DEVELOPMENT OF A PLANAR SENSOR FOR MONITORING ORTHOPAEDIC HEALTH

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Abstract— The significance in usage of wearable textile materials as the substrate of an antenna is increasing rapidly because of miniaturization of the system. Some of the major applications of the wearable antennas are navigation, computing and public safety, health treatment etc. The work presented in this paper deals with the design and development of a microstrip patch antenna for orthopaedic treatment. Here, the reflected EM waves obtained by application of microwaves in bones were analyzed and the cracks had been detected if present. The basis for bone crack detection with microwave imaging is the change in dielectric properties of normal and cracked bones. The patch antenna was optimized for resonance at a frequency of 2.45GHz, with a reasonable return loss. This method involved illuminating the targeted bones with propagating electromagnetic waves using a rectangular microstrip patch antenna and then we synthetically analyzed the reflections from the target using a
network analyzer. As a result, we measured the shift in the return loss of the micro-strip patch antenna and utilized it to monitor the changes in the bone and its orientation. Here, we had demonstrated the feasibility of detecting the osteoporosis and bone cracks using radiating patch antenna.

Keywords— Bone crack, osteoporosis, microwave imaging, rectangular patch antenna, network analyzer, resonant frequency

I. INTRODUCTION

Osteoporosis is a condition where there is a reduction in the density of the bone. Lack of consumption of Vitamin D, mainly Calcium brings about the brittleness in the bones which eventually leads to these fragile bones cracking under their own weight. Osteoporosis usually occurs in the hip, spine, rib and wrist bones. It is notably observed in women around forty years age when they undergo menopause. Activities like smoking, lack of exercise and alcohol consumption also causes bones to be more porous and lose its mass. This is a major topic of concern as certain causes of this condition is beyond one’s control. Factors such as body size, race and family history play a vital role in one’s chances of obtaining osteoporosis.

In Europe, studies indicate that osteoporosis is more prevalent than all forms of cancer barring lung cancer. Women who concur a fragility fracture are not properly diagnosed and treated for possible osteoporosis [1].

For the past few decades, many techniques have been adopted to detect Osteoporosis in the field of medicine. Several methods to detect fractures have been executed in the past. Techniques such as X-Ray imaging, Computed Tomographic (CT) scan and Magnetic Resonance Imaging (MRI) scan have been successful in monitoring bone cracks. However, it’s not wise to implement these procedures in the case of osteoporosis as it delivers high doses of radiations and it is not a handy device. MRI scans also have a teratogenic effect on women i.e. it poses a risk of pre-natal defect as it adversely affects the developing embryo or foetus. Sometimes X-rays will be unable to detect wrist fractures, hip fractures (in older people) and stress fractures [2]. Hence it is recommended to adopt an alternative to diagnose bone defects, thereby improving the efficiency and eliminating the disadvantages of traditional methods.

One such method which overcomes the drawbacks of the traditional methods is by using a microstrip patch antenna which uses scattered microwave radiation. As X-Rays poses a radiation threat and is carcinogenic when high doses of it are exposed to the human body, we operate the antenna in a microwave frequency range. This allows us to decrease the size of the antenna in order to enable us to use it in wearable and line of sight technology. Having a larger frequency range than X-Rays, the wavelength of the microwave is less and is also coupled with a low beam width. Hence the antenna will have a better directivity and a larger bandwidth. The small size of the antenna becomes effective as it is portable and consumes low power.

This paper will shed light on the use of flexible textile materials in designing a microstrip patch antenna for orthopaedic treatment. Wearable antennas extend the applications of textile materials in the field of wireless bodycentric sensing systems [3]. The excellent performance of these materials at microwave frequencies, flexible nature, durability makes them highly preferable as a substrate for the wearable sensors.

