ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

DETECTION IMPROVEMENT OF HIDDEN HUMANS RESPIRATORY USING UWB RADAR

M.Sc. THESIS

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Department of Communication Systems

Satellite Communication and Remote Sensing Programme

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BİLİŞİM ENSTİTÜSÜ

UWB RADAR İLE DUVAR ARKASINDAKİ İNSANIN TENEFFÜSÜNÜ ALGILAMA YÖNTEMLERİNİN İYİLEŞTİRİLMESİ

YÜKSEK LİSANS TEZİ

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İletişim Sistemleri Anabilim Dalı

Uydu Haberleşmesi ve Uzaktan Algılama Programı

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HAZİRAN 2013

Saeid KARAMZADEH, a **M.Sc.** student of ITU **Institute of Informatics** student ID **70111011**, successfully defended the **thesis** entitled “**DETECTION DETECTION IMPROVEMENT OF HIDDEN HUMANS RESPIRATORY USING UWB RADAR**”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To gratitude to God Almighty,

FOREWORD

In an endeavor to successfully complete my thesis, I received assistance from many people and I take this opportunity to thank those who have helped me along the way to achieve this success.

I am grateful to my research advisor, Assoc. Prof. Dr.Mesut Kartal for his guidance and continuous support throughout my thesis. His patience and knowledge have been invaluable throughout my research and I express my deep sense of gratitude to him.

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June 2013 Saeid KARAMZADEH

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ABBREVIATIONS

CST : CST Computer Simulation Technology
CWT : Continuous Wavelet Transform
EM : Electromagnetic
LLNL : Lawrence Livermore National Laboratory
MWEE : Microwave Engineering Europe's
RADAR : Radio Detection and Ranging
RCS : Radar Cross Section
RF : Radio Frequency
SAR : Specific Absorption Rate
STFT : Short-Time Fourier Transform
UWB : Ultra Wide Band

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DETECTION IMPROVEMENT OF HIDDEN HUMANS RESPIRATORY USING UWB RADAR

SUMMARY

Ultra-wideband radars are used for several applications such as military services, medical activities, and rescue missions. The detection of humans hidden behind walls or rubble, trapped in buildings on fire or avalanche victims are of interest for rescue, surveillance and security operations. Ultra-wideband technology is favored for these applications due to its inherent property of ultra-high resolution and the ability to penetrate most of the non-metallic building materials such as bricks, wood, dry walls, concrete and reinforced concrete.

Detection of human beings with radars is based on chest movement and respiratory motion detection.

These motions cause changes in frequency, phase, amplitude and periodic differences in time-of-arrival of scattered pulses from the target, which are result of periodic movements of the chest area of the target.

In this thesis, the emphasis is on improvement of detection techniques for a stationary human target behind the wall using Ultra-wideband radar.

Acquiring the optimal transmitted signal, to obtain the best detection result in receiver’s output is the novelty and the aim of our proposed work. For this purpose, we test Gaussian signal and some derivatives of this signal as transmitted signal and compare the receiver output results. Also, to extract the required information about the target from receiving signal and subtract the background noise, the wavelet transforms are the adequate methods and are used in this work. At the signal processing part, different wavelet transforms will be considered, depending on some parameters such as the distance between the radar and the target or the wall’s substance. With choosing the appropriate the wavelet transform, we can detect accurate human breathing signal affected by background noise.

The result of hidden human detection will be performing with CST (CST Computer Simulation Technology) Microwave Studio simulation.

UWB RADAR İLE DUVAR ARKASINDAKİ İNSANIN TENEFFÜSÜNÜ ALGILAMA YÖNTEMLERİNİN İYİLEŞTİRİLMESİ

ÖZET

Günümüzde Aşırı Geniş Bantlı Radarlar (UWB Radar) çeşitli kullanım alanlarında kullanılmakta ve kullanımı giderek yaygınlaşmaktadır. O yüzden bu konu araştırma dünyasında da önemli bir yer alıp ve çok ilgi çekmiştir. Kullanılması düşünülebilir alanlar ise hastanelerde yoğun bakımda olan hastalar, huzur evlerinde ve hatta evlerdir. 24 saatlik kalp atışları ve teneffüsünün kontrol edilmesine ihtiyaç duyan hastalar için çok yararlı olabilecek bir teknoloji sayılır. Hastaya temas etmeden uzaktan algılama yöntemi olarak işlem yapan bir biyomedikal cihaz olabilir. İkinci uygulama olarak duvar arkasında olan insanı tespit etmekten yola çıkılarak depremde ve çığ altında kalan insanları bulmakta yardım alabileceğimiz bir cihaz olabilir. Hatta sivil uygulamalar dışında, bir polis servisine, bina içinde saklananları bulmakta yardımcı olabilir.

