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Aviation Accident Rescue Operation Enhancement by Geo-Tagging Pilot Communication

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ABSTRACT

Keywords: *Air accident, Communication, Geo-Tagging*

Knowledge of an airplane's last position and trajectory is of the utmost importance for search and rescue in aviation today. In case of an accident, this information is necessary for rapid response.

The existing method of reporting the whereabouts depends on pilot reports during flight or signals from special equipment such as emergency location transmission. Future renovation to the ATC system has been planned, requiring the installation of ADS-B. However, it will take some time to implement such systems in all airplanes and provide the necessary infrastructure. This paper proposes Geo-tagging the pilot communication using the CDMA method. It is an intermediate yet inexpensive solution for worldwide application in aviation, which can be implemented quickly. It takes advantage of the existing equipment both in the air as well as on the ground. The simulations presented show the applicability and efficiency of the proposed routine.

Nomenclature

ACARS	Communications Addressing and Reporting System
ADS – B	Automatic Dependent Surveillance-Broadcasting
ATC	Air Traffic Control
ATS	Air Traffic System
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
CDMA	Code Division Multiple Access
CRC	Cyclic Redundancy Check
ELT	Emergency Locator Transmitter
EuroControl	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FSPL	free-space path loss
GA	General Aviation
GAMA	General Aviation Manufacturers Association
GNSS	Global Communication, Navigation, and Surveillance System
GPS	Global Positioning System
HF	High Frequency
ICAO	Internal Civil Aviation Organization
MHz	Mega Hertz
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
PPS	Precise Positioning Service
SESAR	Single European Sky Air Traffic Management Research
SPS	Standard Positioning System
SSB AM	Single Side Band Amplitude Modulation
VHF	Very High Frequency
TDMA	Time Division Multiple Access

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Introduction

Ever since its invention by Wright Brothers in 1903, human life has been significantly impacted by airplane. Air transportation is now an unbreakable part of our daily life. Every day millions of people are taken into the air for business trips, vacations, or many other purposes. Aviation has been expanding due to the demand for air transport, and the number of airplanes has been steadily growing. Over 2000 airlines operate worldwide with over 23000 airplanes [1], and 1,207,873 GA airplanes have been registered from 1983 to 2021in Canada and North America alone [2].

In case of an accident, the knowledge of the airplane's last position can help the search and rescue operation. A transponder is installed in the airplane, which interacts with active ATC radar for the aeroplanes deployed in scheduled flights. In an emergency, the pilot enters a code called Squawk 7700, which helps the air traffic controller follow the airplane on its radar screen [3]. In a related matter, ICAO mandates the ATS to prepare an emergency response checklist which should include the reported last position as well as the method this position was determined" [4].

Chapter 10 of the FAA Emergency Assistance document necessitates determining the time and place of an air accident's last known position and airspeed [5].

Changing from ground-based tracking to combined ground and space tracking through elaborate projects in the United States [6], Europe [7], and Australia [8] are long-term objectives. In lieu of this modernization, there is a low-cost near-term solution, namely, the Geo-tagging pilot communication. Since pilots frequently call ATC to inform them of their status or receive directions for their next maneuver, Geo-tagging automatically records the airplane position.

In order to clarify the proposed method, this paper first reviews airplane radio frequencies used for communicating with ground stations. The discussion continues with the airplane accident location problem in aviation. It then focuses on Geo-tagging pilot communication as an intermediate solution, especially for worldwide applications where elaborate solutions are not possible for at least the near future. The data transmitted via analog channels could be affected by several factors, including fading and interference from other pilots making calls to ATC, which can affect the decoding of recorded position data. A simulation was performed and presented in the paper to analyze the behavior of the communication link in this environment and check the integrity of the received data in the control center. Finally, the results are presented and discussed.

Airplane Communication

When an airplane departs from an airport, wireless communication becomes an essential part of the flight and gives the pilot the ability to be aware of events happening in his environment. In his analysis of the cockpit environment [9], Jeremy Cox points to three functions in today's modern aviation; Aviate, Navigate, and Communicate. Through communicating with ATC, the pilot receives information on the traffic and weather condition in the flight path and any irregularities, such as atmospheric turbulence, and gives the controllers his/her commands. In addition, listening to other pilots makes it possible for them to plan better.

