Recognising People Using Smart Phone Antennas A Fuzzy Biometric

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Abstract

Many calls are made to mobile phones by machines and for nuisance avoidance it would be useful to know if the caller was human or not. Also for convenience it would also be useful to know if the person using a mobile was the same as the one normally using it and if that person was an adult or a child. A wrong result could be used to trigger a request for a key code. Using the hand and four mobile frequency band antennas this paper has investigated the effects of different people on the input impedance of mobile phone antennas with the aim of establishing whether the effect is distinct enough to allow a fuzzy biometric to be achieved. Hands were placed at a range of distances from the antenna, using a test rig designed specifically for this experiment. The frequencies of operation were 900 MHz, 1800 MHz, 1900 MHz and 2.4 GHz. Results showed that the effect of each volunteer on the antenna's input impedance varied significantly when their hand was 30 mm or less from the antenna and that below 10mm they were distinct between volunteers.

1 Introduction

Humans affect various measurable antenna parameters when their head or hand is near them [1-6]. One of these parameters includes the input impedance of an antenna [1,4,6]. It has not yet been investigated whether each person affects an antenna's input impedance uniquely. It may be possible to use the input impedance of smart phone antennas to recognise a person, providing each person has a unique effect on the input impedance. If it is possible to recognise different individuals using smart phone antennas, there could be several uses for this technology.

Many mobile phones currently have several authentication methods including passcodes or personal identification numbers (PINs) and biometric methods such as fingerprint, facial and iris recognition [7]. However, passcodes or PINs can easily be shared or stolen [8] and there are issues of spoofing where current biometric methods are concerned [9]. Using the mobile phone's antennas could provide an additional authentication option to work concurrently with existing authentication methods or as a stand-alone option to replace them. This user recognition method could be used to either unlock a mobile phone, or as a method of recognising who is using the mobile phone after it has already been unlocked. This could provide the advantage of restricting the user's access to certain content on the mobile phone, depending on the user. Another use of this recognition technology could include recognition of a person to provide them with a personalised 'set-up' for shared devices or items. An example of this could include a car shared by a family, where use of the recognition technology could set the car seat into the preferred position automatically for the user.
There has been research into the effects that humans have on the input impedance of an antenna. This research has been conducted for various reasons; some has focused on aiding the design of antenna impedance matching (AIM) circuits to counteract the effect, whilst others have investigated the effects of different grips on a mobile phone antenna's input impedance [10-12]. The experimental approaches used in these papers have included conducting tests with volunteers [11,12], phantoms [11] and simulations [10,12].

The factors that contribute towards effects on the impedance of a planar inverted-F antenna (PIFA) was investigated in [10]. It was concluded that the composition of the hand varied the effect on the input impedance; when the hand was modelled as muscle there was a greater effect on the impedance than when it was modelled as bone. This implied that the unique anatomy of a person's hand may cause unique impedance effects.

Comparisons between the effects that real people and phantoms have on the impedance of a mobile phone antenna were investigated in [11]. Although each person could grip the mobile phone with their hand in a way the individual considered natural, the grips were monitored and people were put into groups that had a similar grip. The results showed that those with a similar grip caused similar effects to the impedance, but every individual had a unique effect. It was concluded that the variation with user interaction was particularly significant in the lowest frequency band used during the measurements. A similar investigation was carried out in [12] which focused only on the effects on real people on a mobile phone antenna's input impedance. The same method of putting people into groups depending on their grip was used during testing and similar results were found to those in [11]. Those within the same group affecting the antenna in a similar way, but each input impedance measured was unique. This implied that the possibility of each person affecting an antenna's impedance uniquely existed and that recognition using antennas may be possible.

In this paper, the input impedance of an antenna was measured when a test volunteer's hand was placed above it at various heights, this was repeated with several different volunteers. The aim of these tests was to investigate whether each volunteer had a unique effect on the antenna's input impedance and if so, identify the distances at which these unique effects occurred. Measurements were taken at the following frequencies: 900 MHz, 1800 MHz, 1900 MHz and 2.4 GHz. The results from these tests are presented and analysed.