Bu çeşit radarlar yüksek bir çözünürlüye sahiptir. Bu özellik geniş banta sahip olmasından kaynaklanmaktadır. Gönderdiği işaretin penetrasyon kabiliyetinden engel arkası çalışmalarda faydalanılabilir. Ancak geniş banttan dolayı ortamda olan çeşitli ferekanslarda çalışan cihazlardan kaynaklanan gürültüden etkilenmesi bir dezavantaj olarak sayılabilir. O yüzden, arkaplanki gürültüyü gidermek, işaret işleme konusunda bir çalışma alanı olarak tanımlanır.

Bu tezde, Aşırı Geniş Banlı Radar ile duvar arkasında olan insan teneffüsünden tespit edilmeye çalışılmıştır. Verici antenden gönderilen işaret havadan ve duvardan geçerek insana çarpıp geri dönmektedir. Alıcıda gördüğümüz işaretin, katmanlardan geçmesinden dolayı ve insanın teneffüsünden kaynaklanan göğüs kafesinin hareketi nedeniyle fazı, frekansı ve bant genişliği değişmektedir. Vericide uygun bir işaret seçmekle geri dönen işaretin değişikliklerini tahmin edebiliriz ve işaret işleme yöntemleriyle istediğimiz bilgileri (insanın teneffüs sinyali) tespit etmiş oluyoruz. Alıcı ve vericide uygun bir anten kullanmak da amacımıza ulaşmakta yardımcı olacaktır. Bu amaçla, Aşırı Geniş Bantta kullanılan en uygun antenler ve özellikleri açıklanmaktadır. İşaret formu olarak Gauss İşareti ve birkaç türevi kullanılıp sonuçları sunulmuştur. Sinyal işleme metodu olarak Wavelet dönüşümü uygun görülüp nedenleri açıklanmıştır. Bu tezde insan olan ortamı modellemek için CST programından yardım alınmıştır. Sonuç kısmında insanın tespitine dair sonuçlar detaylarıyla sunulmaktadır.

Müzelerde koruma amacıyla ve hatta daha büyük bir alanı gözlemleme amacıyla kullanılabilir bir cihazdır.

Bu radarın engel arkasında olan insanı tesbit etmesi bir başka ve hatta en önemli kabilliyeti sayılır. Kullanım alanlarısa, depremde göçük altında kalan insanı bulmak çok hızlı ve doğru yanıt vermesi çok önem taşımaktadır. Hatta önce bahsettiğimiz gibi bir bina içinde saklanan insanların bulmasına polise yardımcı olan bir cihaz olabilir.

Bu kullanımda bahsettiğimiz insan tesbiti için iki ana yöntemden yaklaşa biliriz. Birincisi, insanın vucud dokusunun dielektrik katsayıların modellememiz gerekiyor. Alıcıdan alınan işareti incenerek gönderilen işaretten farkı göz önünde bulundurulup işaretteki bu farklılığa nasıl bir dokunun sebep olduğu gözlemlenmiştir.Bu amaçla, farklı çalışmalarda olan insan dokusu modelinden faydalanılmıştır. Örneğin göğüs kanseriyle ilgili çalışmalardır.

İkinci yaklaşım, teneffüsden kaynaklanan göğüs kafesinin yer değiştirmesi, her ne kadar küçük bir değişim olsa da, dopler etkisine sebep olup insanın bulmasında yardımcı olacaktır. Bu tezde bu yötem tercih edilmiştir. En önemli neden olarak engel arkasında ve çeşitli ortamlarda daha doğru yanıt vermesi söylenebilir. Bilindiği gibi, engel arkası çalışmalarda tüm ortamın dielektriğinin modellemesi ve her yerde kullanılabilecek genel model elde etmek oldukça karmaşıktır.

