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RTL SDR ADS-B Data Analysis for Predicting Airports and ATS Routes

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***Abstract*: In contrast with the past, air traffic service providers are transitioning away from radar surveillance towards Automatic Dependant Surveillance Broadcast (ADS-B) systems to track planes on the ground as well as aircraft more accurately and reliably. The Federal Aviation Administration (FAA) in accordance with this has mandated every aircraft in the US to equip ADS-B OUT to travel within the controlled airspace by January 2020.**

In this research, the ADS-B data is obtained using a low cost RTL-SDR radio known as R820T RTL2832U and a Raspberry Pi-3B Single-Board Computer. The data is recorded in the Raspberry Pi-3B (which is the ADS-B receiver) and is rendered and visualized with the help of a self-written code. Following this, data is captured and analysed for the city Bangalore, India to determine all the aircraft travelling within the bounds of fifteen unique ATS routes, derived the airports where the aircraft are bound to land and the runway direction of the airport.

Keywords- ADS-B, RTL-SDR, Raspberry Pi, ATS Routes.

I. INTRODUCTION

A. ADS-B Basics

ADS-B is currently among the most accurate surveillance systems in the aviation industry. It is the primary component in the Next Generation Transportation System of the FAA. It is desirable for the air traffic controllers in providing precise aircraft location information. Aircraft employ ADS-B to determine its position using GPS and periodically broadcast its precise location and other information so that it can be tracked.

ADS-B consists of two functionalities- ADS-B OUT and ADS-B IN. ADS-B OUT is ADS-B's broadcast segment where information on aircraft ID, altitude and airspeed are periodically transmitted to the ground stations for reception. For ADS-B OUT capability, the minimum required equipment consists of an ADS-B approved transmitter which is either a dedicated 978 MHz Universal Access Transceiver (UAT) or a 1090 MHz Mode S transponder along with a Global Positioning System (GPS) enabled by Wide Area Augmentation System (WAAS) and a pre-installed Mode S transponder. Likewise, the ADS-B IN is ADS-B's receiver segment. Its deployment on aircraft is optional and is mainly deployed in ground stations. These ground stations periodically receive updates from aircraft within the range of transmission.

ADS-B provides two major services in Traffic Information Services-Broadcast (TIS-B) which provides information on air traffic and Flight Information Services-Broadcast (FIS-B) which mainly provides information through weather alerts. While the former is available to both 978 MHz UAT and 1090ES (Extended Squitter) transponder users, the latter is restricted to ADS-B users with a dedicated 978 MHz UAT.

ADS-B applications can be installed onto any smart device for the users to study and to monitor commercial aircraft. Fig. 1 displays the live monitoring of airlines, airports and flights detected by the ADS-B receiver including certain information such as flight names, ICAO (International Civil Aviation Organization) addresses, current positions, ground speeds and altitudes. The flight plots and their corresponding flight data are shown in Fig. 2 and Fig 3 respectively.

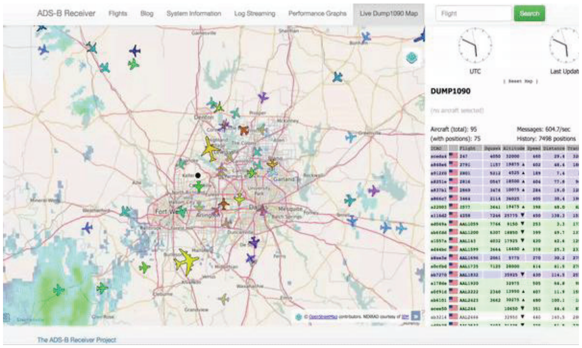

Fig. 1. Dump1090 web portal plot

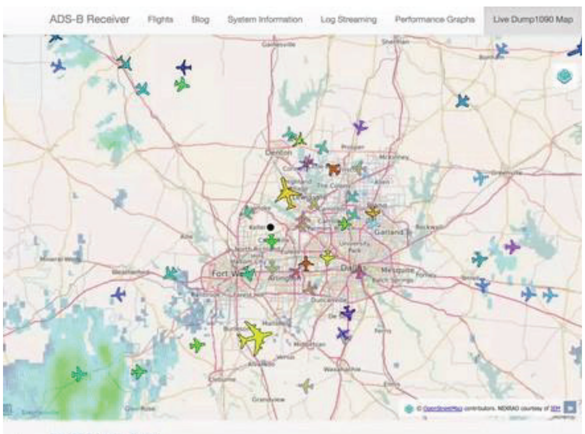

Fig. 2. Dump1090 web portal plot (Flight plot)