2 Procedure for Measurements

Experimental measurements were completed in the 5G Research Centre (5GRC) laboratory at Loughborough University. To take the measurements, a test rig was designed and manufactured. The test rig was designed using Siemens NX CAD software and then manufactured by Wolfson School Mechanical Workshop at Loughborough University, the design can be seen in figure 1. The test rig was constructed from Styrofoam, due to having a relative permittivity of ε_r=1.04[13] close to that of air which has a relative permittivity of ε_r=1.00[14]. Styrofoam is also relatively low loss. This ensured that the test rig caused no superfluous effects on the antenna under test. The test rig allowed the distance from the palm of the hand to the antenna to be varied from 205 mm to 45 mm in increments of 20 mm, and 30 mm when the platform was placed on the base.

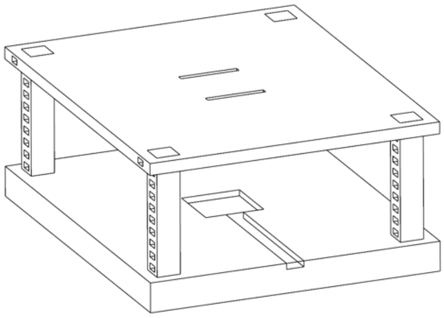

Figure 1: Test rig designed on Siemens NX

A portable vector network analyser (VNA) was used to take the measurements, the antenna was connected to the VNA with a 50 Ω coaxial cable. Whilst designing the tests, it was important to consider the systematic and random measurement errors that using this equipment could introduce [15]. To correct systematic errors which include imperfections of the VNA and test set up, the VNA and coaxial cable were calibrated with a one port calibration. "The 1-port calibration is an OSL (open/short/load) calibration that removes source match, directivity, and frequency response errors" [16]. To reduce random measurement errors the VNA was allowed to warm up sufficiently to decrease the effects of thermal drift. To ensure repeatability was maintained, high quality connectors and coaxial cable were used during testing. The cable's position was maintained throughout testing to sustain repeatability; the end of the cable connected to the antenna was in a fixed position to prevent any movement. Noise can also produce random measurement error, with thermal noise superimposed on measured values and the noise figure of the VNA [15].

Two different antennas were used, a tri-band antenna to measure at 900 MHz, 1800 MHz and 1900 MHz and an antenna to measure at 2.4 GHz. These frequencies were chosen as they are commonly used by mobile phones for cellular, Wi-Fi and Bluetooth communications.

Before volunteers were tested, the output power of the VNA was measured to ensure that specific absorption rate (SAR) regulations as specified by the International Commission on Non-Ionising Radiation Protection (ICNIRP) [17] were not broken, since test time was likely to take place over a one hour period with very short breaks between each measurement. Following measurement of the output power of the VNA and calculation of the maximum power density of the antennas, it was found that the ICNIRP standards were not broken.

Volunteers selected for the experiments were aged 19-23 years old and a combination of males and females. The volunteers were instructed to wear appropriate clothing, remove any jewellery and ensure that their hands were dry to prevent any superfluous effects on the antenna.
During testing, the experimental set up consisting of the test rig, antenna, coaxial cable and VNA were placed on a wooden table. The volunteer sat at the table on a wooden stool as shown in figure 2 and was instructed to place their hand on the test rig, with their fingers together, thumb as close to the index finger as possible, palm flat and sat at a position in which the wrist and arm were straight as shown in figure 3. The test rig allowed for the volunteer to lightly rest their hand and forearm on the rig, to prevent straining and therefore, prevented movement of the hand which may have affected results.

To begin testing, the antenna was fixed in a position on the test rig, that ensured that the volunteer's hand was directly above it. One end of the coaxial cable was then connected to the VNA and the other end connected to the antenna and was fixed into place on the rig to prevent any movement. On the VNA, in the measurements menu, S_{11} was selected and then log magnitude to set markers to the required frequencies for the antenna under test. The smith chart measurement was selected to measure the complex input impedances of the antennas, the magnitude of the input impedance measured was calculated after testing. The impedance of the antenna under test was measured prior to a volunteer sitting at the table, to attain a free space measurement for each test rig height. The volunteer sat on the stool and placed their left hand on the test rig, input impedance measurements were recorded. Then the right hand was placed on the test rig and measurements recorded. This was repeated for each available height on the test rig. Further tests to measure at distances of 25 mm, 20 mm, 14 mm, 13 mm and 12 mm between the hand and antenna, involved removing the test rig's original top platform from the rig. This was replaced by Styrofoam sheets of various thickness, placed directly on the base platform of the test rig. Measurements were conducted in an identical manor to those which used the original test rig platform.

