Primary Surveillance Radar (PSR) and Secondary Surveillance Radar (SSR) of Martello S743D Detection Optimization through Automatic Dependent Surveillance-Broadcast (ADS-B) Adaptation

Abdullah 'Irfan Bin Abdullah
Faculty of Electrical Engineering
Universiti Teknologi Mara, Shah Alam (UiTM)
40450 Shah Alam, Selangor, Malaysia
airish.irfan@gmail.com

***Abstract*— This paper presents the analysis of Primary Surveillance Radar (PSR) and Secondary Surveillance Radar (SSR) of Martello S743D radar detection by adapting the aircraft information from Automatic Dependent Surveillance – Broadcast (ADS-B) receiver. It is performed by taking the detection information from both sensor and the comparison of the information by using the MATLAB Graphical User Interface (GUI). This research will show the functional of ADS-B receiver will solve the cone of silence of the PSR and SSR detection.**

***Index Terms*—Primary Surveillance Radar (PSR), Secondary Surveillance Radar (SSR), Automatic Dependent Surveillance – Broadcast (ADS-B), aircraft tracker.**

I. INTRODUCTION

There are many studies in the future operational requirements for military long range sensors (surveillance radars) for the last 30 years [1]. These long studies have a clear indicated for the three-dimensional 3D radars preference with the very best possible Electronic Counter Measures (ECM) resistance. The use of (3D) radar is continually making progress in replacing the two-dimensional (2D) radar for military application [1].

The example of 3D radar is S743D which is a Long Range Radar (LRR) with a unique phased array concept that combined the advantages of synthesised stack beam and parallel receivers together with multiple distributed solid-state transmitters [2]. The radar outputs consist of parallel data from all the elevation receiving beams, height, being assessed on every return by monopulse elevation extractor. Transmission occurs within an approximately fan beam radiation pattern so that all targets within the radar cover are illuminated by every radar pulse.

In radar system, the height accuracy is dependent on whether the radar is operating in spot frequency or in a frequency agile mode and the azimuth beam position is unaffected by frequency changes within the operating bandwidth. Thus there is complete freedom to exploit the operating frequency as required for combating ECM [2].

The S743D incorporates a Secondary Surveillance Radar (SSR) system to aid in target identification. This radar will detect and automatically extract and report over digital links to the remote display system [2]. The SSR radar system not only detects and measures the position of aircraft such as range and bearing, but also requests additional information from the aircraft itself such as its identity and altitude. Unlike primary radar systems that measure only the range and bearing of targets by detecting reflected radio signals, SSR relies on targets equipped with a radar transponder that replies to each interrogation signal by transmitting a response containing encoded data [3]. SSR is based on the military identification friend or foe (IFF) technology originally developed during World War II; therefore the two systems are still compatible.

The PSR and SSR have been the main two components of an Air Defence station for the last decade. PSR has the capability to detect large metal objects, including cooperative and non-cooperative targets, while SSR works only for transponder-equipped aircraft. SSR relies on aircraft with corresponding transponder. Both PSR and SSR were designed for low and medium traffic situations [4].

However, due to the insufficient range ambiguity, they are unable to meet the challenge of high traffic volume. Moreover, ground-based surveillance radar has limitations at low altitudes and cone of silence effect.

This paper will signify to determine the best approach of ADS-B system as the paradigm of communication, navigation, and surveillance. This ADS-B system will detect its own position using Global Navigation Satellite System (GNSS) and periodically broadcasts its four-dimensional position 4D (latitude, longitude, altitude and time), track and ground speed, aircraft identification, and other additional relevant data as appropriate without interrogation from the ground [4].

