HUMAN ACTIVITY CLASSIFICATION USING ON-BODY MINIATURIZED ANTENNAS

Thesis submitted to
Visvesvaraya National Institute of Technology, Nagpur
in fulfillment of requirement for the award of
degree of

Bachelor of Technology
In
Electronics and Communication Engineering

by

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under the guidance of

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Declaration

I, **Neha Yogesh Joshi**, hereby declare that this project work titled "**Human Activity Classification using on-body Miniaturized Antennas**" is carried out by me in the Department of **Electronics and Communication Engineering** of **Visvesvaraya National Institute of Technology, Nagpur**. The work is original and has not been submitted earlier whole or in part for the award of any degree/diploma at this or any other Institution / University.

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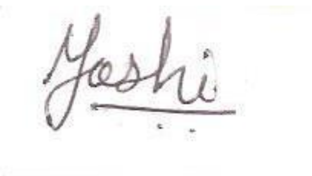

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Know 'everything' about 'something' & 'something' about 'everything'!

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Date: June 2020 **Neha Yogesh Joshi**

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LIST OF ABBREVIATIONS

HAC	Human Activity Classification
GHz	Gegahertz
EM	Electromagnetic
SAR	Specific Absorption Rate
VNA	Vector Network Analyser
DTW	Dynamic Time Warping
UWB	Ultra wide band
STFT	Short Time Fourier Transform
CP	Circular Polarization
SIW	Substrate Integrated Waveguide
ARBW	Axial Ratio Bandwidth
BW	Bandwidth
PDMA	PolyDiMethylSiloxane
BAN	Body Area Network
FCC	Federal Communications Commission
Eu distance	Euclidean distance

ABSTRACT

Human Activity Classification (HAC) is one of the most interesting area of research in current era as the world is witnessing an evolution from human assisted work to machine and robot assisted chores. Humans are being replaced by robots in most of the accuracy demanding applications. The most prominent area being medical treatments, the technical back-end needs to be very accurate. The applications where HAC is of prime importance are athlete training, surveillance, physiotherapy, robotic action classification, gaming etc. The performance of HAC has been done in literature traditionally by various methods like optical motion capture system, image analysis, video analysis, sensor based classification and so on. However, all these methods face some or the other limitations. The methods either have low accuracy or are totally unaffordable. Thus, a simple, affordable and user friendly HAC setup is highly desirable.

The present work focuses on HAC using on-body miniaturized antennas. The activities performed by the user are classified using the real time return loss performance of the antenna. The antenna is tied on strategic positions on human body and then if the action is performed, the specific obstruction of EM waves lead to unique and distinct channel features for different activities. These channel features are exploited to classify the activity. The designed antennas are compact and safe for on-body use. We have proposed total 4 antennas for this purpose and all of them can individually perform activity classification when tied on body.

The final deployable device would be battery based so 2 of the used antennas are designed to be circularly polarized for minimum battery drain. The antennas are of the size of human wrist watch. Finally, an ultra-thin flexible antenna is designed, fabricated and tested on human body. The entire testing set-up has been demonstrated and 3 different activities are classified successfully using the 4 designed antennas. Dynamic Time Warping (DTW) algorithm has been used for the signal processing of the obtained channel features. The classification accuracy was found out to be 99.375 % and 95% respectively on individual and average basis for the considered test cases.

CHAPTER 1

INTRODUCTION

INTRODUCTION

Today, the entire world is travelling towards technological development and countries are striving hard to improve their working force. In order to allow humans do high proficiency tasks, it is important to replace humans from simple and time consuming tasks or the tasks requiring high accuracy which humans may not achieve. This replacement is obviously brought about by robots and machines. There are many other areas where humans are being replaced like athletic trainings, surveillance, high accuracy medical treatments etc. Thus, as machines perform the job of humans or assist people to perform it, there ought to be a mechanism for the machines to understand the human activity performance. Here comes the basic need of Human Activity Classification(HAC).

The performance of HAC has been done in literature through various methods including optical motion capture system, sensor based wrist bands, video recording based analysis, image capture and its analysis. These methods are discussed in the following sections in depth but all of them face some or the other limitation. Also, the methods are application specific. No methods is generic and all of them face the issue of being highly complex and costly. The methods are extremely bulky and face compatibility issues when used on human body.

There have been thousands of reports where the malfunctioning of machines/ robots assisting humans have proved fatal. The robots are employed in medical activities like surgeries to obtain supreme accuracy and to reduce the rate of unsuccessful operations due to the doctor's error. However, it has been reported in [1] that a robot surgeon had killed 144 patients, injured 1,391 and had malfunctioned 8,061 times in 2005 in USA. Similar case has been reported in [2] where a robot killed various workers in a manufacturing industry due to its dysfunctional behaviour. This clearly states the need of proper activity analysis which may give a feedback to the system so as to avoid fatal action performance.

It has been stated in [3] that horrifying malpractices are occurring in the area of physiotherapy where improper treatment has lead to permanent disability to thousands of people. There are also hundreds of cases reported where home-based physiotherapy has shown adverse effects on the patient's recovery. The patient is unable to decide the extend to which the injured body part needs to stretch. Similar occurs in case of athlete training where specific exercises are to be performed. These tasks need highly accurate compatible device to provide the activity feedback. We have also discovered that the spread of the deadly Novel Corona virus- COVID-19 can also be reduced using the concept of HAC. The virus spreads through direct contact with the infected and then touching own eyes, nose or mouth. The spread could be reduced if the person gets aware while performing the spread-specific activity and stops to perform it. Thus, the above informations drags me to work in the area of HAC as it is of prime importance in a spectrum of fields which are suffering due to inaccurate HAC.

1.1 Motivation

The substantial need for accurate and affordable HAC set-up was realized through various case studies. It has been stated statistically that thousands of people had witnessed irreplaceable and fatal losses due to inaccurate HAC by robots. Improper physiotherapy or athlete training has led to permanent disabilities in many people. All the issues can be solved by an efficient HAC system. The traditional techniques used for these purpose are very costly yet bulky and inefficient. This situation has inspired me to build up a simple and cost effective HAC set-up. It was studied from literature that antennas could be used for HAC. This can be done by exploiting the antenna channel features. However, no such practical system is built till date. Also, the antennas used in the previously proposed systems are impractical and unsafe for on-body use.

This gave a strong motivation to build a Human Activity Classifier which should be simple, easy to use, safe and flexible like a wrist band. It was kept in mind that the device, in its final deployment should be compact, energy efficient, simple to use and affordable. Keeping these aims in mind we propose -"Human Activity Classification using on-body miniaturized antennas".

1.2 Description of the System and the Overall Work

The overall work is summarized sequentially as follows:

1. Extensive literature survey was done in order to understand the traditional as well as modern methods to perform HAC. It was concluded from literature that one of the most novel but unexplored idea is to use antennas for HAC. The concept based on which the antennas classify human activities was then studied. It was found that when an antenna is tied on human body, the near field EM radiations of the antennas travel on the body. Now, as an action is performed, the channel features of the antenna change selectively with the action. The EM waves get perturbed and thus these channel features arise. The change in channel features is reflected in the input impedance and thus the return loss performance of the antenna. As a result, we find activity specific return loss signatures while measuring the real-time S11 characteristics of the antenna.

2. The main aim of the work is to miniaturize and optimize the antennas used. For this purpose 4 novel antennas were designed and the entire testing and classification is performed using these antennas individually. To study the benefits of various antenna features, two antennas were designed to be circularly polarized and one of the antenna is Ultra-thin and flexible. All the antennas are extremely safe for on-body use as found from SAR analysis.

3. The fabricated antennas were then used for testing and reference dataset collection using a VNA. The reference data set was collected using 10 subjects average aged 22 years and having mean 58.4 Kg weight performing 3 activities while the antenna was tied on their wrist.

4. The antenna was then used to classify the 3 activities using Dynamic time Warping (DTW) algorithm.

1.3 Challenges

The HAC using on-body antennas faced the following challenges which were fully overcome during the course of the project:

1. **Real time dataset collection**: The equipment used for real time dataset collection is a Vector Network Analyser (VNA). However, the feature of VNA required for dataset collection in real time mode was not available. Thus, we introduced a new method where the return loss is measured in real time on fraction basis while activity performance. This solved the problem of data collection. This also helped in reducing the number of sampled per activity dramatically as compared to the works in literature.

2. **Bending effect on return loss in flexible antenna**: It was predicted that the antenna resonance would vary as per the bending of the flexible antenna when tied on wrist like a band. A detailed study and measurements of the antenna was done employing different subjects to observe the resonance as a function of antenna's bending. However, the effect found was negligible and tolerable as far as the HAC application is concerned.

3. **Practical Deployment of the system**: The measurement and testing of the system was done using the VNA 9923 A. However, it is totally impossible to include a VNA in practical deployment of the system. The work previously done in the literature paved a way to get out of this issue since a miniature device which can monitor the S11 over real time has already been developed [4]. This could be used in final prototype of the device in place of VNA.

4. **Safety for on-body use**: The antennas used in literature for HAC are huge monopoles which were never tested to be compatible and safe for on-body use. Whenever we desire and EM device to work on human body, it must be tested with respect to its SAR. Thus, we developed a human wrist phantom on HFSS and then tested the SAR of the designed 4 antennas. All the antennas were modified in

design to make the resonance in place and to make the SAR value below the limit.

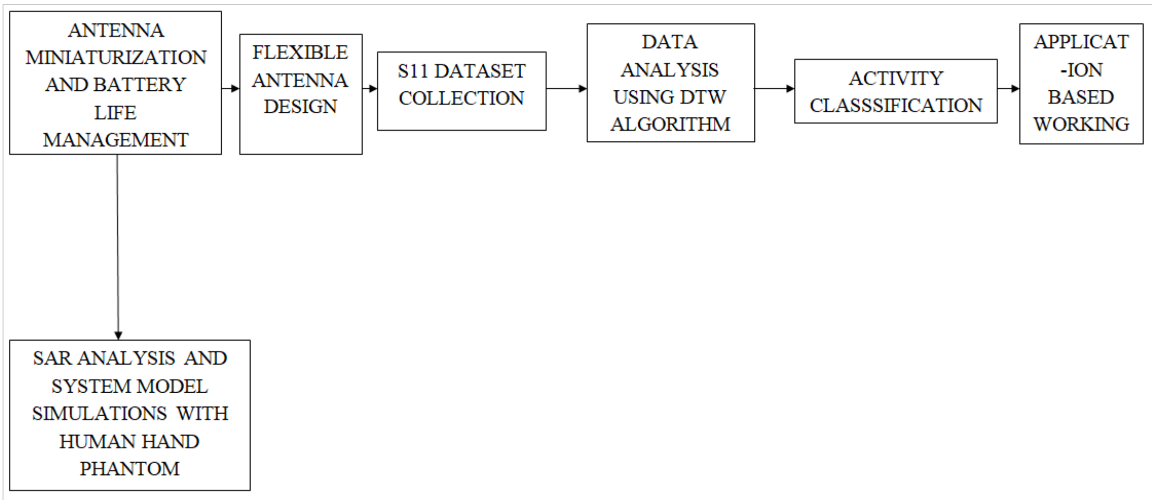


Figure 1.1: The project's block diagram

1.4 System Setup and Hardware specifications

The experimental equipment consists of a VNA and 1 meter long cable which connects the antenna to it. The set-up is shown in the figure 1.2 which demonstrates the data collection procedure also. The antenna used is VNA 9923 A. The data collected by the VNA gets stored in the connected USB drive. The collected data is in .csv format. Once the data is opened in the PC, it is plotted using microsoft excel and then analysed. The analytical study is done by accessing the data in matlab 2014b software. The codes related to DTW algorithm design, application and accuracy calculation are written in the same.

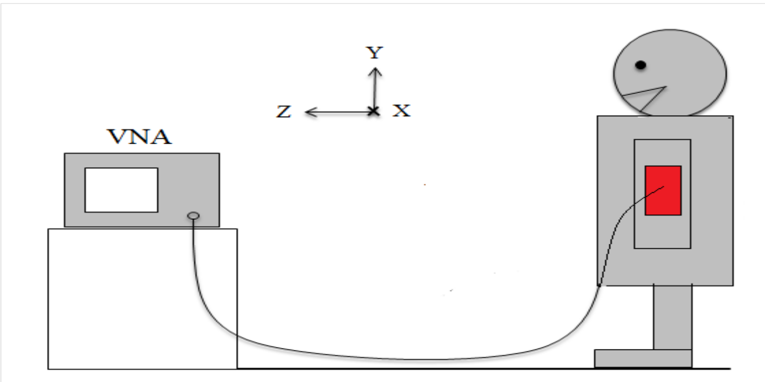


Figure 1.2: The experimental set-up animation

Figure 1.3: The Actual System model

The entire antenna design simulations were performed on HFSS 15.0 and then executed by fabrication on the selected substrates using itching procedure on a PCB printing machine.

1.5 Thesis Overview

The thesis is organized as follows: Section 2 gives a bird's eye view of the extensive literature survey done, Section 3 describes the antenna design and its performance. Section 4 gives an elaborate idea of experimental set-up and dataset collection. Section 5 finally describes the DTW algorithm and activity classification details. Section 6 concludes the work and describes its future scope.

CHAPTER 2

LITERATURE SURVEY

LITERATURE SURVEY

An extensive literature survey was conducted for selection and optimization of technique for HAC. It was understood that the performance of HAC can be done for a broad spectrum of applications ranging from medical care to gaming. The medical applications like robotic surgeries are very critical and here, HAC is used to provide feedback to the doctors and associated team regarding the activity performance. In case of any error, the corrective actions can be taken immediately. Thus, the loss due to malfunctioning of robots can be avoided.

Another application which our designed system can perform is security surveillance. The crowded places like airports and pilgrimages have huge threat of terrorist activities and these can be avoided by proper area surveillance. The proposed (an antenna band) can be given at the entrance of the place to be tied on the wrist. Any suspicious activity, including the band removal can be then classified and reported. Today, most of the games are having the feature of replicating player's actions and this can be done only because of accurate HAC.

Physiotherapy treatment is one of the major application of HAC. It is often observed that home-based physiotherapy proves dangerous as the patient may over-stretch or under-stretch the part under treatment. An efficient Human Activity Classifier can be employed here which will indicate the performance of incorrect action. Other common applications of HAC include military operations, dance posture correction, yoga posture correction, rehabilitation treatment etc.

2.1 Traditional Methods for HAC

It has been reviewed from [5] that an ocean of methods exist for HAC purpose which use vivid principles to classify the motions.

2.1.1 Video based HAC

The most extensively used method till date for HAC is video analysis. The video of the subject performing the activity is captured and further analysed frame by frame to get an idea of relative change in position of pixels. For this method to work in real time , live video streaming is required. The biggest disadvantage of this method is the need to handle large amount of data. For the method to work accurately, it is important that the video quality is proper. For this, the supporting resources like wireless connectivity, camera quality etc are also very important. Another issue faced by this method is latency in classification. The main shortcoming of video based HAC is its immobility. The activity to be classified has to be performed infront of the cameras allotted for the application. This makes the method non-compact and non-generic for its use in our desired applications.

