Collision Avoidance at low cost using ADS-B

Auburn REU on SMART UAVs 2021
Technical Report# CSSE21-02

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June 16, 2021

Abstract

We present the implementation of Automatic Dependent Surveillance-Broadcast (ADS-B) technology on Unmanned Aerial Vehicles (UAVs) for collision avoidance between aircraft at low cost. Currently, the FAA does not require ADS-B on UAVs, but this is likely to be changed with the growing popularity of UAVs. ADS-B is a surveillance technology that is used to broadcast important information about the aircraft using satellite or other sensors. It provides pilots and ground controllers with real-time precision and shared situational awareness. Ground controllers at Auburn Airport cannot accurately count aircraft in their vicinity in a cost-effective way. An ADS- B receiver will be developed to address this problem. It will then be incorporated into the UAVs for aircraft collision avoidance. We will use a software-defined radio receiver to decode ADS-B radio signals into binary bits. Then ADS-B decoder software will be installed on the raspberry pi to extract the ADS-B information. The decoded information will be used to maneuver UAVs without aircraft collision.

1 Introduction

Unmanned Aerial Vehicles (UAVs) refer to aircraft that do not directly have a pilot on board controlling it; also called a drone. Pilots controlling the drone can be several meters away or several thousand. In some implementations, UAVs do not even need a pilot and can fly autonomously. Research in autonomous UAVs has become a major interest in academia and industry. There are many variations of UAVs in size, implementation, and type. The size of UAVs range from group 1 (<20lbs) with speeds of about 115 mph, group 2 and 3 (21-55lbs or <1320) with speeds <287.7 mph, group 4 (>1320 lbs) with operating altitude of <180ft, and group 5 (>1320lbs) with operating altitudes of >180 ft [5]. Some UAVs fly using fixed wings like most aircraft while others use several rotary propeller motors to hover, similar to a helicopter. The use of UAVs has become increasingly popular in recent years particularly in the civilian sector but also in other fields. The cost of UAVs has also become more affordable which has contributed to this increase. Their uses range from monitoring wildlife, conducting geological surveys, to finding missing people. The application of UAVs has already been deployed for military uses and because of their efficiency and enhanced safety, they are now being applied for commercial and private use. Integration of UAVs into the various national airspaces is a major concern particularly with Small Unmanned Aerial Systems (SUAS) [3]. In the US, the Federal Aviation Administration (FAA) has outlined a set of regulations that all aircraft must follow to be

(a) Raspberry Pi 4

(b) RTL-SDR

Figure 1: Raspberry Pi and RTL-SDR dongle

able to fly in the National Airspace System (NAS) but explicitly excludes SUAS. In 2014 the FAA addressed this issue by enacting regulations on hobby-type UAVs between 250 g and 25 kg [3].

The FAA also published an Automatic Dependent Surveillance-Broadcast (ADS-B) requirement in heavy aircraft in 2010 and mandated that all aircraft must have ADS-B Out by 2020 [7]. Due to the massive growth in the number of flight operations and the growing popularity of UAVs in civil applications, it has made it difficult to work with traditional radar systems. Traditional radar systems use radio waves to determine the distance, flight angle of the aircraft which can be limited since it is heavily dependent on line of sight. In other words, radio stations built to a low altitude can have problems accurately detecting every aircraft. Unlike the traditional radar system, ADS-B uses GPS satellites, transmitters, and receivers to broadcast aircraft information. Since the ADS-B messages are broadcasted in the air, traffic can be monitored at low altitudes and on the ground. Furthermore, it is effective in remote areas where radar coverage is limited or no radar coverage at all. ADS-B systems are much cheaper to maintain and deploy than traditional radar systems [7].

ADS-B broadcasts provide real-time situational awareness to air traffic controllers and aircraft pilots. It tracks active aircraft information such as aircraft identification, altitude, speed, and velocity. It comprises two subsystems ADS-B Out and ADS-B In. ADS-B Out transmits ADS-B messages containing aircraft information such as location; which is received from GPS satellites, altitude, speed, etc. to aircraft and ground stations. ADS-B In receives the ADS-B messages from the nearby aircraft transmitting. The benefit of using ADS-B is that it helps aircraft to safely navigate dense airspaces and avoid mid-air collisions [4]. The ADS-B regulation falls under one of the FAA's Next Generation Air Transportation System (NextGen) modernization programs which focus on safer, more efficient, and more predictable flights. The concentration of this program is to develop and deploy innovative and transformative technologies to improve safety, efficiency, environmental performance, and passenger experience even in busy airspace [1]. Regulation of UAVs and SUAS is likely to grow as popularity continues to rise.