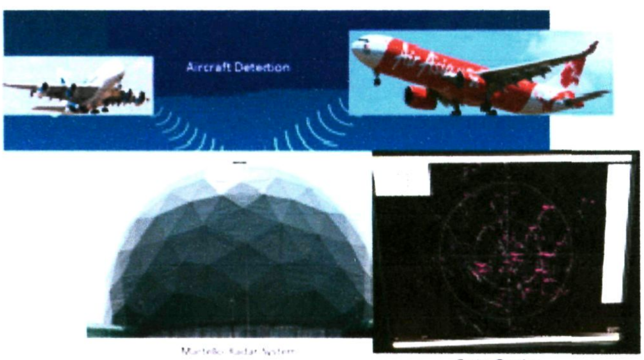
The limitation of this paper are to analysis the detection at the cone of silent area .When an aircraft fly above the radar antenna, the contact loss occurred because of the gap which is known as the cone of silence [5]. The ADS-B system is expected to fill the gap that occurs at PSR/SSR of S743D Martello Radar systems.

II. Experimental Set Up Description

A. Hardware Setup

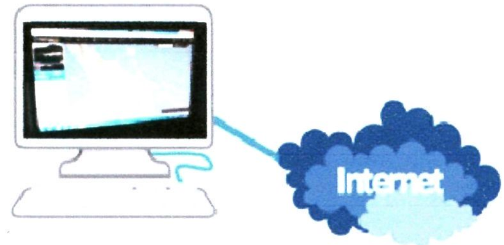
Three methods of the Martello S743D Radar, ADS-B Receiver and Flightradar24 were used to collect the aircraft information. The research is conducted at RMAF Gong Kedak Airbase Jerteh, Terengganu (Latitude: 5.7833, Longitude: 102.493).

Figure 1(a) shows the Radar Martello is setup according the Standard Operation Procedures for Martello Radar System [6][7]. The operational status of the radar system is essential to perform the data recording activities.



(a) Radar Martello Setup Configuration

(b) ADS-B Setup Configuration



(c) Flightradar24 Setup

Figure 1: Experimental Setup

The aircraft is tracked based on the ADS-B receiver detection. ADS-B is able to detect up to100 nautical miles effective range while the S743D detection is up 256 nautical miles. The Flightradar24 however can detect the aircraft tracks from the departure until the aircraft arrival.

The ADS-B System is setup by using Digital Audio Broadcast (DAB)/ Digital Video Broadcast-Terrestrial (DVB-T) USB Stick as the ADS-B receiver as shown in figure 1(b). The adsbSCOPE 2.7 software is installed and configured to generate the aircraft information before recording the data [8].

There were 11 different aircrafts tracking that are used in this paper. The altitude of the aircraft tracked is ranging from 35,950ft – 40,000ft. The details on the aircraft general information of the detection are as in Figure 2:

Aircraft ID	**Aircraft Type**	**Mode 3C / Squawk**	**Speed (kt)**	**Altitude (ft)**
AIQ359	Airbus A320-216	0702	448	37,000
FDX6091	Airbus A300B4-662	0126	467	35,950
GIA865	Boeing 737-86N	6112	432	37,000
GIA868	Boeing 737-86N	2336	455	36,000
JSA516	Airbus A320-232	6136	443	37,025
MMA232	Airbus A319-111	0146	473	36,000
NCA254	Boeing 747-4KZF	2237	445	38,000
SLK701	Airbus A320-233	0775	439	37,025
SLK702	Airbus A320-233	2214	450	36,000
TGW2182	Airbus A320-232	0127	469	38,000
THA402	Boeing 777-2D7	2243	476	40,000

Figure 2: Aircraft Detection General Information

B. Data Collection

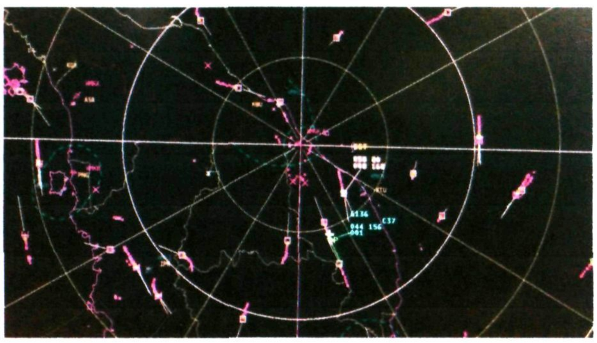
The data collection phase is the key step in research methodology. The main variable that is recorded is the values of the aircraft coordinate (latitude and longitude. The altitude and heading of the track also can be recorded but the project will focus on the latitude and the longitude of the aircraft track to determine the aircraft position.

