THESIS TITLE

Presented by:
NAME

Prepared for:
Dr. Amit Mishra
Dept. of Electrical Engineering
University of Cape Town

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Foreword and Acknowledgments

Abstract

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Chapter 1

Introduction

Chapter 2

Literature Review

2.1 Microwave Radar Motion Detectors

This section provides a detailed investigation into different, affordable radar motion detectors that have been used to identify objects and their speeds. Radar motion detectors identify and measure the movement of objects using the Doppler effect [2]. Such radars are often applied in security systems (to identify intruders) and in traffic systems for vehicle monitoring. These radars work by transmitting microwave beams towards a moving target whilst simultaneously receiving the signals that have been reflected off of the target. The speed of the target is obtained by observing the frequency difference between the transmitted and received signal [1]. These signals are sent and received by a microwave transceiver.

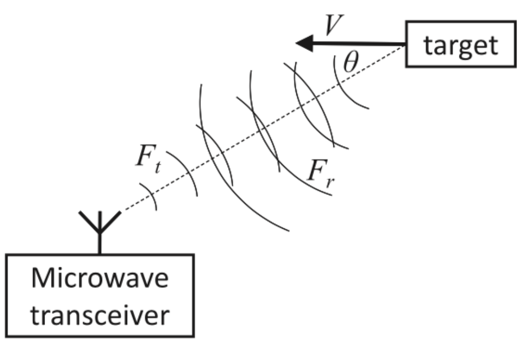


Figure 2.1: Visualisation of how microwave Doppler radars measure speed [1].

The frequency shift caused by the Doppler effect is proportional to the velocity of the target meaning Doppler radars are blind to stationary targets. The following equation describes the Doppler frequency calculation:

$$F_d = |F_t - F_r| = 2 \times V \times \frac{F_t}{c} \times cos(\theta) \tag{2.1}$$

Where F_d is the Doppler frequency, F_t the transmit frequency, and F_r the received frequency. V is the velocity of the target and θ is the angle between the direction of motion of the target and the radar beam. c is the constant speed of light ($3 \times 10^8 m/s$) [1]. The following subsections explore specific microwave Doppler radars and their applications in various target detection scenarios.

2.1.1 HB100

HB100 is a low cost microwave Doppler radar transceiver module that operates at a fixed frequency of 10.525GHz in the X-band. It is a bi-static radar, meaning it's transmitter and receiver are at separate locations on the radar. It is capable of a max radiated power output of 20dBm and can detect objects up to 10-15m away. The antenna beam spread looks as follows:

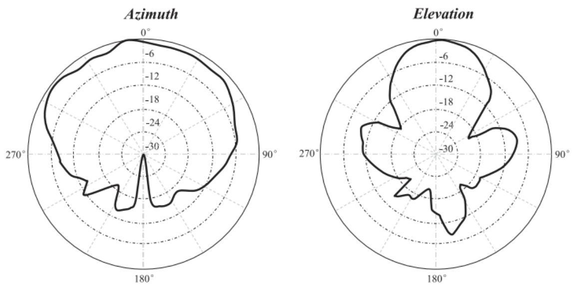
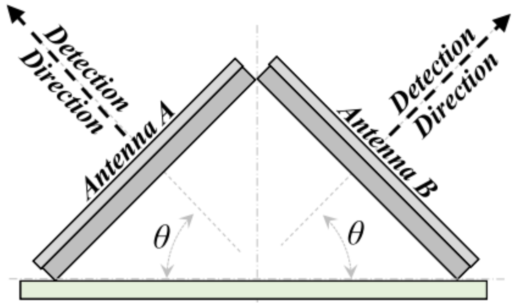


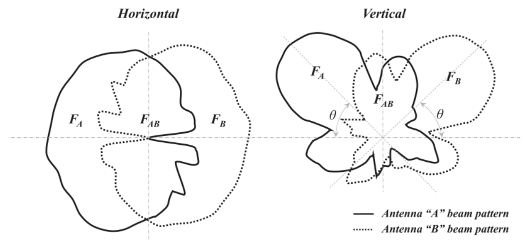
Figure 2.2: Plots showing the HB100 antenna beam Azimuth and Elevation [1].

