BEng Aerospace Project

Interim Report

Identifying the position of small airborne vehicle by using radio technology

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# Introduction, aims and objectives

## Introduction

Radio positioning is an ancient method for navigation compared to state of art global navigation satellite system (GNSS). However, in the past 2 hundred years of aviation, radio was proven a reliable way achieving navigation. Meanwhile, radio navigation is continuously evolving itself to meet contemporary requirements of modern aviation, and it is playing a more important role as one of the alternative methods when GNSS is malfunction. This project focus on a compatible solution bridging the VOR (Very High Frequency Omnidirectional Range)/TACAN (Tactical Air Navigation) like system and GNSS system. In this study, VOR-like signal will be implemented at a GNSS signal frequency, which is generated by using MATLAB and Simulink. During the project, two different implementations will be examined in the further stages of study, which involved some lab works.

In the meantime, theories of two implementations are roughly developed. First evaluation will exam the phase modulation on a simulated GPS signal. And second evaluation will testify an alerted higher frequency VOR-like signal and transmit it in the different time with simulated GPS signal.

The final test will be carried out with a fixed transmitter and a receiver installed on a moving vehicle.

## Aims

This project aims to achieve a prototype standalone navigation system by using radio.

## Objectives

1.The principle of the navigation theory related to combination of time and known position should be proved by using MATLAB

2.The algorithm of solving equation of time and location difference should be explored and examined with MATLAB

3.Ground station signal including time and location source should be determined

4.The system receiver prototype can be implemented into real time system or relevant simulation environment

5.The deliverable / prototype system shall include real hardware where possible, which may include creation of a PCB for both the drone and ground station

6.The produced system will be subject to a field test

7.Target Requirement: to obtain the flying speed of the aircraft

8.Target Requirement: to achieve the accuracy of 100m

9.Target Requirement: coverage range of 1km minimum

# Literature review work progress to date

The history of radio navigation can be traced back to late 19th century before the first world war(Bauss, 1963), and before people started using radio, they had already used compass and stars for thousands years. However, the radio is a game changer which overcame major difficulty of the old navigation method.() In the past century, mankind has developed it from analogue to digital, from ground to space, from inaccurate to accurate, from immobile to portable, from specialized to daily uses.

The first ever radio relative system was radio direction finder, which is tuned to the certain station’s frequency and then using antenna to point at the direction. Then it can determine the bearing of the station, which enable aircraft or ships drive towards the station. By listening two stations, the captains and pilots are able to draw an intersection of two radio station on the map and determine its own position. However, it requires a rather long antenna to provide better angle information, which is not practical for small aircraft. In later development, ADF was a great progress, which benefits from modern electronics such as transistor. It works with NDB which stands for non-directional beacon. It uses phase comparison technic to determine the bearing of the aircraft (Watson & Wright, 1971). However, the accuracy of the system is critical issue for the uses of modern aviation and not suitable for small scale aircraft due to its huge antenna size.

VOR was a significant evolution from ADF and NDB, and it features better accuracy and a voice channel, which is used to identify the station. It consists of 3 parts, the first one is the voice, and the second is a continuous signal transmitted from the omnidirectional antenna as the reference signal and the third is a signal rotating at 30Hz and the signal was changed in phase corresponding to the direction it faced (LAMB, 1948). By comparing the difference of the phases from two received signal, a bearing can be worked out easily. It has an advanced version named TACAN, which implies higher frequency and more division of phases. Its principle

Due to the limitation of this project, the study does not include hyperbolic navigation system due to the performance and size issue. Since the most hyperbolic system worked at low frequency in trade of wide coverage, their precision is much lower than the required specification of this project and meantime, they require a long antenna to work.

Beam system, for example, the Adcock by Macaroni known as LFR (Low Frequency Range) is also a good idea of navigation (Beck, 1971), however, it uses a beam to navigate the object facing the beam direction, and it requires that the object remain in the coverage of the beam. Therefore, considering the project is to know a position of aircrafts, the Adcock system has little value in it. Though, it was used as ILS (Instrumental Landing System) equipment in old days, it was fully manual operative by listening to Morse code. It has same sort of inspiration of using radio, whereas, it can only show directions when the object is in the covered range, which in another word, directional. Thus It has limits of the uses for a general purpose navigation.