UWB Radarda kullanılan Vivaldi ve Horn gibi bir kaç anten uygun görülmektedir. Bu tezde ise geniş bir bant genişliğine ihtiyaç duyuluyor ve aynı zamanda duvardan penetre etmek gereğini de göz önüne almak lazımdır. Her iki anten de test edilmiştir ve farkı farklı özelliklerinden faydalanılmıştır. Örneğin Horn ve Vivaldi Antenlerin boyutu küçük olduğu için mikrostrip anten olarak kullanılırlar. Bu antenler yüksek ferekans ve bant genişliğine sahiptir ve yüksek çözünürlükde performansı makbuldur. Ama anten'den çıkan işaretin duvardan geçmesi için düşük frekansları kullanmamız gerektiğinden Horn Anten seçilmiş ve daha uygun görülmüştür. Horn Anteni ise daha büyük boyutlu olması dezavantajı sayılır.Ancak hem yüksek ve hem de düşük ferekansklarda kullanışlıdır.

İşaret formuna gelince her iki (zaman ve ferekans) domende lokalize olan bir işaret olarak Gaus işareti seçilmiştir. Bu işaretin farklı türevlerinin işaret formu ve matematiksel ifadesi daha önce hesaplanıldığı için çok yararlı olacaktır. Daha doğrusu işaretin değişiklikleri adım adım vericiden alıcıya çeşitli katmanlardan geçerek tahmin edildikten sonra işlem yapmakta kolaylık sağlayacaktır.

Bu tezde işaret işleme yöntemleriyle arkaplan gürültüsünü yok etmek veya en aza düşürmek amaçlanmıştır.

İşaretin zamanla değişmesinden dolayı geri dönen işareti incelemek için Wavelet dönüşümünün kullanılması uygun görülmüştür. İlerleyen bölümlerde Wavelet Dönüşümü'nün Fourier ve STFT gibi başka dönüşümlerle olan farkı da açıklanmıştır. Buradan yola çıkılarak neden Wavelet'in seçildiği anlaşılmış olacaktır. Wavelete Dönüşümününde farklı Ana Waveletleri denenmiş ve ortaya çıkan sonuçlar tartışılmıştır.

Sonuçta alıcıda ve vericide doğru bir anten seçerek doğru bir işaret formu göndererek sistem en optimal şekilde tasarlanmış oluyor. Çeşitli işaret formları çeşitli ortamlar için deneyler sonucunda önerilmiştir.

Uygun işareti verici ile gönderdikten sonra alıcıdan aldığımız işaretten Wavelet Dönüşümünü kullanarak duvar arkasında olan insanın teneffüs sinyali izlenip doğru sonucu tesbit edilmiştir.

Farklı ortamlar için uygun Wavelet Dönüşümü önerilmiştir. İşlemlerin sonucudan elde edilen bilgiler doğru ve hatta yanlış yöntem seçimi sonucunda olan bilgiler detaylı bir şekilde sunulmuştur.

1. INTRODUCTION

One of the most important challenges about using UWB signals is to eliminate environmental noises from the desired signal. In spite of many advantages, UWB signals are always exposure to noise because of operated frequency domain. Also in human respiration detection with UWB radars, background subtraction is always be considered, because of the sensitivity of respiration signal and its enormous influence ability by environmental noises.

1.1 Purpose of Thesis

In this thesis for the hidden human detection behind a wall, extract the human respiratory signal from received signal will be consider. The wavelet transform as the best method for background subtraction will be presented. For acquire, the acceptable result in different condition like different wall material and different distance between target and radar the appropriate signal in transmitter antenna will be introduced. In the receiver part for processing the received signal, and optioning the appropriate result (human respiratory signal) the proper wavelet transform will be used.

1.2 Literature Review

1.2.1 Radar

Radar was originally conceived to detect large objects at far ranges. Emphasis was primarily on air traffic control and surveillance, detection of sea vessels and navigation (figure1 shows the primary system of radar). Channel separation was motivated both by the physics of electromagnetic propagation and coexistence with other radio systems. At the time, little effort was made to explore the possibilities of short-range measurements on complicated structures.