Today there are two modes of communication; digital and analog. Digital communication can be via satellites. For analog communication in aviation, three frequency band has been used; the VHF band, 30 – 300 MHz and 118 – 136.975 have been used since the Second World War. The other analog frequency band is HF, between 2.31 to 25.82 MHz which is used for long-distance communication since the ionosphere reflects it and the signal can travel several thousand kilometers [10].

Modern commercial airplanes such as Airbus A380 [11] take advantage of both digital and analog communication systems. All GA airplanes are equipped with analog VHF communication [12]. The HF is used for long-distance flights and flights over oceans.

Airplane accident location

Based on the statistics provided by Hugh Morris, "Between 1948 and 2014, 85 airplanes have vanished without a trace, according to the Aviation Safety Network. Of those, 26 were passenger jets; 59 were lost at sea, while 26 went missing over land." [13]

During 2009-2014, the following four accidents occurred in commercial transportation:

1- Air France flight 447 (2009)
2- Malaysia Airline Flight 370 (2014)

3- Air Algeria fight 5017 (2014)
4- Indonesia Air Asia flight 8501 (2014)
ELT, which transmits specific signals, is one way of determining where an airplane has crashed. It is activated upon impact or by the pilot after landing if equipped with a pilot activation key [14]. The ADF system receives the signal from ELT on a rescue airplane or helicopter at 121.7 MHz frequency. More recent ELT used 403 MHz frequency which can be detected by specific satellites. It should be noted that not all ELT systems always work properly. In a study by NASA, several ELTs were used in a Cessna airplane crash test, and the result showed that some of the systems did not work properly [15].
ADS-B is another device proposed by FAA in the NextGen program. NextGen is a new national airspace system for the United States and is to transform the ATC from a ground-based system to a satellite-based system from 2012 to 2025. This change would use GPS to reduce airline time and fuel consumption and enhance safety and capacity. The NextGen has been explained fully by FAA [3]. Konyak et al. [16] point to its advantages and makes a comparison between the NextGen and Single European Sky SESAR Program initiated by EUROCONTROL. In ADS – B, GPS data on the airplane position is known, and the data is fed into the airplane transponder, which would then enable the Air Traffic Controller as well as other pilots to be aware of its position and keep the airplanes well separated [12]. In this regard, Fritz [17] discusses the FAA mandate on ADS-B. Furthermore, he reviews the current positioning methods and compares the PPS, GPS, and SPS. Based on the accuracy required for position, velocity, integrity, design assurance, and source integrity level, he discusses the ADS-B requirement for broadcasting signals. According to GAMA, approximately 28,810 U.S.-registered airplanes were equipped in compliance with the ADS-B rule by the end of 2016 [18].
The aviation accidents prompted ICAO to form a task force and set a deadline of 2018 for implementing some tracking methods. The result of this task force was presented in the “ICAO working paper” [19]. Article 2 of this paper mandates regular and automatic transmission of airplane position in a 4D (Lon., Lat., Alt., and Time) format. Several companies, including Fokker [20], devised specific instruments to be installed in airplanes for this purpose. The instrument would collect GPS data and would transmit them automatically to a communication satellite, such as Inmarsat. On the other hand, Article 4 of the working group paper suggests sending GNSS data via a communication network. The present paper proposes Geo-tagging pilot communication based on this article.

Geo-tagging pilot communication

There are five pieces of information that are essential for precise position fixing as well as trajectory determination. These include the airplane designation, which is usually a fixed set of characters, latitude, longitude, altitude, and ground speed, which can be extracted from the GPS data stream. When this data is added to the voice communication using an appropriate method (that will be discussed later) it can be transmitted via the VHF voice communication to the ground control and recorded using the existing equipment. Minimizing the number of digits used for this purpose avoids distortion of voice communication. The problem of data transmission on a multi-accessed voice channel can be resolved using CDMA. In this technique, several transmitters can send information simultaneously over a single communication channel. This will enable different users to have access to the channel and share its bandwidth. Taking advantage of spread–spectrum technology, the airplane designation can be used as the user code. It should be noted that the incorporation of data into voice transmission has been proposed before. Howland [21] proposes digital communication using VHF and proposes digitizing voice and combining it with data for transmission. However, it should be pointed out that the scheme presented in this paper does not require the change of present ATC analog communication which would require an equipment burden on the control centers. Yet, adding Geo-tag data to the current signal in the cockpit, and recovering it when necessary, requires processing ATC tapes using the available advanced voice processing techniques. In addition, one can point to the paper by Matolak [22], which comments on CDMA for Aeronautical Communication and makes a comparison between TDMA and CDMA. He presents diagrams for the implementation of CDMA in both transmitter and receiver and points to the difference between aeronautical and cellular communication.