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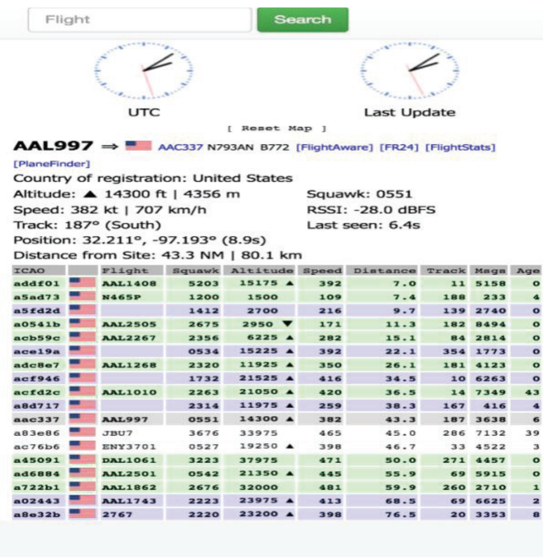

Fig. 3. Dump1090 web portal plot (Tabular data of flights)

B. *ADS-B Message Structure*

The 1090 MHz Extended Squitter (1090ES) and Universal Access Transceiver (UAT) are the two major standards for ADS-B data link where the latter supports TIS-B and FIB-S along with ADS-B. The 1090ES which is used widely in commercial aircraft is on the basis of the traditional Mode S system. The 1090ES ADS-B message format as shown in Table 1 which includes 5-bit Downlink Format (DF) indicating the message type, 3-bit Capability (CA) indicating Mode S transponders capability, 24-bit International Civil Aviation Organization address (ICAO), 56-bit payload size of ADS-B and 24-bit Parity Information (PI).

TABLE I. ADS-B MESSAGE STRUCTURE

DF (5bits)	CA (3bits)	ICAO (24bits)	Data (56bits)	PI (24bits)

II. RELATED WORK

The RTL-SDR dongle being available at very low cost provides immense opportunities to explore SDR with the help of software like MATLAB, GNU Radio or Simulink which are extremely helpful to design SDR based systems [5]. Users could monitor the movement of aircraft for up-to-date live tracking display of flights with the help of ADS-B applications by installing them on any smart device [8]. However, it was concluded that security flaws persist in this type of system and it is vulnerable to security attacks. A cost effective and accurate way to determine GPS coordinates of the airplanes at all times was suggested [2]. Also, the protection and security of ADS-B data and can be done by two one-way hash chains of keys. The implementation of an FM receiver was practically done using RTL-SDR as a compatible and low cost RF front end for a broad range of signal frequencies [3]. A software defined receiver with an array antenna and a specifically designed analog front-end were used to implement a multi-channel receiver to analyse channel traffic and test signal processing algorithms for the 1090 MHz ADS-B signals [9]. With the help of the developed system, data can be secured and ensured that jamming or spoofing could not occur thus improving the reliability of the system. A technique was proposed on the basis of ADS-B for implementing error calculation in a fusion system for each sensor [6]. Business intelligence techniques were used for understanding each sensor's error condition in a geographical area. A simulation of an ADS-B replay attack was carried out using a basic $200 software defined radio (SDR) transceiver to determine whether interference could occur through a ground station with an aircraft in flight [1]. It was demonstrated that such an attack could not occur by using the low cost SDR transceiver. An inexpensive and a fully automatic Spectrum Alerting System (SAS) on the basis of software defined radio was implemented to avoid collision if any of the sensitivity thresholds were crossed by generating an alert [7]. ADS-B data obtained from satellite and ground will complement each other, thereby increasing the coverage of air traffic space and help to improve the monitoring of the whole space [4]. This in-turn would provide better efficiency of the system and cost effectiveness. A practical system was proposed for the fusion estimation of numerous heterogeneous sensors including radar and ADS-B, which exhibit contrasting sensor characteristics and measurements [10]. It was demonstrated that although ADS-B at times provides abnormal data as it is a dependent sensor unlike radar, it significantly provides a higher refresh rate and more accurate measurements.

