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A Hands-on Project for Avionics Systems Course in Aviation Engineering Technology Program

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A Hands-on Project for an Avionics Systems Course in an Undergraduate Aviation Engineering Technology Program

Abstract

There are electrical and electronic systems courses that are compulsory for students majoring in Aeronautical Engineering Technology (AET), an undergraduate program accredited by the Engineering Technology Accreditation Commission of ABET (ABET-ETAC). In order to prepare students for the FAA Airframe and Powerplant Certification exams, and future success in their careers, students in the AET program are expected to develop an integrated ability of understanding theoretical knowledge and proficient hands-on skills. This paper introduces a hands-on project for an upper level electrical and electronic systems course to better develop project-oriented, problem-solving experiences. This hands-on project requires assembling an Automatic Dependent Surveillance – Broadcast (ADS-B) flight tracking system that is a real-world aeronautical system. ADS-B is one of the major components of the Next Generation air transportation system. In this project, students are asked to apply relevant electrical and electronic knowledge and skills to build a light-weight ADS-B receiver, and deploy the receiving system to collect and decode flight data broadcast by aircraft. This project is expected to help students develop the ability of integrating skills from different electrical and electronics courses to solve real aviation problems. This course project, based on current avionic technology, allows students to have better understanding of their theoretical knowledge, as well as a good practice of hands-on skills.

Introduction

The Aeronautical Engineering Technology (AET) program at Purdue University prepares students who are interested in aviation and aeronautics with necessary aeronautical knowledge and aircraft maintenance skills. In addition, it helps students prepare for the FAA Airframe and Powerplant Certification exams. An appropriate course design is crucial to facilitate the development of anticipated abilities for students. The electrical and electronic systems is one of the primary components of AET curriculum. The series of electrical and electronic systems courses in AET program consists of three courses: *Aircraft Electrical Systems*, *Avionics Systems*, and *Aircraft Electronics*. The curriculum content ranges from the basic electrical theory, electrical circuit analysis, major aircraft electrical and electronic systems, and advanced avionics, as well as the hands-on skills development in corresponding lab work. The series of electrical and electronic systems courses has been viewed as one of the most difficult parts of AET program by students, because the electrical theories are abstract and not easy to demonstrate in the traditional classroom.

As one of the major components of the Next Generation air transportation system, the ADS-B is a precise satellite-based surveillance system, which retrieves an aircraft’s location, speed, altitude, and other data from the Global Positioning System (GPS) and broadcasts that information to ground stations and nearby aircraft, as shown in Figure 1 [1].

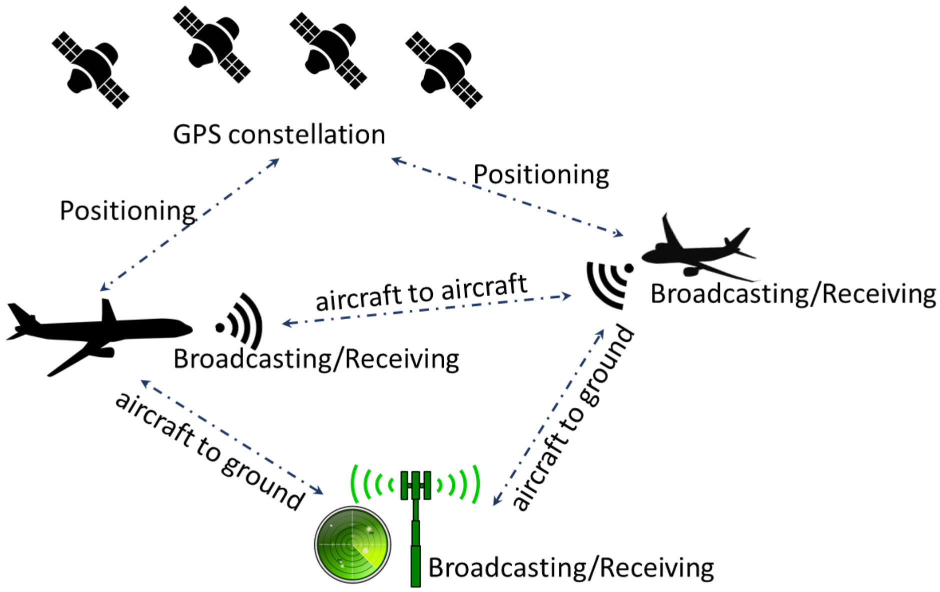

Figure 1. Overview of the ADS-B Structure, adapted from [1]