This paper focuses on the design and implementation of an ADS-B receiver to count the number of aircraft flying near Auburn airport and the incorporation of the receiver into UAVs for collision avoidance. A computing device known as a raspberry pi and a USB software-defined radio (SDR), both available at low cost, will be used to pick up radio signals from the air. ADS-B decoding software such as Dump1090 will then be used in conjunction with the SDR to decode ADS-B packets. The ADS-B decoding software will then be modified to include a function that will accurately track all take-offs, landings, and overflights. The receiver will be used in UAVs to get the aircraft information in its proximity. The UAV's autonomous flying software will be installed and Closed Loop Rapidly-exploring Random Tree (CL-RRT), a collision avoidance algorithm, will be implemented and modified according to the received data from the ADS-B receiver. The rest of the paper consists of problem description, related works, algorithm description, implementation, and conclusion.

2 Problem Description

For our research problem, we wish to address two issues that build upon each other. Firstly, Auburn Airport is unable to accurately count all aircraft in its vicinity. Auburn Airport uses educated guesses to estimate the number of aircraft taking off, landing, and passing through. Current software and hardware that can count aircraft accurately exists but is expensive which makes it cost-ineffective to buy/rent the equipment that allows for proper tracking of aircraft. Secondly, because of the FAA requirement of ADS-B Out in all aircraft we see a viable way to implement UAV aircraft collision avoidance using this technology along with existing collision avoidance algorithms.

3 Related Works

We will discuss some previous research applicable to our project that range from using ADS-B radar systems to using path planning algorithms.

I.Camera-based approaches have been proposed but are usually limited by long navigation distance and weather. One study discusses the usage of ADS-B not only for situational awareness and also using the physical broadcast itself as a radar pulse [6]. In this way, ADS-B can be used as radar for collision avoidance and would be effective with all air traffic and in all weather. A standard ADS-B transponder was used which broadcasted from a UAV every second through an omnidirectional antenna. The broadcasted ADS-B radio signal was then reflected by the UAV which had 4 directional antennas mounted. Detection of the obstacles and their distances could be achieved by comparing amplitudes and angles-of-arrival phases of the signals received by each of 4 individual antennas. For this method to be effective, a lookup table must be created by simulation and/or lab measurements to accurately estimate distances and angles (0 degrees being the front of UAV). A problem found with this method though is that it is generally assumed that the target is detected in the direction of the main beam(max gain), but if the UAV tilts then the main beam may not point toward the target which results in an angle-of-arrival estimation error. It was found that a UAV tilt(bank) of +/- 15 degrees resulted in an acceptable error, but anything outside of this caused inaccurate obstacle estimations. Patch antennas were used instead of horn antennas because they were lighter and smaller, but the antenna patterns had to be known beforehand. In the experiment, a standalone ADS-B radar transceiver was constructed and was tested without the UAV. ADS-B broadcasts were transmitted and reflected with different signal power from targets at different distances. They found that when the target was within 2km there was a high chance of detection and a low chance of false alarm. Past 2km detection probability is 90% and false alarm probability is high at 40%. This issue can be mitigated by increasing the transmitted power but this would require larger, heavier, and more expensive amplifiers [6] which would not be practical in our application.

The implementation in this report solely discusses how to detect but not how to autonomously avoid obstacles/aircraft which is what we wish to achieve. Also as discussed in the introduction, as the NAS continues to experience increased aircraft activity radar systems may not be optimal. Nonetheless, this implementation can likely be adopted into approaches similar to ours where once an obstacle is detected by a running algorithm uses this information to avoid the collision.

II.One such example is a research paper in which incoming aircraft is autonomously avoided using an algorithm known as Closed Loop Rapidly Exploring Random Tree (CL-RRT) [2]. In this paper aircraft collision avoidance is defined as a path planning problem where a collision-free path is generated connecting all waypoints that costs the shortest length given some initial state. The path must also maintain some certain given horizontal and vertical distance from other aircraft. Closed-loop dynamics are used with a low-level controller that takes two inputs. It takes a reference command r = (x,y,z) which is the desired UAV location in 3D space and the UAVs current state x = (x,y,z, speed, yaw, pitch); a state is defined as some 3D space coordinates, speed, yaw, pitch. The controller then outputs a control u which controls and adjusts the UAVs motors' speed which maneuvers it to the next state. The controller uses the CL-RRT algorithm to run a forward simulation to predict the next possible states and then checks each against the constraints (i.e. horizontal/vertical distance from aircraft). The algorithm essentially predicts a path using closed-loop dynamics by generating random waypoints for some time interval, predicting a path from the waypoint to the start location, and checking to see if constraints are satisfied. If satisfied, temporarily add the waypoints as child nodes with the start node as the parent. At the end of the time interval, the temporary child node with the shortest length is added to the tree. In this manner, rapid tree expansion occurs which eventually yields a collision-free path to the goal location. For the experiment, real ADS-B data was collected and used in a simulated environment to test the CL-RRT algorithm. The UAV and the controller hardware ran the same in the simulation as they would in real flight[7]. More than 80 runs were conducted with various aircraft approaching the UAV from different angles and only 5 failed the given constraints of 50m vertical distance and 300m horizontal distance from all other aircraft. Of the runs that failed none resulted in a collision and were fairly close to the constraint boundaries.