Idea and Method Description

Air-to-ground communication of airplanes is possible via a different medium. All the airplanes are equipped with radio systems for air-to-ground communication. Radio communication is possible in VHF and HF frequency bands. The bandwidth and frequency are regulated by ICAO for the aviation industry. Communication is mandatory for all airplanes. Radio communication is necessary from the beginning of takeoff to the end of landing.

As proposed earlier, radio communication is tagged by geographical data in order to trace the airplane. In order to Geo-tag a radio communication, Geo-data shall be added to the analog data signal. The Geo-tag data is obtained from a GPS massage which consists of longitude, latitude, altitude, and time; therefore 30 bytes of the data packet. For the assessment of the proposed method, the following should be evaluated separately.

- Procedure
- Validity
- Possibility

The proposed method will be described later. For assessment of the validity of the method, a simulation is performed to show a Geo-tagged radio communication with a fixed GPS sentence. Radio noise and interference by other radio communications are the main sources which can affect radio communication. In the simulation, 10 other users of the radio communication are simulated to affect the main communication. A 20-second of radio communication is tagged with a data massage in the presence of a variety of interferences in the simulation. Simulations show the coded and decoded data and compare them to assess the validity of geo-tagging data with radio communication.

For assessment of the possibility of the proposed method, a spectrum of a radio signal is shown for different distances. An illustration shows the possibility of receiving radio signals over long distances in order to be sure about radio communication coverage. Knowing frequency, transceiver power, and receiver gain, a signal power-distance scatter is shown, which presents the maximum distance the signal is successfully captured.

First, the procedure of Geo-tagging will be described. The process of Geo-tagging is automatic and triggered with the talk button on the radio. Whenever the pilot pushes the talk button, a data packet of 30 bytes will be transmitted first. Then the communication of the pilot will be established. To be sure about the accuracy and validity of the data packet, the packet will be transmitted twice. One of the packets is transmitted at the beginning of communication, and the other packet is transmitted at the end of communication. The first is triggered by the push button press and the last is activated by the push button release.

The radio system used by airplanes uses an SSB AM modulator. The transmitted signal is an analog signal which is not very suitable to be used as a digital data transmission medium. The data packet here is converted to analog data in amplitude threshold separation.

The radio communication received in the ground station will be separated into three parts. The first part is the Geo-tagged communication. The second part is the communication itself, and the last part is the echo of the Geo-tag, which will be used as a check phrase for the first part. The check phrase will be utilized as a validity bit for the tagged data to be considered as a data packet. Fig. 1 shows the flow chart for Geo-tagging.

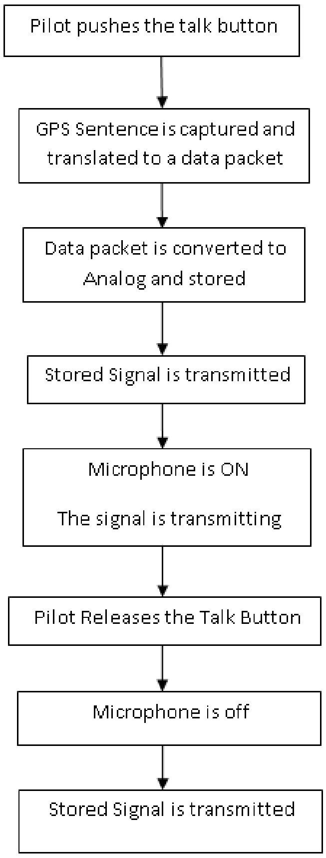


Fig. 1 The algorithm flow chart.

The GPS sentence is captured as the pilot pushes the talk button. In the GPS sentence, there are standard data, such as satellite signals, time, validity, etc. The required data, which is considered as position vector and velocity vector in the presented method, is extracted and packetized in a standard frame which obviously has CRC or Checksum value. The packet, which is assumed to be 30 bytes in length, shall be converted to an analog signal. As the radio system used in airplanes is an amplitude modulator, the amplitude range is divided into two ranges; the upper half for bit 1, and the lower range for bit 0. The binary value of the packet is converted to an analog signal considering each bit as a data sample.