ADS-B has two types of broadcast functions: ADS-B In and ADS-B Out. ADS-B Out periodically broadcasts structured, encoded messages containing flight information; ADS-B In receives and decodes the messages broadcasted by ADS-B Out. Theoretically, ADS-B In capable ground stations and aircraft are able to receive the aircraft information broadcasted by all other ADS-B Out capable aircraft within the maximum range of the ADS-B Out signal, while communication satellites could provide a solution to extend the coverage of the ADS-B service. With the upcoming ADS-B mandated implementation date of January 1, 2020, there will be more aircraft equipped with ADS-B Out than ever before [2],[3]. Therefore, the understanding of ADS-B technology, both from theoretical and practical points of view, is expected to be critical for AET students in the future job market.

Applications of ADS-B are found in the academic literature. ADS-B has been explored to support airport surface operations [4]. An aircraft conflict detection approach was proposed based on ADS-B input data [5]. McNamara, Mott, and Bullock [6] investigated the use of ADS-B data in fleet management and airport operations. In 2017, ADS-B was explored as an alternative data source for flight data monitoring in general aviation [7].

In this paper, an ADS-B build-test-operate project is presented in terms of its connections to the overall avionics courses and to an Aeronautical Engineering Technology undergraduate program that is ABET-ETAC accredited. The materials, costs, assembly instructions, and operation instructions are outlined so that this project may be implemented in other ET courses.

Avionics Courses Structure

In order to deliver a successful electrical and electronic systems course, all avionics courses in this accredited program include lectures and lab sessions. Theoretical knowledge and examples of electrical and electronic systems are introduced in the lecture sessions, and relevant applications and hands-on skills are developed in the lab sessions. In addition, it is important to enable students to integrate electrical knowledge with other relevant skills to elevate students' capability to better use knowledge in problem solving. This paper introduces a hands-on project for avionic systems course to better enhance a practical education for AET students. This hands-on project asks students to assemble an Automatic Dependent Surveillance – Broadcast (ADS-B) flight tracking system as a real-world aeronautical example, and is expected to stimulate students' interest in avionics by working out an operational electronic device.

In this project, students are expected to apply electrical and avionic knowledge to build up a light-weight ADS-B receiver, and deploy the receiving system to collect and decode flight data. This project requires students to have basic electrical and electronics knowledge, and basic computer programing skills. In the series of electrical and electronic systems course of the AET program, this project would be proposed in the second course on electronics. The connections to the first and third courses will be detailed in the section of Avionics Courses Structure. To accomplish this project, students will need to assemble an ADS-B receiver using provided hardware and software, load the code into hardware, deploy system to collect and decode data, and analyze the results. Students could modify the hardware and software to improve the performance of system if necessary. In that case, the project engages students with many skills, such as circuit analysis and design, soldering, programing, system field testing, and data analytics. The project helps students develop the ability to integrate skills from different courses to solve real aviation problems. A course project related to cutting-edge technology and output an operational project product allows students to have better understanding of avionics and its relevant applications.

The series of electrical and electronic systems courses in AET program has three relevant courses covering necessary avionic knowledge with different concentrations respectively.

Aircraft Electrical Systems is the entry-level class with the concentration of developing students an understanding of electrical principles as they relate to aircraft system operations. This course also teaches the construction, analysis, and isolating faults in circuits. Upon successfully accomplishing this course, students will be able to demonstrate troubleshooting procedure for direct current electrical aircraft components and power distribution circuits.

Avionics System is the second course of avionics series. In this course, the theory of operations and application of common electrical components used in various aircraft circuits is introduced; the operational theory, installation practices, and troubleshooting concepts of common aircraft communication and navigation systems are also demonstrated, in addition, the theory and mathematical relationship of alternating current, reactance, impedance, and phase shift are also explained.

