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GLOBAL ACADEMIC EXCELLENCE

LTE-BASED PASSIVE FORWARD SCATTERING RADAR FOR HUMAN DETECTION WITH NEMO HANDY SUPPORT

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Abstract:

A radar used for radar detection includes a setup of a transmitter and a receiver, which may identify any human or animal object that travels between the receiver and the source of illuminator of opportunity via the system. The targets in this study were mainly human, comparable to the situation where intruders enter the country illegally, and by distinguishing between human sizes, the detection can be conducted, which is focused on the body dimension. There have been many cases such as kidnapping at the border in Lahad Datu, Sabah. In order to improve border protection, the passive forward scattering radar system could support the research investigation on the transmitting strength of 4G Long-Term Evolution (LTE) networks that concentrated on Reference Signal Received Quality (RSRQ) and Reference Signal Received Power (RSRP) parameters using Nemo Handy to measure the signal strength and validate the findings of human detection using the setup of this radar system. In addition, this radar system was employed to detect any object that crossed between a commercial transmitter and receiver with a bistatic angle of about 180° which is forward scatter and produced a Doppler signature. This investigation was carried out utilizing the 1.8 GHz LTE frequency in three separate locations: Batu Laut (Selangor), Port Dickson (Negeri Sembilan), and Taman Suria (UiTM, Selangor). The receiver's data is then extracted and analyzed using MATLAB software. There are four period ranges, namely morning, night, evening and afternoon in this study. Conclusively, Nemo Handy can describe the best time range to support passive forward scattering radar system to provide the best period for human detection. In addition, this system can contribute to many areas such as border or street, to detect human detection and for some reason as protection, security and research.

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Keywords:

Passive Radar; Human; Forward Scattering; Doppler Frequency; LTE, Nemo Handy

Introduction

One of the newest and most widely adopted technologies is 4G Long Term Evolution (LTE), which is an advanced technological advancement over earlier generations. Generally, the creation of new services, especially 4G LTE, lowers costs for network operators and end consumers (ElNashar, 2014). With the adoption of the standard by all major wireless carriers, 4G LTE was initially deployed in commercial broadband globally. A few years ago, public safety responders in the field could use the speed and data transfer capabilities of this technology (Yarali, 2020).

It is practically necessary to employ a commercial measuring tool, such as Nemo Handy, to measure the outcomes of an active 4G LTE network. According to Reference Signal Receive Power (RSRP) and Reference Signal Receive Quality (RSRQ), Nemo Handy is a tool for analyzing the several potential connections between LTE measurement information (Anite, 2021). The RSRP, which is represented in dBm, is the parameter that allows for the comparison and handover of various cells utilizing the same carrier frequency or cell reselection decision (Raghunandan, 2022).

However, when RSRP is insufficient to make a trustworthy handover or cell reselection choice, RSRQ is the parameter that offers more information (Boixadera, 2009). The Nemo Handy tool was also employed in an actual test scenario using a drive test experimental activity to investigate the measurement and optimization of LTE radio performances that had been conducted by another researcher (Zinno, 2018). Moreover, previous investigation on a Radio Frequency (RF) fingerprinting framework for locating user equipment measurements explained in LTE was conducted using a signal strength mean value technique also employing Nemo Handy for field data collection (Khandker, 2016). In addition, another study used Nemo Handy to collect real-time data on radio and physical layer parameters and integrated it with machine learning methods to forecast 5G (Zinno, et. al, 2023).

Consequently, this technology, which is known as the passive forward scattering radar support system, used a signal from 4G LTE. Passive radar is a technology that employs electromagnetic waves emitted by an existing commercial telecommunications antenna. It then receives and processes the signal using its own receiver antenna (Griffiths and Baker, 2022) The passive radar system, which consists of a receiver and no co-located transmitter, can lower radar system costs because there are no transmitter system costs to be provided (Abdul Aziz, et. al, 2022). The direct communication between the transmitter and the receiver is interrupted when their line-of-sight crosses, according to the forward-scattering concept for target detection (Luca, et.al, 2017).

The benefit of passive radar system is for ground activity where it can identify and group various ground targets. For example, people and automobiles. Previous studies have explored the relations between dimension of target, speed of target and Doppler signature that it has been proved the dimension and speed do indeed affect the characteristic of the Doppler signature

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where the investigators have shown that when the speed of target was raised, the Doppler signature performed to reduction (Abdul Aziz, et. al, 2022).

Furthermore, forward scattering radar can detect objects blocking signals at a bistatic angle of 180˚ (Willis, 2005). The ability of forward scattering radar to detect low signal targets with a low-cost system has been discovered to have numerous applications in civil, defence, maritime, medical, and security systems. Furthermore, forward scattering radar has contributed to the border detecting defence system (Gould, et.al, 2002).

Eventually, Nemo Handy can characterize the ideal period to support a passive forward-scattering radar system in terms of detecting people (Abdul Aziz, et. al, 2019). In which this method can be used in a variety of settings, including roads and borders, to detect people, and for other purposes like research, safety, and defence

Methodology

Human As Ground Moving Target

Two people had to be the moving object in this experiment in order to gather data at three distinct locations and four different times. The width, height, and dimensions of each person's body vary. Each location's data was gathered four times: in the evening (5 pm to 6 pm), night (8 pm to 10 pm), morning (5 am to 7 am), and afternoon (1 pm to 3 pm). Besides, the information was gathered at three distinct locations: Taman Suria in UiTM Shah Alam, Batu Laut in Selangor state, and Port Dickson in Negeri Sembilan state.

In all three locations, Person 1's width and height were 0.29 and 1.81 meters, respectively. Person 1's radar cross sectional area are 0.53 m^2. While, Person 2's width and height were 0.26 and 1.73 meters, respectively. Person 2's radar cross sectional area are 0.45 m^2.

Due to the data collection is not follow the exact time sequence of the day but is arranged in a logical order based on the observational situation, the times in Table 1. The order of morning, night, evening, and afternoon is corresponding to the typical shift in human activities that take place throughout these periods such example working in the morning, leisure tasks in the afternoon, socializing in the evening, and rest at night.