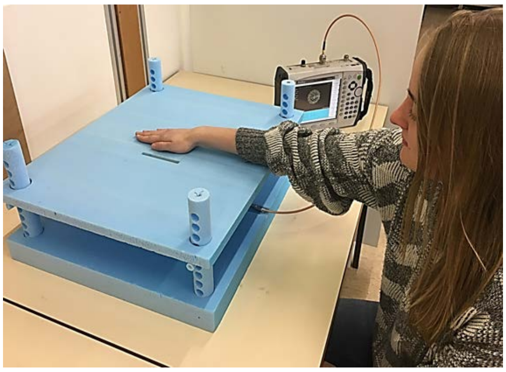

Figure 2: Experimental set up including the test rig, VNA, coaxial cable, antenna and volunteer

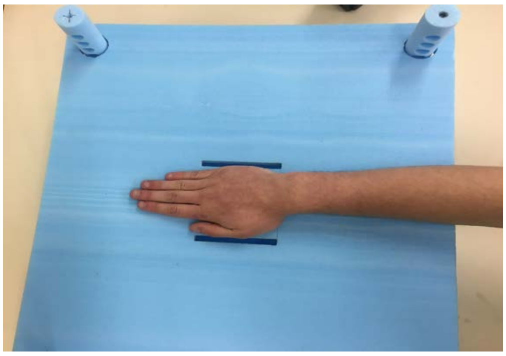

Figure 3: Correct test volunteer hand positioning with fingers together, hand flat and within the predetermined region

Initially, each volunteer was tested independently. However, it was found that test results were better to be compared to each other when all volunteers were tested together, in one session. This is because, although the test rig and VNA were set up in the same position with the coaxial cable and antenna fixed into place for each test session, free space impedance measurements were slightly different. Therefore, all further measured input impedances were affected and could not be compared with measurements from other test sessions.

3 Results

Initial results showed that the input impedance measured was very similar for each volunteer at distances of 30 mm to 205 mm between the hand and antenna. Figure 4 shows the results from the initial tests comparing two volunteers at the four chosen frequencies. There were very slight differences at the distances tested, but not by a considerable margin. It was clear that each person did not affect the input impedance uniquely at these distances. This was consistent across the four different frequencies and for both the left and right hand of each volunteer.

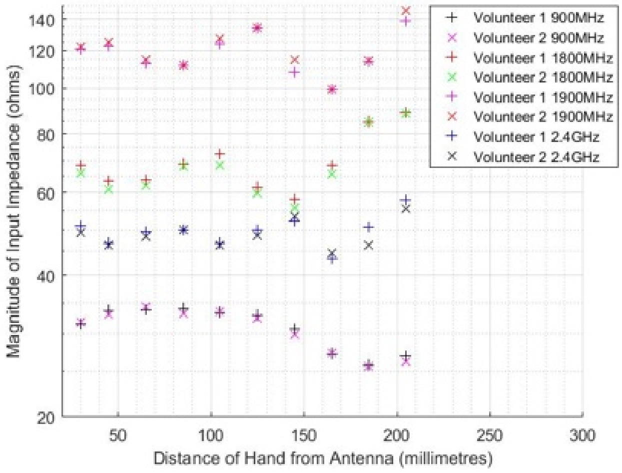

Figure 4: Comparison of measured input impedance at 900 MHz, 1800 MHz, 1900 MHz and 2.4 GHz with two volunteers during initial testing, at distances 30 mm – 205 mm between the hand to the antenna.

When the tests had been modified to include distances of 12 mm to 205 mm, there were very similar results at 45 mm to 205 mm for each of the three volunteers tested. In general, for each frequency, noticeable differences of the effect of each volunteer were observed at distances of 12 mm to 30 mm. Within this range, it appeared that each volunteer affected the antenna uniquely.