The consistency of the data capture is required in order to get the stability and reliability test data. The data recording is based on the time interval that has been defined for the particular target aircraft detection.

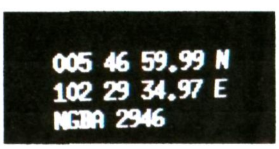
III. Measurement of Results

A. Display- Detection

The first sensor used is Martello S743D Radar. The aircraft information tracking can be determined at the workstation display called ZADRAD Terminal as shown in Figure 3 [7].



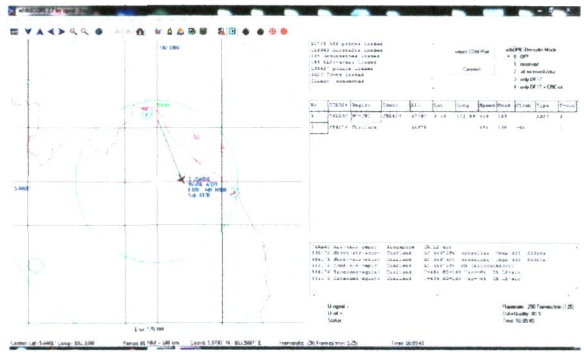
(a) Radar Martello Display



b) Latitude and Longitude Indication

Figure 3: PSR/SSR Martello Detection

The second detection method is established by the ADS-B Receiver connection using the adsbSCOPE 2.7 Software [8]. This is to determine the real-time aircraft information as shown in figure 4 (a).



(a) adsbSCOPE 2.7

The Table of Aircraft below will show the details of the Aircraft information once the ADS-B signal is picked up by the receiver.

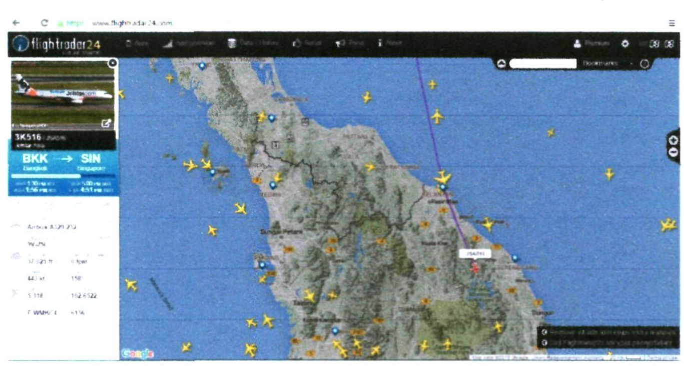
Nr.	ICAO24	Regist.	Ident	Alt	Lat	Long	Speed	Head.	Climb	Type	T-ou
16	75010E	9M-AFG	AXM6438	750	2.78	101.70	163	328	2432	A320	0
15	75025B	9M-MTH		26075			438	263	-3008	A333	5
14	750004	9M-FYA								AT75	10
13	884202	HS-PPB		10675			302	155	-448	A319	2
12	7503B8	Malaysia		4950			183	300	1280		13 M
11	76CEF9	Singapore									15 M
10	76CF27	9V-SYG	SIA494	34000	2.74	101.85	506	308		B773	9
9	750149	9M-AFW	AXM883	7925	2.60	101.70	328	149	-1664	A320	48 M
8	750219	Malaysia	MAS2611	7050			259	247	-1664		272
7	75025D	Malaysia	MAS53	7075	2.60	102.03	237	211			30 M
6	76C092	Singapore					140	326	-396		20 M
5	76CC46	9V-SBF	SLK349	33975	2.28	102.19	435	141		A319	0