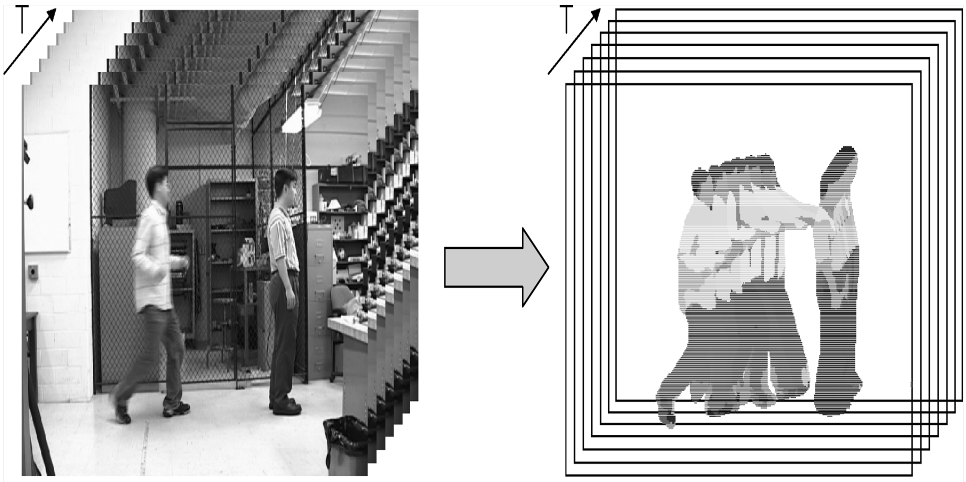


Figure 2.1: Illustration of video based HAC [5]

2.1.2 Graph based HAC

[6] describes a very interesting but complex algorithm for graph based HAC. In this particular method, the entire human body is modelled using lines and nodes. The nodes represent the body joints while the straight lines show continuous region of long bones and muscles. The idea is to plot the trajectory of the activity in the form of a graph which will be further analysed. This method involves large data aggregation as well as

processing. If a person needs to classify only an arm activity, still the entire body model gets analysed. This particular shortcoming makes the operation tedious and complex. Thus, graph based HAC is not preferred.

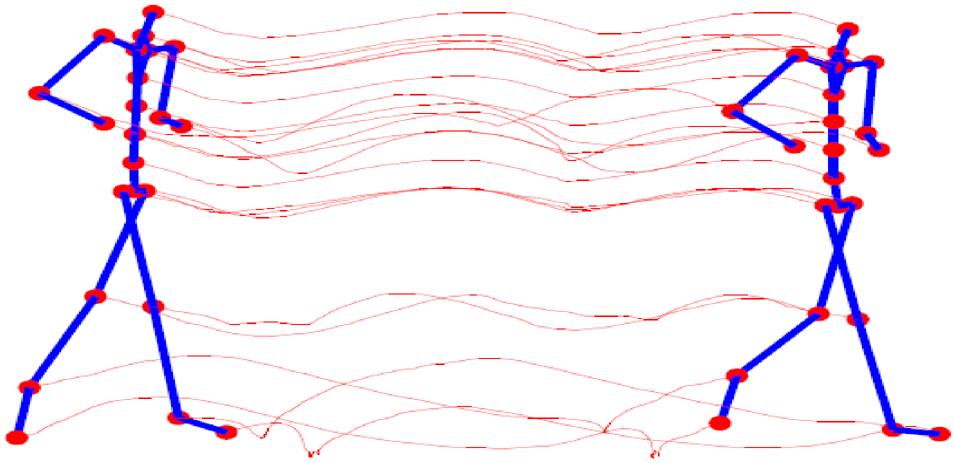


Figure 2.2: Illustration of graph based HAC [6]

2.1.3 Optical Motion Capture System

So far, Optical Motion Capture System is the most accurate HAC method discussed in the literature. The method involves multiple cameras mounted around the subject while he/she performs the activity. These cameras capture a full 360^0 view of the subject. As a result, complete information of the performed activity is available [7]. This results in very high accuracy. However the method is extremely bulky and non-portable. One can never think of using such apparatus for personal use. The set-up is extremely costly as well. As a result, the method is preferred only for high priority and accuracy seeking applications.

2.1.4 Sensor based HAC

Today, the most trending gadget in the world- the smart bands reply on some of the most common sensors for step counting, temperature monitoring etc. Same concept can be applied for specific HAC devices. HAC can be performed by an integrated result of readings given by various sensors like accelerometers, gyroscopes, magnetometers etc. These sensors measure the human motion based on the co-ordinates of initial and final position. Continuous monitoring of these positions can lead to classification of activities [8]. However, sensor performance is highly dependent on temperature, humidity, moisture etc which is completely environment dependent. Another possible disadvantage of this method can be encountered if any one of the integrated sensors fail. This would lead to complete collapse of the system. As a result, this method was also avoided in the work.

2.1.5 Antenna based HAC

A novel method of HAC has been described recently [9] where on-body antennas are employed for activity monitoring. Surprisingly, there is no physical image/video/ acceleration tracking done. The antennas when tied on human body, make EM waves in its near field to propagate on the body. As a result, when the body moves, these EM radiations gets perturbed. This perturbation results in creation of distinct channel features which reflect in the form of change in input impedance of the antenna. As a result, the antenna's return loss changes over time while activity performance in the same way every time the activity is repeated. Thus, distinct channel features are obtained in the real- time return loss performance specific to the activities considered. This particular feature is exploited to perform HAC using on-body antennas.

Kim. et.al. proposed 2 antenna system for HAC in [9] where one antenna is mounted on the chest while the other lies on the arm performing the motion. The transmission co-efficient(S21 parameter) of the two antennas is then analysed to get channel features. These signatures in S21 parameter along with individual antenna's S11 signatures were then converted to a spectrogram using Short Time Fourier Series (STFT). The spectrogram was treated as an image and HAC was done by the image classification method. The image classification is performed using Deep Convolutional Neural Networks. A very high accuracy of 98% was obtained using this method.

[10] proposed similar work by replacing the two antennas used by a single on body antenna. The antenna was employed on human arm and activity was performed. The antennas used in both [9] and [10] were rigid monopole antennas with no SAR analysis

before on-body deployment. The method in [10] uses lucid and robust DTW algorithm for analysis of the collected data. The method is successful in obtaining same accuracy as that of Kim's work with a single antenna.

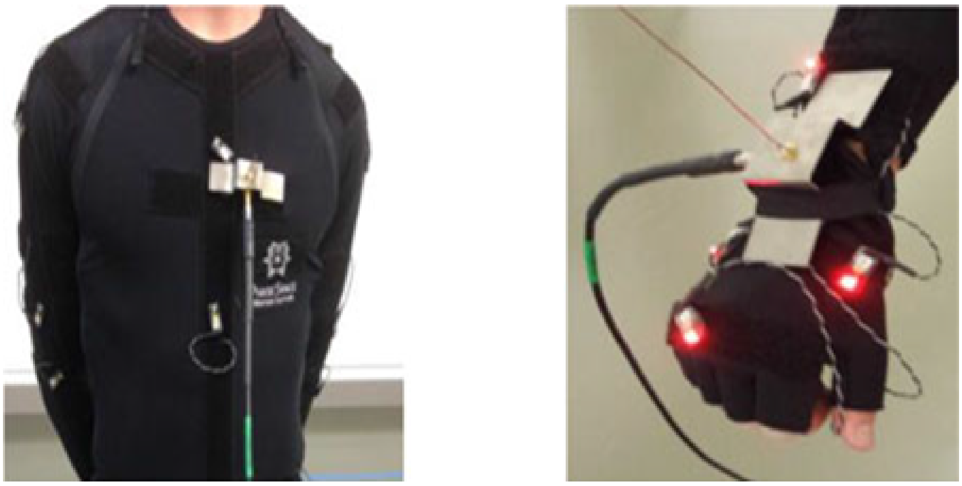


Figure 2.3: Set-up for HAC using antennas [10]

It has been proposed in [11] that human head and neck motions can be classified accurately using neck-mounted series of antennas. All these antennas were monopoles and multiple head and neck motions could be classified using these antennas. The method of data analysis used was similar to [9]. [12] describes similar method where micro-doppler signatures are studied and used to classify the activity. Spectrograms are plotted and Support Vector Machine(SVM) is used for data analysis. This method specially employs both transmitter and receivers to use the Radar working principle. It has been observed in [13] that hand gestures can be efficiently recognized and used to perform various applications if we can trace the variation in input impedance of the used on-body antennas. Transfer learning is used here for the analysis purpose. All the above methods using antennas for HAC have a similar flaw, these methods use large bulky and non-compact monopole antennas on body. It is impossible and non-practical to use such antennas on body of an athlete or a patient. These antennas were never tested with respect to their SAR and thus may not be safe for on-body use. The data processing involved is very tedious and time consuming. All these factors are considered and improved in our presented work. The optimal antenna placement was decided from the analysis stated in [14].

2.2 Circular Polarization in antennas for optimum battery usage

In order to acknowledge the fact that the final deployment of the designed setup would be in a battery operated system, it is tried to keep the antennas optimized for minimum battery usage. It has been stated and proved that antennas drain minimum battery when they are Circularly Polarized [15]. As a result out of the four designed antennas, two are designed to be circularly polarized. The literature has witnessed very robust and battery efficient operation of on-body antennas if the possess CP. The task of obtaining CP is not very simple but needs careful design and analysis. Two orthogonal modes need to get excited through the antenna feed in order to obtain CP.

There are numerous methods to obtain CP in an antenna. The most conventional method to obtain CP is to bring about asymmetric imperfections in the patch. [16] describes multiple ways to do this. Along with this the book explains dual feeding technique to obtain CP. Due to dual feed excitation at $\lambda/4$ path difference, two orthogonal modes in the antenna get excited and thus produce CP. The literature was extensively studied to understand novel and simpler techniques to make the antenna Circularly polarized. A SIW slot antenna has been proposed in [17] which shows excellent CP characteristics. The antenna radiates through the patch which has an X-shaped slot placed over the waveguide. The main advantage of these design features is minimum cross-polarization. From the point of view of transmitting information, the technique performs well, however such complicated structures are difficult to fabricate. High cross polarization rejection is not required in our designed system as no information is being transmitted. Similar SIW based Circularly polarized antenna is described in [18] which is relatively small in size but involves shorting pins. This increases the antenna complexity and cost. The antenna is multi-layered and involves co-axial feeding. We prefer microstrip line feeding over co-axial feeding to reduce the losses and trial and errors in antenna design process [19].

Dielectric resonator antennas are quite popular for obtaining CP. These are large number of papers in literature which claim good quality CP by the use of such resonators

[20], [21]. An antenna proposed in [22] has total 4 layers namely- copper patch, a layer of metallic and non-metallic vias, ground plane and feeding substrate. The simulation as well as the fabrication of vias is extremely difficult. The embedded resonator is told to improve the axial ratio bandwidth. At this point, it is important to note that an antenna is technically known to be circularly polarized if its Axial Ration is below 3 dB. Here the literature proved that use of dielectric resonators improves this ARBW.

A novel idea of using 2 parallel plates to obtain CP has been introduced recently. This technique uses the difference between the phase velocities of EM waves at the two plates to obtain EM fields which are Circularly Polarized [23]. The antenna structure is huge and rigid with a slot in the area between the two plates. The slot size now controls the impedance matching of the antenna. Another type of antennas used for obtaining CP is stacked patch antennas [24]. A stacked antennas designed in [25] has total 5 substrate layers and 2 of them are hollow (Air cavities). The antenna is also expanded in the form of an array to get improved results. Antenna arrays are proposed by many in the literature to obtain CP. [26] describes the design of low-radar cross section antennas which obtain CP via frequency selective absorbers. A 4 x 4 array of these antennas is formed to get CP. Another 1 x 2 antenna array is presented in [27] where short circuited metal patches form a single dipole. The antenna's size and shape is perfect for on-body application. However, design of such antennas for low frequency use is rare. This antenna shows CP at high mmWave frequency range. A wearable MIMO antenna is designed in [28]. The antenna performs exceptionally well in terms of ARBW. It has simple 3 layered structure with copper on both sides of the substrate. However, the MIMO antenna has 4 SMA connectors soldered which make it heavy and bulky for on-body use. An extensive study has been performed by placing the antenna on chest, hand and leg. The antenna was proved to be completely safe for on-body use. A miniature, body implantable, CP antenna has been developed in [29] which has wide impedance as well as ARBW. It consists of 2 shorting strips responsible for obtaining CP. It has very tiny dimensions and thus is ideal for use in BANs. Another CP antenna has been designed in [30] which utilizes the traditional spiral structure to obtain a very low value of Axial Ratio. The antenna has huge dimensions and thus is not-practically on-body deployable.

A number of techniques are discussed in order to get CP. A few more antennas are presented in Table. 2.1 to get an idea of performance of CP antennas with respect to their ARBW and resonances. It has to be noted that along with CP, the antenna also needs to be body-deployable. This is discussed in further sections. Till here, we have understood in depth all the traditional as well as novel techniques to obtain CP in an antenna.

Table 2.1: Characteristics of some CP Antennas in Literature

REF	RESONANT FREQUENCY	SIZE	RETURN LOSS	AXIAL RATIO	BW	ARBW
[31]	10.13 GHz	-	-45 dB	1.286 dB	500 MHz	80 MHz
[32]	2.45 GHz	$0.491\lambda * 0.491\lambda$	-45 dB	1.1 dB	182 MHz	40 MHz
[33]	5.75GHz	$0.86\lambda * 0.86\lambda$	-30 dB	1.9 dB	1.75 GHz	900 MHz
[34]	2.7GHz	$0.72\lambda * 0.72\lambda$	-20 dB	3 dB	1.02 GHz	590 MHz
[35]	1.61 GHz	$0.307\lambda * 0.307\lambda$	-35 dB	3 dB	60 MHz	45 MHz

2.3 Use of on-body Flexible Antennas for HAC

The entire world is moving towards flexible electronics for design of foldable and portable devices. The gadgets like smart bands, watches, conformable electronic devices like mobile phones, televisions not only add towards luxury and comfort but also brings about profound development. Thus, the final step of this project consists of design, fabrication, testing and dataset collection using Novel on-body flexible antenna designed by us. Various flexible antennas designed in the literature using different substrate material are elaborately discussed in this section.

An antenna has been designed in [36] which is fabricated on a paper based substrate. The antenna is directly printed on the paper which acts as a substrate. This work stands like a milestone in flexible electronics as very high frequency resonance was obtained for the 1st time in paper based antennas. Obtaining positive gains in dBi for flexible antennas is very difficult. However, the work has shown a considerable gain of 1.2 dBi. The antenna thickness is 250 μm. The antenna designed in [37] has been printed on resin coated paper substrate. The antenna feeding has been done by simple SMA connector. It has simple design and compact structure. The patch has inter-digitated capacitor finger like structure. The antenna performs well in terms of bending as well as gain. Another antenna proposed in [38] is a fractal antenna with multiple layers. It has two metallic patch layers and 2 substrate layers with a common ground plane. It has dual band resonance and excellent return loss performance. Irrespective of the antenna performance,its design simplicity is also important. The antennas with complex structure are very difficult to fabricate. A novel paper based flexible antenna has been implemented in [39] which uses graphene based ink. This ink is highly conductive and thus used for patch and ground plane design. The antenna patch has a snake like structure described as a dipole. The size and shape of the antenna makes it very ideal for on-body use like a wrist band. An innovative transparent paper like antenna is explained in [40]. The substrate is actually made up of transparent indium-tin-zinc film and thus can be used in wearable glasses application. The effect of the antenna on human eye and body in general is studied extensively and the antenna is found perfectly safe for on-body-near-eye use. Thus, paper based antennas are a good choice for BANs but face a few limitations. These antennas do not have a long life as they are mechanically weak and can get teared off easily. They also face serious limitations in the presence of water, humidity or sharp materials.