III. SYSTEM DESIGN

In Fig. 4, the antenna receives the 1090 MHz signal and it is then sent to the RTL-SDR. The Raspberry Pi acts as an ADS-B receiver to process the signals and track/monitor the flight path. Multiple communication devices can be connected to LAN to view the real time paths on a web portal using the decoded data of the RTL-SDR.

The RTL-SDR radio is capable of using a sampling rate in the range 200 KHz to 2.8 MHz. The data sent from the SDR to the Pi is then processed by the BASH code running in the background to deliver desired data that can be viewed on the web portal.

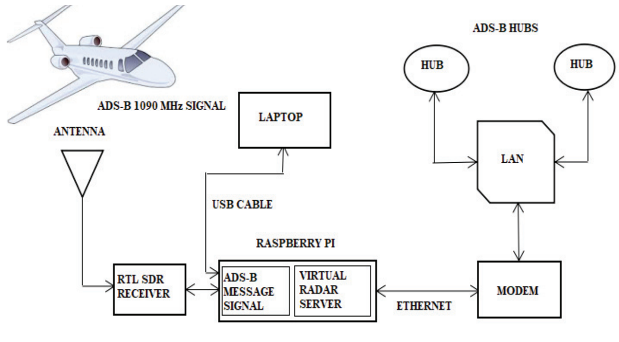

Fig. 4. Receiver block diagram

IV. COMPONENTS USED

The following components are used for the reception and analysis of ADS-B data:

i. Raspberry Pi 3 Model B
ii. RTL-SDR Radio and Antenna
iii. Open Source Software: Dump1090

The components are briefly described below:

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A. Raspberry Pi 3 Model B:

Raspberry PI is a cost-effective, single board computer which runs on the Debian based Linux operating system and provides a set of general purpose input/output (GPIO) pins that help in exploring the Internet of Things (IoT). The Pi being used for this work is the 3B model. It is powered by the Broadcom BCM2837 system-on-chip (SoC) which contains a 64-bit ARM Cortex-A53 processor clocked at 1.2 GHz. It includes 1GB of RAM with the 802.11n wireless LAN (Wi-Fi) and Bluetooth 4.1 being the new additions to this model.

B. RTL-SDR Radio and Antenna:

Software Defined Radio (SDR) is an RF communication system which implements radio components such as modulators, demodulators and tuners into software rather than their traditional hardware implementation for simpler signal processing and flexibility in the system. The RTL-SDR is a low cost software defined radio based on DVB-T (Digital Video Broadcasting- Terrestrial) USB receiver dongles with the RTLSDR2832U chip in them. Packed with the powerful RTL2832U and R820T tuner, it is able to tune signals from 24 MHz up to 1850 MHz which also includes the 1090 MHz ADS-B signal. This software being very cheap is nevertheless extremely powerful for applications like tracking aircraft positions with ADS-B decoding mainly because of its 8-bit ADC (Analog to Digital Converter). The smaller telescopic antennas (2x 5cm to 13cm) work decently up to L-band 1.5 GHz frequencies covering the 1090 MHz ADS-B signals.

C. Dump 1090:

Dump1090 is an RTL-SDR compatible program that is commonly used for ADS-B decoding. Dump1090 when run on Raspberry Pi, turns the whole Pi into an ADS-B data processor. Dump1090 is notably robust and good at decoding weak signals. It has the ability to decode DF11 and DF17 messages. These two messages are squittered at a nominal rate of 1 Hz by Mode S transponders. The DF17 extended squitter messages are used for the ADS-B system which contain information such as airborne velocity, aircraft position and identity. Dump1090 also contains an embedded HTTP server that displays the currently detected aircrafts on Bing Map. Fig. 5 displays the ADS-B data obtained from an RTL-SDR receiver. The receiver setup for obtaining flight data over the course of 4 days in the city of Bangalore, India is shown in Fig 6.

