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|  | Aerospace Engineering. |

BEng Aerospace Project

Individual Research Report

Identifying the position of small airborne vehicle by using radio technology

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# Abstract

This paper aims to develop a radio navigation system for airborne vehicle to obtain vehicle’s direction (heading) and speed. It uses VOR (Very High Frequency Omnidirectional Ranging) principle to determine the bearing of the vehicle and obtain its speed by analysing Doppler frequency shift of the signal. The approach uses Software Defined Radio (SDR) to carry out the research of the signal and uses MATLAB for signal producing and processing.

The system consists of a Red Pitaya as a SDR for transmission, and uses a RTL-SDR receiver only system as the terminal for drones. The method proposes a low cost navigation implantation for drones and other micro vehicles, in the fact that RTL-SDR is cheap to obtain.

It also covers the potential ability to be a GNSS (Global Navigation Satellite System) compatible navigation solution by developing its Pseudolites potential of combing GPS navigation mechanism with the system proposed in this paper.

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# Glossary

VOR

GNSS

ILS

TACAN

ADF

NDB

LFR

Nomenclature

Acknowledgement

I would like to express my greatest thankfulness to Mr. Eddie Ball for this great opportunity to do the project and special thanks for his great patience throughout this project.

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# Introduction, aims and objectives

## Introduction

Radio positioning is an old method for navigation compared to the state-of-the-art global navigation satellite system (GNSS). However, in the past two hundred years of aviation, radio has proved to be a reliable approach of navigation. At the same time, radio navigation is continuously evolving to meet contemporary requirements of modern aviation and playing a more important role as one of the alternative methods when GNSS malfunctions. This project focuses on a compatible solution bridging the VOR (Very High Frequency Omnidirectional Range)/TACAN (Tactical Air Navigation)-like system and the GNSS system. In this study, VOR-like signal will be implemented at a GNSS signal frequency, which is generated using MATLAB and Simulink. During the project, two different prototypes are examined with MATLAB, and one prototype is implemented in the Red Pitaya platform and RTL-SDR.

Meanwhile, preliminary theories of the two implementations have been developed. The first evaluation investigates the signal modulation of the original VOR system. The second evaluation will test an alerted signal at higher frequency, in another word, the VOR-like signal transmits at GPS frequency, i.e. 1.54GHz.

The final tests are carried out with fixed transmitters and a receiver positioned at different angle.

## Aims

This project aims to achieve a radio navigation system that provides bearing and speed information.

## Objectives

1. The principle of the navigation theory related to VOR are proved by using MATLAB

2. The algorithms of solving directions are explored and examined with MATLAB

3. The system prototype will be tested in real situation or relevant simulation environment.

4. The system will be subject to a field test

5. Target Requirement: to obtain the flying speed of the vehicle

6. Target Requirement: to obtain the flying direction of the vehicle

# Literature review

## Background

The history of radio navigation dates back to late 19th century before the First World War (Bauss, 1963). Before starting using radio, people had already used compass and stars for thousands years. However, the radio is a game changer, which overcame major difficulties of the old navigation method. In the past century, it has been developed from analogue to digital, from ground to space, from inaccurate to accurate, from immobile to portable and from specialized to daily uses.

The first ever radio relative system was radio direction finder, which is tuned to the frequency of a certain station and pointed at its direction using an antenna. This allows pilot to determine the bearing of the station, which enable aircraft or ships to drive towards it. By hearing from two stations, the captains and pilots are able to draw an intersection of two radio station on the map and thus 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 (Automatic Direction Finder) was a great progress, which benefits from modern electronics such as transistors. It works with NDB, i.e. non-directional beacon, and uses phase comparison technic to determine the bearing of the aircraft (Watson & Wright, 1971). However, the accuracy of the system is a critical issue for the usage of modern aviation and not suitable for small scale aircraft due to its huge antenna size.

VOR exhibited a significant improvement from ADF and NDB, featured with the better accuracy and a voice channel that can be used for communication.

It consists of three parts: the voice including a Morse code identifier, the reference signal consisting of a continuous signal transmitted from the omnidirectional antenna that frequency modulated at 9960 Hz and a AM modulated signal contains the directional signal which mechanical or electronical rotated at 30Hz causing different phases corresponding to the direction it is facing (LAMB, 1948). By comparing the phase difference between the reference and the directional signals, as explained in figure 1, a bearing can be worked out easily. It has an advanced version named TACAN, which implies a higher frequency carrier and more divisions of phases with the distance measuring feature.