Aircraft Electronics is the last course of avionics series. Students are anticipated to demonstrate an understanding of design, operation, and troubleshooting concepts of advanced digital and analog systems found on modern aircraft.

The curriculum content and relationship between these three courses are shown in Figure 2.

200 level Aircraft Electrical Systems

Credit Hours: 3.00. An in-depth study of aircraft electrical components, both individually and as systems in the aircraft. DC electrical circuits, series and parallel circuits, magnetism, and electromagnetism are covered, as are DC power systems, schematics, and aircraft wiring practices. Aircraft charging systems, main power distribution, solid state electronics, batteries, and motors are also discussed.

300 level Aircraft Electronics

Credit Hours: 3.00. A study of the computer-based electronic systems used to control both flight and engine parameters on modern aircraft. The course examines the various systems with an emphasis on how each component integrates into the electronic structure of the aircraft. Typically offered Fall, Spring, Summer.

400 level Avionics Systems

Credit Hours: 3.00. This course covers the theory of operation and applications of common electrical components used in various aircraft circuits. The theory and mathematical relationships of alternating current, reactance, impedance, and phase shift are examined. Operational theory, installation practices, and troubleshooting concepts of common aircraft communication and navigation systems are investigated.

Figure 2. The Content and Structure of Avionics Courses [8].

Project Description

Based on the structure of avionics series courses, the proposed project is more appropriate for the second or third course since students need to master basic electrical and electronic knowledge and hands-on skills first; some computer programing knowledge is preferred but not required in this project. This project could be arranged as an individual project to demonstrate specific mastery and/or as a team project to balance multiple required skills. This project is designed to be accomplished over a four-week period of one laboratory session per week, 2.8 hours per session, and three lectures sessions per week, 0.8 hours per session. An outline of the project tasks is presented by week.

Project Tasks

- Understand the operating principles of ADS-B In and Out, and the technical standards of ADS-B Out. (Week 1 Lecture, one 0.8-hour session)
- Understand the framework of designated ADS-B receiver, data flow and the function of each component. (Week 1 Lecture, one 0.8-hour session)
- Check for understanding using a short quiz on architecture and data flow. Discuss applications of ADS-B in industry (Week 1 Lecture, one 0.8-hour session)

- Verify that all students have completed the previous labs in the course so that they are ready to begin assembly next week. (Week 1 Lab)
- Discuss the components, operational theory, and system architecture (Week 2 Lecture, one 0.8-hour session)
- Introduce data content and structure using standards. Provide sample ADS-B data and assign students to calculate basic flight metrics such as average vertical speed, average ground speed, and a plot of flight altitudes. (Week 2 Lecture, two 0.8-hour sessions)
- Assemble the ADS-B receiver by the students using the provided components, test connectivity, power up. Emphasize problem solving and use of equipment to understand and solve problems encountered. (Week 2 Lab)
- Discuss and demonstrate prominent decoding algorithms, driver programs, operating systems, and decoding programs. Discuss ethical issues in addition to regulatory issues. (Week 3-4 Lectures, four 0.8 hour sessions)
- Observe and practice working with sample ADS-B data by comparing, contrasting, and discussing data characteristics in terms of the theory of how data are encoded, broadcasted, and retrieved. (Week 3 Lab, one 2.8-hour session)
- Understand the decoding algorithms for ADS-B messages (Week 4 Lecture, one 0.8-hour session)
- Select appropriate drive programs and flight data decoding script. Test students for understanding. (Week 4 Lecture, one 0.8-hour sessions)
- Test and deploy the assembled ADS-B receiver by students; collect, analyze and present data by students. (Week 4 Lab)

ABET-ETAC Implications

This project is designed to improve student's integrated problem-solving ability with these course objectives for the 300-level and 400-level courses:

> *Objective for 300-level course – Demonstrate the understanding of how each component integrates into the electronic structure of the aircraft.*
>
> *Objective for 400-level course – Master installation and troubleshooting of common aircraft communication and navigation systems.*