Table 1: Data of Experiment

	NUMBER OF SAMPLES							
TIME	**MORNING**		**NIGHT**		**EVENING**		**AFTERNOON**	
PERSON / LOCATION	1	2	1	2	1	2	1	2
BATU LAUT	40	40	40	40	40	40	40	40
PORT DICKSON	40	40	40	40	40	40	40	40
TAMAN SURIA	40	40	40	40	40	40	40	40
TOTAL	960							

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Experiment Site

Batu Laut, Tanjong Sepat in Selangor, with latitude of 2.68^{o}, and longitude of 101.5^{o}, served as the initial trial site for data searching. Before deciding where to carry out the experiment, a number of points needed to be made clear. It is necessary to locate the LTE base station that serves as the signal transmitter before beginning the experiment. Subsequently, as seen in Figure 1, the receiver antenna was positioned 382.92 meters away from the communications transmitter antenna. Prior to the experiment, a spectrum analyzer was used to determine the transmitter's frequency at the base station. The commercial transmitter at the base station sent data to the receiver at 1.8 GHz (signal of LTE).

At latitude 2.45^{o} and longitude 101.85^{o}, the second experiment site was chosen close to the beach of Teluk Kemang, Port Dickson, Negeri Sembilan, Malaysia, as shown in Figure 2. The radar reception system was located around 565.50 meters away from the commercial transmitter antenna. The transmitter's proximity and suitability for receiver data collecting were the main factors in the selection of this location. Prior to the experiment, a spectrum analyzer was used to detect the transmitter's 1.8 GHz.

Figure 1: Site of Experimentation at Batu Laut.

Figure 2: Site of Experimentation at Teluk Kemang.

The final experiment location was Taman Suria, located at latitude 3.07^{o} and longitude 101.50^{o} in the Faculty of Chemical Engineering, UiTM Selangor. At 164.05 meters from the radar receiver baseline, the telecommunication transmitter antenna sent the signal power intensity at 1.8 GHz to the passive radar system. The experiment site is located as depicted in Figure 3.

Each participant, whose body measurements varied, underwent the experiment at a separate time. To observe the impact of time on data collecting, the experiment was conducted in the morning, evening, afternoon, and night. When a human passes between the commercial transmitter antenna at the base station and the receiving antenna, which serves as a passive radar, it detects their presence. Aside from that, a total of 80 trial samples in the morning, 80 in the evening, 80 in the afternoon, and 80 in the evening were gathered at Batu Laut for two people. To determine the classification accuracy for data analysis, the entire number of samples for each period was then split into training and testing phases. In addition, four samples were selected for the testing process from among the various samples for everyone at various periods. All the processes of training and testing were important to see the accuracy of the classification process.

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The setup for the data collection phase of the experiment is depicted in Figure 4. A human is an object moving in the direction of the commercial antenna transmitter base station and passive radar receiver. To gather information from the transmitter, Nemo Handy was positioned on the same level as the receiver. The signal intensity for different frequency types is measured using this equipment.

Figure 3: Site of Experimentation at Taman Suria, UiTM Shah Alam

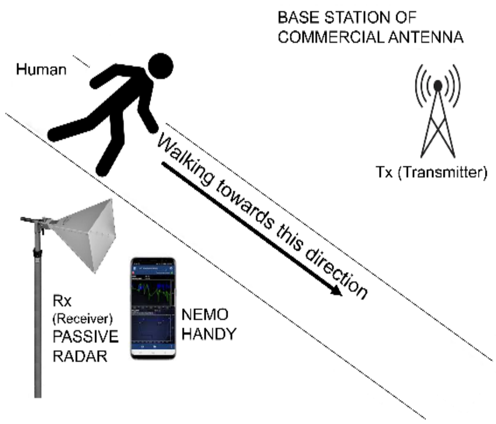

Figure 4: Simple Illustration of Experiment Site

Data processing

In this study, MATLAB software was used to analyze all collected data. Engineers and programmers usually use this software to optimize problem solving. Based on a matrix language, MATLAB can express in mathematics. To produce various types of findings that will be displayed in graphs, MATLAB software is used in a variety of ways. The target can then be categorized once the MATLAB software has acquired a complete signal Doppler signature. The steps taken for the data analysis is as shown in Figure 5, which shows all the steps that were done using MATLAB software and Nemo Outdoor software. After being recorded for 20 seconds, the Doppler data was later divided into 2 seconds segments. The human Doppler signature is shown by the two-second data. Following data segmentation, a denoising procedure was used to eliminate the noise from the data. In the process, images of the denoised data signal were also saved. The power spectral density (PSD) illustrates how strong given energy is in relation to frequency. Alternatively, it demonstrates the range of energy at which it can be either strong or weak. PSD provides the data prepared to undergo principal component analysis (PCA), the following processing step. Reducing the dimensionality of a data set that contains many related variables is the purpose of PCA. Every result is stored and plotted on the graph.

Nemo Handy is a tool to measure the strength of the signal at a base station. For data recording, data are recorded during the process of data collection by using the Nemo Handy smartphone. Data were recorded from the beginning until the end of the data collection for each person. Then, only RSRP and RSRQ parameters were selected for data select process. Then, for the data extraction process, all the parameters chosen were combined into one file in Excel format and extracted in the MATLAB software. For the graph plotting process, some coding was used to show the result of the data in a scatter graph shape. For the classification process, the result of the graph plotted measured the strength or weakness of the signal, by referring to Table 2. Then, the results were compared between human detection and Nemo Handy.