Fabric based flexible antennas also got a boost in the recent years are they are relatively stable and mechanically robust as compared to paper based antennas. An exceptionally innovative antenna is presented in [41] which uses PDMS material as a substrate while conductive fabric tissues for patch design. The antenna design is extremely inventive and creative. The antenna transparency is 0.5-0.7 out of 1 and it is fed using a simple SMA connector. The antenna works at multiple frequencies spanning over 1 - 25 GHz. Its gain and efficiency is phenomenal and its fabrication is quite simple once the substrate is available. Another fabric based antenna is designed in [42] which is

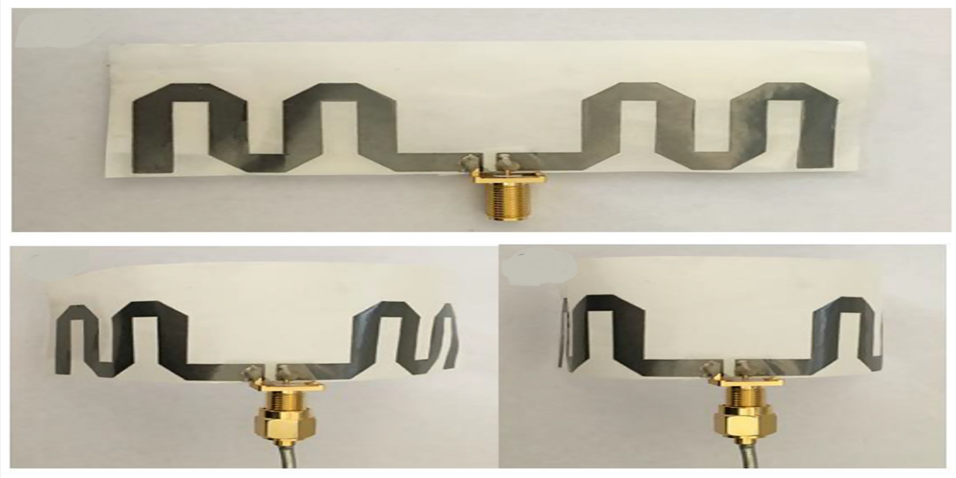


Figure 2.4: Paper based flexible antenna[39]

washing durable and can withstand same performance upto around 15 wash cycles. The patch design is simple with a slot on the top and a continuous ground plane. However, the fabrication process is quite complex and need advance technical equipments. Another subset of flexibility is the extent to which the antenna can be stretched. This particular feature has been explored in [43] which describes a stretchable E-fibre wire antenna. The antenna patch consists of a wire bent at different positions to obtain the desired resonance. It works at WBAN band of 915 MHz and proves that E-fibres can be used efficiently for antenna design. [44] and [45] have also discussed E-fabric based antennas which are flexible, compact and safe for on-body use. It has been noted that paper and fabric based antennas face mechanical limitations and thus a more stable and mechanically robust material is needed for antenna design for our on-body application.

Figure 2.5: Fabric based flexible antenna[45]

Finally, we discuss the use of ultra-thin Kapton polyimide based novel patch antennas to get full-fledged references for flexible antenna design. [46] describes the design of a compact, flexible Kapton-based antenna which resonates at 4 bands. The material used for substrate is mechanically robust, flexible, thin and easily available. The work explains the material properties in depth and compared it with other paper and fabric based substrates. The material has high tensile strength, dielectric strength and wide working temperature range. The patch printing on the substrate can be done in various ways like chemical etching, inkjet printing, flexography etc.

Figure 2.6: Kapton polyimide based flexible antenna[47]

A 130 μm thick flexible antenna is designed and tested in [48] which consists of Kapton substrate and polyaniline doped with carbon nanotubes as the conductive material. The antenna has been tested for 2 way simultaneous bending and performs well in terms of bandwidth as well as return loss. The antenna resonates at three commercially important frequencies and thus is very useful. A substrate slotted MIMO antenna is designed in [49] and fabricated using ink-jet printing. The overall antenna size is reduced by introducing two radiators on the same patch. This technique can be further utilized in any antenna design problem for its miniaturization. However, the antenna gain is extremely low and is negative in terms of dBi even at the resonance. The antenna needs further modifications in order to improve its gain. An antenna array is described in [50] which is utilized for IoT based smart skins. The antenna has a compact structure and can be safely used on human body.

2.4 The design principles of on-body antennas

When an antenna is designed for BANs,the EM waves radiated from the antenna must follow certain specifications. The credibility of an antenna for on-body use is measured using its Specific Absorption Rate (SAR) value. SAR is defined as the amount of energy an incremental mass of tissue absorbs in a given volume. This function is further integrated over the entire volume to get the exact value of SAR [51]. As per the universal limitations imposed by FCC and IEEE, the SAR averaged over the entire mass of body should not exceed the value 4 W/Kg. However, there are organ wise limitations imposed which protect the body from the harmful effects of EM radiations when exposed for long durations. The SAR value also depends upon the distance of the EM device form human body. The general limit of SAR for on-body devices is set to 1.6 W/Kg in American standards and 2 W/Kg in European standards. Thus, we will need to ensure that all the designed antennas should have an SAR less than 1.6 W/Kg.

For the SAR analysis of the designed antenna, we have designed a human hand phantom on HFSS. The antennas are destined to be deployed on human wrist and thus the same was simulated on HFSS. Various models for body phantoms are available in literature. The model and its layer specifications are position as well as operating frequency dependent. The frequency dependence of various body layers considered in phantom models is presented in [52]. The author has also described the simulation details like the distance between the antenna and the phantom in HFSS. The working human hand phantom model has been adopted form [53] in the present work which defined the human arm in three biological layers namely skin, muscle and fat.

Further details of phantom design and SAR analysis were referred from [54] and [55]. It is known that the value of thickness of skin layers differ from person to person but the minimum is considered such that if the antenna is safe on this phantom, it ought to be safe on any other actual human arm. Thus, the considered widths are 2 cm for skin layer, 3 cm for fat layer and 5 cm for the muscle. The antenna is placed just above this phantom.

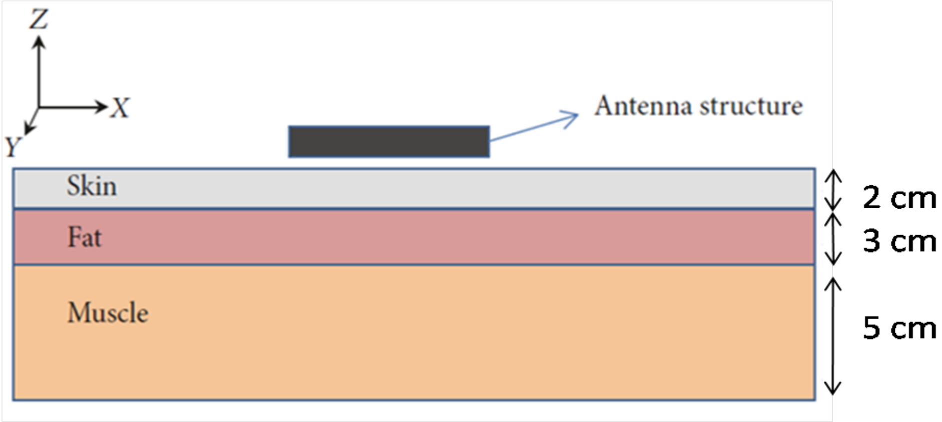


Figure 2.7: Human hand phantom model [53]

2.5 Dynamic Time Wrapping- the applied Signal Processing Algorithm

A vast literature study was carried on to find the perfect algorithm for the data analysis. It was known that the number of samples used should be minimum to reduce the computational complexity of the system. It was seen in [10] that Dynamic Time Warping provided an efficient platform for signal processing for HAC. [56] states that DTW finds out the inter-Euclidean distance between two temporal signals. This algorithm is successful to find the minimum degree of similarity between two signals inspite of variation in speed and phase between the signals. The algorithm is simple to implement and has $O(N^2)$ complexity. The figure 2.8 gives an idea of how the two signals are mapped with respect to their similarity.

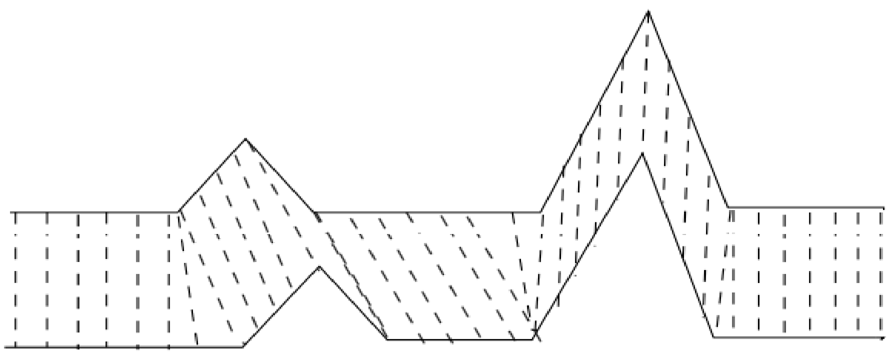


Figure 2.8: The dynamic time warping algorithm.

The DTW algorithm is implemented as follows-

1. Represent the two signals in the form of a 2D empty matrix with the sample values written at horizontal and vertical axis co-ordinates.

2. Apply the following rule to compute the matrix entries

$$DTW[i, j] := A[i] - B[j] + min(DTW[i-1, j], DTW[i, j-1], DTW[i-1, j-1]) \tag{2.1}$$

3. Now compute the distance between the two signals finding the least sum.

$$MinSum := CurrentSum + min(DTW[i-1, j], DTW[i, j-1], DTW[i-1, j-1]) \tag{2.2}$$

Thus, on the basis of MinSum, the test signal can be classified into different subgroups of the reference signals. DTW performs exceptionally well in [10] and gives about 98 % classification accuracy.

2.6 Desired system outcomes

- A compact antenna to replace the large rigid monopoles used in literature for HAC.
- Incorporation of Circular Polarization in the antenna to obtain battery life optimization.
- Miniaturization of Antenna to an extend of a wrist watch dial.
- Design, fabrication and implementation of an ultra-thin flexible antenna for HAC.
- data-set collection using minimum number of samples and performance of HAC.
- Improving the classification accuracy as compared to the work done in literature (maximum obtained in literature is 98%)
- Use of HAC using antenna (proposed technique and system) in prevention of the deadly COVID-19.

- Classification of multiple complex activities using the system for HAC.

2.7 Summary

The entire literature study was focussed on the design and analysis of on-body antennas for HAC and further the signal processing of the data obtained from the antennas. The first section explores the concept and related methods of HAC used previously and states their disadvantages. We further arrived on antenna based HAC and found the improvements needed for practical system deployment. From the battery life improvement point of view the CP antenna design was studied. In order to make the antennas deployment practical and comfortable, flexible antenna design was explored. Then we arrived on safety issues faced while design of EM devices for BANs. Finally the signal processing of antenna data was studied and DTW algorithm was learnt in detail. The next chapter begins with the designs of the proposed antennas and their results. The chapter also highlights the outstanding performance of the present system as compared to those in literature.

CHAPTER 3

PROPOSED ANTENNA DESIGN

PROPOSED ANTENNA DESIGN

The work focuses on design of optimized and miniaturized antennas, sensitive enough to change their input impedance with the channel features and thus show activity specific S11 signatures. We have also considered the battery life optimization and so incorporated CP in two of the used antennas. In order to make the antennas body deployable, their SAR values are brought below the limit in the simulation stage itself. As a final prototype, a flexible antenna is designed, fabricated and tested for HAC. In total, four antennas are designed and fabricated in the work as described in the subsequent sections.

3.1 A Rectangular Patch Antenna for HAC- Antenna 1

It was noted that a few people have performed HAC using antennas but all of them have used rigid monopoles, large in size and these can not be used in practice as the intended subject would be an athlete or patient or a robot. In order to solve this problem, all the antennas designed in this work are small sized patch antennas. The first antenna designed is a simple rectangular patch antenna working in ISM band commonly used in BANs ie. 915 MHz band. The antenna was designed by placing it on hand phantom. The antenna resonates at 915 MHz only in the presence of the phantom. The task of designing antennas specifically for HAC is a bit special as the sensitivity of the antenna needs to be checked. The is no proper tool to check the sensitivity in software but we can not fabricate the antenna without knowing whether it shows variation in S11 parameter while activity performance. Thus, the antenna's system model was also simulated in HFSS.

3.1.1 Antenna Design with Human Hand Phantom

It can be seen from the Fig. 3.1 that the antenna patch is a simple rectangle with a microstrip feed line given to it. It should also be noted that the ground plane is untouched in order to have design simplicity and thus is a plane rectangle of the dimensions same as that of the substrate.

The Figure 3.4 shows the HFSS model of the antenna with 3 layered hand phantom[53]. The substrate used is FR4 with dielectric constant 4.4 and loss tangent 0.02. The substrate is very easily available and low in cost. The antenna is relatively small in size as compared to the monopole antennas used in literature.

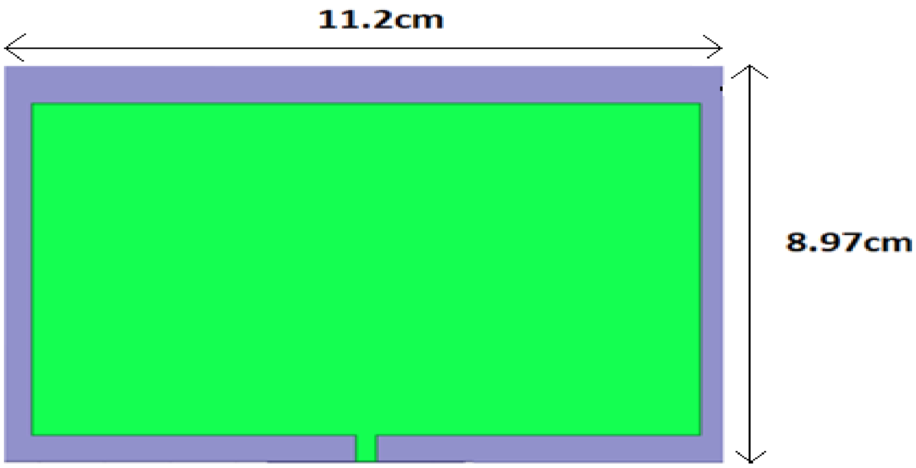


Figure 3.1: Patch Antenna of Antenna 1

The antenna was then fabricated and the results are mentioned in the subsequent sections. The simulated and measured results are in very good correspondence of each other.

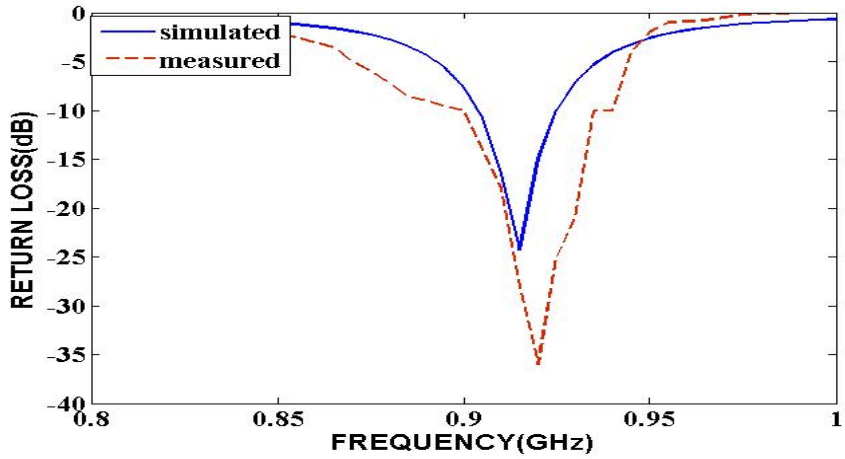


Figure 3.2: Comparison between the Simulated and Measured Return Loss of Antenna 1

The Fig. 3.3 depicts the smith chart of the antenna which proves perfect impedance matching.

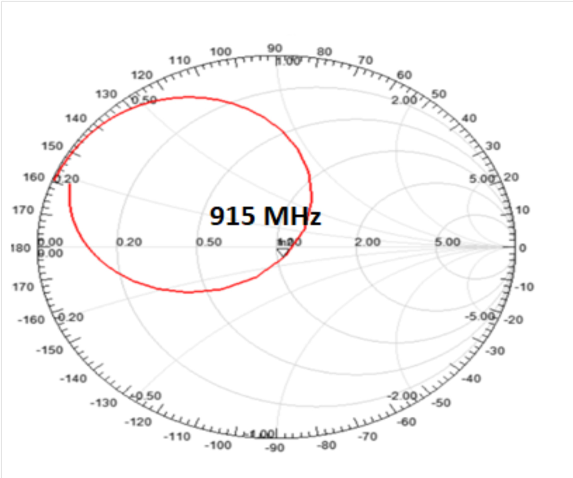


Figure 3.3: Smith chart for Antenna 1

3.1.2 The Antenna's System Model Simulation

The antenna's system model was simulated by keeping 2 similar antennas in same radiation box and then parametrically changing the distance between the two antennas. Fig. 3.5 depicts how the S11 varies with antenna motion. The parametric study basically varies the distance between the antennas in steps of 5 cm taking the practical values under consideration. The variation is done upto 60 cm distance between the two antennas. The antenna system model was simulated along with the phantom, thus the effect of EM waves travelling over the body is also considered. It has been state in [10] that if the 2 antenna system works, the single antenna system ought to work. Thus, the simulation was performed with 2 antenna system. It was found that the antennas worked well with respect to their sensitivity and thus can be used for HAC stet-up.