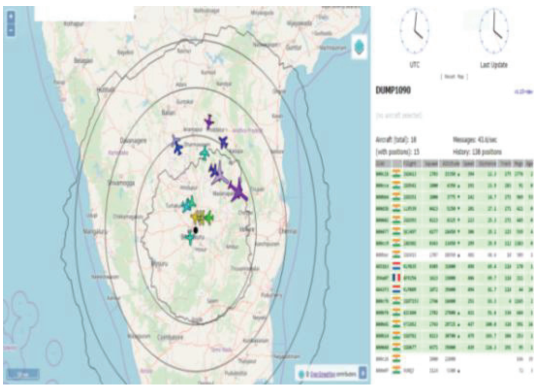

Fig. 5. Aircraft plot on Dump1090 web portal

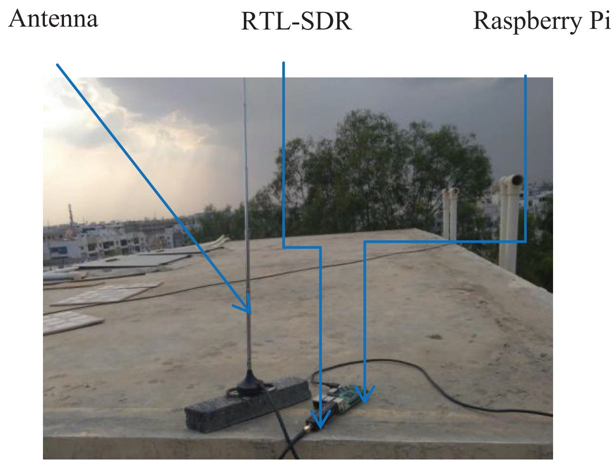

Fig. 6. ADS-B Receiver Set-Up

V. ANALYSIS

The aircraft data is captured using the RTL-SDR receiver and the aircraft data are plotted on the web portal. Real time images of the aircraft travelling within the radius of the receiver are viewed on the portal. In the hardware setup, one end of the RTL-SDR (NESDR Smart) is connected to a telescopic antenna mast of variable frequency capability and the other end is connected to the Raspberry Pi. To view aircraft on the web portal, an Ethernet cable is connected to the Pi which is then connected to the laptop's USB Port to connect with the same LAN. The Raspberry Pi acts as an ADS-B data processor to process the signals and track/monitor the flight path using the data received by the RTL SDR. The data sent from the SDR to Pi is then processed by the BASH code running in the background to deliver desired data that can be viewed on the web portal. On the web portal, aircraft information such as ICAO code, flight name, altitude, ground speed, track angle, position, squawk code (discrete transponder code) and messages are displayed. The aircraft parameters are displayed to the side of the screen and these parameters are continuously updated. The aircraft and their information are able to be detected as long as they remain in the confines of the antenna's detection radius.

With the data in hand, the first analysis is to determine the landing position and the runway position. In the collected aircraft data, the range of the altitude lies from 1000 ft to 45000 ft. A relatively lower range of 1000-3500 ft is considered to detect every aircraft which is either bound to land or take off from an airport. The collection of flight data at this range forms a runway and the centre of mass of all these points depicts its landing position.

The second analysis is to predict the ATS routes being followed by a particular aircraft with the data in hand. An ATS route is defined as a designated route for maintaining the orderly flow of traffic to help assist aircraft in real-time. Fig. 7 is a flow diagram to predict the landing position of a runway. Fig. 8 is a flow diagram to predict the ATS route followed by individual flight satisfying a particular threshold value.