In this report, we see that it is viable to use the CL-RRT algorithm to autonomously avoid collisions and approach collision avoidance as a path-finding problem. In our application, we continue this work by physically realizing the use of the CL-RRT algorithm for collision avoidance with a physical UAV. Another feasible implementation for autonomous collision avoidance could be a combination of the transceiver used in the previous report that used ADS-B as radar and the CL-RRT algorithm. The transceiver could be used to detect obstacles and provide this data to the CL-RRT algorithm which would then adjust the UAVs path to avoid the collision. However, in our implementation, we want to achieve autonomous collision avoidance of other aircraft at low cost, so we instead choose to use the ADS-B broadcasted data in conjunction with CL-RRT.

III.While the popularity of UAVs has grown tremendously in recent years, it has also increased the threat of collisions among manned aircraft and UAVs at low altitudes. A Conflict Detection and Resolution (CD&R) system was developed and implemented on both manned aircraft and UAVs to address this problem. A Quasi ADS-B transceiver was designed and implemented based on existing ADS-B technology to transmit and receive flight information. The main purpose of this research was to develop a Quasi ADS-B transceiver in the CD&R context for General Aviation(GA) such as private aircraft and UAVs. The transceiver used 900MHz -XBee pro as a data transponder to broadcast flight information. It was used to broadcast and receive data packets, using standard ADS-B Compact Position Reporting (CPR) format, from its vicinity aircraft. In this research, UAVs were treated as moving objects such that they were not part of the flight control system. UAVs were considered a higher priority than manned aircraft so that all manned aircraft avoided collision with UAVs.

The 900 MHz radio station was used which followed the same CPR format as ADS-B. The Quasi ADS-B transceiver architecture was designed based on the Time Division Multiple Success (TDMA) mechanisms. Both manned aircraft and UAVs were equipped with ADS-B Out transmitters whereas only manned aircraft had ADS-B In receivers with situational awareness displays. ADS-B Out data output cycle ran every second and this cycle consisted of two sub-parts: 1) slot sorting section 2) the transmission cycle. The slot sorting section included sending a slot message which contained aircraft ID and slot number. In case of conflict of data, an automatic slot change mechanism with ID priority would be activated. In the transmission cycle, the data was transmitted for UAVs which included coordinates of the current position and next waypoint. Both data packets were broadcasted in a 50 ms slot by ID sequencing. During broadcasting, the data would be converted into binary bits by CPR and the higher-order bits would be used for the position of the aircraft.

After the transceivers were designed, they were incorporated in two ultralight aircraft to check the capability of flight data transmission. The manned aircraft was used to detect and avoid collisions whereas the UAV was used to simply fly from one waypoint to another. During the flight operation, the manned aircraft was able to detect the flight activities and intruders in its proximity and was able to sense the intrusion. It was able to detect any aircraft within 3 Km of it by using a CD&R algorithm. Two CD&R algorithms were adopted to validate the transponder performance of the transceiver in a real flight test: (1) Probabilistic Grid Detection (PGD) (2) Time and Sector Recognition (TSR). The PGD algorithm was used to detect the flight path for multiple aircraft based on the probability of the aircraft reaching the same sector at the same time. This algorithm would create the grid for each second based on predicted coordinates in a certain time interval using the Gaussian Function. The conflict prediction between the aircraft was estimated using the probability grid. TSR algorithm was used to generate the sector-shaped flight path in the tangential direction. TSR would trigger if PGD crossed the given threshold or the intruder was within a kilometer range from the aircraft.

During the experiment, the transceiver collected the UAV and GPS satellite data and this data was used in the CD&R algorithm for simulation and function verification. While the flight test experiment was carried out, it was hard to locate the crashed UAVs so, an additional function was added to detect the location of those crashed UAVs. As a result, this application was also used for search and rescue programs for injured mountain hikers. Most of the related works discussed in this paper shares a common idea of using existing ADS-B technology with some collision avoidance algorithm. In our research, we will use the ADS-B broadcasts as an input for our collision avoidance algorithm as well. In the previously discussed research papers (II and III), both used the collected data from the transceiver for simulation. However, in our experiment, we will be implementing live ADS-B data in conjunction with the CL-RRT algorithm on UAVs for collision avoidance.

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