Validity of Method

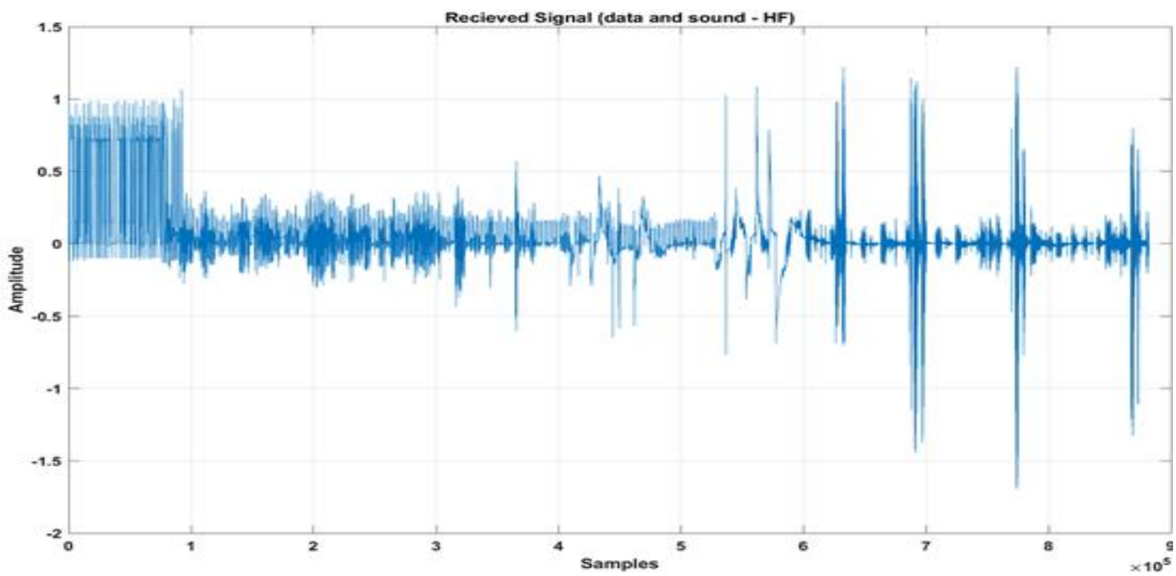
To be sure about the accuracy, availability and validity of the proposed method, a simulation is performed. The simulation aims to check whether a data packet will be transmitted, received and translated correctly during radio communication. To check this, communication between an airplane and a ground station is considered. VHF (13.92 MHz frequency) and HF (2.35 MHz frequency) are used for radio communication. An ordinary radio system with SSM AM modulator has 30 Watts of power. In the simulation, a free space loss is considered for 25 kilometers as assumed and calculated by the formula (1) [23].

$$FSPL(db) = 20\log_{10}(f\ ) + 20\log_{10}(\mathrm{d}) + 32.45 \text{ dB} \quad (1)$$

where the frequency is measured in units of MHz, and distance is measured in units of kilometers.

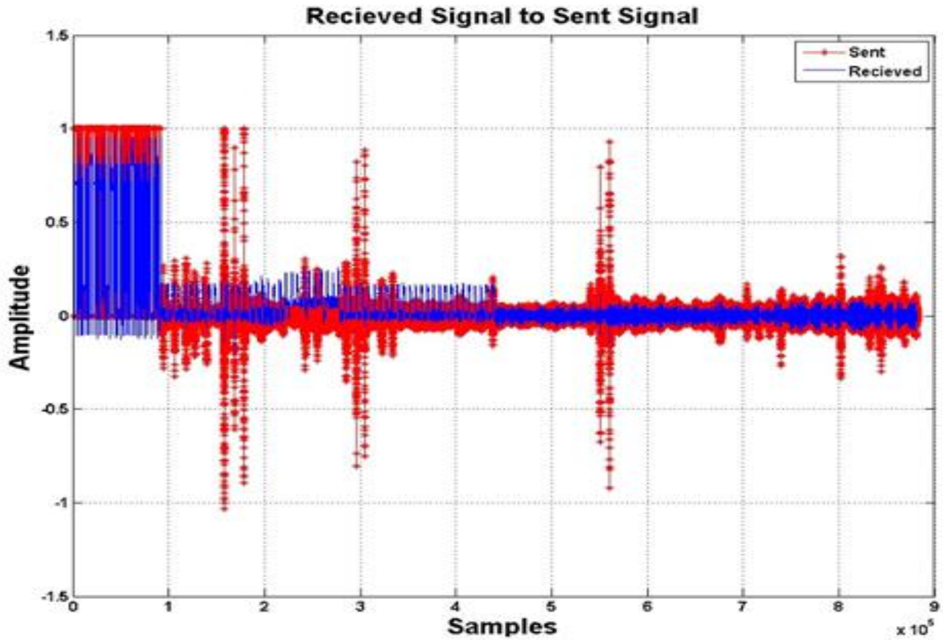
Gaussian noise and pilot sound echo are considered as disturbances in the pilot transmission. To be more realistic, three other airplanes are considered to be the sources of colored noise for communication. On the other hand, seven other airplanes are considered to cause radio interference for the main radio signal. To sum up, 10 sources of radio noise, pilot echo and Gaussian noise are added to the pilot communication. Communication of 20 seconds in length with a fixed data sentence is simulated in the presence of all the noises and interferences. The data sentence is first added to the source signal, transmitted in the presence of noises and interferences, received, amplified and decoded. The results of the simulations are shown in Figs. 2, 3, and 4. Fig. 2. shows the received signal in the receiver. Fig. 2.a. is in the VHF band, and Fig. 2.b. is in the HF band. As is obvious in the figure, the duration of the data message is very short and high in amplitude. Although the amplitude of the data message is high, the short duration minimizes the harm to the person who is listening to the sound. It can be seen in the figure that the noise interferences are in the form of sharp edges on the signal.