II. DESIGN OF PATCH ANTENNA AND ARM MODEL

Microstrip antennas are referred to as patch antennas as it consists of a rectangular patch printed on a dielectric substrate which has a ground plane material on the other side of the substrate. These type of patch antennas are made of certain width and length over the ground plane and a dielectric material of constant height (h) and dielectric constant (εr) [4].The resonant frequency and return loss are the most important parameters describing the performance of the antenna structures. The efficiency of the antenna is determined by the magnitude of the return loss and the resonant frequencies indicate the frequencies at which the minimum return loss can be noticed. The size of the patch can be reduced using high dielectric material as substrate [5]. But to have high efficiency it is advisable to use low dielectric fabrics.

When considering the design of patch antenna, there are certain essential parameters to be considered namely, (i) frequency of operation (fo), (ii) dielectric constant of the substrate and, (iii) height of the dielectric substrate.

An important requirement of a patch antenna is that it should be light-weight and comfortable. Also, these type of antennas have very thin low profile structures and hence it is used mostly in wireless communications. They possess light weight and planar configuration and can be designed of any regular shape. The rectangular patch and the ground plane, both made of conductive metals, form an EM resonant cavity that radiates at a specific resonant frequency [6].

In general, textiles material has a very low dielectric constant that suppresses the surface waves and increases the impedance bandwidth of the antenna. In addition to this, flexibility becomes an important property for designing these wearable patch antennas. There are several implications posed on the substrate to be used. It should have zero conductivity ideally with constant thickness and permittivity. Therefore, a material like a polyester resin is a chosen in our study for designing a wearable patch antenna because of its ease of availability, water resistance and very low conductivity. Generally optimum feeding position is chosen as approximately a one third of the length and the width to excite the two radiation modes [7].

In this present work, microstrip patch antennas to detect the crack length and propagation along different orientations are designed. The antenna used in the detection of cracks should be wrapped above the arm model and those cracks are to be detected. The parameters considered for the design of rectangular microstrip patch antenna is shown in Table 1.

Table 1: Values of the different parameters considered for designing the antenna [3].

S.No.	Design parameter	Value of the parameter
1	Frequency of operation	2.45 GHz
2	Dielectric constant	1.4
3	Substrate Height	2.85 mm
4	Length of the patch	48.70 mm
5	Width of the patch	55.89 mm

Fig.1. depicts the stacked layers of the arm model (skin, fat, muscle and bone) placed on the reflective plate which acts as a patch antenna. The dielectric constant of the arm model as shown in Table 2 is considerably too high when compared to the dielectric constant of polyester and copper on which the arm model is placed. So the received scattered parameter gets detuned because of the high difference in the permittivity matching. Hence a layer of foam (air) is introduced between skin and the radiating patch antenna such that the detuning effects of the high difference in dielectric constant is nullified to certain extent..

Table 2: Dielectric constant of the different materials used in the work.

S.No.	Material	Dielectric constant
1	Air	1.006
2	Teflon	2.1
3	Polyester	1.4
4	Skin	31.29
5	Fat	4.602
6	Muscle	53
7	Bone	12.66

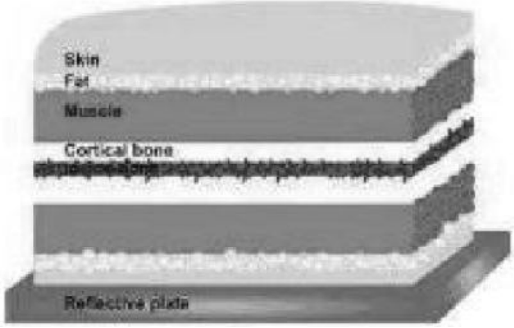

Fig.1. The representation of the layers of the arm placed on a reflective plate (patch antenna) [8].

III. EXPERIMENTAL PROCEDURE AND RESULTS

The microwave signal propagation around the human body is a complex phenomenon though it covers only short range of distance. Hence the reflections from nearby obstacles in the environment influence the performance of the single port patch antenna. So intense care in optimizing the antenna structure is required while fabricating it [9]. The variation in the dimensions of the patch antenna due to stretching and compression of the fabric substrate has a critical impact on the electromagnetic characteristics of the antenna. The substrate thickness changes the frequency at which antenna resonates, which can be analyzed by observing the return loss of the antenna using a network analyzer [9]. The patch antenna resonates at 2.515GHz when the truncated arm model is placed on it with a return loss of -21.1916 dB. The design frequency used in this paper is chosen to be 2.45 GHz due to the fact that there is no license needed to operate at that particular frequency and that it lies in the ISM band range of frequency.

