.82m in x and y direction. The

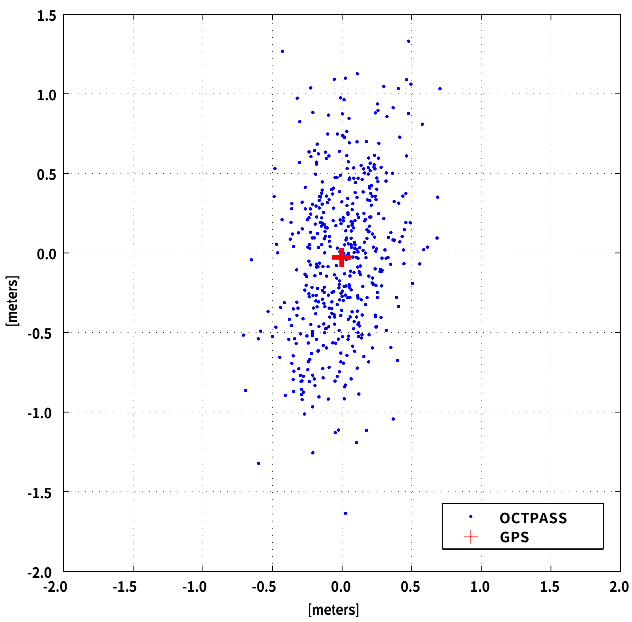

Figure 5 Measurements at the fixed point

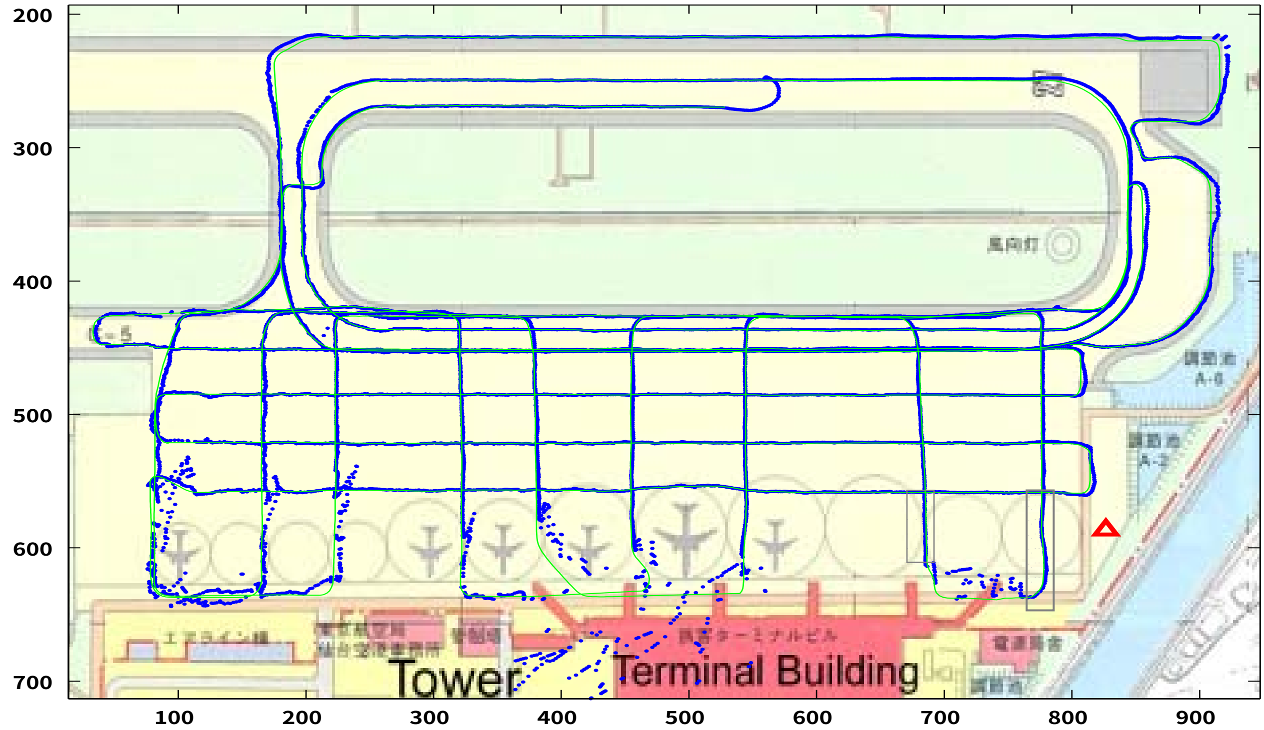

Figure 6 Measurements of a moving target

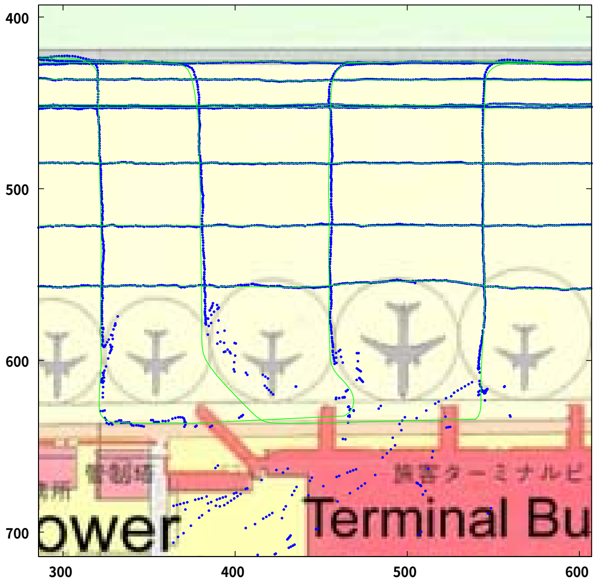

Figure 7 Enlarged view of spots

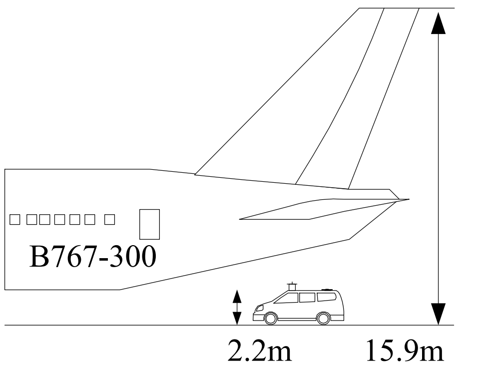

Figure 8 The size of the vehicle and aircraft

2RMS (Root Mean Square) error is 1.10m. The results are also listed in the table III.

<u>Measurements of a Moving Target on the Airport Surface</u>

Following the fixed position measurements, we measured the positions of a moving target vehicle on the airport surface. The vehicle runs at the speed of approximately 5 km/h.

The measured raw position data is smoothed by the $\alpha\beta\gamma$-tracker. It tracks a target for 5 seconds. We compare the smoothed tracks with the K-GPS tracks. The detection rate is derived by dividing tracker output positions by the total period of the test.

Results of OCTPASS measurements are shown in Figure 6. An enlarged view of spots is shown in Figure 7. Blue dots are the measured positions. A green curve behind the dots is a track of the K-GPS measured positions. The measured positions keep track of the K-GPS track in Area 1 and 2. We clearly distinguish each OCATPASS track. In Area 1 where is on the runway and taxiways, the 2RMS errors in x and y direction are 4.79m and 2.86m, respectively. The 2RMS range error is 5.58m. In Area 2 where is on the apron, the 2RMS errors in x and y direction are 2.81m and 1.43m, respectively. The 2RMS range error is 3.15m. The 2RMS errors compared to K-GPS are listed in Table III. The accuracy in both areas satisfies the minimum requirement of position accuracy, which is 7.5 meters or less （95%≈2σ）, for Mode S multilateration by the European Organization for Civil Aviation Equipment (EUROCAE) [9].

Table III Errors compared with K-GPS track

	Test Periods	Number of Tracker Output	Detection Rate(%)	Errors(2RMS)		
				x	y	Range
Fixed Point (Not tracked)	480	480	100.0	0.48m	0.99m	1.10m
Area 1 : Run & Taxiways	2534	2518	99.4	4.79m	2.86m	5.58m
Area 2 : Apron	5939	5930	99.8	2.81m	1.43m	3.15m
Area 3 : Spots	1480	1478	99.9	11.12m	21.25m	23.98m