(b) adsbSCOPE 2.7 -Table of Aircraft

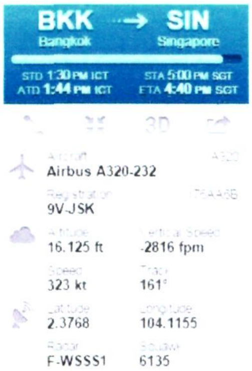
Figure 4: ADS-B Detection

The third method is using the Flightradar24 which is internet based application as shown in Figure 5. This application will track the real time air traffic from around the world [9]. The Flightradar24 is used to determine the flight plan information that will have a route in the Radar site area.

This application received flight information from the ADS-B receivers that will feed the data to the Flightradar24 server as shown in Figure 5.



(a) Flightradar24 Web-based Aircraft Tracker



(b) Flightradar24 Aircraft Detail

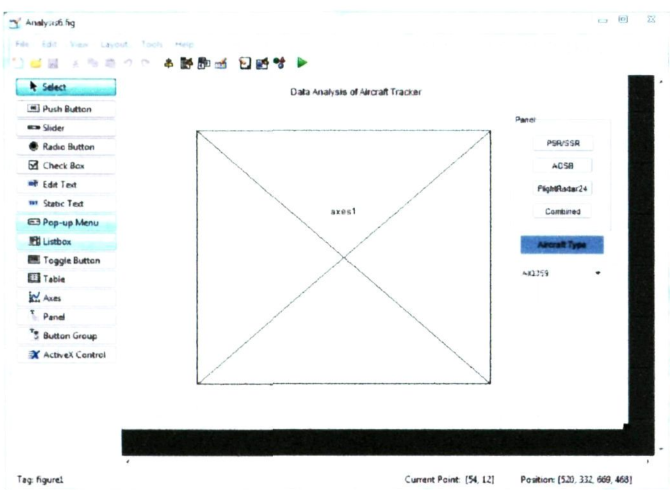
Figure 5: Flightradar24 Detection

B. MATLAB Graphical User Interface (GUI)

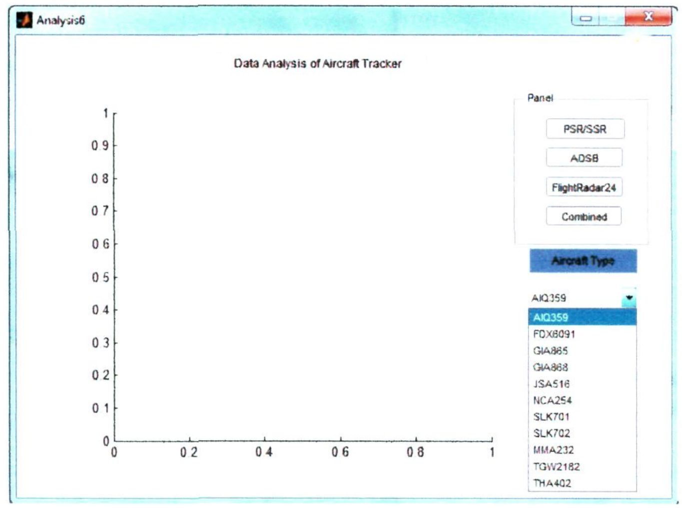
Figure 6 shows the MATLAB design of the GUI development and programming. The GUIDE is used to customize the layout and object component view [10].

GUIDE Layout Editor is used to populate a GUI framework by connecting the GUI components such as axes, push buttons, and pop up menu into the layout area. The pop up menu string is send to push button function by using handles.

GUIDE will automatically generate a program file comprising of MATLAB functions that controls how the GUI operates. MATLAB Editor is used to add programming code of the research analysis.



(a) Layout Editor



(b) Data Analysis of Aircraft Tracker GUI

Figure 6: GUIDE Environment

The Data Analysis of Aircraft Tracker GUI is created to generate the Latitude and Longitude plotting of the Tracked Aircraft. There are four push buttons which are PSR/SSR, ADS-B, Flightradar24 and Combined and one popup menu is used to generate detection graph.