3.1.3 The fabricated prototype

The antenna was then fabricated and the prototype is shown in fig. 3.6

This antenna was further used for dataset collection and the collected data was analysed using DTW and finally HAC was performed. These steps are discussed in the next chapter.

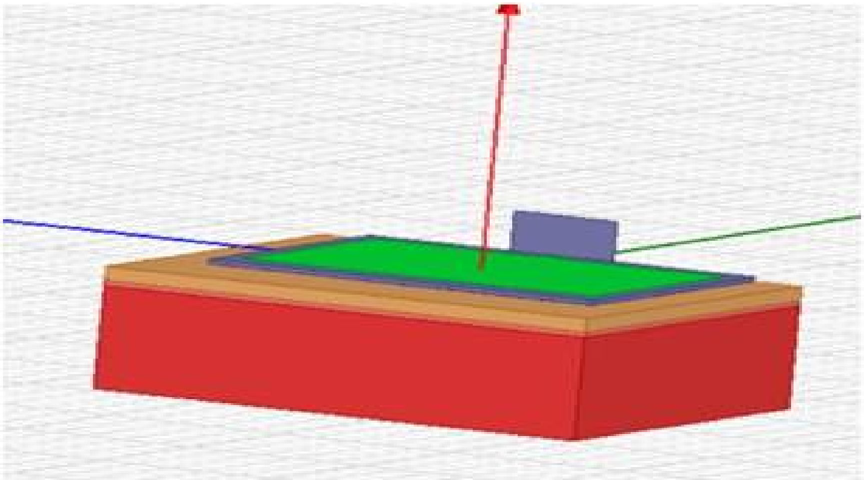


Figure 3.4: System model for Antenna 1

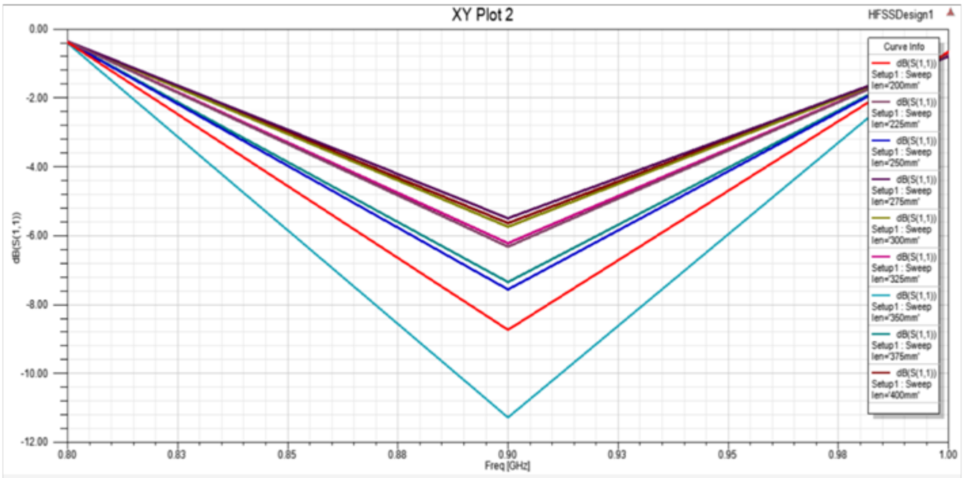


Figure 3.5: S11 variation in the System Model for Antenna 1

3.1.4 SAR Measurements of Antenna 1

The SAR measurement tool of HFSS was used to measure the antenna's SAR. It was found that in all the three layers of human hand phantom, the SAR is well below the limit. Thus, it was concluded that the antenna is safe for on-body use. The value of SAR in skin, fat and muscle is 0.11 W/Kg, 0.875 W/Kg and 0.019 W/Kg respectively.

Thus, the antenna 1 was analysed in depth with respect to its measured and simulated results. It was found perfectly fit for use in HAC.

- The antenna performed well but was slightly big in size when it comes to tying on wrist.

- The antenna drains huge amount of battery so we need to incorporate CP in the

Figure 3.6: The fabricated prototype of Antenna 1

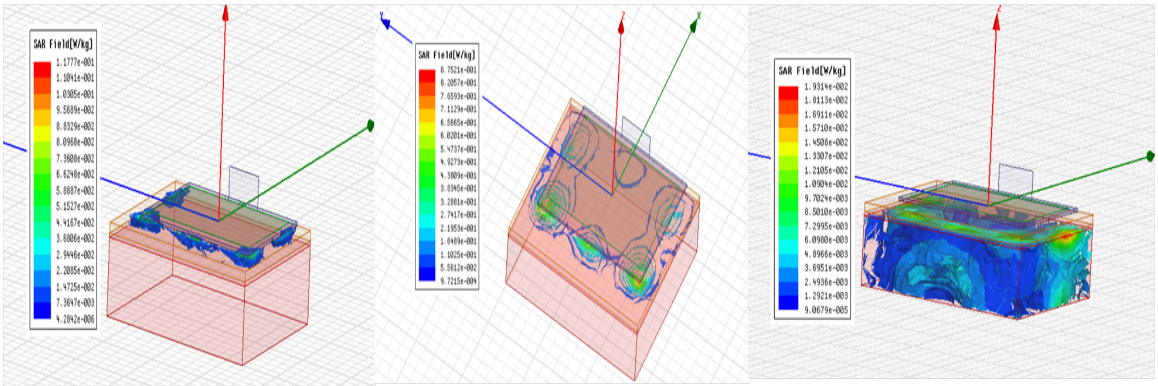


Figure 3.7: The SAR analysis for Antenna 1.

next step of antenna design.

These modifications are implemented in the next designs.

3.2 Design of a Circularly Polarized miniature patch antenna-Antenna 2

3.2.1 The antenna design

In order to optimize the battery life of the antenna, the antennas were designed to be circularly polarized[15]. The literature survey has paved various ways to bring about CP in the antenna[16-35]. The antenna 2 was designed using dual feed technique to make the antenna Circularly polarized. The dual feeding was done at $\lambda/4$ path difference on the patch. This leads to the generation of two orthogonal modes in the antenna and thus produce CP.

The antenna resonates at 7 GHz and is a simple circular patch with a smaller radius slot in it. As we have designed the complimentary ground plane, the ground is a circular area exactly coinciding with the slot in the patch. This forms the complimentary ground plane. The substrate used is FR4 with dielectric constant 4 and loss tangent 0.02. Except the dual feed, the antenna has no design complications. No shorting pin related issues are present. The antenna dimensions are of the size of a wrist watch dial. Thus, antenna 2 is more compact as compared to antenna 1 inspite of being CP.

The antenna design has been shown in the following figure. The detailed dimensions of the antenna are Ls=30 mm,Ws=30 mm,Ro=8 mm,Ri=7.1 mm,Wf=3 mm.

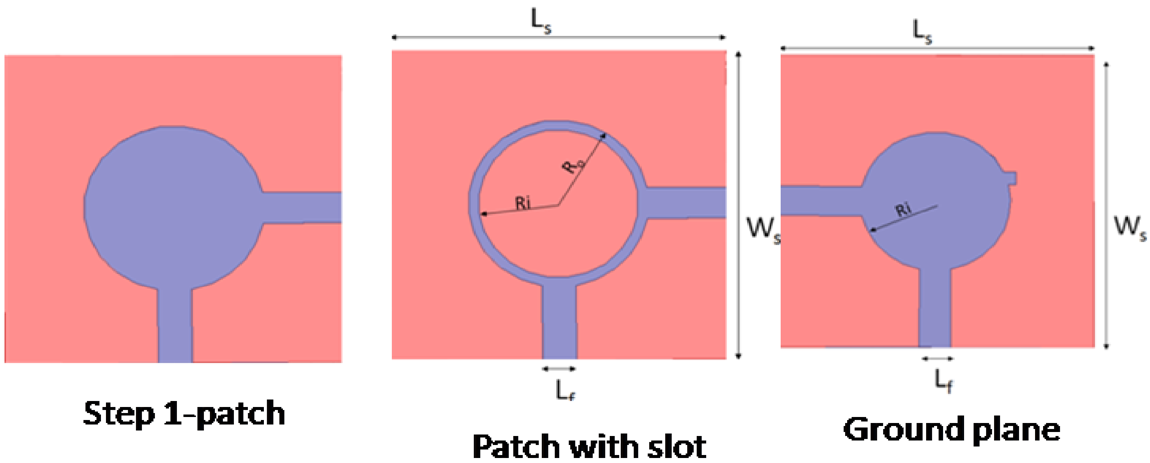
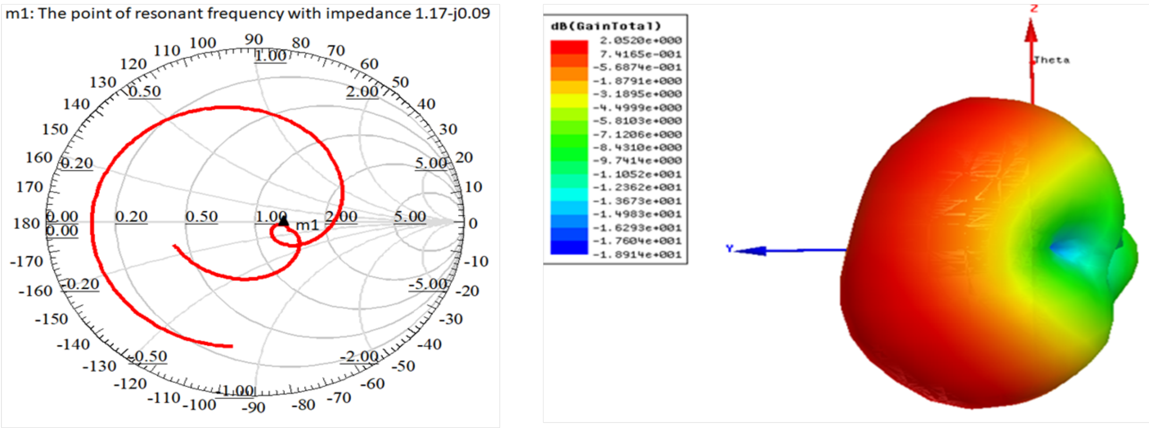


Figure 3.8: The design of Antenna 2

A small stub has been added in the ground plane for perfect impedance matching. The smith chart of the antenna is shown in the following figure 3.9. The antenna also performs well in terms of gain which can be also seen from Fig. 3.9 .

3.2.2 Parametric Analysis

The antenna dimensions were finalized in simulations using a parametric analysis for the inner radius of the ring and thus the radius of the ground plane. In the simulations, at each step, these two radii were varied. The radius was changed in steps of 0.1 mm and the S11 as well as Axial Ratio was plotted simultaneously . Comparatively, it was seen that from all the radii, 7.1 mm radius performed the best in terms of bandwidth, return



Smith chart for antenna2 3D polar plot for antenna2

Figure 3.9: The Smith Chart and Gain for Antenna 2

loss as well as axial ratio. Thus, the radius of 7.1 mm was finalized as the inner radius of the slotted ring as well as the ground plane.

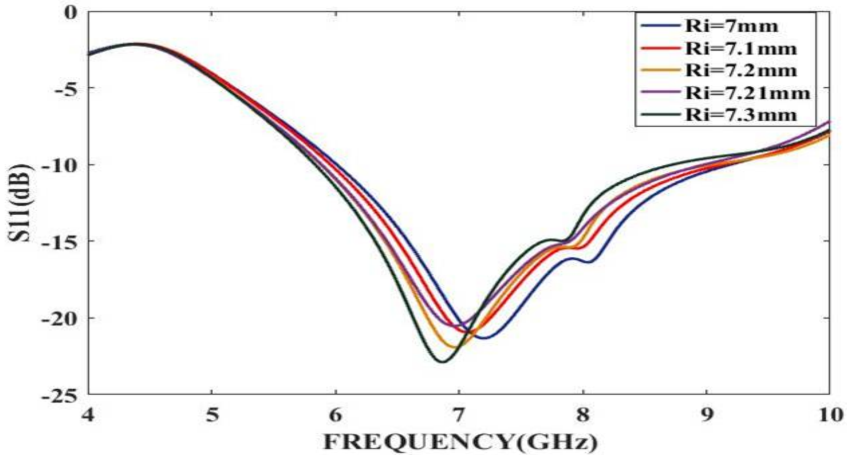


Figure 3.10: The return loss plots for Parametric analysis of Antenna 2

3.2.3 Surface Current Distribution of the Antenna 2

The main evidence of CP in an antenna is its Axial Ratio. However, circular current flow also depicts CP. The surface current distribution of the antenna is shown below. It was noted that the current flow was in circular manner which proved the presence of CP.

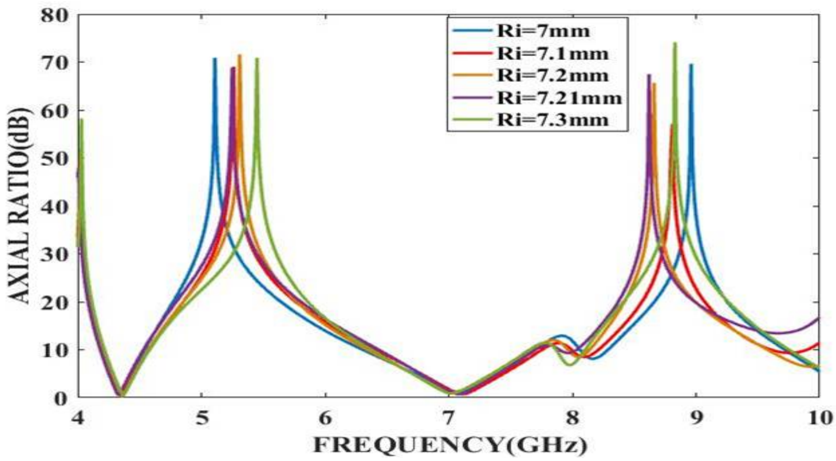


Figure 3.11: The axial ratio plots for Parametric analysis of Antenna 2

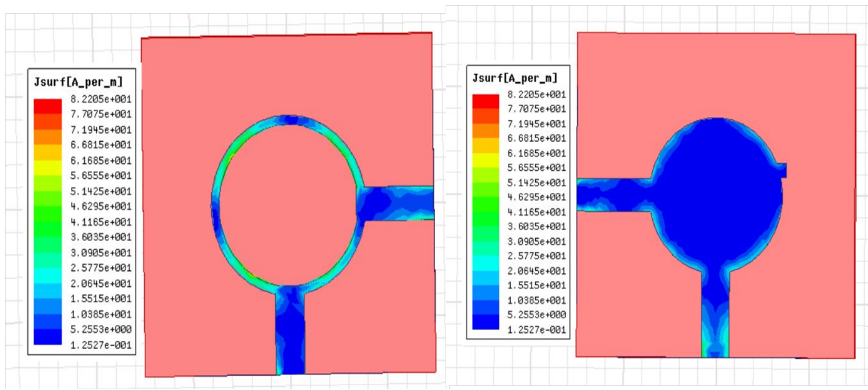


Figure 3.12: The Surface Current Distribution of Antenna 2

3.2.4 Experimental Results of Antenna 2

The simulated and measured results of the antenna are in very good agreement of each other. The antenna performs exceptionally well interms of axial ratio which is below 1 dB at resonance. The ARBW is around 400 MHz while the impedance bandwidth is 3.16 MHz. The antenna has considerably good gain and its dimensions are optimized parametrically. The antenna S11 performance, axial ratio measurements and fabricated prototype are presented below.