The results are excellent especially in Area 2. However, in Area 3 where is in parking spots and adjacent to building, the error is more deteriorated. In area 3, the 2RMS errors in x and y direction are 11.12m and 21.25m, respectively. The 2RMS range error is 23.98m. In this area, the stations, especially the main station, observe many indirect path signals since aircraft hide the vehicle from sight as shown in Figure 8. The amplitude of indirect path signals is much smaller than that of signals expected from its distance. Since these small indirect-path signals are easily affected by not only the receiver noise but also multipath signals (indirect path signals with longer-delay and bigger-amplitude), the errors get worse.

A solution of this problem is the placement of both the target's and station's antenna in higher places where no obstacle is blocking the line between target's and station's antenna. By installing at the place, direct path signals with enough amplitude are available in stations. These signals are more durable to the receiver noise and multipath. Therefore, the errors will get better. For aircraft surveillance, we only need to place station's antennas at high places because aircraft's antennas have already been installed at high place (usually on the top of the fuselage).

The gray-masked areas in figure 6 (near the main station) are such areas that the direct paths are available in all stations. In these areas, 2RMS range errors of 122 points data are 3.70m. This shows that the system computes positions correctly in parking spots as long as the stations can obtain direct-path from the target.

5. Conclusion

In this paper, we have described a new multilateration system for airport surface surveillance, which was named as Optically ConneTed PAssive Surveillance System (OCTPASS). We have presented an overview of OCTPASS, the test system and the results of tests in an airport.

The results show that OCTPASS is capable of positioning targets with high accuracy under multipath environment. The positioning accuracy is less than 5.58 meters in runways, taxiways and apron. This satisfies the minimum requirement for Mode S multilateration. On the other hand, in parking spots, since aircraft hide the target and direct path signals are not available in stations, the poisoning accuracy is deteriorated. However, this problem will be solved by installing antennas at higher places where no obstacle is blocking the line between target's and station's antenna. This antenna installation will enables stations to acquire direct path signals with enough amplitude.

Our future work is to conduct tests with an improved test system and with modified antenna heights.

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