C. Distance Calculator

The distance between the positions is calculated by using the formula as below:

$$a = \sin^2(\Delta\varphi/2) + \cos\varphi 1 \cdot \cos\varphi 2 \cdot \sin^2(\Delta\lambda/2)$$

$$c = 2 \cdot \operatorname{atan2}(\sqrt{a}, \sqrt{(1-a)})$$

$$d = R \cdot c$$

φ is latitude,

λ is longitude,

R is earth's radius (mean radius = 6,371km);

c is the angular distance in radians

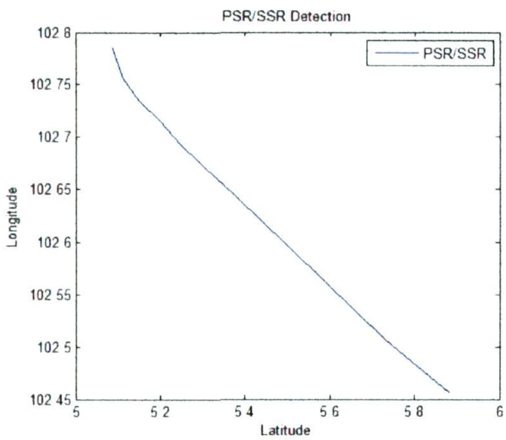
This formula is also called Haversine Formula which is used to calculate the great-circle distance between two points [11]. This formula remains particularly well-conditioned for numerical computation even at small distances.

IV. RESULT

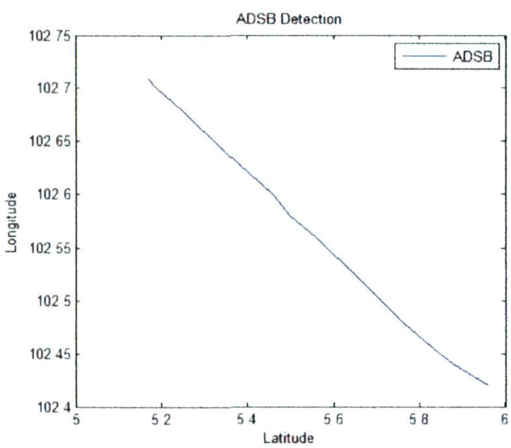
For the example result in MATLAB GUI, this paper will focus on the JSA516 aircraft data.

A. Detection of JSA516

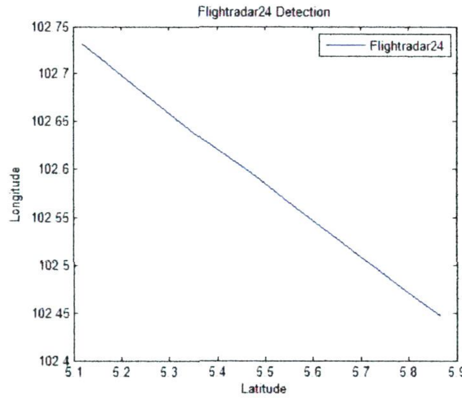
Figure 7 shows the plots of the detection of the Jetstar Asia Aircraft (JSA 516) which departure from Bangkok (Suvarnabumi Airport) and heading to Singapore (Changi Airport). These plots are displayed the detection of the aircraft JSA 516 while flying above the S743D Radar site and the ADS-B Receiver antenna is located. That particular detection of target aircraft will displays different positions of the aircraft varies with time.



(a) PSR/SSR Detection



(b) ADS-B Detection



(c) Flightradar24 Detection

Figure 7: Detection of JSA 516

From the figure, the PSR/SSR detection capability are 256 nautical mile of radius from the radar site. While for the experiment, the plots only begin from 12 to 20 nautical miles from the radar site to synchronise with the ADS-B Receiver Detection in figure 7(b). From the plot, the PSR/SSR detection is recorded starting at 6.39 nautical miles from the radar site and end at 45.39 nautical miles from the radar site.