GPS is the best system in term of both precision and feasibility (Staff, 1900). It remains the most popular choice for navigation since it was operated. Meanwhile, there were many system, as mentioned above, dying or died because of widely usage of GPS. GPS was the system designed and operated by USAF (United State Air Force), and its huge military potential was well recognized by US military, therefore, the system had two different ranging mode for civil uses and military uses at the beginning. The civil code, however, is less accurate compared with military code. It works with simple logic, by using trigonometry. GPS system has multiple satellites on low earth orbits, which were well designed, to guarantee that at the most surface area of earth, there will be at least 4 satellite can be found above the sky. It was so well designed that in most time, there were actually more than 4, which provides a potential opportunity to increase the accuracy. The algorithm relays on 3 known satellite position and signal’s time of arrival. An extra satellite is needed for time reference in case of wave propagation error. By knowing the time taken during the propagation, the distance can be worked out, then combine three of worked out distance, a matrix can be introduced to provide multiple solutions, whereas only one of them is the correct positon. Furthermore, the result need to be transfer from polar form into panel form and should be projected on the map with coordinates provided.

Pseudolites application implies simulating satellite signal with a ground or aerial station, which can be deployed to GPS’ blind zone (Wang, 2002). It has a huge potential in warfare or special circumstance like mining or cave exploring where GPS signal may not viable. Therefore, it is a good object to study for this project. It has a potential to be compatible with current system and adapt to new environment. This is will be the major direction of this project.

Software Defined Radio is a new way of planting and testing the design, which required individual transmitter or receiver in the past (Seo et al., 2011). SDR (software defined radio) can be operated easily by using MATLAB and Simulink for signal generating and receiving (Lo, Enge, & Narins, 2015). A cheap SDR kit can be found in market with price of £20 with relatively good performance. RTL-SDR is a SDR receiver works from 24 MHz to 1766 MHz, which is great for the uses of this study. This project requires the signal working at GPS frequency, which is 1.5Ghz roughly.

To know the bearing of the vehicle is not enough to determine the specific position of it, thus a distance from station and object is crucial for the navigation (Lo & Enge, 2012). A DME(Distance Measuring Equipment) is capable for this, however, it has a capacity. To explore the improving oppturnity, Pseudolites technic can be adapt to the situation, where the bearing and angle is obtained by radio, and distance is determined by Pseudolites.

# Current status of the work

* Review of previous systems mentioned above.

Radio navigation was evolved from analogue to digital, and GNSS shows its dominance for the navigation industry. Nowadays, previously deployed system such as Loran-C, NDB, Omega, etc. were discontinued and replaced by GNSS navigation. However, VOR/TACAN remained their necessity for modern aviation, though they are not capable with the newly booming trend of aviation, drones.

The main reasons for developing VOR to further stage to offer navigation to drones were considered as follow:

The drones are unmanned vehicle, their movements are highly relaying on the navigation system on board. Due to safety concern, currently most drones have to follow visual flying rule, which means they cannot operate outside drone pilots’ eyesight, even with GPS equipped. Despite the regulation, the reliability of GPS is a potential failure point of self-driving drones. Therefore, multiple solutions are worked out in the past few years, regarding computer vision, inertia navigation and so on. Thus, alternative navigation should be maintained during the flight and another good solution is to improve VOR.

A potential solution as purposed in this project, is to operate VOR at GNSS frequency, and transmit both Pseudolites and VOR-like signal at GNSS frequency to increase system reliability and compatibility.

* Research the RLT-SDR to analyse GPS signal and VOR signal

RTL-SDR is a good tool to obtain the GPS signal and also VOR signal. Whereas the VOR usually only deployed near airport, which made it hard to obtain at this stage. It is important to study this tool to deal with upcoming tasks.

* Understanding VOR

VOR is a short range radio navigation for aircraft which operates from 108 – 118 MHz range. ()It has three components in its signal. Voice, Morse code and 30Hz signal with angle shifted. However, in this study, the voice and Morse code are omitted because they are irrelevant. The left component is 30Hz signal, which is modulated into the carrier, and the reference 30Hz modulated into the 9960Hz subcarrier first then modulated into main carrier. The modulated 30Hz signal will then be transmitted via a mechanically rotated or electronically scanned directional antenna. On the receiver side, it will receive signals at designated frequency, then a 30 Hz filter will pick up directional signal at 30 Hz, and a 9960 Hz filter will pick up reference signal which is modulated inside of 9960 Hz subcarrier. Then a phase shifted signal can be compared with reference signal, and work out phase difference to solve the bearing of the course.