These two objectives tie to the ABET-ETAC baccalaureate program Criterion 3 Student Outcomes found in *Criteria for Accrediting Engineering Technology Programs 2016-2017* [9] that is referenced by the *Accreditation Policy and Procedure Manual 2016-2017* [10]. Three outcomes that may be applicable are quoted from [9]:

> a. an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities;
>
> b. an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;
>
> j. a knowledge of the impact of engineering technology solutions in a societal and global context;

Assessment of student learning outcomes in Criteria 3.a, 3.b and 3.j may be accomplished during the courses. For instance, an instructor may choose to use project assessments, test questions, quizzes, or presentations, among other choices. For Criterion 3.a. examples: selected test questions or quizzes may be used to assess student's knowledge of ADS-B architecture and component options, or safe and correct assembly of the ADS-B device may be used to assess student's ability to select and apply techniques and skills. For a Criterion 3.b. example: completing data analysis assignments may be used to assess the ability to select and apply mathematics and technology to aviation principles. For a Criterion 3.j. example, discussion of ethical implications of data collection via broadcasted signals may be used to assess the implications in a societal context. Other options may be considered based on the needs of specific programs.

In addition, Criterion 5 Curriculum requirements are also met. For instance, Technical Content focused on applications of science and engineering and "c. Develop student competency in the use of equipment and tools common to the discipline." [11]. For AET baccalaureate programs there are three program specific outcomes specified. In one of these outcomes, there are connections to this course project: a. technical expertise in electronics option as opposed to the electrical power option.

The theory and application of ADS-B are summarized: description of the receiver, components, and assembly and deployment sections. The data collected may be either comma or space delimited depending on the specific software selected by the instructor, and may be uploaded into spreadsheet software for analysis.

Description of the ADS-B Receiver

There are two types of FAA-compliant physical layers to support ADS-B Out – Mode S Extended Squitter (Mode S ES) working on 1090 MHz, and the Universal Access Transceiver (UAT) working on 978 MHz; the selection of solutions depends on the aircraft operation altitude in the U.S. [1]. Theoretically, the ADS-B Out device broadcasts a data frame once per second, which contains the basic flight parameters, such as aircraft identity, surface position data, airborne position data, airborne velocity, and other operational data [12]. The ADS-B receiver remains operational constantly to intercept the ADS-B Out messages for data collection.

For this class project, there is a specific data flow developed as shown in Figure 3. When the receiver intercepts an ADS-B Out message, a timestamp is attached to each data frame received. In the meantime, the ADS-B Out message may be decoded and converted into readable flight parameters automatically by flight data decoding software on the computer. Different flight parameters are identified by checking the Type Code of an ADS-B Out message, and the source of flight data is identified by matching the aircraft identity. The decoded flight data can be projected on digital map for air traffic tracking and management, or other research purposes. The data flow from ADS-B Out capable aircraft to an ADS-B receiver is depicted in Figure 3.