These plots help visualise the field of view of the radar, with azimuth giving a horizontal cross section of the radar's view, and the Elevation giving a vertical cross section of the radar's view. The radar is powered using 5V DC and requires 30mA of current. This radar transmits a continuous wave signal and outputs signals oscillating at the various received Doppler frequencies returned by moving targets in the radar's field-of-view. This Doppler frequency is useful for determining the velocity of the target, however it can be challenging to find more information about the target using these frequencies [4]. Whilst it is challenging, there are methods of characterising targets using just their returned Doppler frequencies.

Bao et al. [1] used a combination of two HB100 radars to monitor cars in parking lots. Their objective was to identify when a car entered a parking bay, was parked in the bay and, was leaving the bay. The layout of the two radars is as follows:



(a) Layout of the two radars



(b) Antenna beams of both radars combined

Figure 2.3: Parking bay monitoring setup [1]

The angle θ of each radar was selected to be 45° because a small θ (around 0°) resulted in too much interference from the ground, and a large θ (around 90°) resulted in the radar's beam being perpendicular to the vehicle's motion and thus no Doppler shift would occur.

The output voltage of the radar is directly proportional to the energy reflected off of the target (around 100 - 200uV peak to peak) meaning this output must be amplified before being fed into an ADC (analog to digital converter). Agilsense (the manufacturers of the radar) recommend a two-stage high gain low frequency amplifier. Bao et al. used two LM324s to amplify the output of each radar. The circuit is as follows:

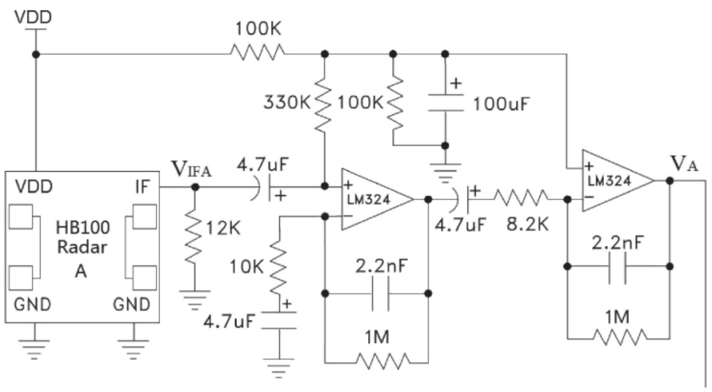


Figure 2.4: The amplifier used by Bao et al. to amplify the HB100 output voltage [1].

Nguyen et al. [2] offer a more detailed approach to designing their amplifier.

1. Set initial values: $G = G_0, d = d_0, \epsilon = \epsilon_0$ where the variables represent Gain, distance and acceptable deviation from desired detection distance respectively.

2. Set Gain = G.

3. Experiment with the radar and set $d = d_{max}$ where d_{max} is the maximum object distance the radar can detect.

4. If $|d_0 - d| < \epsilon$ end the process and use the G selected in step 2.

5. Else, set $G = Gain \times (d_0/d)^4$ and repeat from step 2 on-wards.

Bao et al.'s system was designed to be placed in the centre of the parking bay such that radar A is facing the entrance to the bay, and monitors for cars as follows:

1. If radar A detects an object slightly before radar B does, then a car is driving into the bay.

2. Subsequently, if both A and B stop detecting any objects then the car has parked in the bay and stopped moving.

3. If radar B detects an object slightly before radar A does, and then loses sight of the car before A does, then a car is driving out of the bay.

Once the amplified output of the radar was fed into and ADC, the data processing was done on a micro controller. A detection time window (W seconds) was selected and the area under the voltage time graph computed for this duration. If the area exceeded under this plot exceeded a chosen threshold (in this case a value of 0.05) then the radar had detected an object.