3.1. Osteoporosis Detection

As discussed earlier, the loss of bone mass or the bone density leads to osteoporosis which becomes difficult to diagnose in the earlier stages. Hence using the patch sensor operating at 2.45 GHz, we can find the thickness of the bone based on the obtained return loss value in dB. In this study the thickness of the bone is varied from 20mm to 31mm and placed on the radiating patch antenna. The Table 3 and the Fig.2. shows the change in the S11 with the change in the thickness of the bone.

Table 3: Values of the S11 for different thicknesses of the bone.

Thickness of the bone (mm)	S_{11} (dB)	Frequency(GHz)
20	-20.71	2.515
23	-21.1916	2.515
25	-21.393	2.515
28	-21.689	2.515
31	-21.823	2.515

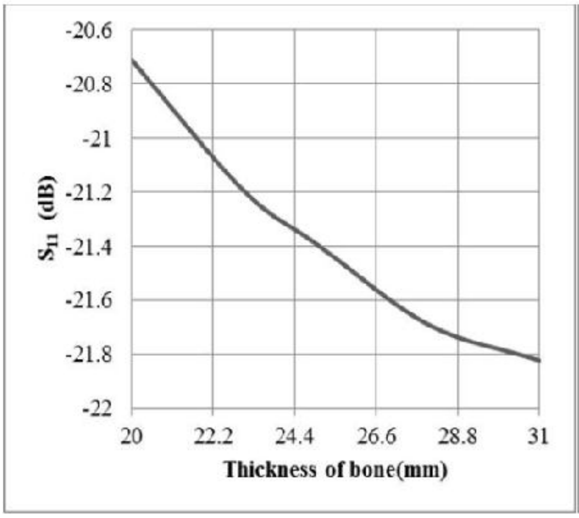

Fig.2. Plot between return loss and thickness of the bone.

The above graph shows that the magnitude of the return loss increases with the increase in the thickness. Thus the thickness of any bone model can be obtained from the graph if the antenna designed is of same specifications. By this if the mass of the bone lies below the threshold value, we can infer that the patient is suffering from osteoporosis.

3.2. Detecting the presence of crack on the bone

Here, the patch antenna is placed over the arm model on various places (say a,b,c,d,e) as shown in Fig.3. and return loss is noted in each position. This analysis is used to detect whether the crack is actually present or not.

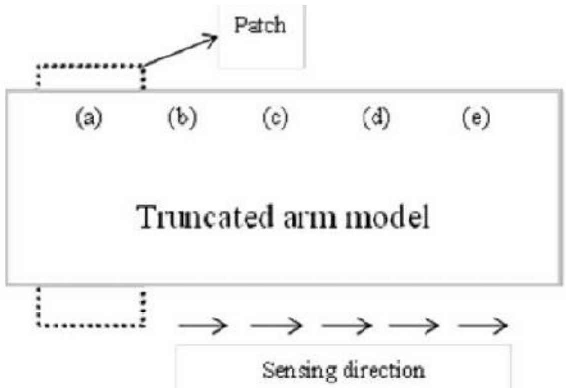

Fig.3. Pictorial representation of various positions assumed in the arm model.

The Table 4 below shows position of the crack and the corresponding value of S11 (in decibels) and frequency (in GHz) and the Fig.4. shows the graph between the position of the crack and S11 in decibels.

Table 4: Values of S11 for different positions on the bone.