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Table 2: Table Network Performance

NETWORK PERFORMANCE		
PARAMETER / CONDITION	**RSRP (dBm)**	**RSRQ (dB)**
Excellent	>=-80	>=-10
Good	-80 to -90	-10 to -15
Medium	-90 to -100	-15 to -20
Weak	<=-100	<-20

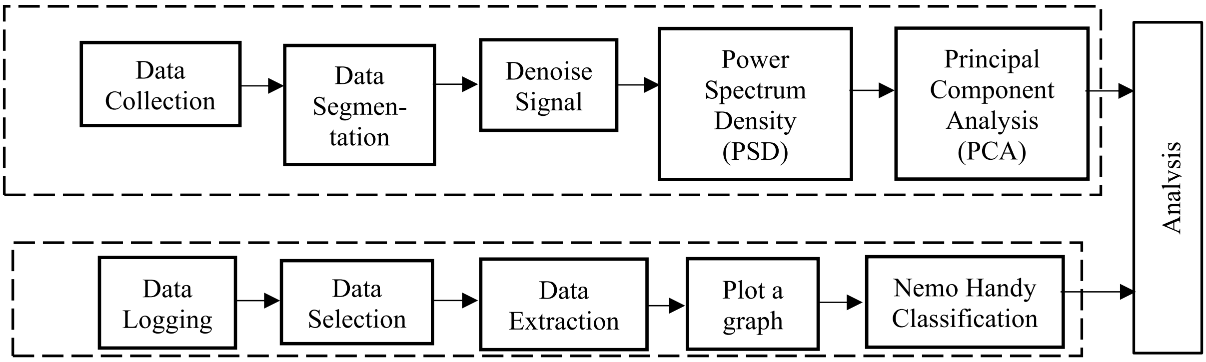

Figure 5: The Data Analysis Process Flowchart

Result and Discussion

Time Domain Following The Denoise Procedure

The results demonstrate the time domain data obtained using 1.8 GHz while two individuals walked successively between the transmitter and receiver. As a result, the amplitudes and diameters varied for each individual. The graph's green line denotes the Doppler signatures of Person 1, while the blue line represents Person 2. After the undesirable signal has been denoised, it also displays the signal's time-based domain. Because it was difficult for the algorithms to distinguish between noise and the Doppler signature, not all of the undesirable data was eliminated. As a result, three separate locations and four different times were used to produce the result.

The results for the time domain at four distinct times for two individuals in Batu Laut and Taman Suria are shown in Figures 6 and Figure 8, respectively. Because of their varied body dimensions, Person 1 (green) took longer in the morning and at night than Person 2 (blue). According to the Nemo Handy result, the signal strength was good at the moment, therefore the difference between the signals is visible. The results for the amount of time spent by Person 1 (green) and Person 2 (blue) significantly declined in the afternoon and evening compared to the results in morning and night. This is because there was not enough signal strength at the time to examine individual differences.

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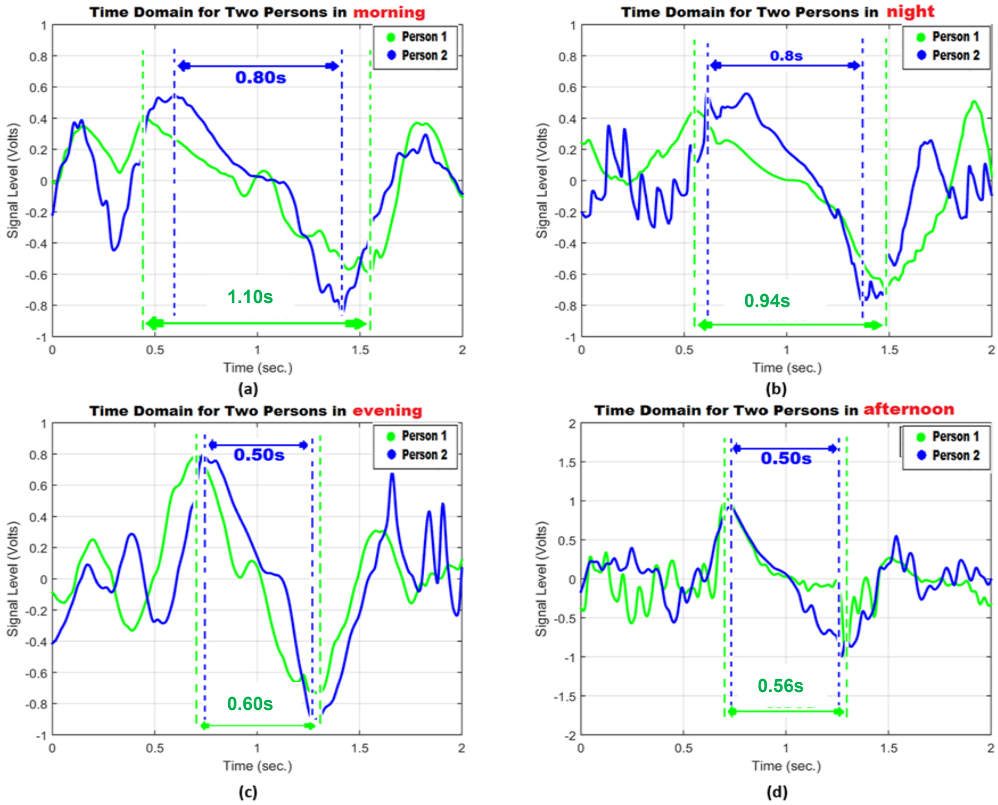

Figure 6: Two Person Time Domain at Batu Laut.
(a) Morning, (b) Night, (c) Evening, (d) Afternoon.

The time domain results for two individuals at Port Dickson at four distinct times are displayed in Figure 7. The findings were inaccurate in the morning and afternoon because, according to the Nemo Handy result, Person 2 took longer than Person 1 because of the weaker signal in the morning. Due to the disparity in their physical measurements, Person 1 spent more time at night and in the evening than Person 2. Since we can observe the differences for each individual, the signal strength was good at this time.