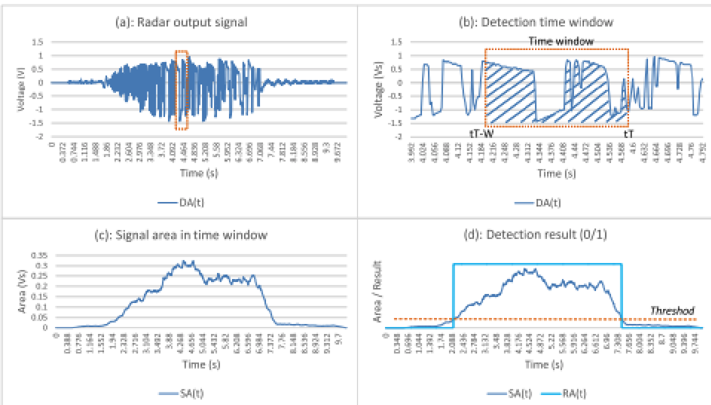


Figure 2.5: Example plots of the data analysis process [1].

Nguyen et al. [2] used a single HB100 radar, placed in the centre of the road above where the cars would drive, to identify the speed and size of vehicles driving on the road. The amplified output signal of the radar was converted to a square wave on the micro controller they used, and oscillated at the Doppler frequency F_d.

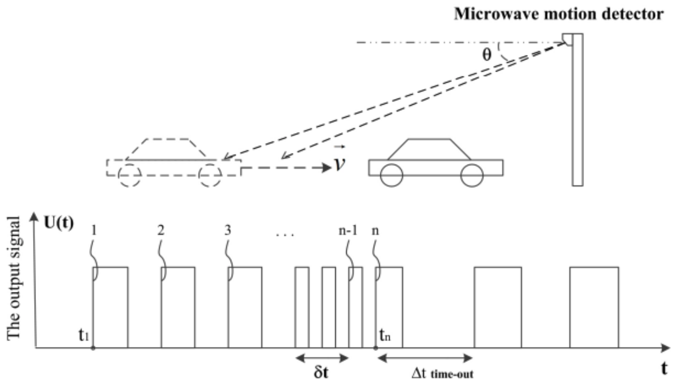


Figure 2.6: Radar setup and voltage output [2].

The length (S) of the vehicle was calculated using the following formula:

$$S = \int_{t_1}^{t_n} \frac{n}{k} \tag{2.2}$$

Where, n is the gross number of time the output signal goes from low to high, and k is a scale factor given by:

$$\frac{2F_t}{c} cos\theta \tag{2.3}$$

If the time Δt that the signal is low exceeds a chosen $\Delta t_{time-out}$ then the car is said to be moving out of the detection zone of the radar.

The $\Delta t_{time-out}$ is selected using the minimum desired detectable speed, the transmit frequency of the radar and the angle the radar makes to the road:

$$\Delta t_{time-out} = \frac{c}{2V_{min}F_t cos\theta} \tag{2.4}$$

The average speed of the vehicle is computed as follows:

$$S = \frac{S}{t_n - t_1} \tag{2.5}$$

This method saw an accuracy rate of greater than 80% when detecting trucks, cars and buses moving in a speed range of 5-40km/h and at a distance of up to 8m away from the radar.

2.1.2 CDM324

CDM324 is another low-cost microwave continuous wave motion sensor. It has a very similar antenna azimuth and elevation as the HB100, however it can only effectively detect vehicles at distances of up to 6m away. The radar operates in the K-band at a frequency of 24.125GHz [7]. It is equipped with 4 pairs of receiving and transmitting antennas.

Liu et al. used this radar in a smart traffic monitoring system, to identify vehicles moving past the radar and their speeds [3]. The radar is placed on the side of the road and detects the presence of a vehicle by observing the Doppler shift caused by the vehicle's prescience. This Doppler shift is smaller than in some of the previous methods seen because the vehicle is not moving directly towards the radar.

The effect of noise on the received data is reduced using low pass filtering as well as thresholding.

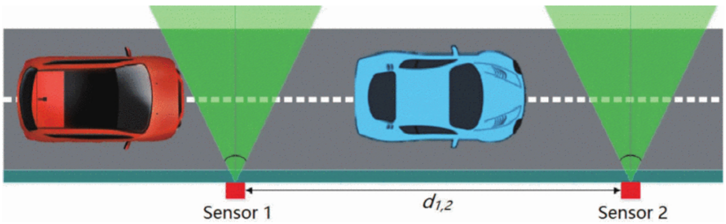
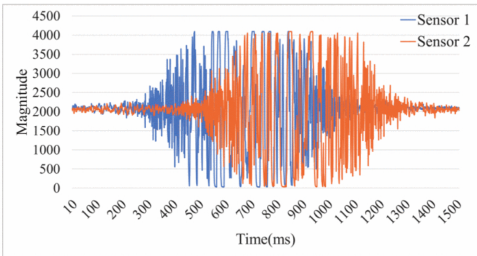