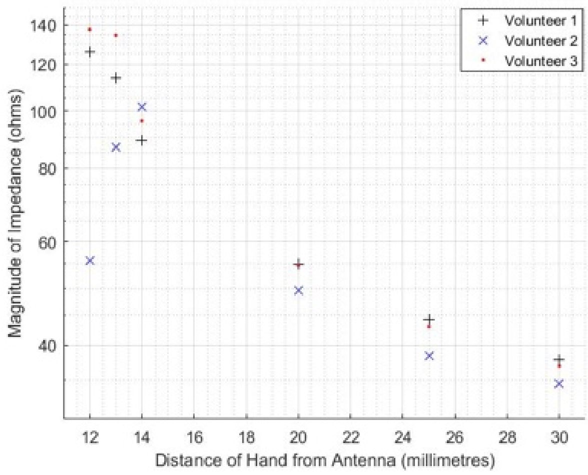

Figure 5: Comparison of measured input impedance at 900 MHz with three volunteers, at distances 12 mm – 30 mm between the hand and antenna

Figure 5 shows that at 900 MHz noticeable differences between the effects of each volunteer began to occur at 30 mm between the hand and antenna. At this distance, there was a 3.42 Ω difference between volunteer 1 and 2. Although, volunteers 1 and 3 had similar effects at 30 mm, 25 mm and 20 mm.

A greater separation was seen at 14 mm, with a difference of 12.66 Ω between volunteer 1 and volunteer 2's measured results. The difference between volunteers' effects increased, as the distance between the hand and antenna decreased. The greatest difference was at 12 mm; volunteer 3's result was 81.79 Ω greater than volunteer 2's.

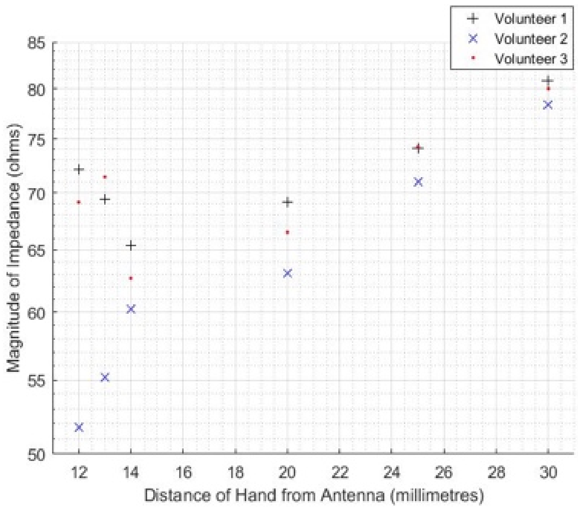

Figure 6: Comparison of measured input impedance at 1800 MHz with three volunteers, at distances 12 mm – 30 mm between the hand and antenna.

Figure 6 shows that at 1800 MHz, volunteers 1 and 3 had a similar effect on the impedance at 30 mm and 25 mm, whilst volunteer 2's effect was noticeably lower, as was observed at 900 MHz. At 30 mm, there was a difference of 3.29 Ω between volunteer 1 and 2's measured results. At 20 mm to12 mm the separation between each volunteer's results increased. The greatest difference was at 12 mm; volunteer 1's result was 20.42 Ω greater than volunteer 2's.

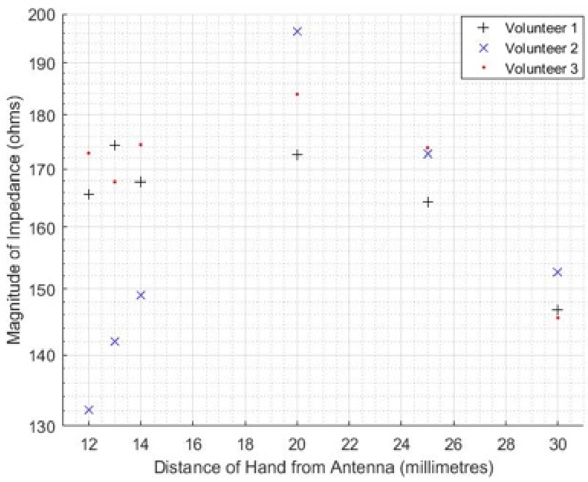

Figure 7: Comparison of measured input impedance at 1900 MHz with three volunteers, at distances 12 mm – 30 mm between the hand and antenna

Figure 7 shows that at 1900 MHz, the volunteers' effects on the impedances at distances of 30 mm and 25 mm, varied by 7.96 Ω and 9.51 Ω respectively. At 14 mm-12 mm the effect each volunteer had on the antenna became increasingly different, as the distance decreased. The greatest difference was at 12 mm; volunteer 3's result was 40.73 Ω greater than volunteer 2's.