Thus, a dual feed, compact, circularly polarized antenna was designed for HAC purpose. The antenna was found safe and sensitive for the application with similar results as that of antenna 1.

- It was observed that the antenna with dual feed became quite heavy and the arrangement for dual feeding network was somewhat difficult as far as practical

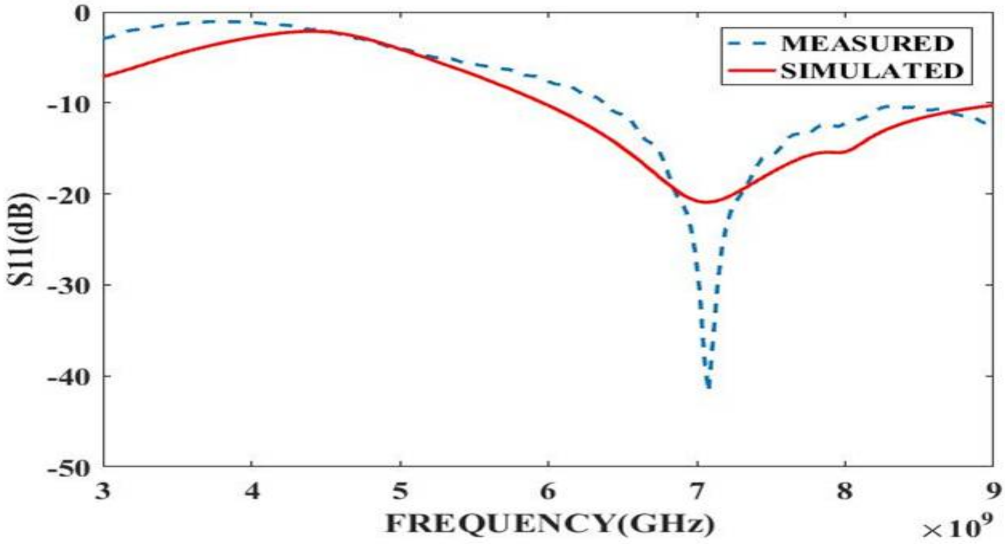


Figure 3.13: The Return Loss Performance of Antenna 2

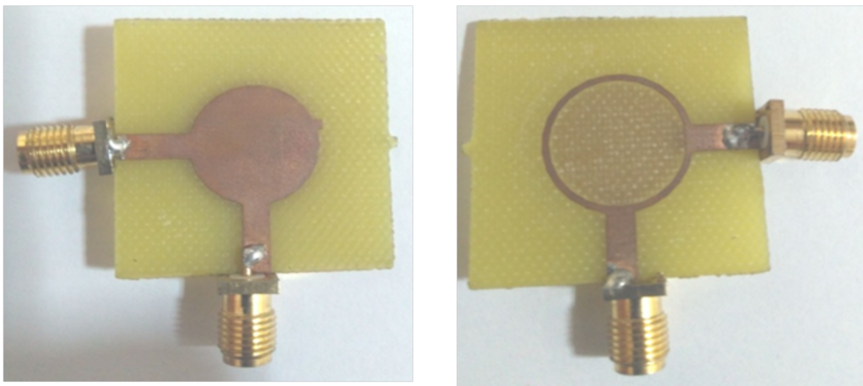


Figure 3.14: The fabricated prototype of Antenna 2

deployment is considered.

- The antenna was compact but a single feed antenna would be more preferable. Hence, we landed upon the next design of a CP compact antenna with a single feed using the same complimentary ground technique.

3.3 Design of a Single Feed, Compact CP Antenna for HAC-Antenna 3

We designed a single feed, compact CP antenna using the same complementary ground technique. The antenna eventually performed well in 2 bands out of which one of the band (lower frequency) was used for HAC. The antenna resonated at 4.55 GHz and

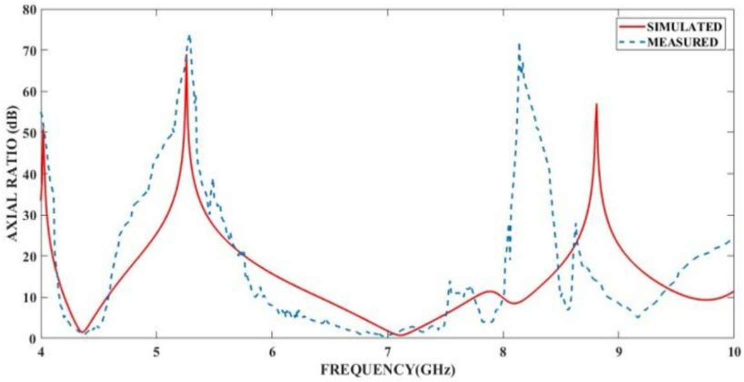


Figure 3.15: The Axial Ratio Performance of Antenna 2

7.58 GHz out of which 4.55 GHz was selected for use in HAC as per the allocations of frequency spectrum.

3.3.1 Antenna Design

The antenna consists of a a circular patch with a segment subtracted from it. The same segment area acts as the ground plane in complimentary fashion.The antenna is fed by microstrip line feeding with an offset provided in the feed to bring about circular polarization. The antenna substrate is FR4 with dielectric constant 4.4 and loss tangent 0.02. The substrate thickness is 1.6 mm. The detailed dimensions of the antenna are R=10mm, F=3.3mm, F1=1.3mm, F2=2mm, L=30mm, W=30mm, P=25mm,Q=17.5mm. The antenna design can be seen in the following figure.

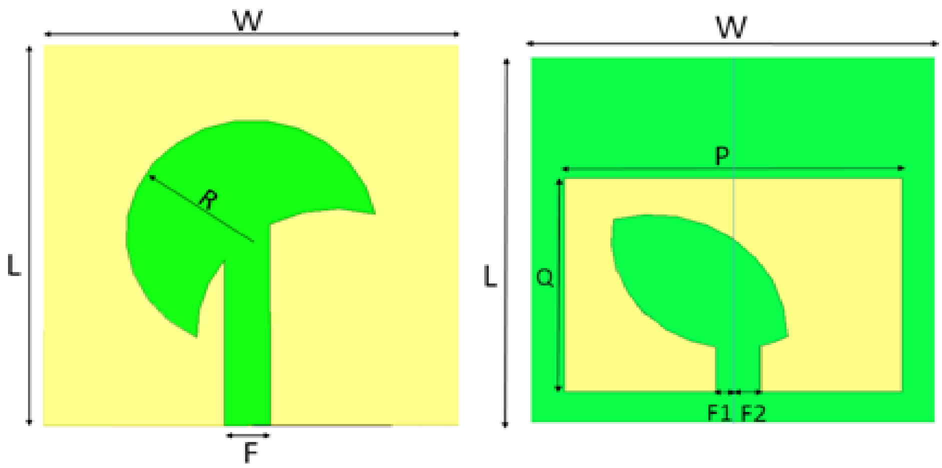


Figure 3.16: The design of Antenna 3

The axial Ratio of an antenna is a very important feature to decide the quality of

CP it produces. As a result different techniques were tried to obtain good quality CP in the antenna. An offset provided in the feed proved to be very effective to imporve the quality of CP in the antenna. It can be seen from Fig. 3.17 that the antenna shows lower axial ratio in the presence of an optimized offset provided in the feedline.

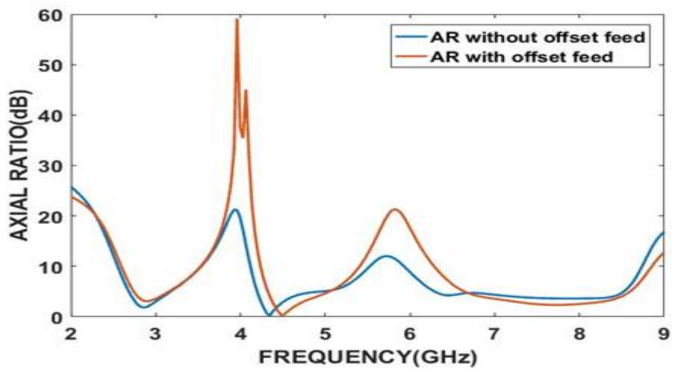


Figure 3.17: The comparison of axial ratio with and with out offset in the feed for Antenna 3

3.3.2 Parametric study to decide the offset in the feedline

In the design of this CP antenna, offset was one of the key parameter which decided its performance. As a result, the offset provided in the feed was optimized parametrically in HFSS. Study of both return loss and axial ratio performance at both the resonances was done to decide the offset. It was found that for an offset of 0.5 mm, the axial ratio was minimum at resonance and ARBW was maximum, on the other hand, the return loss was also considerable. Thus, the offset of 0.5 mm was finalized in the antenna.

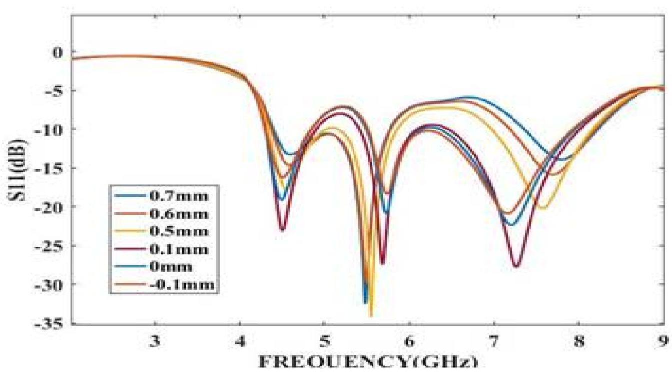


Figure 3.18: The Return Loss Performance When Offset was varied parametrically for Antenna 3

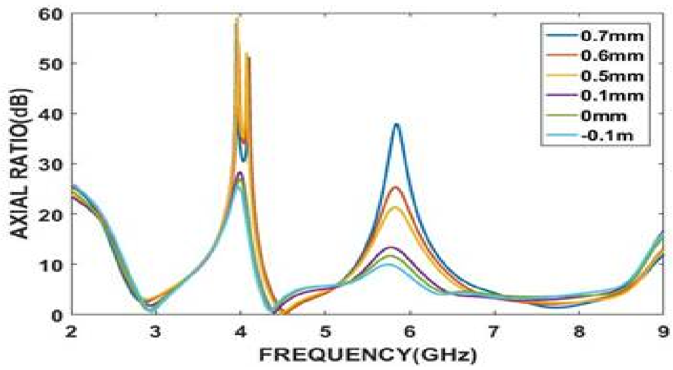


Figure 3.19: The Axial Ratio Performance when Offset was varied parametrically for Antenna 3

Finally, the antenna was fabricated and tested. There was great agreement in the simulated and measured results of the antenna. The peak at 5.5 GHz was in simulations maybe due to some unconsidered practical effects as it got suppressed in the actual measurements.

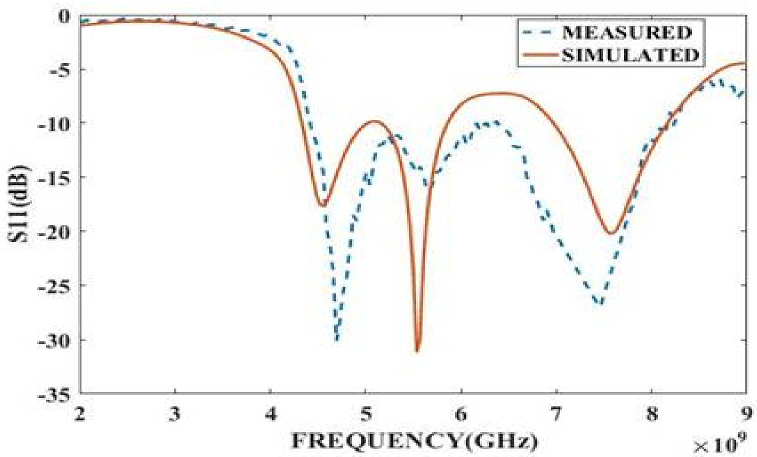


Figure 3.20: Comparison between Simulated and Measured Return Loss of Antenna 3

The radiation pattern of the antenna in E and H plane was calculated at 4.55 GHz and is shown in Fig. 3.23.

3.3.3 Surface Current Distribution of the Antenna

The antenna was simulated with respect to its surface current flow. As mentioned in prior section, the current flows in circular manner in case of a CP antenna.

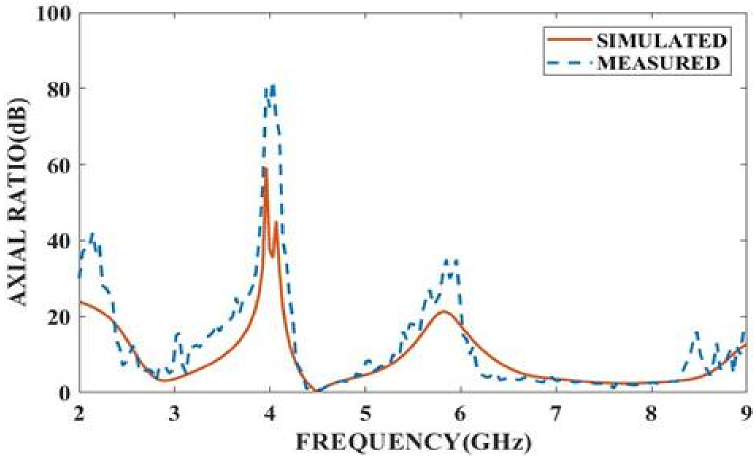


Figure 3.21: Comparison between Simulated and Measured Axial Ratio for Antenna 3

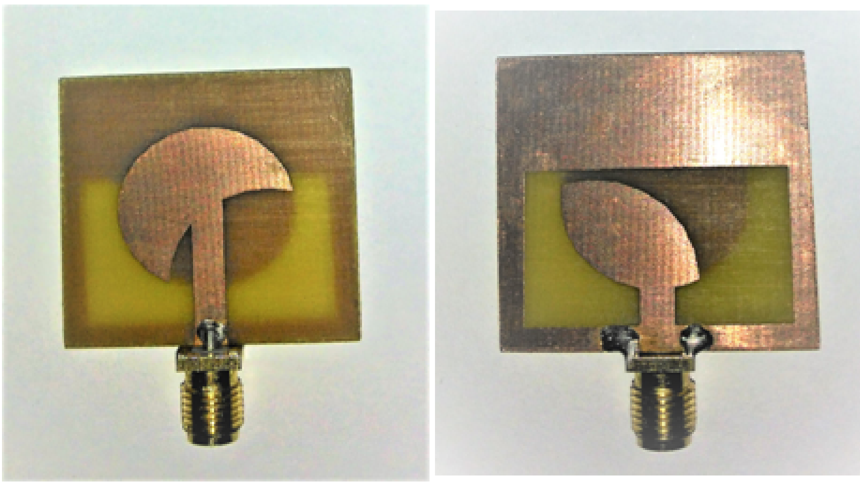


Figure 3.22: The Fabricated Prototype of Antenna 3

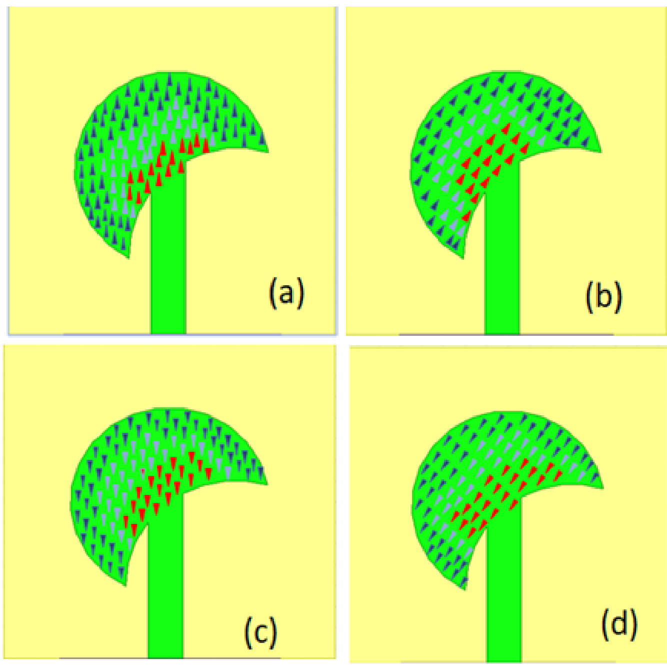


Figure 3.24: The Current Distribution for antenna 3 at (a)60^0(b)120^0,(c)180^0 and (d)240^0 phase

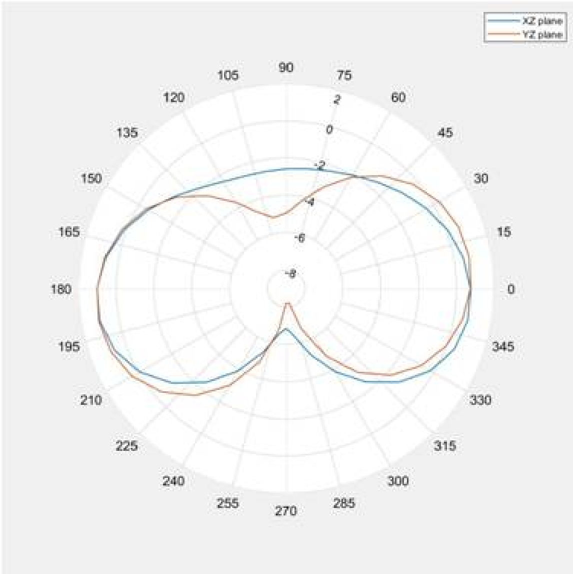


Figure 3.23: Radiation Pattern of Antenna 3

The figure 3.24 gave a proof of the circular current flow with respect to phase and assured the presence of CP in the antenna. This is the nature of current when animated in HFSS.