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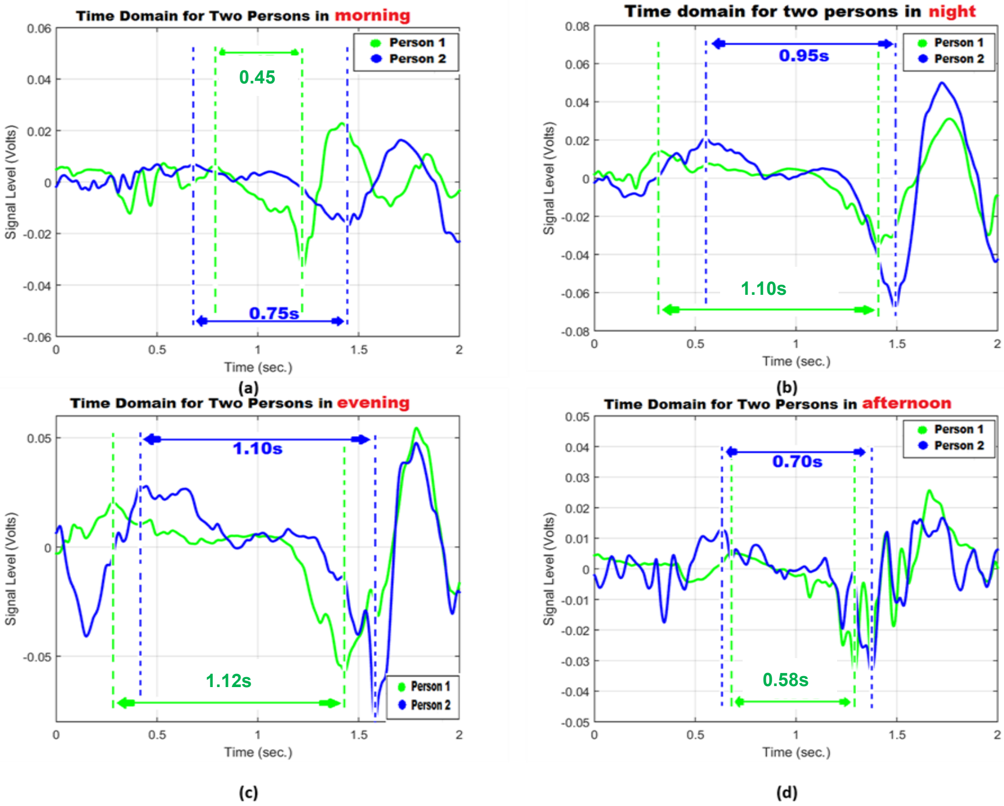

Figure 7: Two Person Time Domain at Port Dickson.
(a) Morning, (b) Night, (c) Evening, (d) Afternoon.

The results for Taman Suria are displayed in Figure 8. Because of their varied body dimensions, Person 1 took longer in the morning and at night than Person 2. According to the Nemo Handy result, the signal strength was good at the moment, therefore the difference between the signals is visible. The results for time spent by Person 1 and Person 2 significantly deteriorated in the afternoon and evening compared to the results in morning and night. This is because there was insufficient of signal at the time to examine individual variances.

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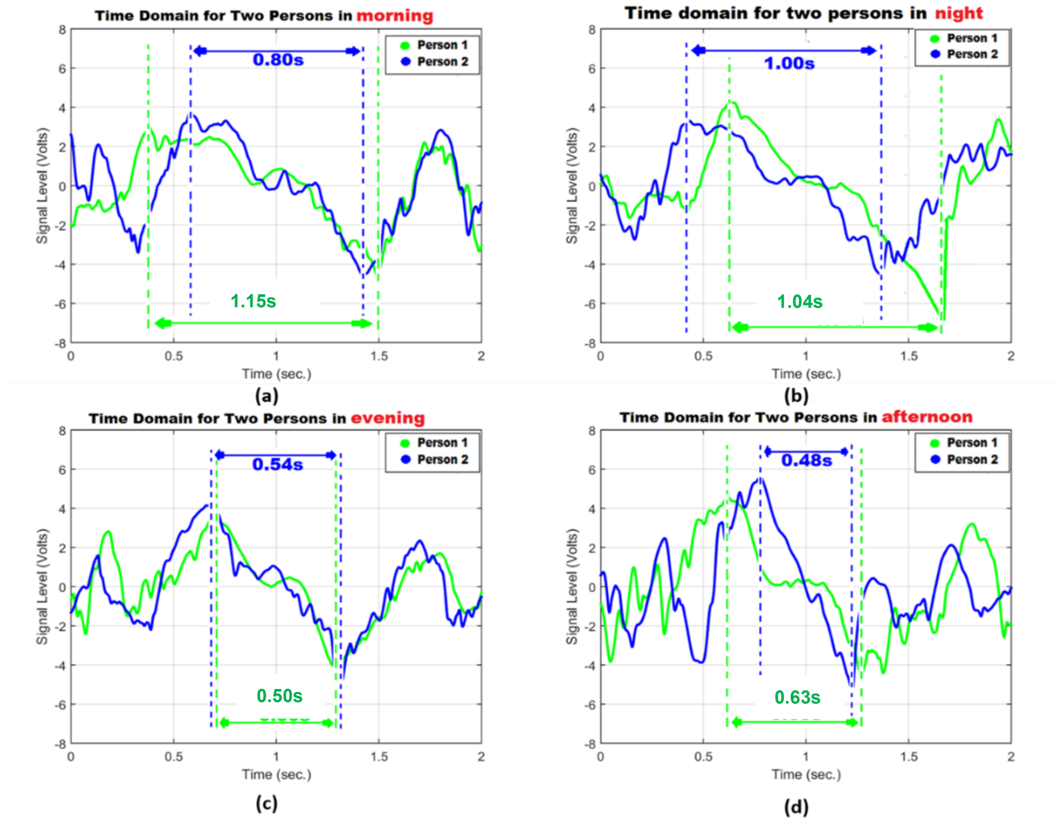

Figure 8: Two Person Time Domain at Taman Suria.
(a) Morning, (b) Night, (c) Evening, (d) Afternoon.

Power Spectral Density For Human Detection

The power spectral density for two individuals at three different locations and times is displayed in this section. The outcome compares the frequency (Hz) and normalized power (dB) for two individuals. Estimating the human range from the antenna receiver and displaying the size differences between each individual are the goals of this connection.