(a)

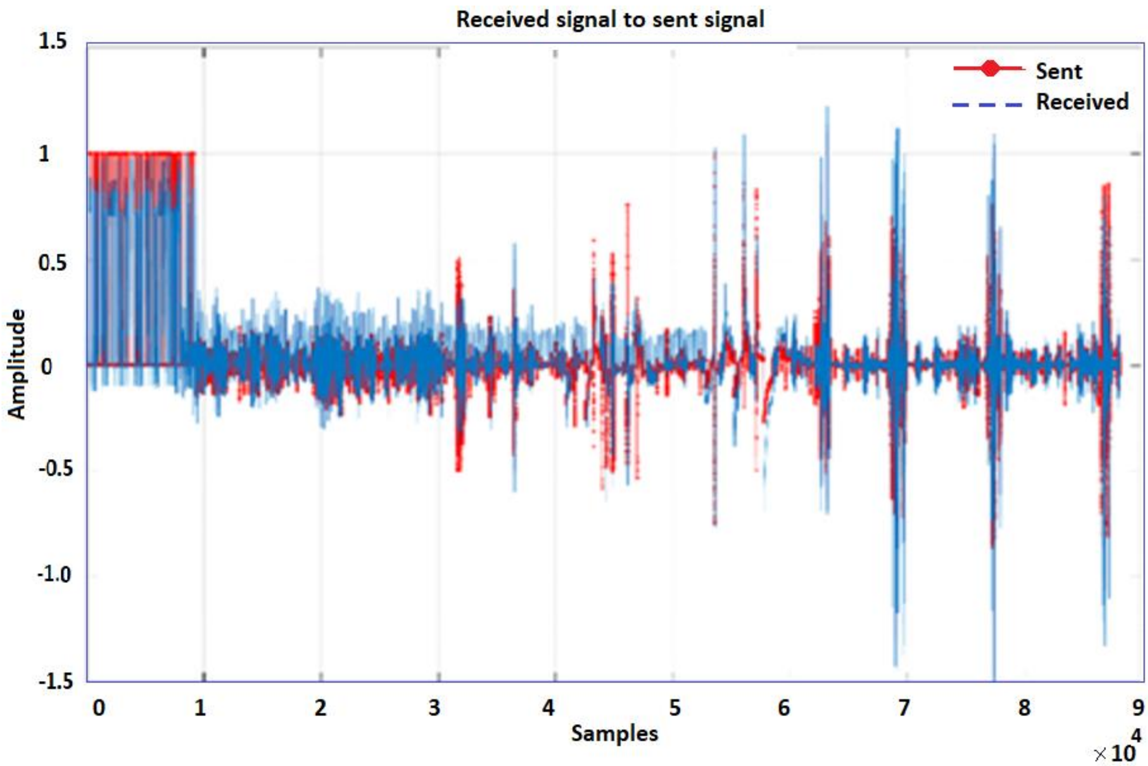


(b)

Fig. 2. Received signal, which includes data and sound.