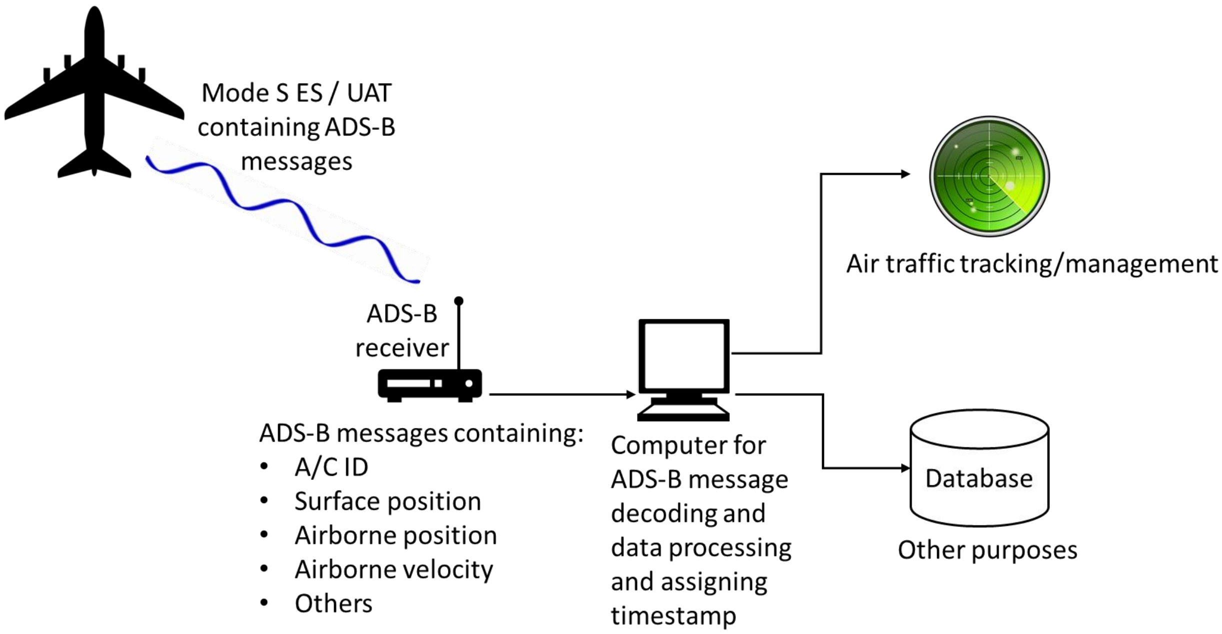

Figure 3. The data flow of ADS-B messages

Components

Currently, there are more than one commercial off-the-shelf (COTS) of ADS-B receiver solutions, ranging from hobby ADS-B receiver to certified ADS-B In avionic systems. Professional ADS-B receivers usually have better performance, for example, better sensitivity to weak signal, larger coverage, faster update frequency. However, professional devices typically need expensive investments, and the professional-level high performance is not necessary for educational purposes in this course project. An affordable solution with the features of easy modification and good flexibility is more practical and helpful in this educational project. Therefore, this project proposes to adopt the Software-defined Radio (SDR) as the primary receiving device working on the Raspberry Pi® platform to build up the ADS-B receiver, shown in Figure 4. There are other architectures available in the market; instructors are encouraged to investigate options by searching the internet resources and to determine the option most suitable for their situations.

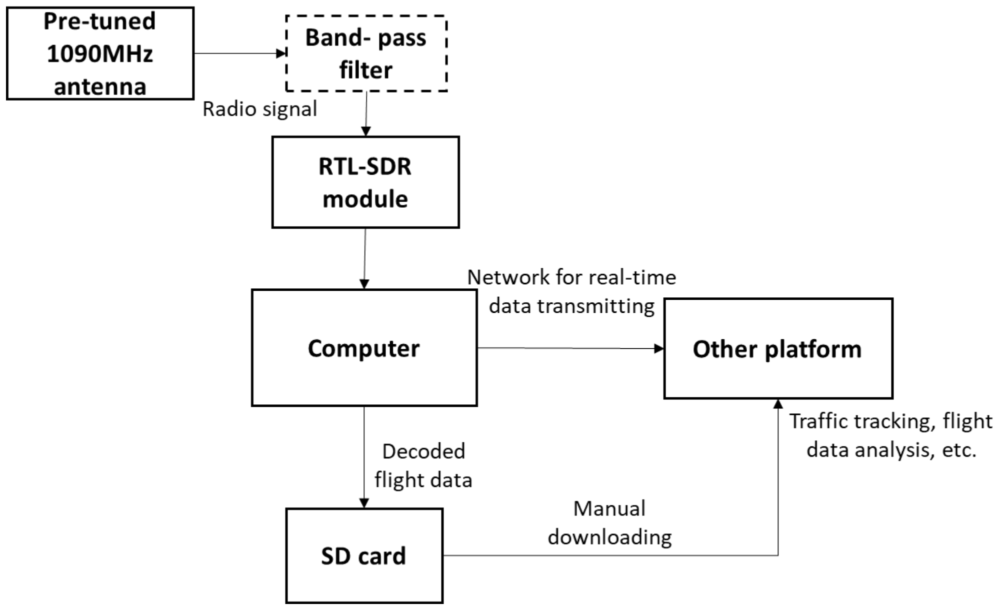

Figure 4. The Architecture of ADS-B Receiver

Software-defined Radio (SDR)

The Software-defined Radio is an integrated radio communication system of which necessary communication components are implemented by the means of radio signal processing software or embedded systems, such as antenna, radio frequency (RF) radio, RF amplifier, local oscillator, and mixer [13]. Several types of SDR boards could be used as the receiving module in this project. Comparing different COTS of SDR modules, the RTL-SDR shown in Figure 5 was selected for this project considering the low price and reasonable performance.