The power spectral density data for two individuals at various times in Batu Laut and Taman Suria are displayed in Figures 9 and Figure 10. Because each person has a distinct body size, Person 1 had a lower frequency (Hz) and a higher normalized power (dB) in the morning and at night than Person 2. According to Nemo Handy reading findings, the signal strength was in good condition both at night and in the morning. Due to the weak signal intensity in the evening and afternoon, Person 1's frequency (Hz) and normalized power (dB) values were lower than Person 2's.

The power spectral density results for two individuals at various periods at Port Dickson are displayed in Figure 11. Person 1's frequency (Hz) and normalized power (dB) were lower than Person 2's in the morning and afternoon. It is because of the poor signal strength at that time, which was affected by the difference between each person. At night and evening, Person 1 had low value of the frequency (Hz) and high value of normalized power (dB) compared to Person 2 because of the different dimension of body size and it was an effect of good signal strength at night.

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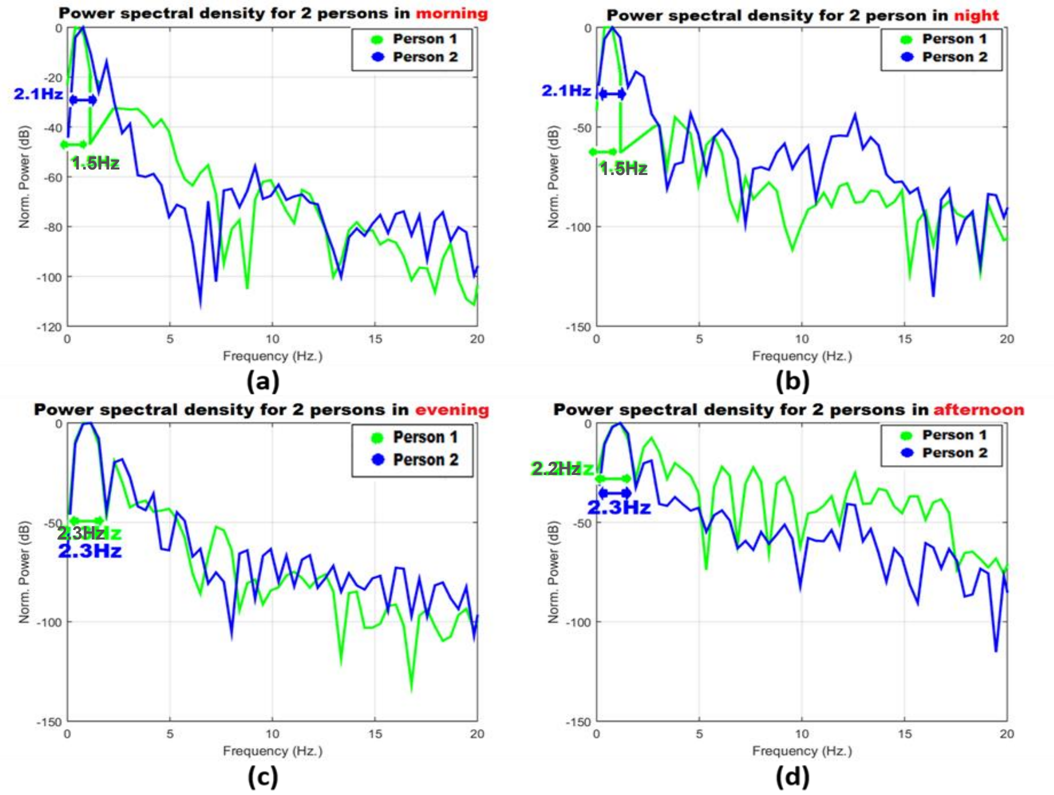

Figure 9: Batu Laut's Power Spectrum Density for Two People. (a) Morning, (b) Night, (c) Evening, (d) Afternoon.

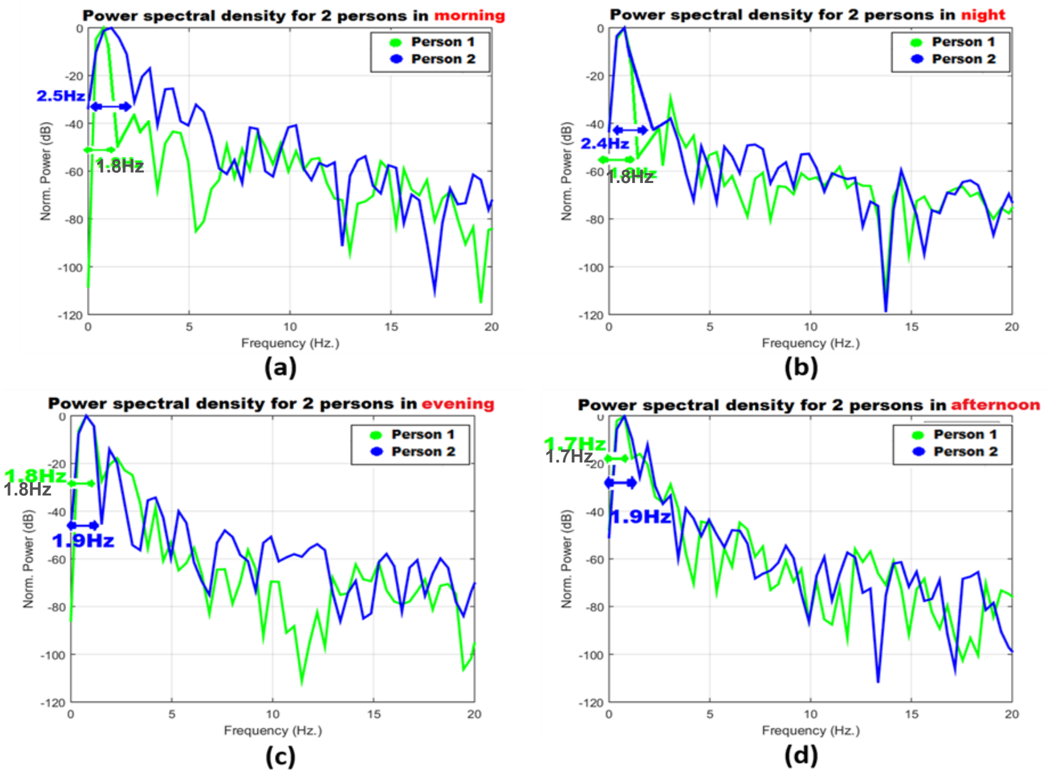

Figure 10: Taman Suria's Power Spectrum Density for Two People. (a) Morning, (b) Night, (c) Evening, (d) Afternoon.