(a)

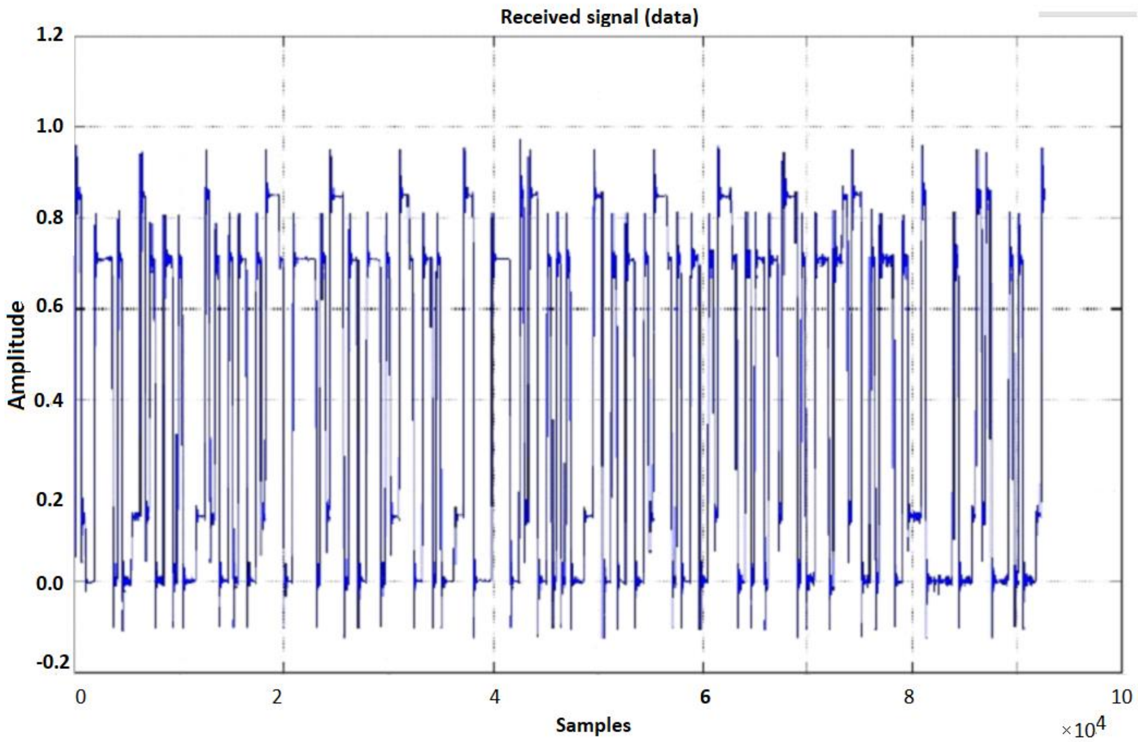


(b)

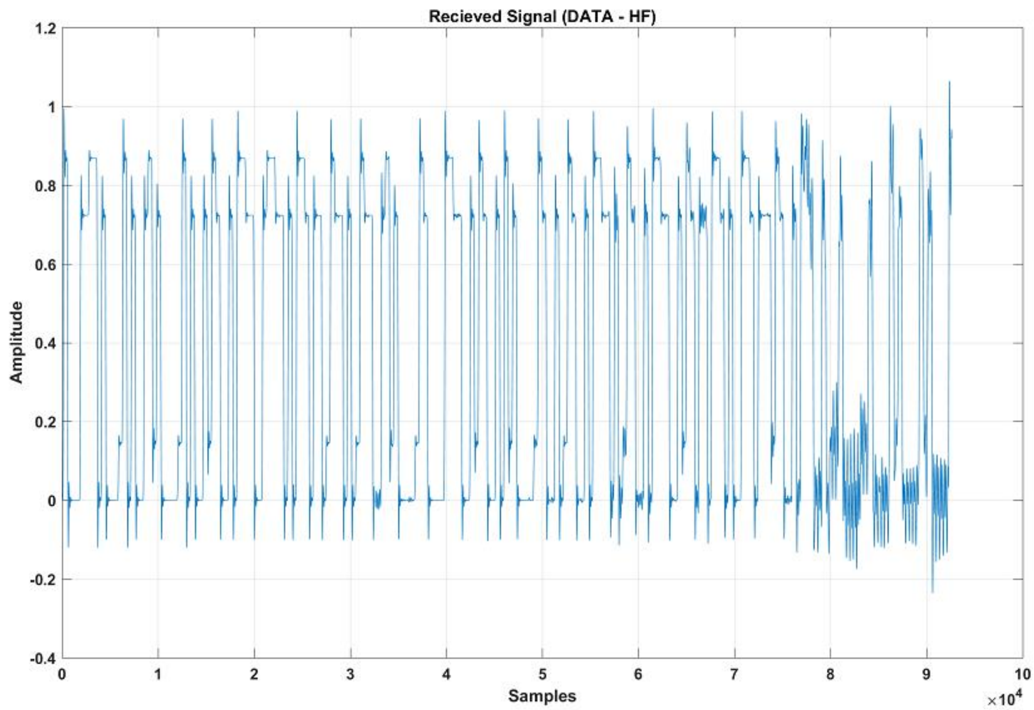
Fig. 3. Received signal with added noise from other sources.