The antenna performance has been compared with other dual band CP antennas in literature and is depicted in Table. 3.1. It can be thus seen that the antenna performs exceptionally well in all terms when compared with other dual band antennas in literature. The antenna is sensitive for HAC as well, proved from the system model simulations like antenna 1. The antenna is also safe for on-body use as found from its SAR measurements. The tabulation of these results is not done in order to avoid repetitive information. The dataset collection and analysis of the antenna is discussed in the subsequent chapter.

- The designed antenna was compact, CP as well as efficiently sensitive to perform HAC.

- The antenna designed was found almost perfect for our desired application. However, in order to make it even more comfortable and compact we entered the area of flexible electronics and designed a flexible ultra-thin antenna which along with related circuitry perform HAC single handedly.

Table 3.1: Comparison of Antenna 3 with Other Circularly Polarized Antennas

REF	SIZE	RESONANT FREQUENCY	RETURN LOSS(dB)	BANDWIDTH	ARBW
[57]	0.306 λ * 0.306 λ	1.227/1.555	-25/-35	250 MHz/390 MHz	11 MHz/13 MHz
[58]	0.291 λ * 0.291 λ	3.5/5.8	-25/-17	470 MHz/280 MHz	110 MHz/250 MHz
[59]	0.933 λ * 0.933 λ	3.5/5.5	-	700 MHz/700 MHz	100 MHz/200 MHz
[60]	0.28 λ * 0.2 λ	2.45/5.5	-25/-20	320 MHz/2.4 GHz	700 MHz/230 MHz
Proposed antenna	0.455 λ * 0.455 λ	4.55/7.58	-17.68/-20.15	1.5 GHz/1.2 GHz	380MHz /1.08GHz

3.4 Design of an ultra-thin flexible antenna for HAC- Antenna 4

The final step of the antenna design is the design, fabrication and testing of an ultra-thin flexible, on-body antenna for HAC purpose. The antenna has been deigned on a 25 μm thin substrate named Kapton Polyimide[47]. The substrate is coated with copper on both the sides with thickness 35μm. Thus the total antenna thickness becomes 95μm.

3.4.1 Antenna design

The antenna patch is a simple rectangle with a smaller rectangular slot in it. The detailed antenna design can be seen in Fig. 3.25 with its dimensions also expressed. The slot was introduced in the antenna to increase the path length of the flowing current. This is usually done to decrease the antenna size. Here, to make it in the shape of a band, the antenna length needed to be smaller than the width. Thus, the slot was introduced to increase the electrical length and reduce its mechanically length.

The antenna is small in size and is perfect for tying on the human wrist as a band. The antenna has been designed by placing on human hand phantom in HFSS. The

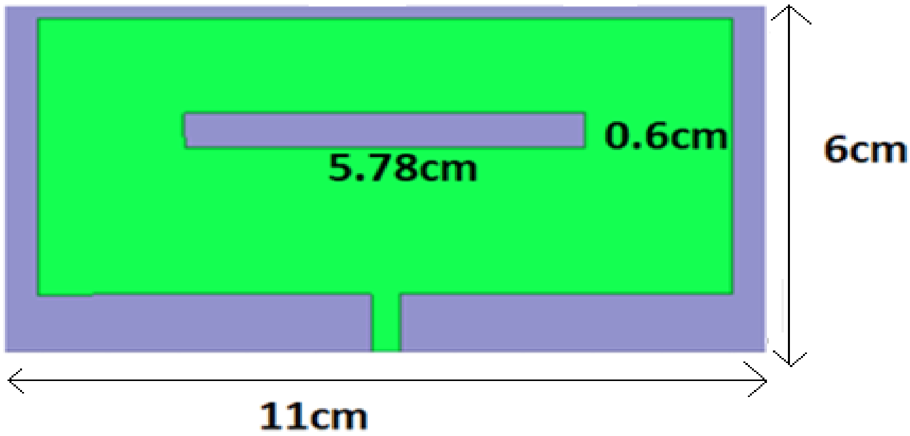


Figure 3.25: The design and Dimensions of Antenna 4

system model of the antenna has also been designed. The antennas system model and corresponding S11 variations are plotted in Fig. 3.26. It is important to note that the antenna is sensitive enough to be used in HAC as its S11 varies with the distance variation between antennas.

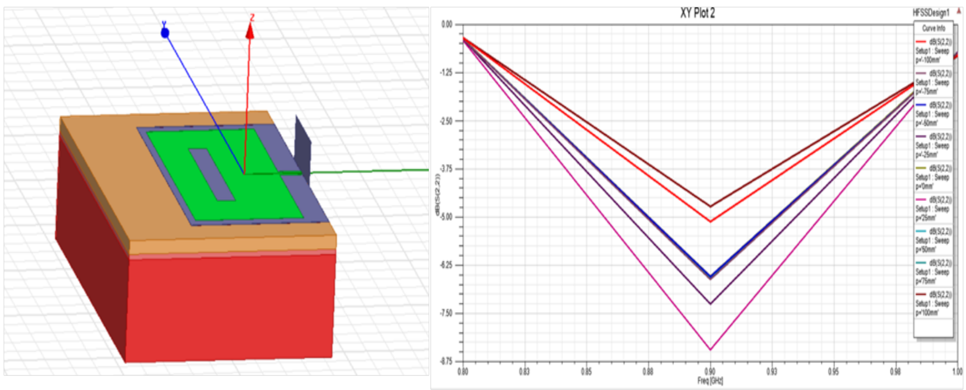


Figure 3.26: The system model simulations for antenna 4

3.4.2 The Antenna Performance

The antenna was designed to operate at 3.6 GHz which is declared license-free by FCC for low power part-15 devices. The system designed is battery operated and thus would require extremely low power. The antenna was fabricated and the measurements were done on VNA. The simulated and measured results are in good accordance of each other.

The 25 μm ultra-thin antenna was then fabricated and can be seen in the following figure. It was learnt from the extensive literature study that the designed antenna is the

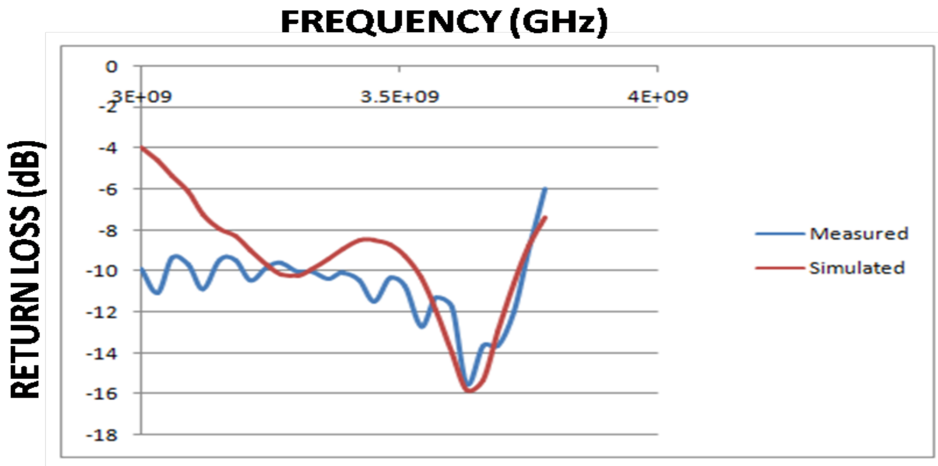


Figure 3.27: The comparison between simulated and measured return loss

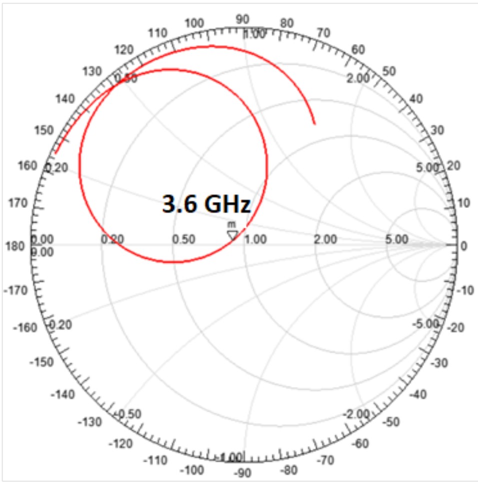


Figure 3.28: The smith chart for antenna 4

thinnest of all ever fabricated in literature. This can be considered as one of the milestone in flexible electronics. The flexible nature of the antenna is also shown in the figure.

3.4.3 The SAR analysis of the Flexible Antenna

The SAR simulations of the antenna were done in HFSS and it was found that the antenna is utterly safe to be mounted on human body as the SAR value is below the limit in all 3 layers of human hand phantom. The maximum SAR in skin, fat and muscle is $7.32\text{x}10^{-3}$ W/Kg ,$4.35\text{x}10^{-3}$ W/Kg and $1.85\text{x}10^{-4}$ W/Kg respectively. The following Table. 3.2 depicts the comparison of the fabricated antenna with other flexible and thin antennas present in literature. It was found than the antenna is thinnest of all ever fabricated in the literature.

Figure 3.29: The fabricated prototype of antenna 4

Figure 3.30: The flexible nature of the designed antenna

Figure 3.31: The Bending Ability of the Flexible Antenna

3.4.4 The variation of return loss of the antenna with bending

It was estimated that the return loss of the antenna would vary depending upon the amount of bending of the antenna. However, we are not transmitting any information using the antenna, so the resonance is immaterial as far as it lies in the bandwidth of interest. The antenna's return loss was measured by bending it at different radius of curvatures. This was done by using different sized bottles. It was observed that there is only a few MHz different in resonance with such variations. This also indicates that the antenna performance and thus the system performance lies in the same band of interest for all the people irrespective of the size of their wrist.

Table 3.2: Comparison With Other Flexible Antennas

REF	RESONANT FRE-QUENCY	SIZE	RETURN LOSS	MATERIAL	THICKNESS
[44]	2.7 GHz	59.8 mm * 59.8 mm	-30 dB	PDMS embedded fabric	0.76 mm
[47]	3.4 GHz	70 mm * 70 mm	-22 dB	Kapton	0.11 mm
[61]	6.1 GHz	20 mm * 46 mm	-15 dB	SU-8/PDMS	0.5 mm
[62]	6 GHz	60 mm * 45 mm	-20 dB	Paper	0.125 mm
[63]	2.42 GHz	55.8 mm * 47.4 mm	-40 dB	Electro-textile	2 mm
Proposed antenna	3.6 GHz	11 mm * 6 mm	-16 dB	Kapton	0.025 mm

Thus, four antennas were designed successfully for HAC set-up. All these were fabricated and the measured results were in very good agreement with the simulations. The Antenna 1 (Conventional rectangular antenna) took a step forward to perform HAC using a patch antenna unlike the work done in literature which employed traditional monopoles of huge size. Next, a CP dual feed antenna was fabricated for HAC set-up. It was thought that this (Antenna 2) would be quite difficult to use in practice due to the requirement of dual feeding source and thus a single feed CP complimentary ground based antenna was designed (Antenna 3). Both these CP antennas were of the size of a wrist watch dial. Further, a step was taken forward to design and fabricate the revolutionary ultra-thin flexible antenna for HAC which proved to be the thinnest antenna fabricated till date (25 μm). The next section will elaborate the use of these antennas for HAC setup and thus prove them to be potent by presenting the measurements and experimental results.

CHAPTER 4

DATASET COLLECTION AND SIGNAL PROCESSING

DATASET COLLECTION AND SIGNAL PROCESSING

The final step of the system design includes the collection of dataset using the designed four antennas and its processing. As discussed earlier, the DTW algorithm is used for processing the antenna data. Finally the accuracy of classification of the antenna system is calculated. The following sections take a deeper dive into this concept and give the final results and classification accuracy.

4.1 Procedure followed for collection of dataset

It was followed from literature that the S11 data of the antenna needs to be collected on real time basis and around 120 samples per second are needed. The work done by [10] has recorded the real time S11 for about 10 seconds per activity. Thus, the total number of samples per activity become 10 x $120 = 1200$. This is a huge number and the signal processing becomes tedious as the number of samples increase. As a result, we have changed the method of dataset collection and decreased the number of samples by almost about $\frac{1}{100}$. This is a significant achievement as compared to all the material available in literature. This simplified the data processing and kept the accuracy unaffected.

The Fig. 4.1 depicts the way we collected the reference dataset. It has been ensured that a variety of data is collected and hence 10 different subjects were employed for dataset collection. 5 of them were male and 5 female. The average weight of the subjects was 58.4 Kg and average age was 22 years. The data was then collected with 9 samples per activity, per subject. Thus, the total number of sets collected using 4 antennas were 120 for 3 considered activities. For the primary deployment purpose, three simple activities namely- Waving one hand, Boxing using both the hands and Clapping were chosen .

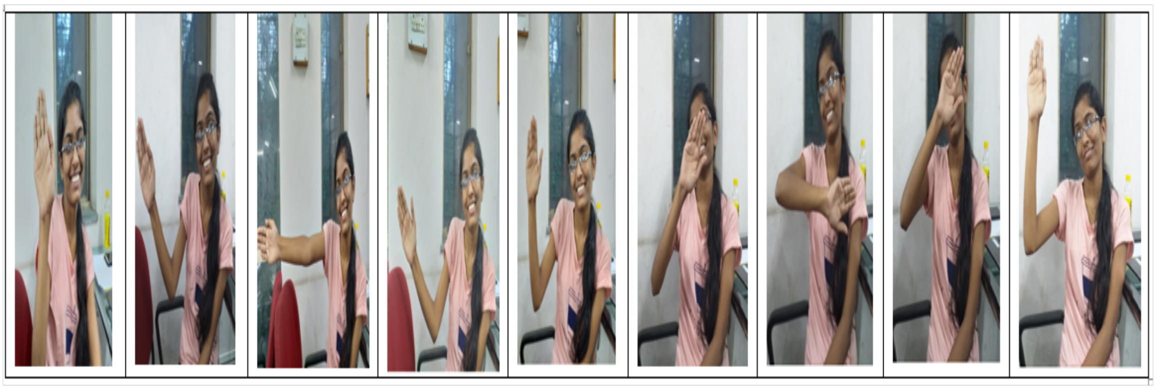


Figure 4.1: Dataset collection

The data thus collected was plotted with position index on X axis and S11 value on Y-axis. Further, the plots were analysed visually to get an idea of the S11 signatures obtained for the 3 distinct activities.