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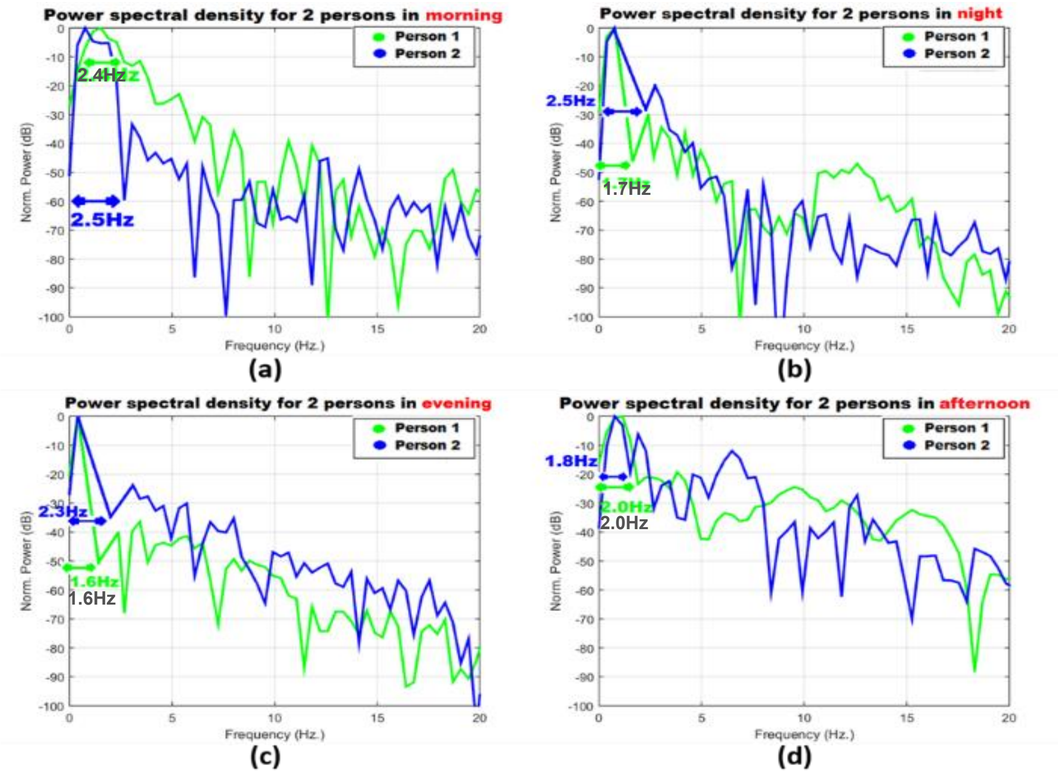

Figure 11: Port Dickson's Power Spectrum Density for Two People.
(a) Morning, (b) Night, (c) Evening, (d) Afternoon.

Principal Component Analysis

Using Principal Component Analysis (PCA), components of the processed data are transformed into principal components, which are linearly uncorrelated variables. The outcome displays the points that were separated and collected to illustrate the individual disparities. The combined data of two individuals at four distinct times and three different locations is displayed in the result.

The results of Principal Component Analysis (PCA) for two individuals at various points in time at Taman Suria are displayed in Figure 12. Both morning and nighttime results indicate that the data were well-classified as a group. The clusters for each individual at this time accurately illustrate how their body measurements differ from one another. Person 2's red dots are on the right side of the graph, whereas Person 1's blue diamonds are grouped on the left. The good signal strength at this time, as indicated by the Nemo Handy result, and the appropriate distance between the transmitter and the receiver during the experiment are the reasons for this good classification. The results worsened throughout the afternoon and evening, and the clusters are poorly ordered as a result of their mixing. This result is unable to demonstrate any differences in the two individuals' bodily dimensions. Nemo Handy's poor reading performance during the experiment is the cause of this outcome.

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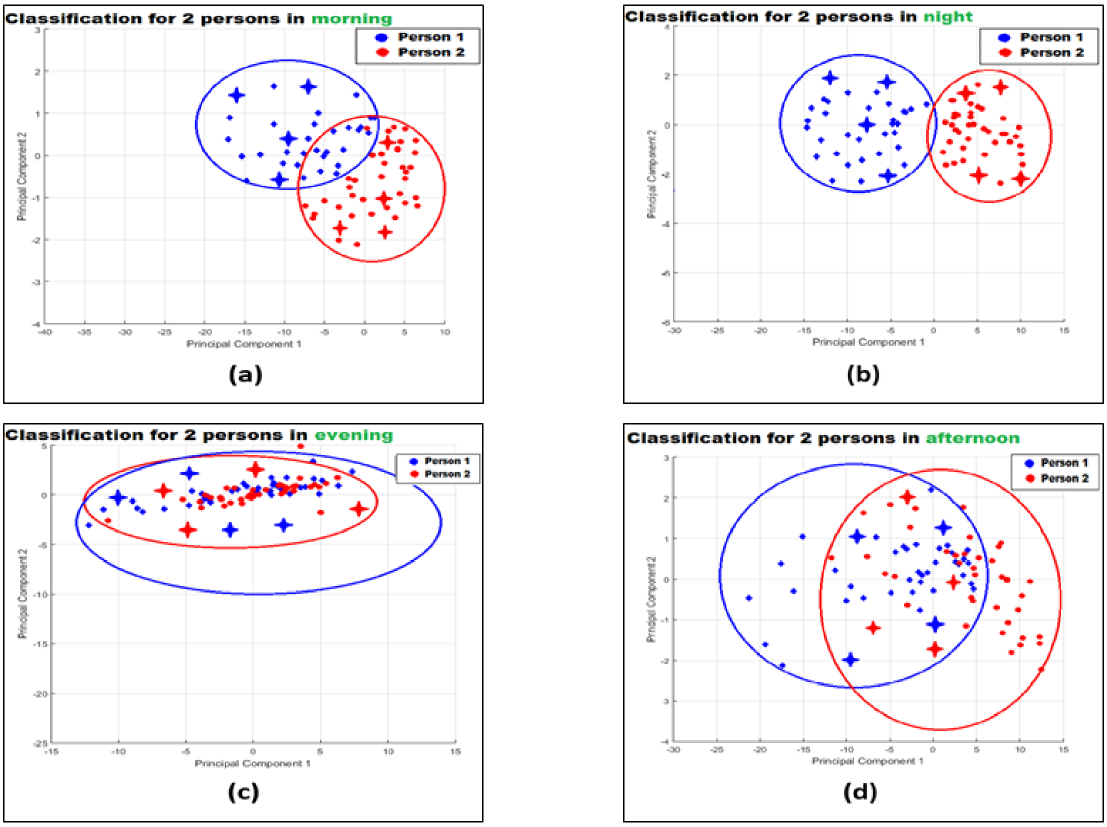