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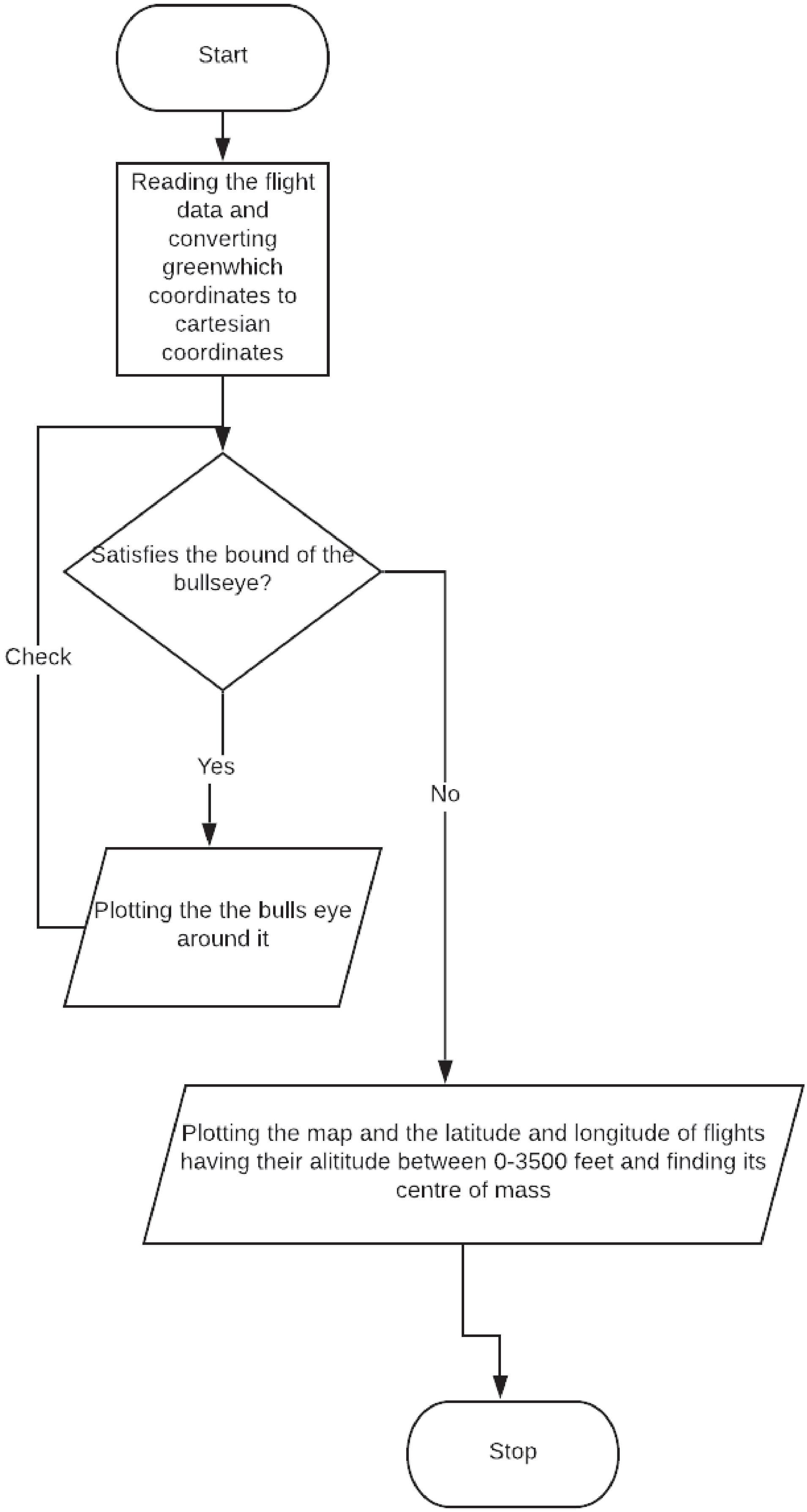

Fig. 7.Flowchart to predict the landing position of airport's runway

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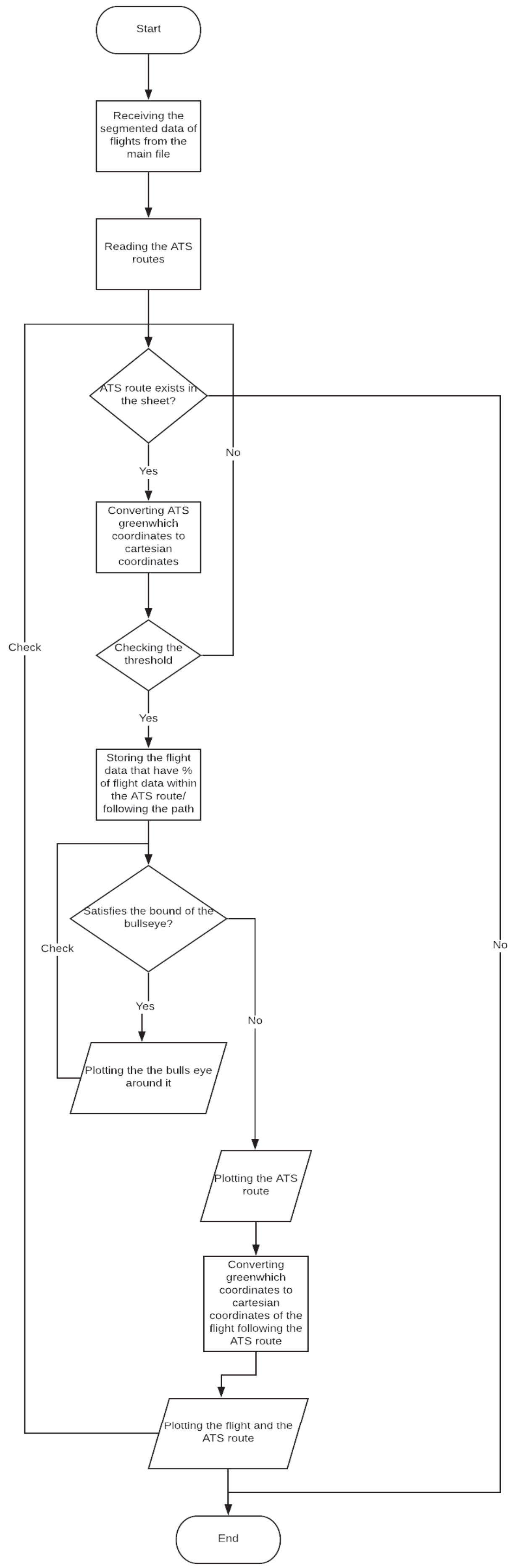