The ADS-B detection is very limited up to 20 nautical miles radius. From the theoretical, the built ADS-B Receiver can detect up to 100 nautical miles but due to some factors, the detection is degraded. The detected latitude and longitude is recorded are from the GNSS data that was send by the ADS-B Transmitter of the aircraft. From the plot, the ADS-B detection is recorded starting at 11.47 nautical miles from the radar site and end at 39.03 nautical miles from the radar site.

While the Flightradar24 detection is used as the benchmark to do the comparison of the position since the data available continuously on the internet. From the plot, the Flightradar24 detection is recorded starting at 5.67 nautical miles from the radar site and end at 42.46 nautical miles from the radar site.

B. Comparison between PSR/SSR, ADS-B Receiver and Flightradar24 Detection

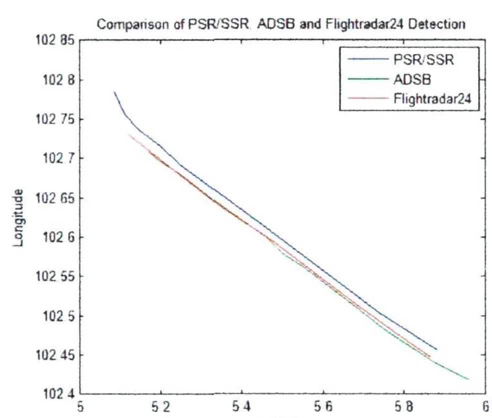


Figure 8: Comparison of all detection

Figure 8 shows the plots of comparison between the method of the detection (PSR/SSR, ADS-B Receiver and Flightradar24). The ADS-B receiver detection result is almost parallel with the Flightradar24. Meanwhile, PSR/SSR detection result is deviated from the others. The comparison of the distance between PSR/SSR and ADS-B Receiver is shown in the table below:

Table 1: Distance Calculation between PSR/SSR and ADS-B.

Time	PSR/SSR Lat	PSR/SSR Long	ADS-B Lat	ADS-B Long	Distance (km)	Distance (nm)
1603H	5.8833	102.4566	5.96	102.42	9.44	5.097
1604H	Contact Lost	Contact Lost	5.88	102.44	0.00	nil
1605H	5.6666	102.5333	5.85	102.45	22.38	12.084
1606H	5.4333	102.6233	5.76	102.48	39.64	21.404
1607H	5.25	102.6933	5.66	102.52	49.46	26.706
1608H	5.2	102.7166	5.56	102.56	43.62	23.553
1609H	5.15	102.735	5.5	102.58	42.53	22.964
1610H	5.113	102.7566	5.46	102.6	42.30	22.84
		Average Distance			31.17	16.83

From the Table 1, the average distance of the aircraft position between PSR/SSR detection and ADS-B detection are 31.17 km (16.83 nautical miles). There is contact loss of PSR/SSR radar at 1604H is due to cone of silence factor which the aircraft directly fly above the S743D antenna. Meanwhile, the ADS-B receiver is able to detect the position of that aircraft.

Table 2: Distance Calculation between ADS-B and Flightradar24 Detection

Time	ADS-B Lat	ADS-B Long	FR24 Lat	FR24 Long	Distance (km)	Distance (nm)
1603H	5.96	102.42	5.8662	102.4475	10.86	5.864
1604H	5.88	102.44	5.7848	102.4767	11.34	6.123
1605H	5.85	102.45	5.6841	102.515	19.80	10.691
1606H	5.76	102.48	5.5764	102.5554	22.05	11.906
1607H	5.66	102.52	5.474	102.5963	22.34	12.063
1608H	5.56	102.56	5.3532	102.6381	24.57	13.267
1609H	5.5	102.58	5.2236	102.6899	33.05	17.846
1610H	5.46	102.6	5.1174	102.7324	40.82	22.041
		Average Distance			23.10	12.473

Table 2 show the average distance between ADS-B detection and Flightradar24 detection is 23.1 km (12.473 nautical miles). Both detections were consistent during the recorded time period since both detection sources are from aircraft ADS-B Transponder that receiver it position from the GNSS constellation.