Figure 12: Taman Suria Principal Component Analysis for Two People. (a) Morning (b) Night (c) Evening and (d) Afternoon.

The results of Principal Component Analysis (PCA) for two individuals at various points in time in Port Dickson are displayed in Figure 13. Because we're unable to discern any distinction in the two individuals' classifications, the morning and afternoon results are the poorest.

Every individual's cluster is disorganized, and their data overlaps. This is due to Nemo Handy's poor result reading at the time, which had an impact on data classification. Because each person's clusters are neatly arranged in distinct groups and not mixed together, the classification results are good at night and in the evening. Because each person's physique is distinct in size, the findings clearly highlight their differences. This is due to the appropriate distance between the vendor's antenna transmitter and the experiment site receiver, as well as the strong signal that the Nemo Handy at the time measured.

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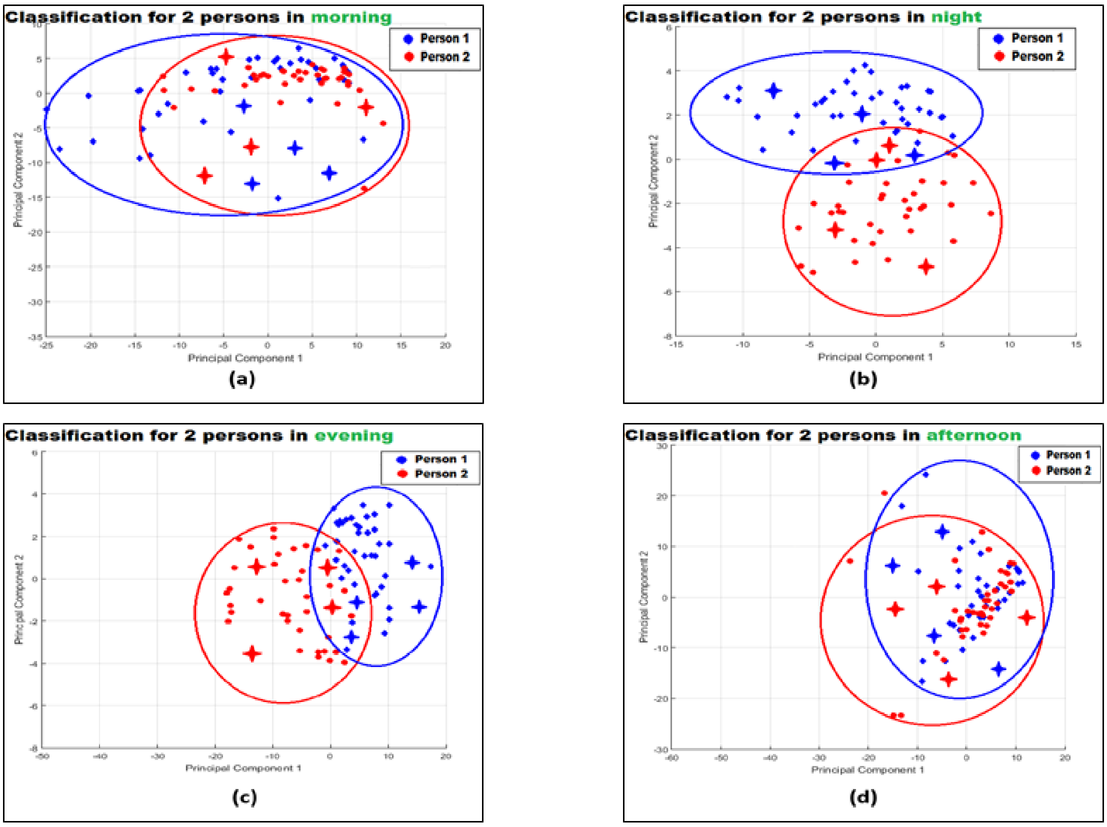

Figure 13: Port Dickson Principal Component Analysis for Two People. (a) Morning (b) Night (c) Evening and (d) Afternoon.

Nemo Handy Analysis

The RSRP and RSRQ thresholds are critical metrics in the context of mobile communication networks, particularly in 4G Long-Term Evolution (LTE) which it measures the signal strength and signal quality, respectively, and play an important role in the communication system's performance. When it comes to radar classification, the correlation with RSRP and RSRQ thresholds can be analyzed in terms of how signal quality impacts radar detection and classification success.

The correlation of RSRP (expressed in decibels, dBm) with radar classification are when it the RSRP is higher typically indicates a stronger signal, which means the device has a better connection to the base station and less interference. This increases the likelihood of accurate detection of radar signals because the communication system can more easily differentiate between the desired radar signals and noise. While lower RSRP can result in poor signal quality, making radar classification more challenging. Weak signals are prone to interference and fading, which can lead to incorrect classification or failure to detect radar signals properly.