Figure 8 shows that at 2.4 GHz, the measured impedances at distances of 30 mm to 20 mm, varied by approximately 3 Ω. There was a greater difference between results at 14 mm and 13 mm, with a difference of 11.42 Ω and 11.69 Ω between volunteer's effects respectively. There was less of a difference between each volunteer's effect at 12 mm; volunteer 1 had an impedance of 5.96 Ω greater than volunteer 2.

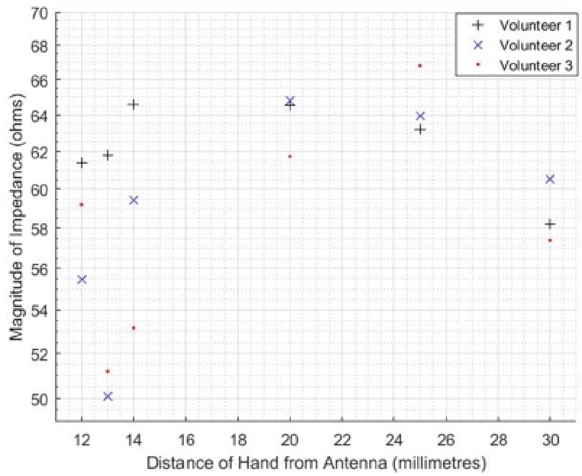

Figure 8: Comparison of measured input impedance at 2.4 GHz with three volunteers, at distances 12 mm – 30 mm between the hand and antenna.

The results for each volunteer's left and right hand effects on the input impedance were compared. Between the distances of 30 mm to 205 mm, the effects of both left and right hand of each volunteer were generally very consistent with one another, varying on average by less than 2 Ω. However, between the distances of 12 mm to 25 mm, there was more variation between each volunteer's left and right hand measured results. As the distance between the hand and antenna decreased, the difference in measured impedance of each volunteers left and right hand generally increased. This may be an indication that the closer the hand was to the antenna; the more positioning of the hand was a factor that affected the input impedance measurement.

For volunteer 1, the left and right hand results mainly agreed at each frequency between 205 mm and 25 mm. Figure 9 shows that at distances of 20 mm and less, left and right results did not agree as well as those at greater distances.

For volunteer 2, of 25 mm and below, left and right results did not agree as well as those at greater distances. Figure 10 shows that here were major variations at 12 mm for 900 MHz and 1800 MHz. the left and right hand results mainly agreed for each frequency between 205 mm and 30 mm.

For volunteer 3, the left and right hand results mainly agreed for each frequency for distances of 205 mm to 20 mm. Figure 11 shows that there was one major difference for 13 mm at 900 MHz. This could because volunteer 3 was the author and was therefore a lot more aware of hand positioning, having done more tests previously.

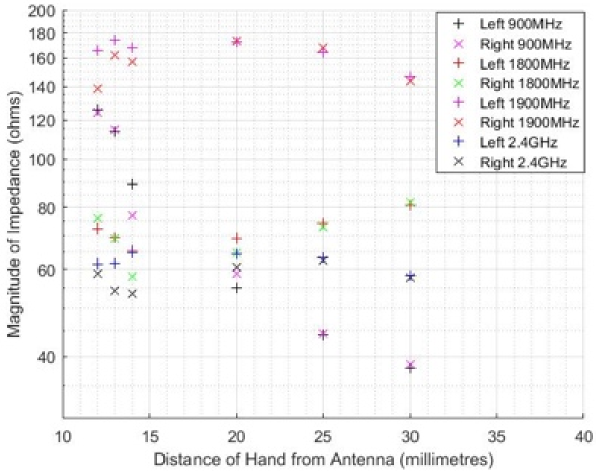

Figure 9: Comparison between the input impedance measured for volunteer 1's left and right hand at all frequencies, at distances of 12 mm to 30 mm