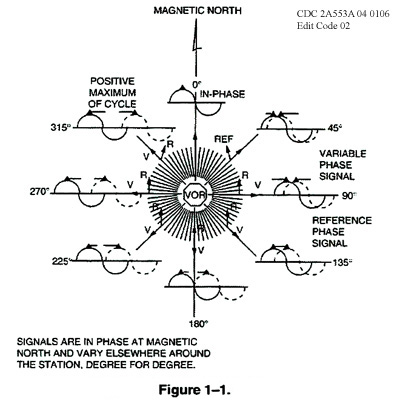


Figure 1 The VOR signal (Beck, 1971)



Figure 2 A VOR station (photo taken by FARHAN FAROOQ )

Beam systems, for example the Adcock by Macaroni known as LFR (Low Frequency Range), is also a good practice of navigation (Beck, 1971), however, it requires that the object remains in the coverage of the beam that is used for navigation, and therefore has little value for projects such as detecting the positions of aircrafts. However, it was later adopted by ILS (Instrumental Landing System) equipment. It remains active in terms of military and police uses. It requires manual operations by listening to Morse code or sound pitches to determine the object location relative to the beam. It has an inspiration of using radio, whereas, it can only tell the relative directions when the object is within the covered range and width of beams, or in other words, it is a directional system. Thus, it has limited uses for a general purpose of navigation.

GNSS is the best system in term of both precision and feasibility (Staff, 1990). The GPS system, as one of the best GNSS system, remains the most popular option for navigation since it has been operational. Meanwhile, there were many systems, such as those mentioned above, dying or died because of the widely spread 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 modes for civil uses and military uses at the beginning. The civil code, however, is less accurate compared to the military code. It works with simple logic using trigonometry. GPS system has multiple satellites on low earth orbits to guarantee that above most of the surface areas of earth there are at least four satellites in the sky. It was so well designed that during most of the time there were actually more than four, which provides a potential opportunity to increase the accuracy. The algorithm relays on three known satellite positions 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 distances can be worked out. Combining three such distances and satellite locations, a matrix can be introduced to provide multiple solutions, whereas only one of them is the correct positon. Furthermore, the result need to be transferred from polar form into panel form and should be projected on the map with the coordinates provided. The problem with GNSS in general is the time to first fix, which takes usually three to four minutes to cold start up and GPS systems are very power hungry.

Pseudolites application implies simulating satellite signal with a ground or aerial station, which can be deployed to blind zones of GPS (Wang, 2002). It has a huge potential in warfare or special circumstance, for instance, mining or cave exploring where GPS signal may not be viable. Therefore, it is a good system to study for this project. It is possible to be compatible with current GNSS systems and adapt it into new system. This will significantly improve the efficiency and accuracy of the system as it is going to be discussed in the further study. In this project, Pseudolites signal is the further objective, and it is intended to be compatible with this project proposal.

Software Defined Radio is a new way of planting and testing the design RF applications, which used to require individual transmitters or receivers in the past (Seo et al., 2011). SDR (software defined radio) can be operated easily by using MATLAB and Simulink for signal generation and signal receiving (Lo, Enge, & Narins, 2015). A cheap RTL-SDR kit can be found in the market with a price of £5 with relatively good performance. RTL-SDR is a SDR receiver works from 24 MHz to 1766 MHz, which is great range of frequency for the study. This project requires the signal working at GPS frequency, roughly 1.5GHz.

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, though it has a limited capacity. To explore the improving oppturnity, Pseudolites technic can be adapt to the situation, where the bearing and angle is obtained by radio, and Pseudolites signal determines distance.

The speed is commonly determined by using Doppler shift phenomenon of the radio propagation. When the observer and source are having relative velocity, the frequency of received signal will shift accordingly.

Due to the limitation of this project, the study does not include hyperbolic navigation systems due to the performance and size issues. Since the most of the hyperbolic systems work at lower frequency to achieve wider coverage, their precision is much lower than the required specifications of this project, they require a much longer antenna, which does not meet project requirement.