Figure 5. RTL-SDR Dongle

The RTL-SDR is an SDR radio receiver based on the Realtek® RTL 2832U and R820T2 integrated circuits (IC) with a frequency capability of 25MHz-1750MHz. The RTL 2832U IC acts as the demodulator and USB interface, and the R820T2 IC works as the radio tuner with better sensitivity over other affordable options considered. An antenna can be connected with the receiver using a male MCX to female SMA adapter.

Computer

In addition to the radio receiving device, a computer is needed for ADS-B message decoding and data processing. However, in order to mitigate the signal fading caused by the coaxial cable, less coaxial cable should be used to between antenna and the RTL-SDR receiving device. Therefore, a COTS portable computer - Raspberry Pi® 3 is adopted for ADS-B data processing in this project, because this portable light-weight computer can be easily powered and directly connected with the RTL-SDR via the Universal Serial Bus (USB). This architecture of ADS-B receiver is expected to reduce the signal fading during transmitting via cable, and also better support outdoor deployment of ADS-B receiver as a remote device. Furthermore, the use of Raspberry Pi® microcomputer in this project could familiarize students with this popular portable computer platform, as well as additional experience of working on integrated electronic circuits. These characteristics of this project are expected to prepare students for further research and development with integrated circuits and electronic systems, more importantly, to stimulate student's interest in avionics.

Raspberry Pi® 3 Model B is used in this project, shown in Figure 6. This version of computer motherboard integrates 1.2 GHz 64-bit quad-core ARMv8 CPU with 1 GB RAM, 802.11n Wireless LAN and Bluetooth modules, and other multimedia and power supply interfaces. The operating system and data storage can be loaded via a MicroSD port on the board.

Figure 6. Raspberry Pi® 3 Model B Motherboard

Antenna

In this project, the Raspberry Pi® 3 computer is used to decode the ADS-B messages received by a software-defined radio (SDR), and to process the decoded flight data. In order to receiver more ADS-B Out messages per minute, an 1090MHz pre-tuned vertically polarized outdoor antenna could be an option to replace the original indoor antenna in the bundle of RTL-SDR found on the market at the time of project preparation, the pre-tuned 1090MHz antenna is shown in Figure 7.

However, 1090MHz pre-tuned antenna can not receive the ADS-B messages broadcasted from the Universal Access Transceiver (UAT) since it broadcasts on 978MHz.

Figure 7. 1090MHz pre-tuned outdoor antenna

Software for Computer

The RTL-SDR module receives the ADS-B radio signal broadcasted by the ADS-B Out capable aircraft, and output the binary flight information [12], [14]. There are many open-source software packages could be selected to decode ADS-B Out messages. Students are encouraged to review necessary references to understand the ADS-B data format and content, as well as the algorithms of decoding the binary ADS-B messages. Two recommended references are: the *Minimum operational performance standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast* published by the Radio Technical Commission for Aeronautics (RTCA) [12], and the *Technical provisions for Mode S services and Extended Squitter* (Doc 9871) published by the International Civil Aviation Organization (ICAO) [14]. The binary information could be decoded on the Raspberry Pi 3 computer using the selected open source decoding software, such as Dump1090 which is released under the BSD three clause license on the Github [16]. Students could also write their own scripts to decode the binary ADS-B messages, based on the algorithms in the two recommended references [12], [14]. The decoded ADS-B data could be either saved to the SD card or transmitted to another platform through a network for other purposes, such as air traffic tracking, and flight data analysis.