Position	S_{11} (dB)	Freq (GHz)
(a)	-21.314	2.515
(b)	-21.314	2.515
(c)	-21.7134	2.505
(d)	-21.314	2.515
(e)	-21.315	2.515

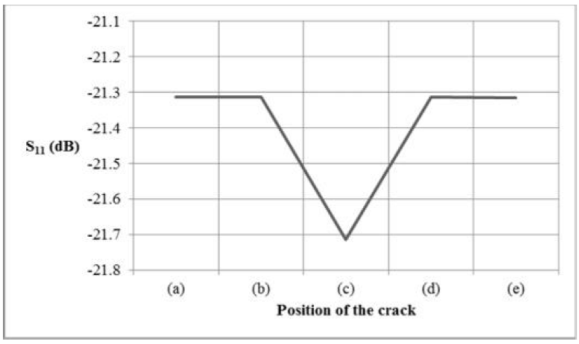

Fig.4. Plot between position of the crack and return loss obtained.

The return loss when placed on the crack (position c) changes suddenly from -21.314 to -21.7134. Hence it is found that the patch antenna is able to detect whether the crack is present on the bone or not.

3.3. Variation of the bone crack with respect to height

In this analysis a crack with the dimensions 30mm X 10mm is introduced. While increasing the height of the crack on the bone, we monitor the change in the reflection coefficient and the variation in the resonant frequency. The variation of S11 and the resonant frequency with respect to the height of the bone crack is presented in the Fig.5. and Fig.6.

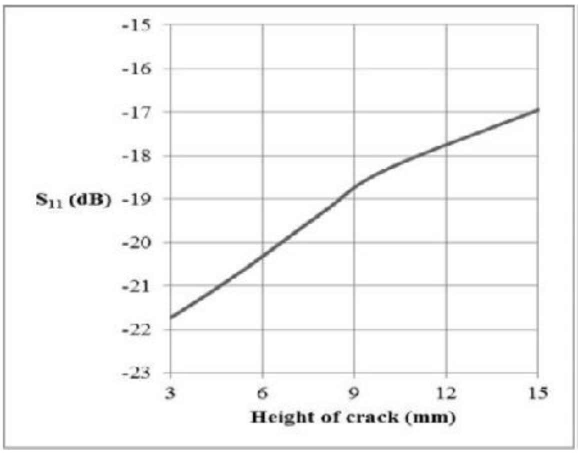

Fig.6.Plot between height of the crack and return loss

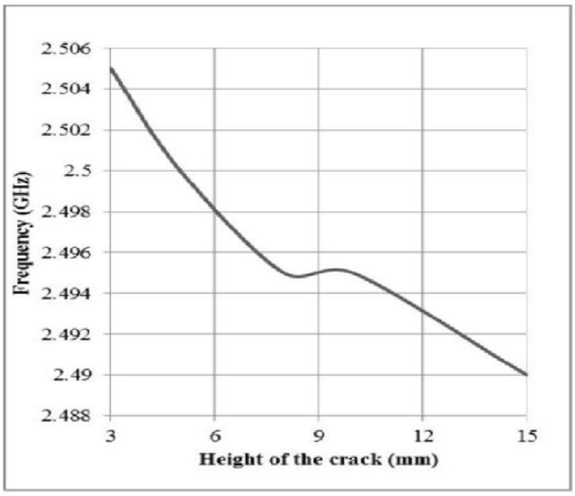

Fig.6.Plot between height of the crack and resonant frequency

As the height of the crack increases, the return loss decreases in magnitude and the frequency shows a negative variation.

3.4. Variation of the bone crack with respect to the length

In this case, a crack is introduced and the length of it is varied, while keeping the width and height constant at 10mm and 3mm respectively. While increasing the length of the crack on the bone we monitor the change in the reflection coefficient. The Table 5 and Fig.7. shows the values of the return loss with change in length of the crack.

Table 5: Values of S11 for different lengths of the bone crack.