The slightly different of Flightradar24 detection is due to the delay of the data transmitted from the application server. Meanwhile the ADS-B receiver is detected the decode signal directly from the aircraft ADS-B transponder. The expectation of both approached results should be synchronised.

V. Conclusion and Future Works

The ADS-B detection has defined as the most significant technology approached that can be adapted to overcome the cone of silence for the Primary Surveillance Radar (PSR) and Secondary Surveillance Radar (SSR) of Martello S743D Detection. The researched has shown that the both radar detections have been optimized by the adaptation of ADS-B and the consistency of aircraft tracking will fully protect the sovereignty of the Malaysian Airspace.

Nevertheless, ADS-B systems are exposed to the ECM activities which are passive attack (eavesdropping) and active attack (message, jamming, replaying of injection) [12].

As for future work, the improvement of antenna receiver performance should be upgrade in order to improve the ADS-B detection for the signal up to 150 to 200 nautical miles. The other improvement that has been defined is to configure more ADS-B receiver source at different location which can increase the coverage of the detection. Thus, permit the study of Radar Error Analysis by using the Radar Error Determination approach [13][14].

References

[1] M. Cicolani, A. Farina, E. Giaccari, F. Madia, R. Ronconi, S. Sabatini, Some phased array svstems and technoloeies in AMS.IEEE International Symposium on Phased Array Systems and Technology,Rome, Italy, 2003.

[2] Student's Manual 743D Maintenance Technician Course. Radar Training Department, Marconi College, Volume 1, Issue P001, 1992.

[3] V. Schejbal, P. Bezousek, J.Pidanic, M. Chyba, Secondary Surveillance Radar Antenna. University of Pardubice Studentska, Pardubice, Czech Republic.

[4] Huang, Ming-Shih, R. Narayanan, Y. Zhang, A. Feinberg, Tracking of Noncooperative Airborne Targets Using ADS-B Signal and Radar Sensing. International Journal of Aerospace Engineering, 2013.

[5] 2015.[Online].Available: http://www.idconline.com/technical_references/pdfs/electronic_engineering/Radar_Coverage.pdf. [Accessed: 15- Dec- 2015].

[6] Standard Operation Procedures for Martello Radar System

[7] The ECCMO's Student Manual for The Royal Malaysian Air Force-Book1, Essex, England, 1994.

[8] Sprut, Manual for the adsbScope Software V2.7 & adsbPIC Decoder V2 Fw14, 2014.

[9] Flightradar24.com, "How it works - Flightradar24.com - Live flight tracker!", 2015. [Online]. Available: http://www.flightradar24.com/how-it-works. [Accessed: 15- Dec- 2015].

[10] Matlab 6: GUI Tutorial. Prepared by Vikram A Bose-Mullick.

[11] W. Chris Veness, "Calculate distance and bearing between two Latitude/Longitude points using haversine formula in JavaScript", Movable-type.co.uk, 2015. [Online]. Available: http://www.movable-type.co.uk/scripts/latlong.html. [Accessed: 15- Dec- 2015].

[12] A.Costin, A. Francillon, Ghost in the Air(Traffic): On insecurity of ADS-B protocol and practical attacks on ADS-B devices, Network and Security Department, EURECOM, Sophia-Antipolis, France

[13] H. Leslie Crane, R. Eftekari, Monopulse Secondary Surveillance Radar Azimuth Error Distribution Analysis. MITRE Corporation, pp L7-1 –L7-11, McLean, Virginia, 2010.

[14] Wang Li-wei , Xiao-song Jiang, An improved radar detection range plotting method based on radar equation, International Conference on Machine Learning and Cybernetics, pp 381-385, Guilin, 2011.