Fig. 8. Flowchart to predict the ATS routes followed by individual aircraft

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$$X = R * \cos(lat) * \cos(lon)$$
$$Y = R * \cos(lat) * \sin(lon) \quad (1)$$

This equation represents the conversion of Greenwich Meridian coordinates to Cartesian coordinates. The x-axis passes through latitude and longitude coordinates (0, 0) and hence the longitude meets at the equator. The y-axis passes through the coordinates (0, 90). R denotes the radius of the Earth (6378 km).

$$X = \frac{\sum_{i}^{n} m_i x_i}{\sum_{i}^{n} m_i} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3 + \ldots + m_n x_n}{m_1 + m_2 + m_3 + \ldots + m_n} \quad (2)$$

This equation represents the centre of mass of all the flight data points. X is the location of the centre of mass and $m_1, m_2, \ldots, m_n$ are the coefficients of $x_1, x_2, \ldots, x_n$.

Following this, more ADS-B data has been captured for the analysis over the course of four days dated from January 20, 2019 to January 24, 2019. It was decoded by the SDR and recorded into a log file of size 5.87MB. The data collected has about 86,413 observations of around 1200 flights. The observations include aircraft ID, flight number, time of detection, message, squawk code, latitude and longitude, track angle, altitude, vertical rate and ground speed. As an example, Table 2 describes these parameters for the first and second flights under observation.

TABLE II. ADS-B RECORDED DATA

	A	B	C	D	E	F	G	H	I	J	K	L
1	ID	FLIGHT	AIRCRAFT	TIME	MESSAGE	SQAWK	LATITUDE	LONGITUDE	TRACK	ALTITUDE	VERTICALRATE	SPEED
2	1	1	2	20-01-2019 05:40	21	2745	13.206161	77.778373	91	4750	1408	232
3	15	1	2	20-01-2019 05:41	75	2745	13.218508	77.825703	48	6325	3136	262
4	23	1	2	20-01-2019 05:41	100	2745	13.226329	77.831967	38	6700	2560	264
5	31	1	2	20-01-2019 05:41	134	2745	13.248367	77.838372	3	7400	2496	279
6	38	1	2	20-01-2019 05:41	146	2745	13.2733	77.831292	336	7925	1344	296
7	46	1	2	20-01-2019 05:42	149	2745	13.2733	77.831292	336	7925	1344	296
8	53	1	2	20-01-2019 05:42	159	2745	13.29639	77.818379	332	8000	-128	331

Fig. 9 and 10 depict the predicted runway with the landing position for the HAL Airport and Kempegowda Airport respectively. Similarly, Fig. 11 and 12 fit the same on Google Maps. Fig. 13 shows a particular ATS route being predicted for flight no.46 from the ADS-B data.

Fig. 9.Runway 1 (HAL Airport)

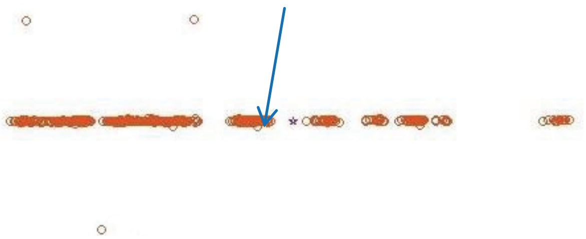

Fig. 10. Runway 2 (HAL Airport)