Length of crack (mm)	S_{11} (dB)	Frequency (GHz)
15	-21.3834	2.51
20	-21.5511	2.51
25	-21.6	2.51
30	-21.7134	2.505
35	-21.924	2.505
40	-21.958	2.505

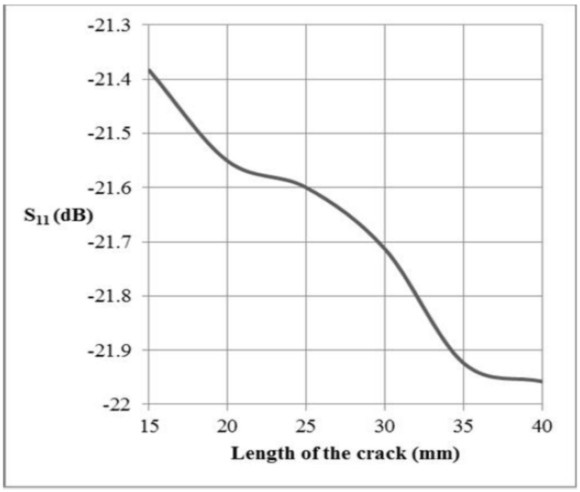

Fig.7.Plot between length of the crack and return loss

Thus with an increase in the length of the bone crack from 15mm up to 35mm, we observe an increase in the magnitude of the return loss.

3.5. Cracks at different depths in the bone

Now, the crack is introduced at a dimension of length 30mm, width 10mm and height 8mm.Whereas, the crack is introduced at different depths from the bone surface. Here the same dimension of crack is introduced at five different depth positions from the surface of the bone. The Table 6 and Fig.8. below shows the depth location of the crack and the S11 (in decibels) and frequency (GHz).

Table 6: Values of S11 for different depths of the crack from the surface of the bone

Depth of the Crack from the bone surface (mm)	S_{11}(dB)	Frequency (GHz)
0	-19.293	2.495
5	-20.7	2.52
7	-21.37	2.515
11	-21.403	2.515
15	-21.19	2.515
17	-21.1	2.515

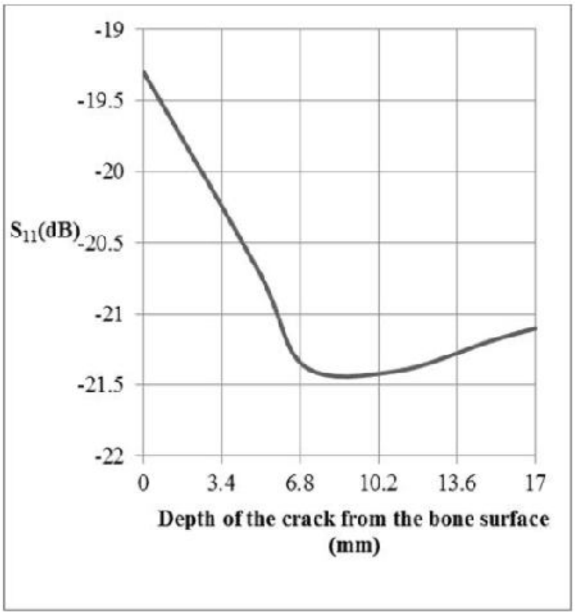

Fig.8.Plot between depth of the crack from the bone surface and return loss

Hence it is found that as the crack is found at a deeper location, the magnitude of S11 shows a increase in its magnitude.

CONCLUSION

The effect of the presence of the crack or the changes in the orientation or bone thickness on the resonant frequencies and return loss of the designed sensor is studied. Experimentations demonstrate that, the return loss are shifted with respect to the different depths, height, length of the bone crack or with respect to the different positions of the crack on the bone surface. The patch antenna can detect even the presence of a sub-millimeter crack with high resolution. On the other side, the bandwidth remained constant throughout the process. This work will allow to develop a microwave Imaging system which will allow to localize the cracks inside the bones remotely using the antenna scanning system. It is validated that the patch antenna sensor have great potential to serve as wireless crack detecting sensor in orthopaedic treatments.

APPLICATIONS AND FUTURE WORK

This method of using the planar sensor for detecting bone cracks can also be extended in detection of the voids, corrosion level or cracks in the metals used in the industries as nondestructive testing. Further it can be applied in military applications, detecting voids in the aircrafts etc. Our work is to be further extended by trying different fabrics for the substrate and compare the performances of the various fabric substrates. Even the performance of the antenna is expected to be increased for a better efficiency by using the optimization techniques.

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