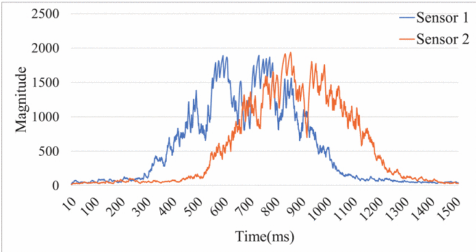
Figure 2.7: Radar setup [3].

This setup uses two radars that are separated by a distance greater than the length of the vehicles being detected. The difference in time between sensor 1 detecting the vehicle and sensor 2 detecting the vehicle is used (along with the distance between the two sensors) to determine the speed of the vehicle.

The two radars have the following outputs when detecting a vehicle (after preprocessing) where the time difference between each detection can be observed:



(a) Before preprocessing



(b) After preprocessing

Figure 2.8: Sensor Data [3].

This system was only tested on a single lane of the road but had a vehicle detection accuracy of 98.3% and speed measurement accuracy of 95.8%.

2.1.3 Other Radars

Fang et al. [4] created a continuous wave K-band radar (24 GHz) with the objective of vehicle monitoring. Their radar is capable of detecting a vehicle, measuring it's speed, and classifying the type of vehicle simultaneously. Their radar module is made up of the following:

- A horn antenna with a receiver that outputs Doppler signals.
- An analog signal amplifier using OPAMPS.
- A Digital Signal Processor (The TMS320F2808 from Texas Instruments).

Their radar was designed to be affordable and costs less than $250. This radar must be positioned above the road to work.

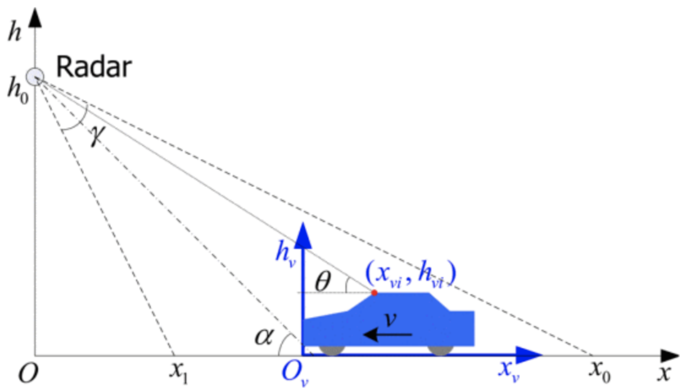


Figure 2.9: Radar Positioning on the Road [4].

The system identifies the vehicle using various scatterings mapped across the car, which each reflect different Doppler frequencies. The Doppler frequency reflected by each scattering is given by:

$$f_{di}(t) = \frac{2vf}{c} cos\theta_i(t) \tag{2.6}$$

Where, $\theta_i(t)$ is the angle each scattering makes with the radar. These reflected frequencies decrease with time due to the increasing θ_i.

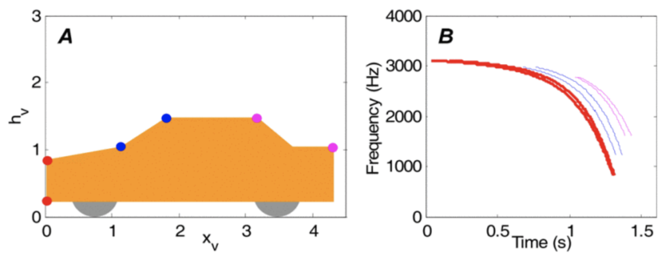


Figure 2.10: Scatterings and their Frequency Time Plots [4].