* Preparing the Block diagrams of proposed system
  + Signal simulation
  + Receiver design
  + Transmitter design
  + System Summary and practical implementation
* The lab plan of the system

The system will be simulated by using signal generator, and result signal will be received by RTL-SDR to analyse and obtain the data of phase difference. The lab intends to examine the VOR-like signal working at higher frequency, aka, 1.5GHz GPS frequency. The phase delay will be generated together with the reference signal and modulation will be completed.

* Learning GPS signal and algorithms

The GPS is the abbreviation of Global Positioning System by using satellites. The system has 32 unit of satellites operating on MEO (Medium Earth orbit) transmit at 2 bands, L1 and L2. The signal is in CDMA format and contains 5 frames of data.

# Self-review

The overall progress is matching up with scheduled, however the practical simulation meets significant difficulty. I spent more time than expected to understand the principle of radio navigation. The major problem for me is the foundation comprehension of radio and electronics. However, after a long period of catching up, it allows me to understand that how the system modulate signal into different phases and a secondary modulation to mix them together. I spent a large amount of time on GPS system to find out the mechanism of GNSS. Whereas, the tremendous gap of knowledge stopped my further research on it. It requires higher level of understanding on geoscience and orbit mechanism. From my point of view, it is too beyond my ability to integrate enough GPS knowledge into this project, therefore the target was lower to meet my condition. My supervisor helped me to refine the objectives and pointed out a suitable approach of getting hands on the work.

# Project management

The plan is divided two part according to semesters. In the first semester, the most work are preparation work for the further study of the project. The project itself is a different field for an aerospace engineering student, therefore a more throughout study on the basis is required before proceed to next stage study and lab works. To the date, the submission of this report, the initialisation is completed and the lab works are planned accordingly.

Current work and planed work for next semester is shown below:

|  |
| --- |
| • Define project equipment  • plan of deliverable content  • Plan for lab works  • Finishing the interim report  • Combing the algorithms with system  • Prototyping of models on the hardware platform  • Researching Hardware  • Developing algorithms  • Modelling of the system  • Radio fundamental studies  • Literature research |
| **Tasks to be completed in semester 2** |
| |  | | --- | | * Implement system on PCB | | * Oral presentation preparation | | * Demodulation using the development board | | * Prototyping on hardware | | * Final Report | | * Field Test | | * Test running through the Prototyping | | * Continue Prototyping of models (MATLAB & Simulink) | | * Combing algorithms with systems | |

# Gantt chart (See Appendix)

## **References**

Bauss, W. (1963). *Radio navigation systems for aviation and maritime use* (1st ed.). Oxford: Pergamon Press; [distributed in the Western Hemisphere by Macmillan, New York].

Beck, G. (1971). *Navigation systems: a survey of modern electronic aids* (1st ed.). London: Van Nostrand Reinhold.

LAMB, J. (1948). Very High-Frequency Techniques. *Nature*, *162*(4107), 83-84. http://dx.doi.org/10.1038/162083a0

Lo, S. & Enge, P. (2012). Capacity Study of Multilateration (MLAT) based Navigation for Alternative Position Navigation and Timing (APNT) Services for Aviation. *Navigation*, *59*(4), 263-279. http://dx.doi.org/10.1002/navi.25

Lo, S., Enge, P., & Narins, M. (2015). Design of a Passive Ranging System Using Existing Distance Measuring Equipment (DME) Signals & Transmitters. *Navigation*, *62*(2), 131-149. http://dx.doi.org/10.1002/navi.83

Seo, J., Chen, Y., De Lorenzo, D., Lo, S., Enge, P., Akos, D., & Lee, J. (2011). A Real-Time Capable Software-Defined Receiver Using GPU for Adaptive Anti-Jam GPS Sensors. *Sensors*, *11*(12), 8966-8991. http://dx.doi.org/10.3390/s110908966

Staff, N. (1990). *Global Positioning System* (1st ed.). Washington: National Academies Press.

Wang, J. (2002). Pseudolite Applications in Positioning and Navigation: Progress and Problems. *Journal Of Global Positioning Systems*, *1*(1), 48-56. http://dx.doi.org/10.5081/jgps.1.1.48

Watson, D. & Wright, H. (1971). *Radio direction finding* (1st ed.). London: Van Nostrand-Reinhold.