However, the unique ability of electromagnetic waves to penetrate non-metallic objects have later come to suggest other uses, such as ground penetrating systems for geological surveys, and probing of the human body. Radar technology was not seriously considered for medical instrumentation until the early 70s. The attention had up to this point been limited to the study of adverse effects of tissue heating or possible curative influence on particular illnesses, such as arthritis. Measurements of minute organ movements and qualitative detection of water condensation in human lungs were among the first proposed uses in medical diagnostics [1, 2].

A radar's ability to extract valuable information about a complex structure, such as the human body, is to a large extent technology driven. For example, continuous wave (CW) radars are very sensitive devices in detecting movement, such as time varying physiological phenomena. The use of CW radar to monitor heart rate and pulmonary motion appears to be the predominant interest in medical radar during the 80s. The potential usefulness of radar in rescue operations was clearly emphasized in experiments to detect vital signs of subjects buried under rubble [3, 4, 5].

Figure 1.1 : Primary radars system.

1.2.2 UWB Radar

Most conventional radar systems operate in a relative narrow frequency band; they use harmonic (sinusoidal) signals as carrier oscillations to transmit the information. The reason for that is rather simple: a sinusoid is an Eigen oscillation of LC-contour, which is the simplest and, so; the most widely used electrical oscillation system. The resonance features of such a system make possible frequency selection of the large number of information channels operating in the common environment (space, guiding and optical communication lines). So, the frequency selection is now the main method to divide these channels, most radars now in use are narrow band systems with frequency band much less than the carrier frequency. The theory and practice of current radar systems are based on this specific feature. However, as known, a frequency band determines the information content of radar systems, as the volume of information transmitted per a time unit is directly proportional to a frequency band. To raise the information capability of a radar system, the widening of its frequency band is needed. The only alternative approach is an increase in information transmission time. In connection with fast informatization of society and continuous increase of information streams, this problem becomes more and actual both for radio communication and for radars. Actuality of this problem determined rapid development in the last years the technologies using ultra wide band (UWB) signals.

According to the definition introduced by Defense Advanced Research Projects Agency (DARPA) in 1990, as Ultra Wide Band, we consider systems and signals with $0.25 < h < 1$, where h can be determined by the formula:

$$h = (f_h – f_l)/ (f_h + f_l) \qquad \textbf{(1)}$$

Where f_h represents the upper frequency of the -10 dB emission limit and f_l represents the lower frequency limit of the -10dB emission limit [6, 7].

The problem of going to UWB signals is of particular interest for radars. The matter is that conventional radars with frequency band no more than 10% from the carrier frequency provide only target detection and coordinates measurement (with relatively low accuracy), but they cannot form target "portrait" or image. Such radars are similar to a person with weak eyes; he sees an object but cannot recognize it. Therefore, in present-day practice, many efforts are being taken to increase the information received from the object observed. In military aviation, identification mode ("friend-or-for") is used; in civil aviation, they use secondary radar channel operating in interrogation-respond mode. To rise the information content in radar data, the target recognition mode is sometimes used; using such, a mode does not provide forming a target image but makes it possible to obtain additional information on the target using some target features ("portrait"), which we can get after special processing. Going to such a mode requires an essential increase in a radar frequency band and, as a result, new approaches in both radar methods and technologies. Further widening frequency band and going to UWB signals help to receive more information on a target and to obtain radar target image.

The overall conceptual working mode of a UWB radar system resembles that of ultrasonic echo transducers used in many applications, from autofocus cameras to proximity and range detectors. The main and fundamental difference being that, contrary to ultrasound-electromagnetic pulses propagate through walls, ground, ice, mud, concrete, and the human body, as well. Increasing the system’s information capacity requires expanding its band of frequencies. The informational content of the UWB radars increases because of the smaller pulse volume of the signal.