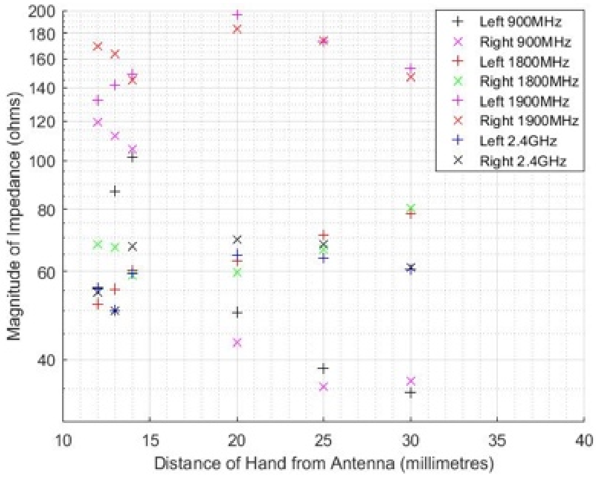

Figure 10: Comparison between the input impedance measured for volunteer 2's left and right hand at all frequencies, at distances of 12 mm to 30 mm

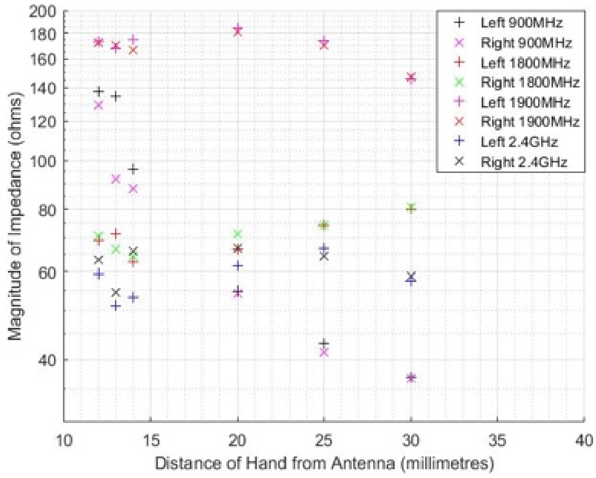

Figure 11: Comparison between the input impedance measured for volunteer 3's left and right hand at all frequencies, at distances of 12 mm to 30 mm

4 Conclusions

In this paper, the effects of different people on an antenna's input impedance, at a variety of distances between the hand and antenna, has been shown. Each volunteer had a very similar effect on the input impedance for distances of 45 mm to 205 mm between the hand and antenna. At distances of 12 mm to 30 mm, the effect that each volunteer had was significantly different from one another. This demonstrated that if different people do have unique effects on an antenna's input impedance, these unique effects would be seen at 30 mm or less between the hand and antenna. The effects that the volunteers had on the free space impedance of the antenna was greater in the lower bands, as in [11]. However, at these distances, there was also a noticeable variation for each volunteer between their left and right hand results, which suggested that the positioning of the hand affected results. It was clear the test rig did not provide an effective way of controlling a volunteer's hand. However, if the hand were to be constrained using a plastic housing to position the fingers and palm then more reliable results are expected. The effect of a plastic housing would be an attenuation in the real part due to loss and mismatch and a phase change due to altered electrical size. Measuring the back of the hand could be a method of measurement used to eliminate effects of individual palm distance; the back of the hand could easily be placed flat on a test rig. Measuring the back of the hand could use the same method as in this paper, moving the hand down towards the antenna but placing the back of the hand on the test rig. Alternatively, the test rig could be reversed, to move the hand up towards the antenna, whilst measuring from the back of the hand.

Once results have been gathered, the rate of change of impedance from position to position could be investigated, to see whether this is also individual to each person. The use of a neural network or a machine learning algorithm may be a beneficial method of using the impedances to match people, both of which are available in MATLAB® [18,19]. These algorithms would require training with a portion of the results obtained and therefore a larger number of results for each person would be required for a neural network or machine learning algorithm to be able to differentiate between each person. If a machine learning algorithm was the chosen method of finding patterns in results, the Classification Learner App in MATLAB® [20] could be considered in aiding the selection of the most appropriate algorithm.

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