In addition, if the ADS-B receiver is deployed at a location that experiences interference from other signals at 1090MHz, a band-pass filter is an option to consider to improve the reception of the receiver. At the receiver end, a band-pass filter allows signals within a specific range of radio frequencies to be received and filter out other unwanted frequencies. An example of band-pass filter in the market is shown in Figure 8.

In addition to the main components, additional parts are needed to assembly the whole system, such as power supply, SD card, and Raspberry Pi 3 protection case. The list of suggested components for assembling the ADS-B receiver in this project and the estimated cost are described in Table 1.

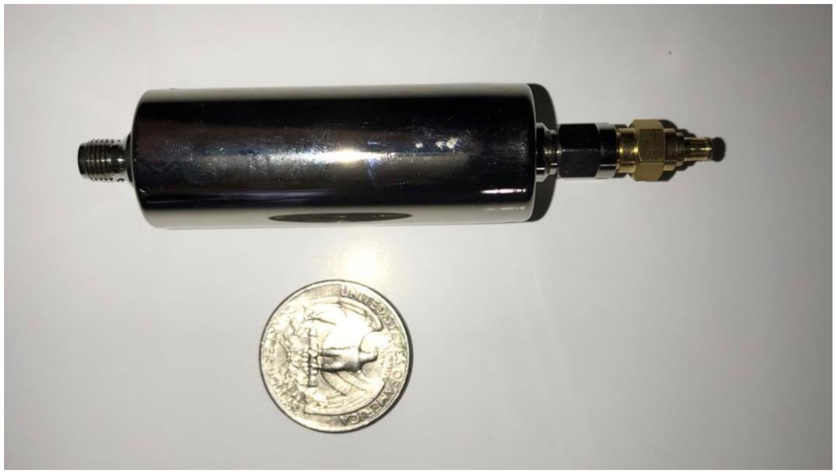

Figure 8. An example of band-pass filter affordable in the market

Table 1. Suggested Components for ADS-B receiver and the Estimated Cost

Item	Quantity	Estimated Unit Price
1090 MHz Antenna – 66cm/26in	1	U.S. $50
1090 MHz Band-pass SMA Filter (Optional)	1	U.S. $25
RTL2832U & R820T2 Radio Tuner	1	U.S. $25
5V 2.5A Raspberry Pi 3 Power Supply	1	U.S. $12
USA-CA RFC240N MALE to SMA MALE Coaxial RF Pigtail Cable	1	U.S. $20
High Speed HDMI 1.4 Cable	1	U.S. $5
16 GB MicroSD Card	1	U.S. $13
Raspberry Pi 3 Model B	1	U.S. $38
Raspberry Pi 3 Case	1	U.S. $10
Dump1090 (or other software)	1	Free

Assembly and Deployment

The main goal of this project described in this paper is to enable students to experience the assembly of an electronic device, and experience the functions of an advanced avionic system of ADS-B Out using a self-built receiving device. Once assembled, the students will be likely to be intrinsically motivated to deploy this device and understand the additional requirements to install, operate, and retrieve data. Upon thorough study of the theories of ADS-B system and technical guidelines of provided electronic components, the next step for students are to assemble the ADS-B receiver and to deploy the operational device for data collection.

The process of assembly involves four main steps, which allow students to learn the selection, testing, troubleshooting of electronic devices, and possibly practice their soldering, measuring, and other electrical and electronic skills:

1. Study the technical manuals of RTL-SDR module and the Raspberry Pi 3 computer; understand the logic and architecture of RTL-SDR; load operating system (OS) on the Raspberry Pi 3, and understand how to run programs on the Raspberry Pi 3.
2. Assembly hardware components according to the manual; load the OS on Raspberry Pi 3, power up, test, and troubleshoot if system does not work.
3. Understand the ADS-B data format and structure; understand the algorithms of ADS-B message decoding; select appropriate open-source software or write the scripts of ADS-B message decoding program.
4. Load the ADS-B decoding program, test and debug the program if necessary.

To design and develop this course project, an example of ADS-B receiver was assembled using the components described previously, and is shown in Figure 9.