4.2 Visual Analysis of the dataset

The collected dataset plots are as shown below (Fig. 4.2- Fig. 4.13) It is very clear form the 12 plots that similar S11 signatures are obtained for similar activities even when 10 different subjects perform it. We hereby visually confirm that the antenna design is successful for HAC. It has to be noted that the signatures are different for same activity when different antennas are used , which is obvious.

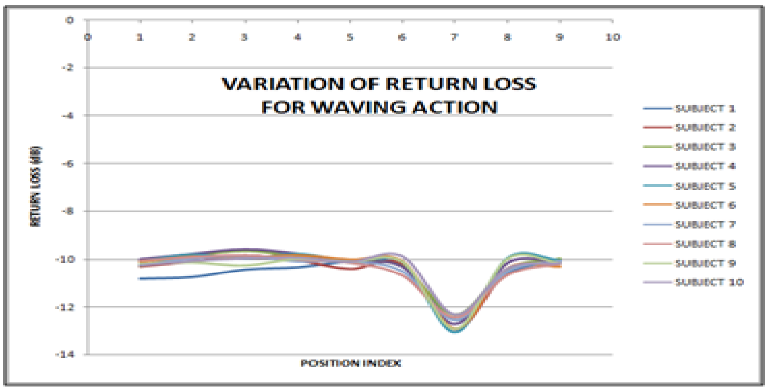


Figure 4.2: Plots for Waving action employing antenna 1

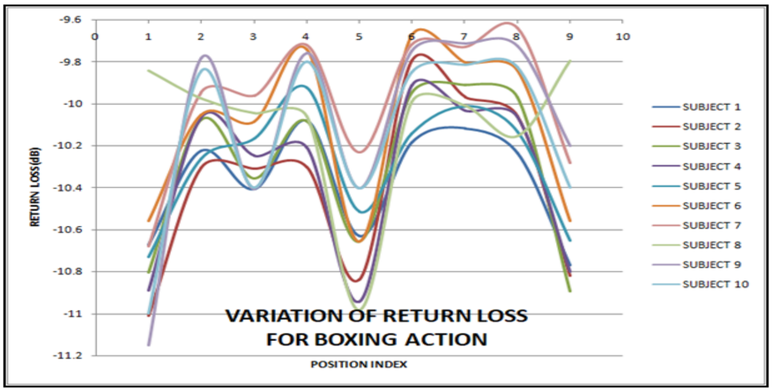


Figure 4.3: Plots for Boxing action employing antenna 1

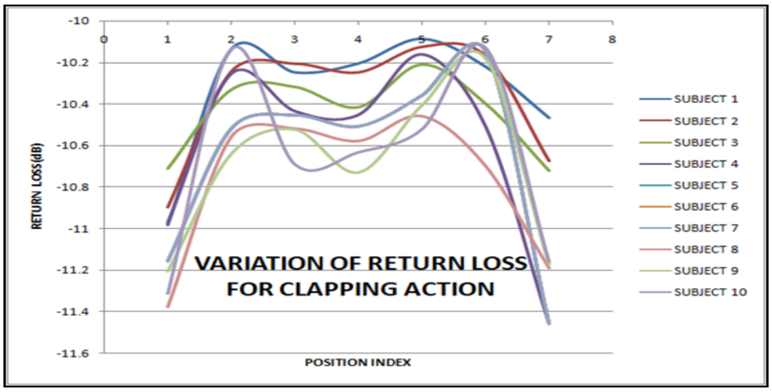


Figure 4.4: Plots for Clapping action employing antenna 1

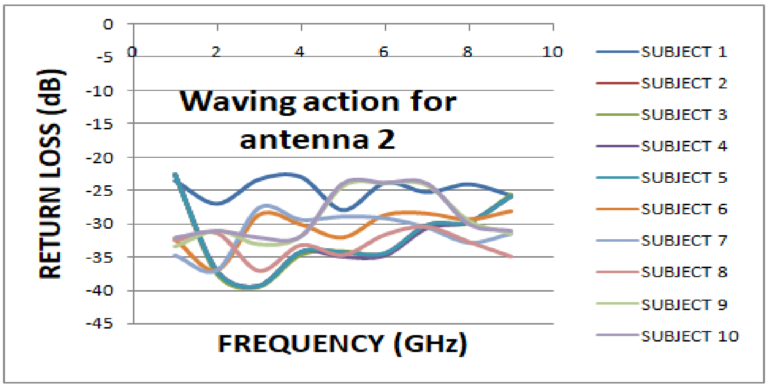


Figure 4.5: Plots for Waving action employing antenna 2

The prime observation done here is that, the antennas are showing distinct signatures for distinct activities when the activities are performed by tying the antenna on the subject's wrist. This observation is same for all the subjects.

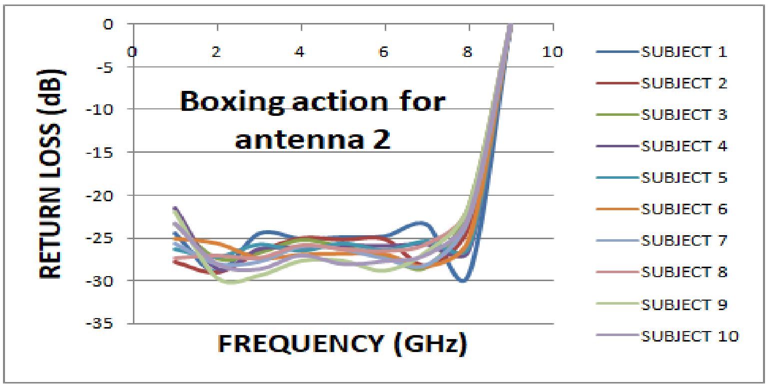


Figure 4.6: Plots for Boxing action employing antenna 2

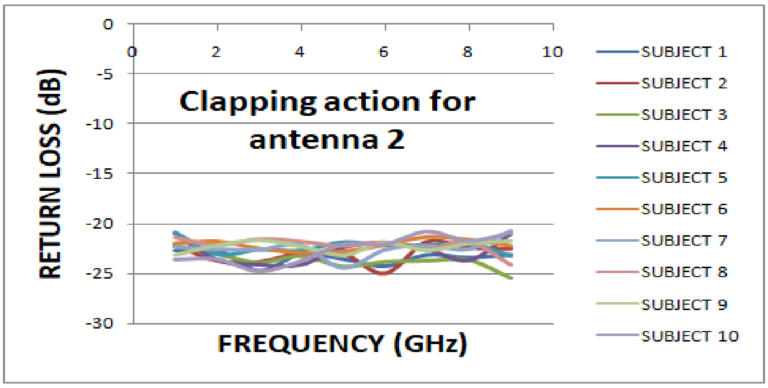


Figure 4.7: Plots for Clapping action employing antenna 2

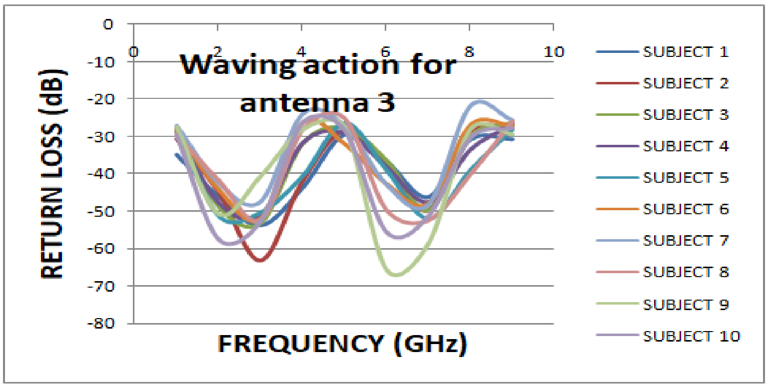


Figure 4.8: Plots for Waving action employing antenna 3

Thus, the principle is proved visually from the plots and the analytical proof is given in the next section. The plots in the same graph correspond to the signals obtained when different subjects perform the same action while the antenna is placed on their wrist.

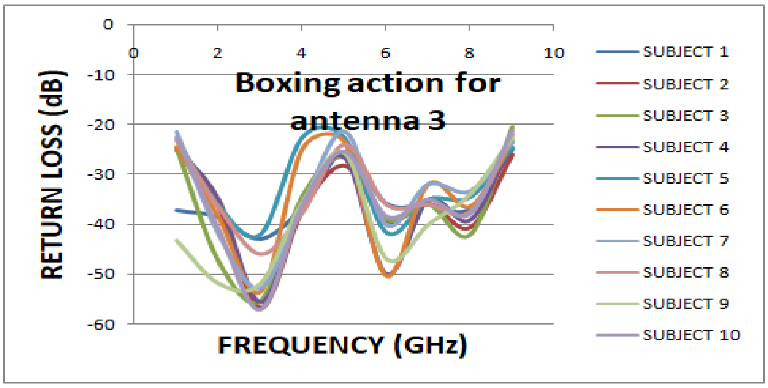


Figure 4.9: Plots for Boxing action employing antenna 3

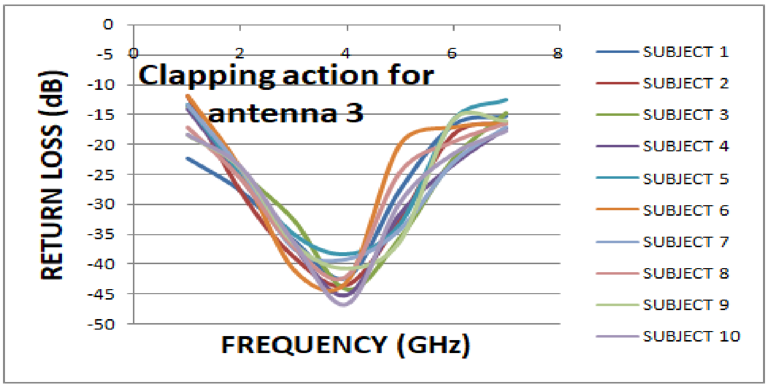


Figure 4.10: Plots for Clapping action employing antenna 3

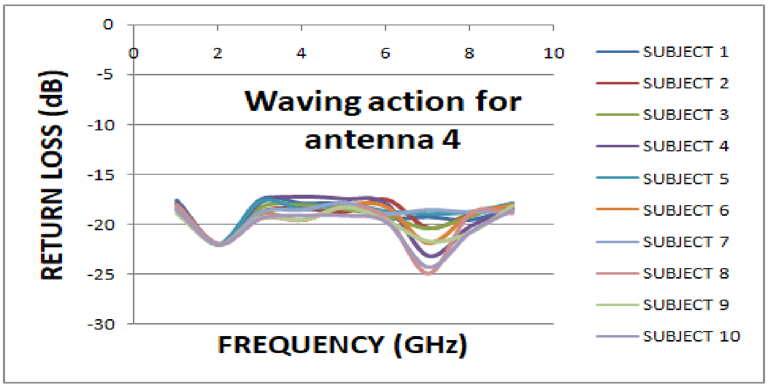


Figure 4.11: Plots for Waving action employing antenna 4

The visual analysis is possible only because the number of samples are low. If the number of samples increase, the visual analysis will become more and more difficult. It has been seen from literature that the plot of S11 look like a visually indistinguishable spectrum when number of samples per activity was 1200.

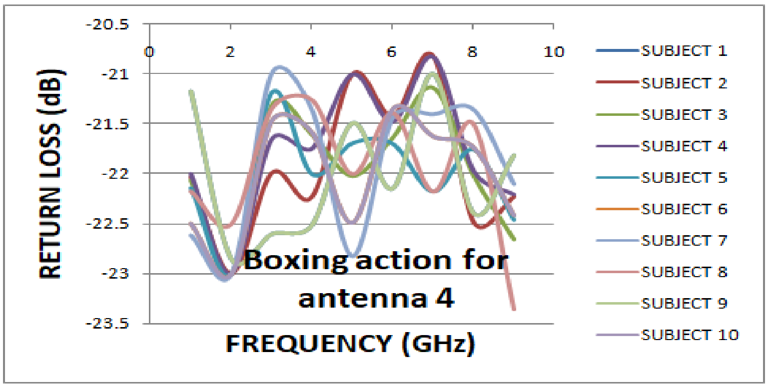


Figure 4.12: Plots for Boxing action employing antenna 4

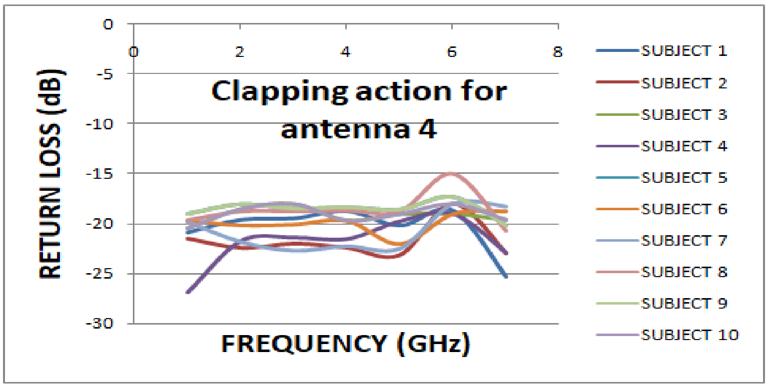


Figure 4.13: Plots for Clapping action employing antenna 4

Table 4.1: Eu distance values for three different actions for Antenna 1

Antenna1	WAVING	BOXING	CLAPPING
WAVING	2.68	15.49	38.65
BOXING	10.99	4.20	37.75
CLAPPING	39.06	38.08	0.00

Table 4.2: Eu distance values for three different actions for Antenna 2

Antenna2	WAVING	BOXING	CLAPPING
WAVING	12.78	33.89	31.32
BOXING	34.43	7.87	24.88
CLAPPING	25.13	25.07	2.80

4.3 DTW analysis of the data

The process of dataset collection was very rigorous and as a result the total data collected had to be managed efficiently[56]. Inorder to classify the activities, the DTW algorithm was used and the minimum average distance of the test signal with the reference signals of all the activities was found out. The Table. 4.1, Table. 4.2, Table 4.3 and Table. 4.4 tabulate these distances with test signal activity labelled on the left and the reference set labelled on the top.