The frequency time plots are obtained by performing a STFT (Slow Time Fourier Transform) on the received signal. The important information in this plot is separated from noise using thresholding. The start point of the plot is found using a low threshold TH_1 and finding the time and frequency (t_{start}, f_{dstart}) when the signal power is greater than this threshold. A lower point is then obtained using a frequency threshold, TH_2 which is set to be ρf_{dstart}. Once this lower frequency and time t_l has been found, a power threshold TH_3 is used at this point. This threshold is much higher than TH_1 and provides a target verification mechanism. If the power is below TH_3 then the detection process is aborted [4].

This detection algorithm was able to successfully detect vehicles in high traffic scenarios. The algorithm was able to eliminate interference from vehicles in other lanes and had a detection accuracy greater than 95%. The speed detection was also very accurate, with an average accuracy of 97%.

The classification of the vehicles use different Doppler signatures caused by the scattering points on the car to identify it's type. This system makes use of a Hough Transform which is a transform used to detect curves in an image. The Hough transform is a transformation between image space into parameter space (for example the gradient and y intercept of a straight line are the parameters of that line), where the intersection of all the lines in parameter space define the line in image space [8].

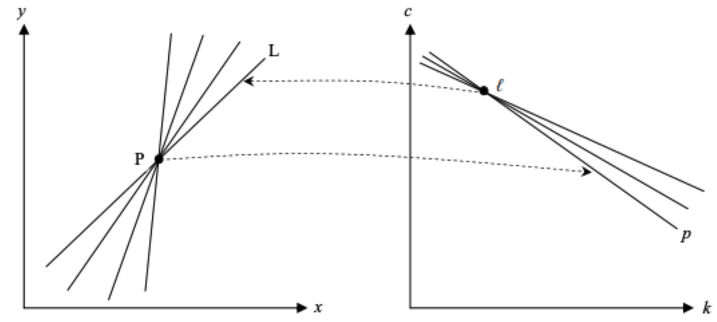


Figure 2.11: Hough Transform Done on a Straight Line [5].

Fang et al. use the Hough transform to transform from a frequency time plot to a x coordinate vs height plot for each scattering.

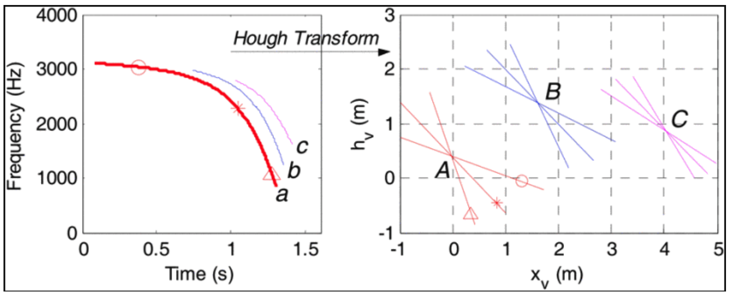


Figure 2.12: Hough Transform Applied to Radar Readings [4].

The intersections of the lines in the transformed plot represent the coordinates of the scattering points on the car. The actual plots are less clear than the figure above but can still be used. The plots are first rotated 45 degrees so that the x's are vertical, then the maximum pixel value is found in each column and used to create a new plot.

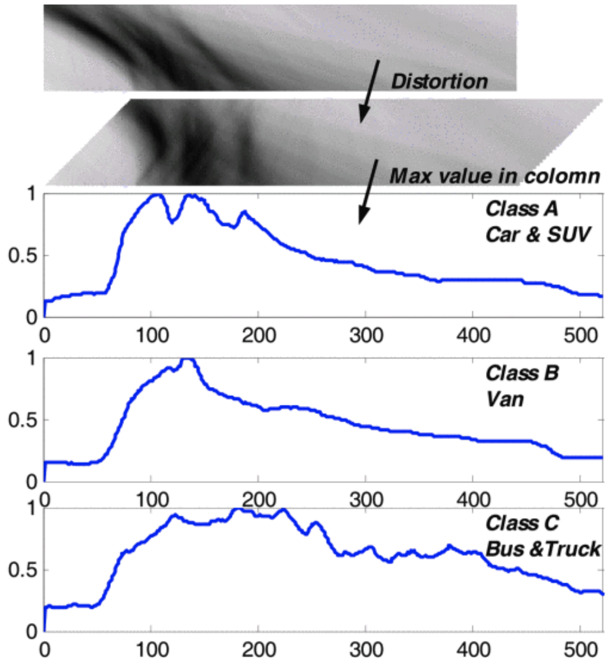


Figure 2.13: Actual Plots of Transformed Data [4].