Fig. 3 shows the sent and received signals in a plot. fig-3a shows the simulation in the VHF band, and Fig-3b shows the HF band. It is obvious that we have a slight loss in sound quality, but still, the quality is suitable for passive voice.

Fig. 4 displays the Geo-tagging data extracted from the received signal.



(a)



(b)

Fig. 4. Data signal extracted from received noisy signal.

Figure 2 shows the signal received in the ground station. This entire signal would be recorded in the ground station. Whenever the need arises for a search and rescue operation, the signal would be processed, and the Geo-tagged data extracted for the position of the airplane during the last contacts.

If the entire signal was to be heard, this would result in an annoying sound from the data part. However, the data part would be filtered by the receiver in the ground station during the routine communication with pilots.

In Figure 3, the same signal is presented. However, interference by other transmitters is added in the form of noise in the free-space medium. Free space path loss is also added. The data packet is extracted from this noisy signal and presented in Figure 4. As it is obvious, the noise of nearby airplanes and noises from the airplane itself cannot destroy the data packet, and it can be recovered with the minimum bit loss.

Range calculation

In order to check the possibility of receiving the radio signal of an airplane, a range of telecommunication is considered. The range is approximately calculated by the formula (2) [24].

$$Range = 1.23\sqrt{h} \qquad (2)$$

The range is calculated in Nautical Miles, while h is the height of flight in feet. Fig. 5 shows the range in kilometers.

The usual flight altitude for airplane during the cruise phase is about 20000 to 36000 feet. As it is highlighted in the figure, in this phase, the range of radio communication is between 320 to 500 kilometers.

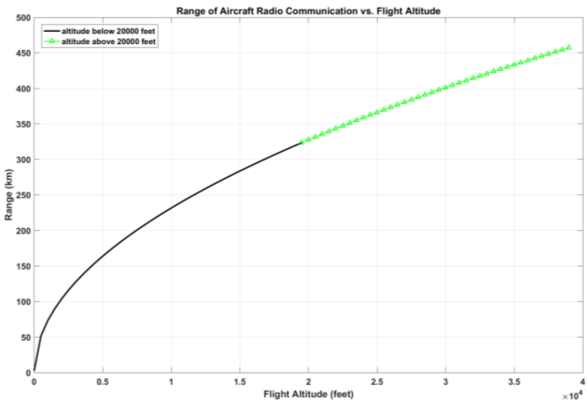


Fig. 5. Airplane radio communication range.

According to ICAO, air traffic controllers can manage air traffic within a radius of 190 km. This shows that it is highly possible that radio communication can reach ATCs safely.

Conclusion

It is essential to know the position and trajectory of the airplane during all phases of flight. This can help aviation authorities to make a safer transportation system and help the passenger and crew in case of an accident. Many developed countries have prepared and started implementing more modern systems for airspace control and communication. However, worldwide implementation requires great resources and will take some time. On the other hand, there are wide bodies of water which are not covered by any specific country and tracking an airplane over international waters will still be a problem. This paper suggests Geo-tagging current pilot communication and fast processing of recorded information to extract specific data in the control center to help track a suspected flight accident. It is obvious that processing the voice communication for Geo-Tagging data is not required on a regular basis which causes undue cost burden on ATC.

However, it should be mentioned that the drawback of this method is that it depends on the pilot communicating with ground controllers. In this case, no communication means no position fixing would be available. Since pilots always make distress calls in case of an accident, Geo-tagging can definitely help fix the last position of the contact.

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