# Methodology

### Introduction

Radio navigation 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 retained their necessity for modern aviation, though they are not capable with the newly booming trend of aviation, such as drones.

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

The drones are unmanned vehicles whose movements are highly relaying on the navigation system on board. Due to safety concerns, currently most drones have to follow VFR (Visual Flight Rules), which means they cannot operate outside drone pilots’ view range, even with GPS equipped. Despite the regulation, the reliability of GPS is a potential disadvantage of self-driving drones. Therefore, multiple solutions have been worked out in the past few years, such as computer vision, inertia navigation etc. Thus, alternative navigations should be maintained during the flight and a good solution is to improve VOR considering its advantages.

A potential solution as proposed in this project is to operate a VOR-like system at GNSS frequency, and transmit both Pseudolites and VOR-like signal at GNSS frequency with the help of time divisions to increase system reliability and compatibility. The benefit of operating VOR at higher frequency can be proved in several aspects. Firstly, the size of the antenna is much smaller due to shorter wavelength, and it makes it more feasible for small drones, and a higher frequency signal can be used to carry more information including GNSS navigation information, which can be used to increase accuracy. In addition, it can minimize the error caused by multipath effect because it works in short range and behaves much more directional.

### Overview

#### RTL-SDR as the receiver

RTL-SDR is a good tool to obtain the signal at GPS frequency. It is important to study this tool to deal with upcoming tasks.

#### Red Pitaya as the signal source

#### Understanding VOR

VOR is a short-range radio navigation for aircraft, which operates from 108 – 118 MHz (Beck, 1971). 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 ignored because they are irrelevant. The left components are 30Hz phase-varied signal, which is modulated into the carrier, and the reference 30Hz signal modulated into the 9960Hz subcarrier first then modulated into main carrier. The modulated 30Hz signal is then transmitted via a mechanically rotated or electronically scanned directional antenna. On the receiver side, it receives 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 the directional signal can be compared with reference signal, and work out phase difference to solve the bearing of the course. The 9960 Hz signal plays the important role to carry reference signal, without it, the reference signal are mixed with the directional phase-varied signal, hence the receiver cannot tell that which is the reference and which is the directional signal. The bearing is worked out from comparing phase difference of two 30Hz signal.

### Prototypes

#### First Prototype

Signal simulation of the first prototype

C:\Users\hao\Downloads\signal.png

Figure 3 Baseband Signal

Receiver design of the first prototype

C:\Users\hao\Downloads\Rx.png

Figure 4 Receiver design

C:\Users\hao\Downloads\TX (1).png

Figure 5 the further development of the system

#### Second Prototype

### System Summary and practical implementation

This system as a prototype focus on replacing carrier frequency with higher one. It will examine the possibility of other subcarrier frequency in next stage too. The signal will be generated using baseband generator, and feed it into a mixer with higher frequency, then it, as a direct input, will be feed into the RTL-SDR to simplify the antenna design at this stage. The receiver will be simulated by using MATLAB and Simulink.

#### Full scope of the system

The prototype shown above is a little progress on the original VOR system. It can be used for next stage research. The full system, which I proposed, is a standalone Pseudolites based VOR system. It, which combines the feature of GNSS and VOR with higher accuracy and better usability, is fully digitalized system that provides bearing, distance, absolute position, and reliable timing. It has a huge potential as alternative navigation.

#### Further Research

##### 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 two bands, L1 and L2. The signal is in CDMA format and contains five frames of data. However, this information is only useful if there is a background knowledge of Geoscience and Astronomy, which is obvious beyond the scope. Thus, a simplified achievable goal is to determine whether the original signal will be distorted during the secondary modulation. The research of GPS will remain at signal level for this project though a higher-level study was planned initially.

# Experiments and Set up

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, 1.54GHz GPS frequency. The phase delay will be generated together with the reference signal and modulation will be completed.

# Results and Discussions

Findings:

Goals achieved:

# Conclusion

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# Appendix

# Project management

## Summary

The plan is divided into two parts according to semesters. In the first semester, most of the 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 proceeding to the next stage of study and lab work. To the date of 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 | | * Keep Prototyping of models (MATLAB & Simulink) | | * Combing algorithms with systems | |

## Gantt chart

# 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, I understand how the system modulates signal into different phases and a secondary modulation to mix them together. I spent a large amount of time on the 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.