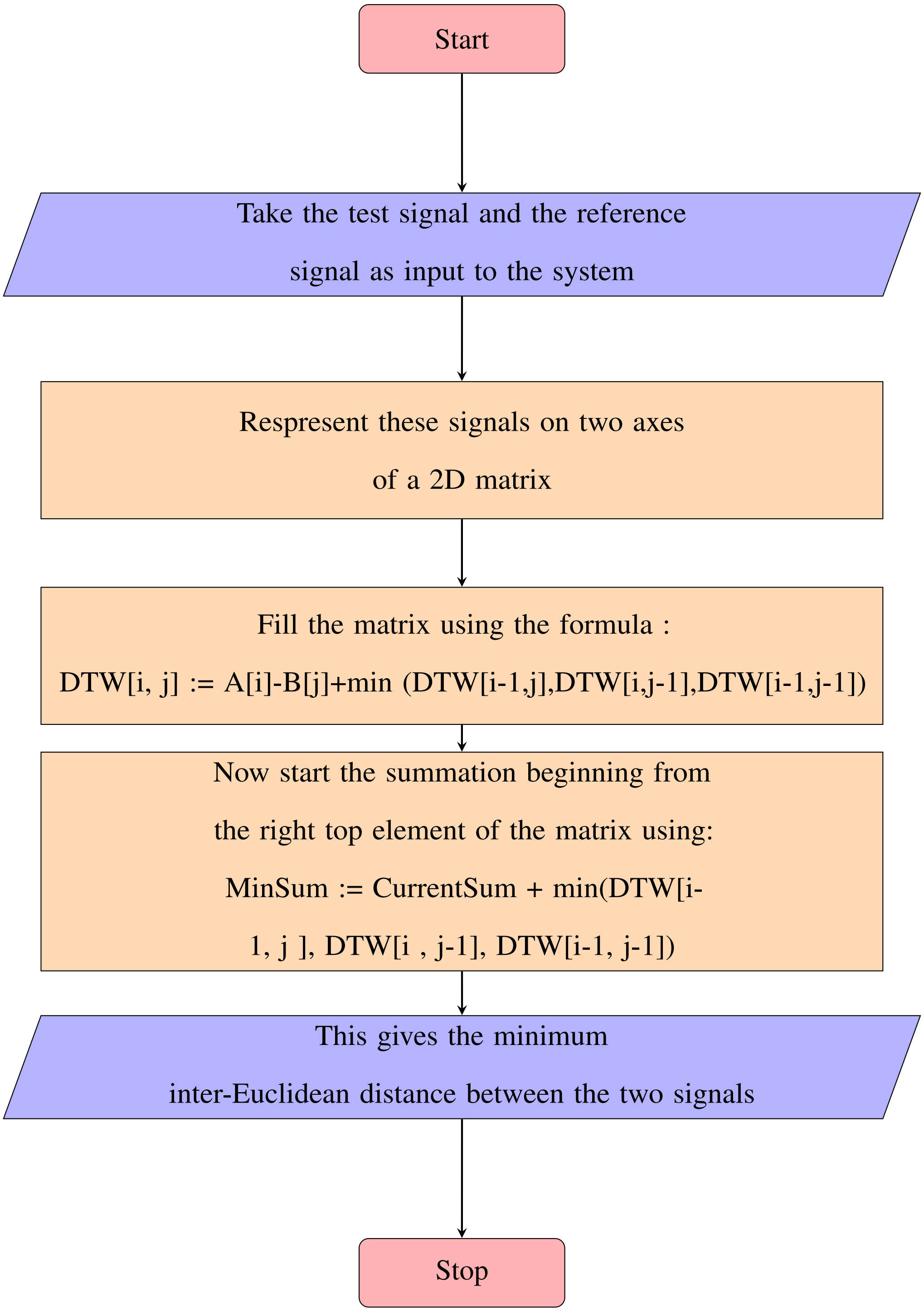
The DTW follows the complexity of O(N^2) and is one for the most efficient algorithm of the desired application. The algorithm finds the minimum inter-Euclidean distance between two temporal signals and thus helps in classification purpose. The similarity among signals is found irrespective of the shifts/ speed and time delays among the signals being considered. The following chart describes the flow of DTW algorithm.

Table 4.3: Eu distance values for three different actions for Antenna 3

Antenna3	WAVING	BOXING	CLAPPING
WAVING	74.88	114.94	324.79
BOXING	153.14	25.89	435.08
CLAPPING	497.72	550.49	0.00

Table 4.4: Eu distance values for three different actions for Antenna 4

Antenna4	WAVING	BOXING	CLAPPING
WAVING	7.93	52.49	80.36
BOXING	75.57	12.86	109.17
CLAPPING	98.73	102.98	0.00



It can be clearly observed that the distance of test signal is minimum with the activity set it belongs to. Thus, analytically, we have proved that the antennas along with DTW processing are successful to classify the 3 considered activities when the human performs it with antenna tied on wrist. We have thus designed a system which successfully classifies 3 humann activities.

4.4 Performance of Classification and System Accuracy Calculation

It is worth noting that the number of samples per activity used by us in the present work are less than $\frac{1}{100}$ times those used in all the papers in the literature. The following steps were followed to find the accuracy of classification using the designed system-

1. A reference array was created where the code (A symbol- w for waving, b for boxing and so on) for actual test activity (the accurate result) was stored.

2. The test signals were taken one-by-one and their average inter-Eu distance with all the reference sub-sets (per activity) was calculated.

3. The test signal was classified as the signal of the activity with which the average calculated distance was minimum. This classified result was stored in the result array.

4. These subsets were taken from all the antennas to increase the size of the data. eg. while classification of an activity say waving from antenna 1, the activity sets of all three activities for antenna 2,3,4 were also considered.

5. The arrays from step 1 and 3 were then compared and number of inaccurate classifications was found.

The accuracy calculation methods in the literature for HAC set-up were not stated clearly[9-14] and hence we calculated both- antenna wise as well as total system accuracy. The classification done by us was using **Actually collected data** as no ready dataset was available for any antenna's S11. This is remarkable that the entire data analysis done by us is using self-collected data employing the designed antennas.

The antenna wise average accuracy for the four antennas was found out to be 99.375% and the total system accuracy was found out to be 95%. The antennas outperform in individual accuracies as the obtained accuracy is highest among all the works presented in literature (maximum 98%) where HAC is done using on-body antennas.

The next chapter gives a holistic summary of the work done, highlights the project outcomes and describes the future scope of the rigorously performed experimentation.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

It can be thus concluded that, all the 4 designed antennas are appropriate to be used in HAC set-up discussed in this work. The antenna 1 brought about an evolution from traditionally used monopole antennas for HAC to a patch antenna of smaller size. Further, keeping the concept of efficient use of battery in mind, 2 Circularly Polarized antennas were designed. One of them was designed using a dual feed and other with a single feeding port, both of them using the innovative concept of complimentary ground plane. The final antenna (antenna 4) was an ultra-thin flexible patch antenna which could be tied on wrist as a band. This antenna is the thinnest flexible antenna ever designed in literature to the best of our knowledge. All these antennas were then used separately to collect the data of real time S11 parameter. When the antennas are tied on human body, the EM waves in the near field of the antenna get obstructed by activity performance and thus specific and distinct channel features are obtained. These features result in production of specific signatures real-time S11 signal when recorded by tying the antenna on body. This principle is exploited in the work taking care that the antennas are safe to be used on body. SAR measurements of the antenna helped in such sophisticated and safe design.

A very rigorous data collection procedure was followed and we were successful to reduce the number of samples used to $\frac{1}{100}$th per activity of what are used in literature. This gave an added advantage of reduced computational complexity. We have designed and deployed a completely successful HAC set-up. The actual test activity classification was also done successfully employing various subjects. The average classification accuracy of all the antennas is 99.375 % which is best when compared to the entire work done in the past on antenna based HAC.

5.2 Project Outcomes

The project has the following distinctive and novel outcomes :

- The flexible antenna designed in the work is the **thinnest antenna** ever designed. Before this design, the minimum substrate height of the antenna was 125 μm (as shown in comparison table 3.2). A revolutionary antenna designed in present work has a substrate height of 25 μm which makes it the thinnest.

- The number of samples for data analysis taken per activity have been reduced to $\frac{1}{100}$th of the samples taken in the work done previously in literature. This has drastically reduced the computational complexity of the system.

- The designed system is one of the most compact system for HAC using antennas as the work done previously in literature includes large monopoles mounted on body while we have designed the HAC set-up using miniature antennas.

- The system has an average classification accuracy of 95% and antenna wise maximum classification accuracy of 99.375%.

- The system thus outperforms in terms of design as well as accuracy when compared all the related systems presented till date.

5.3 Future Scope

The presented work is HAC using on-body antennas and the obtained accuracy is very good for any classification problem. The work has successfully classified three preliminary activities which can be directly applied in the field of physiotherapy. The future extension of the work is thought in the following ways:

5.3.1 HAC using on-body flexible antenna for COVID-19 prevention

The world is facing a disastrous situation due to the novel Corona virus COVID-19. The virus has lead to a steep decline in the economy of almost all the countries and has proved deadly, causing huge damage in even the most developed countries. The virus spreads rapidly through direct contact with the infected. A healthy person may also get infected by touching his/her eyes, nose or mouth consecutively after touching a surface with the virus. Such surface get infected when a COVID-19 patient coughs or sneezes near it.

It is concluded that the spread of this virus can be stopped if an infected person avoids to cough in public by covering his/her face and if a healthy person avoids to touch his/her eyes,nose and mouth. This particular fact can be kept in mind and a system can be designed which classifies the actions of sneezing, coughing and touching the face from other normal activities. Once any of these 3 activities is detected by the wrist band antenna, it can trigger an actuator which may further vibrate to make the user aware of this dangerous activity. In this way, the spread of the virus can be dramatically reduced.

5.3.2 Increasing the number of activities classified by the system

The current system is designed for the classification of 3 activities. However, if we need to make the designed device generic, it will need to classify a number for activities. This would also increase the number of samples per activity chosen to get the same level of accuracy. Thus, the system can be re-configurable and can be used on a large scale without change in any hardware or software eg. A flexible antenna based activity classifier can be designed which corrects 30+ yoga postures. This particular device can have huge demand as the number of activities classified are large. We can also include leg motions along with the arm motions to design a generic physiotherapy assistant.

5.3.3 Using different data processing algorithms as the data size increases

If the data size at all increases with the increase in number of activities, some advance and complex algorithms can be employed. [10] suggests to convert the obtained signal into an image using STFT and then performing image classification using Deep Convolutional Neural Networks to classify the corresponding activity.

LIST OF PUBLICATIONS

1. **Neha Y. Joshi,** Paritosh D. Peshwe, and Ashwin G. Kothari."Dual Wide Band Circularly Polarized Microstrip Patch Antenna with Offset Feed." **Wireless Personal Communications** :(SCI, IF=1.20).

2. **Neha Y. Joshi,** Paritosh D. Peshwe and Ashwin Kothari."A Compact, Circularly Polarized Antenna for Human Activity Classification." **National Conference on Communications (NCC 2020), Indian Institute of Technology, Kharagpur**, 21-23 Feb. 2020.

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Appendices

BT16ECE054- NEHA JOSHI-CHECK

ORIGINALITY REPORT

5%	2%	5%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Neha Joshi, Paritosh Peshwe, Ashwin Kothari. "A Compact, Circularly Polarized Antenna for Human Activity Classification", 2020 National Conference on Communications (NCC), 2020 Publication	1%
2	Neha Y. Joshi, Paritosh D. Peshwe, Ashwin G. Kothari. "Dual Wide Band Circularly Polarized Microstrip Patch Antenna with Offset Feed", Wireless Personal Communications, 2020 Publication	1%
3	tel.archives-ouvertes.fr Internet Source	<1%
4	LIN, JESSICA, SHERI WILLIAMSON, KIRK BORNE, and AND DEBARR. "Pattern Recognition in Time Series", Chapman & Hall/CRC Data Mining and Knowledge Discovery Series, 2012. Publication	<1%
5	Lecture Notes in Electrical Engineering, 2015. Publication	<1%

Appendix B- Dataset Collection demonstration

The appendix is arranged as follows. The figures A.1, A.2 and A.3 describe the actions of waving, clapping and boxing as performed by 3 out of 10 considered subjects. Following these is the certificate of paper presentation at NCC, IIT Kharagpur, 21st-23rd February 2020. Finally, the snapshots of 1st page of our published papers are attached.

Figure 1: The waving action performed by our subject 1

Figure 2: The clapping action performed by our subject 2

Figure 3: The boxing action performed by our subject 3

NCC 2020

NCC 2020

Certificate of Presentation

This is to certify that

NEHA YOGESH JOSHI

has presented a paper (oral/~~poster~~) in the Twenty Sixth National Conference on Communications (NCC 2020) held during 21st to 23rd February 2020 at Indian Institute of Technology Kharagpur, West Bengal, India.

TPC Co-Chair

TPC Co-Chair

A Compact, Circularly Polarized Antenna for Human Activity Classification

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***Abstract*—In the present work, a dual feed, compact circularly polarized antenna is designed for activity classification purpose. It consists of a circular ring on the top of the substrate which acts as the radiating patch. The ground plane exactly compliments the patch and thus is a circle with radius equal to inner radius of the ring. A rectangular stub is added to the ground plane for impedance matching. The antenna has been fabricated and the measured results are in very good agreement with the simulations. Excellent circular polarization performance is observed in the antenna which is highly desirable for the intended application. The transmission and reflection co-efficient of the antenna are a function of motion activities. This is due to specific obstruction of EM waves by the antenna when involved in performing daily human activities. Datasets have been collected by actual activity performance involving the fabricated antenna. Specific and distinct signatures of S11 parameter have been obtained for different activities. Thus, the antenna can be used for activity classification purpose.**

***Index Terms*—Circular polarization, axial ratio bandwidth, human activity classification.**

I. INTRODUCTION

Human activity classification has become a prime area of research and innumerable techniques have come up for proper and accurate classification of Human daily activities [1]- [2]. There are numerous instances where this becomes extremely important and critical. This can be directly applied in fields where a human needs help for proper activity performance.

The transmission co-efficient of an antenna is a function of human activity/motion. The EM waves generated by an antenna get obstructed in a similar manner in a periodic fashion when a specific activity is performed. Thus, specific signatures are obtained in the measurement of the transmission and reflection co-efficients of antenna when involved in activity performance [3].

It has been proven in [3] that when an antenna is tied or placed on the human body, the electromagnetic (EM) waves travelling on the body (generated by the antenna) get obstructed by the body movements or actions . This results in distinct features of the channel for even minute change in the posture. It has been stated that the channel features are a function of the EM waves in the Antenna's near field perturbed by the human body due to action performance. This wave obstruction is same each time the particular activity is performed. As a result, the variation in channel features and thus the reflection co-efficient is same in case the same activity is repeated any time. It is also proved in literature that the antenna impedance varies due to obstructed EM waves in Antenna's near field [4]. Even small activities like breathing or heartbeats could be tracked using this change in impedance of the body mounted antenna. The return loss/antenna reflection co-efficient is a measure of the antenna's impedance matching. As a result when there is a variation in the impedance of the antenna, the reflection co-efficient will definitely change. Thus, again it is proved theoretically that when the near field EM waves get obstructed due to activity performance, the trend in S11 parameter can be efficiently tracked.

A potent application of this can be found in the area of physiotherapy. Home based physiotherapy of a patient after some injury/ accident may prove to be dangerous as the exercise desired may go wrong without an instructor. Many high cost, bulky and non-user friendly devices for physiotherapy are available in market. In order to make the device extremely cheap and user friendly, we propose a simple antenna for design of an activity classifier. The other areas where this can be used are athlete training, security surveillance, robotic motion classification and rehabilitation [5]. The security surveillance is of prime importance in public places like airports, pilgrimages, tourist destinations etc. A simple band with the designed antenna and related circuitry tied to it can be used for suspected activity detection at such places to avoid any terrorist/destructive activity. The antenna can classify the suspected human activity and thus avoid any such threat in public places. A very similar application is discussed in [3], [6]- [7] where quarter wave monopoles are used as a part of human activity classification setup. It is impossible to use such huge antennas in practice for this application. The work has left the future scope of designing miniaturized antennas, sensitive to human motions, giving specific signature for each motion. These devices when brought in practice are battery based and the antenna can create huge battery drains if there exists polarization mismatch [8]. As a result, we design circularly polarized antennas to tackle this issue. The combination of all above practical implications inspires to design an antenna for activity classification purpose keeping all the restrictions and requirement of the application in mind.

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Dual Wide Band Circularly Polarized Microstrip Patch Antenna with Offset Feed

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Abstract
A compact, dual band circularly polarized antenna has been proposed and investigated. It has been designed with single feed and has simple structure. The antenna has a unique complimentary ground structure along with offset feeding which promotes the circular polarization (CP). These peculiarities in the structure also help in widening the axial ratio bandwidth (380 MHz and 1.08 GHz respectively at the two resonances) and improving the quality of CP. It has large return loss as well as axial ratio bandwidth. The antenna operates in C band and has resonances at 4.55 GHz and 7.58 GHz respectively. This makes the antenna suitable for all the emerging wireless communication applications where circular polarization is required. As a proof-of-concept, the prototype of the antenna has been fabricated and the measured results are in very good agreement with the simulated ones.

Keywords Axial ratio bandwidth (ARBW) · Axial ratio · Offset feed · Complimentary ground structure

1 Introduction

The design of circularly polarized antennas has evolved over years, fulfilling the need of receptors which can receive signals of any type of polarization. When a transmitter transmits a signal, it undergoes multiple reflections before it reaches the receiver. To avoid loss of information or misalignment of the received signal, the receiver antenna should be circularly polarized. This signifies the use of circularly polarized antennas in major radar applications. The antenna produces circular polarization if two perpendicular modes get excited as a result of the excitation given to the antenna. Thus, various techniques are developed in order to achieve circular polarization. Also, in order to use

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