Furthermore, the correlation of RSRQ (expressed in dB) and radar classification are when a high RSRQ value indicates better signal quality, meaning the signal is less affected by noise and interference. With better quality, radar signals can be detected more accurately, and classification algorithms are more likely to succeed. While, lower RSRQ indicates poor signal quality, which may result from interference, weak signals, or multipath fading. In these cases, radar signals may be harder to distinguish from noise, leading to classification failures or errors.

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Based on RSRP versus RSRQ data, Figure 14 classifies Persons 1 and 2 at four distinct times in Batu Laut. The results show that the morning and nighttime RSRP versus RSRQ measurements are within the excellent range. The value was between -10 and -4 dB for RSRQ and less than -80 dBm for RSRP. The RSRP and RSRQ readings were in the moderate range in the afternoon and evening which the RSRQ ranged from -16 to -20 dB, while the RSRP value was between -95 dBm to and 110 dBm.

Figure 15 classifies Persons 1 and 2 at four different times in Port Dickson. According to the outcome, the RSRP against RSRQ values in the evening and at night fell between the excellent and good ranges. The value of RSRP for both people was between -70 dBm to -83 dBm. The value of RSRQ for both people was between -7 dB to -13 dB. Both individuals' readings of RSRP vs RSRQ in the morning and afternoon fell within the moderate and poor ranges.

Based on the RSRP versus RSRQ data, Figure 16 classifies Persons 1 and 2 at four distinct times in Taman Suria. According to the findings, the morning and nighttime RSRP versus RSRQ measurements fell between the good and excellent range. For RSRP, the value for both people were between -65 dBm to -85 dBm. For both individuals, the RSRQ value ranged from -6 to -13 dB. Both individuals' reading results for RSRP against RSRQ in the afternoon and the evening fell into the moderate range.

When both RSRP and RSRQ exceed certain thresholds, radar classification systems have better chances of success because the system can detect radar signals with higher accuracy. The classification algorithms can differentiate between radar signals and interference more easily. When RSRP or RSRQ fall below a certain threshold, the classification performance tends to degrade. With weak or poor-quality signals, it becomes difficult for the radar system to correctly identify and classify the radar signals, leading to a higher likelihood of misclassification or missed detections.

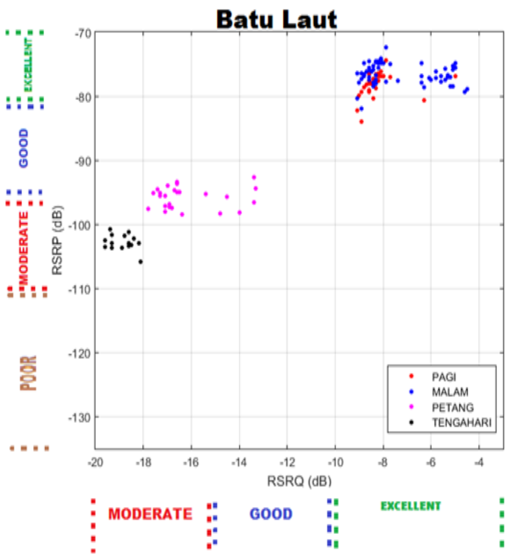

Figure 14: Classification of Nemo Handy at Batu Laut.

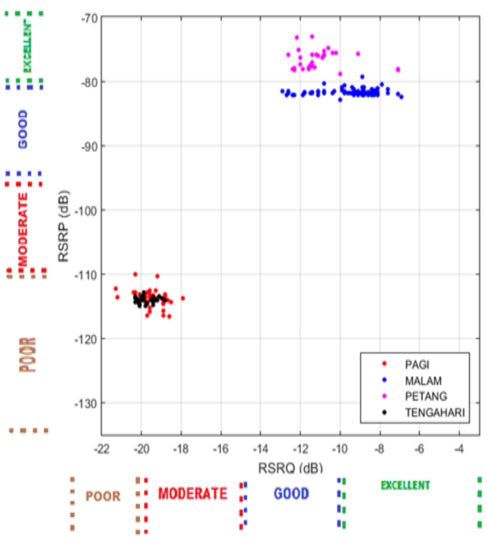

Figure 15: Classification of Nemo Handy at Port Dickson.

Taman Suria

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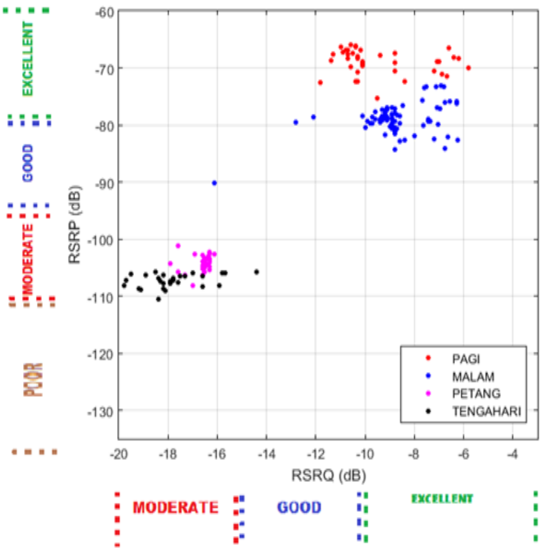

Figure 16: Classification of Nemo Handy at Taman Suria.

In summary, radar classification success is positively correlated with good RSRP and RSRQ thresholds. Higher RSRP means stronger signals, and higher RSRQ means better signal quality. Together, these factors increase the likelihood of successful radar signal detection and classification. When these thresholds are below the necessary levels, radar classification can be hindered by interference, weak signals, and low signal quality. Therefore, maintaining high RSRP and RSRQ is crucial for improving the accuracy of radar classification systems in environments where both communication and radar signals coexist.

Conclusion

In summary, this project was successful because it concentrated on the Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) parameters that help the passive forward scattering radar system, which allowed it to detect the signal strength of the 4G LTE network. Due to Reference Signal Received Power (RSRP) values below -80dB and Reference Signal Received Quality (RSRQ) values below -10dB, nighttime was the optimal time of day for all locations. That is why it gave the best performance for human detection and classification. For future recommendations, this passive forward scattering radar could be evolved into an autonomous system that detects the presence of humans and provides Doppler signature findings in under a minute.

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