These final plots are then classified using a machine learning algorithm.

2.2 Wireless Data Transfer

This section aims to investigate different communication protocols between various devices, in the event that the traffic monitoring system requires multiple nodes that must communicate to each other. The systems investigated in this review are LoRa (Long Range) and BLE (Bluetooth Low Energy).

2.2.1 LoRa

LoRa is a new communication technology that is seeing popularity in the IoT (Internet of Things) industry because of its advantages over other technologies such as ZigBee, Wi-Fi and Bluetooth. Its main advantage is that it can transmit data over long ranges whilst consuming very little power [9]. The LoRa physical layer transmits data using frequency modulated chirps. These chirps have practically the same duration and vary from some frequency f_0 to some other frequency f_1 [10]. LoRa operates in the 433-, 868- or 915-MHz frequency bands but some countries have further restrictions on the bands that can be used.

This physical layer works with a system of nodes connected to a gateway. Each node is located by a sensor and the information from the sensor is transmitted by the node to a centralised gateway. This gateway can then connect to the internet, or have a local WiFi network, that a user can connect to and view the information from all nodes [6].

On top of this physical layer, there is the LoRaWAN (Long Range Wide Area Network) MAC (Medium Access Control) protocol [6]. This uses a star topology, meaning that all the end devices (nodes) only communicate with the gateways, and cannot communicate directly with one another. These gateways then communicate, over the internet, with a central network server. This network server then connects to application servers where users can access their data. This system allows new creators to connect to people's existing gateways allowing for a much wider range of communication. However, this may be limited in rural areas where there are few to no other gateways being setup. This protocol was standardized by the LoRa Alliance [6].

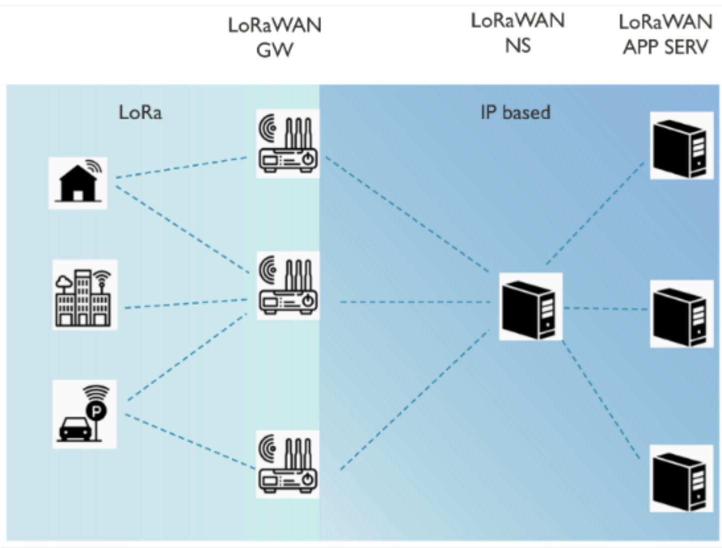


Figure 2.14: Visual of the LoRaWAN Setup [6].

The main disadvantage of LoRa is its limited data rates, which range from 0.3kbps to 11kbps [11].

Chapter 3

Requirements Analysis

The following are the project's requirements, which were derived from the project description. The overarching requirement is to design a sensing system to monitor traffic on the roads. This system must:

1. Observe a 2x2 grid on the road (two lanes of the road, two cars deep).
2. Count the number of vehicles in the grid at a given time.
3. Store this data with timestamps, allowing the user to observe traffic density at different times in the day.
4. Be affordable, around $100.
5. Not obstruct the drivers on the road.
6. Identify the types of vehicles in the grid in this time e.g sedan, truck, bus etc.
7. Be durable enough to withstand outdoor conditions on the roads.
8. Detect vehicles up to 70m away (might be a specification not a req.).
9. Detect vehicles moving at speeds up to 162km/h (might be a specification not a req.).

Chapter 4

Design

Chapter 5

Implementation

Chapter 6

Results

Chapter 7

Discussion

Chapter 8

Conclusion and Future Work

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