Figure 9. The Example of Assembled ADS-B Receiver

The deployment of an ADS-B receiver allows students to learn and practice the theory and process of radio frequency (RF) transmitting and receiving, and the installation techniques of RF devices, especially operating in or nearby airports. The ADS-B receiver deployment includes these four steps:

1. Identify local and nearby airports and the operational characteristics, so that the deployment of ADS-B receiver, especially the height of antenna, will not violate the regulations nor become a potential threat for aviation safety. For those unfamiliar with aviation regulations, a discussion with local airport managers is recommended and may benefit both the instructors and the students.
2. Understand the characteristics of radio frequency at 1090MHz; select several potential locations for deployment.
3. ADS-B receiver deployment and on-site testing; troubleshooting if necessary.
4. Collect ADS-B data using ADS-B receiver; observe and analyze the collected ADS-B data; conclude project or continue further study.

During this project development, an assembled ADS-B receiver was deployed near Purdue University Airport – the east side of the extended center line of Runway 23, shown as Figure 10 and Figure 11. The terrain of location is relatively higher than the surrounding area, and the clear sight without blocking is helpful for transmitting and receiving radio signals.

However, implementation of this project in education does not need an operational airport nearby. This 1090MHz ADS-B receiver is more tuned for commercial flights since Mode S ES ADS-B solution is more liked used by commercial aircraft than general aviation aircraft. Students can deploy this device in campus where the antenna is not blocked by any buildings or other obstructions. Flight data broadcasted by nearby commercial flights are expected to be received by the device. By running an operational ADS-B receiver, students should be able to observe what the actual ADS-B data look like, and explore further studies by using collected data.

Figure 10. Close-up photo of deployed ADS-B Receiver.

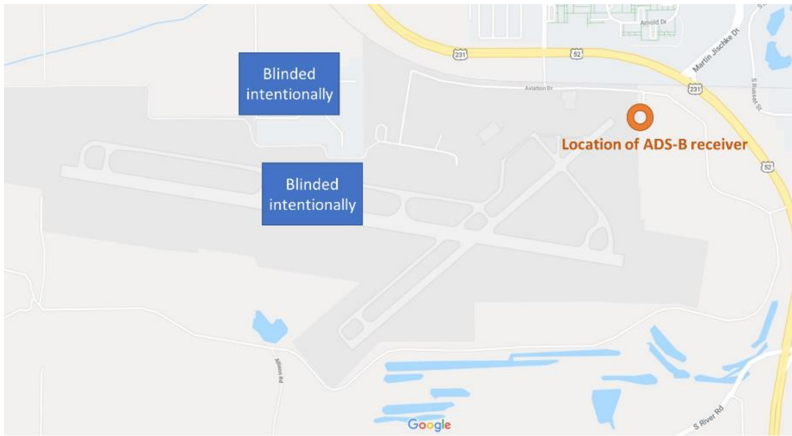

Figure 11. Deployment Location near an Airport.

Conclusion

The ADS-B technology is an advanced air traffic surveillance and traffic situational awareness improvement solution for air traffic controller and pilot. In addition, ADS-B provides a practical platform for developing innovative applications in aviation. An ADS-B build-test-operate project is presented in terms of its connections to two avionics courses and to ABET-ETAC Aeronautical Engineering Technology undergraduate program criteria. The ADS-B project is described in terms of system architecture, data flow, materials and costs. Assembly requires basic electrical skills. Operation considerations are outlined so that this project may be implemented in other ET courses.

The current courses are in Purdue University are part of programs accredited through ABET-ETAC and the FAA. As such, extensive planning is necessary prior to implementation, and includes budget changes and curricular content changes to be documented. The plan is to demonstrate the ADS-B device in Spring 2018 in the 200-level course, and then implement the project in the 300-level course in Spring 2019.

In this paper, ADS-B technology is proposed to be used in an aeronautical engineering technology program. This ADS-B receiver described is only recommended for educational purposes, and not for professional operational purposes such as air traffic control and management. This project is expected to highly stimulate student's interest in avionics courses, extend their knowledge through participating project, practice hands-on skills by building up an actual operational electronic device, and encourage students to continue innovative further research.

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