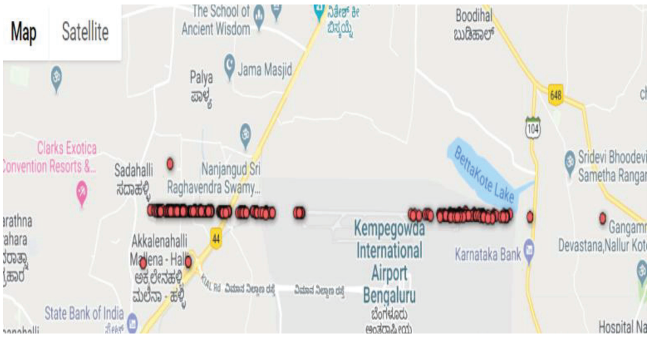

Fig. 11. Kempegowda International Airport on Google maps plotted using ADS-B data

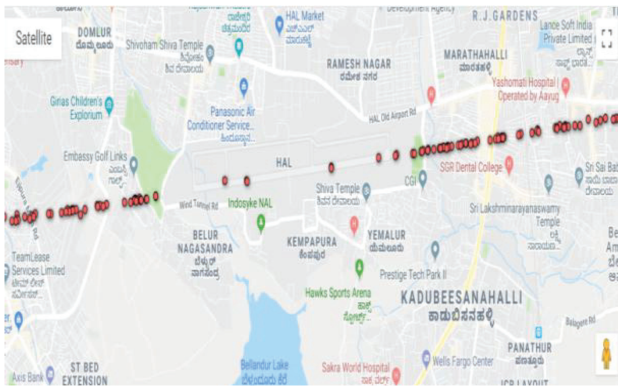

Fig. 12. HAL Airport on Google maps plotted using ADS-B data

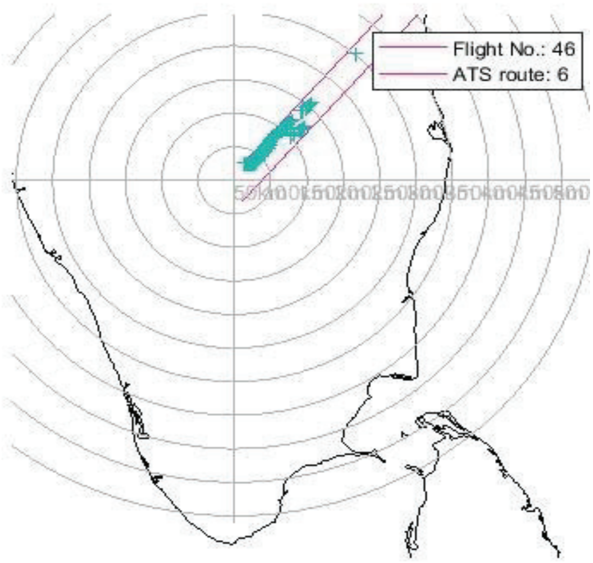

Fig. 13. ATS Route prediction for flight number 46

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The verification for the above analysis of routes and the flights following their designated routes was done by demonstrating the whole project at the HAL airport with the ATC with the radar results obtained by them. However, the data and the display of the above from the ATC were confidential and could not be obtained.

VI. CONCLUSION

From the first analysis, two airports namely Kempegowda International Airport and the HAL Airport have been predicted using the lower altitude range of the flights and the centroids of each runway have also been determined which are nothing but their respective landing positions. In the other analysis, a fixed threshold of data points has been determined for each flight to satisfy in order to follow its designated ATS route. The threshold is obtained to be 90% which is the ratio of flight data points inside the polygon (which is the maximum width of an ATS route i.e. 20 nmi) to the total data points of that particular flight.

VII. FUTURE PERSPECTIVE

A very low monetary investment is required for the software and hardware described in this paper. Across the board, the hardware cost amounted to less than $80. ADS-B is a rapidly upcoming technology which has a very high update rate with high accuracy and integrity as compared to primitive radar systems. In remote area slacking conventional radar coverage, aircraft equipped with an ADS-B receiver connected to a suitable display can view nearby aircraft thereby enhancing aircraft's visibility and reducing the risk of air to air collision. Unlike radar, ADS-B's accuracy is not dependant on range from ground stations. It can also easily be deployed with a minimal ground station cost. This work is bound to help ATC's and small airports to track flights accurately and reliably mainly due to its low cost of hardware and will also help aviation hobbyists acquire a strong understanding on this swiftly expanding domain of aviation.

ACKNOWLEDGEMENT

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