The UWB radar reduced signal length can:

Improve detected target range measurement accuracy. This results in the improvement of the radar resolution for all coordinates, since the resolution of targets by one coordinate does not require their resolution by other coordinates. The analysis of fields of application for UWB radars demonstrates that radars of that type could be used practically in all cases where we need highly precise remote observation of moving objects at short distances. UWB radars can be used in security systems as security signaling sensors, which provide detection of unsanctioned intrusion into the guarded area. In a rescue, service to detect people buried under building obstructions or snow slips by their movement. If a person is motionless, the detection can be performed using person's heart and thorax beats. UWB radars can be also applied in a police service for searching criminals concealed themselves under various covers. UWB radars are useful in hospitals and at home, where they can provide remote measuring heart and respiratory beats and other parameters of patient's vital activity. UWB radar can perform nondestructive control over building constructions, detect hidden communications in old buildings and so on.

Thanks to the reduction in pulse volume, UWB radar gets some new features:

Higher range measurement accuracy and range resolution; this leads to a rise in radar resolution along all coordinates, as target resolution along one coordinate does not require target resolution along other coordinates. Reduction in radar "dead" zone. Recognition of target's class and type as well as formation of target's radar image, as the received signal contains the information not only on the target as a whole but also target's separate elements. Higher radar immunity to all passive interference, such as rain, fog, clutter, aerosols, metalized strips, etc. The reason for this is that interference radar cross section (RCS) in small pulse volume becomes comparable with target RCS.

Increase in radar immunity to extraneous electromagnetic radiations and noises. Increase in target detection probability and reliable target tracking resulted from increasing target RCS. Increase in target detection probability and target tracking reliability caused by elimination of lobe structure of targets' secondary patterns, as signals scattered by separate target's elements do not interfere. Reliability of target tracking at low elevation angles increases, which is a result of eliminating interference nulls in antenna pattern, as a signal scattered by the target and a signal re-scattered by the earth surface are time divided and can be selected. It is possible to change radiation parameters (pattern's width and form) by varying radiated signal parameters, among them, obtaining an ultra-narrow antenna pattern; Increase in radar operation security [6, 7].

1.2.3 Some Application of UWB Radar

1.2.3.1 Medicine

Although UWB and ultrasound are in fact very similar and many of the signal processing techniques used in ultrasonic systems can be applied to UWB systems the major difference is that:

Ultrasound is basically a line of sight technology and it is very short-range works only over a few inches. However, UWB RF pulses and has high gain this makes viable for wide area applications where obstacles are certain to be encountered. The feature makes it easy to image organs of human body for medical application. Another feature of UWB is the high precision ranging at centimeter level based on the ultra-short pulse characteristic. High precision of ranging also means strong multi-path resolving capability. The third feature of UWB is the low electromagnetic radiation due to the low radio power pulse less than -41.3dB in indoor environment.

The low radiation has little influence on the environment, which is suitable for hospital. Furthermore, the low radiation is safe for human body, even in the short distance, which makes it possible to apply UWB to the clairvoyant equipment.

Which also enables the usage of long-life battery-operated devices. Below figure shows the patient monitoring with UWB radar in a hospital [8, 9].

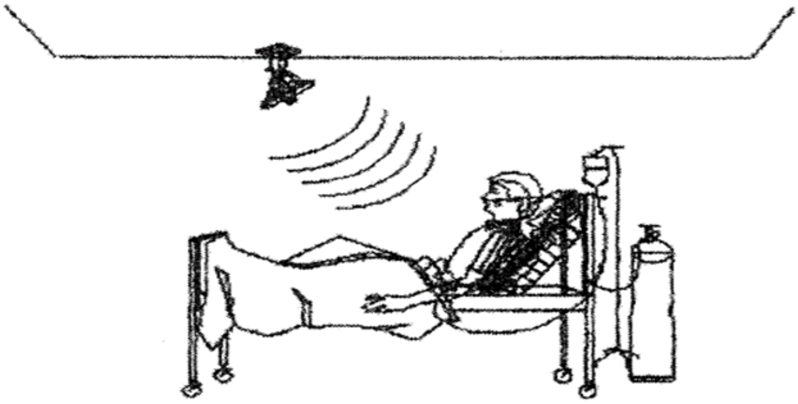


Figure 1.2: Patient monitoring.

1.2.3.2 Obstetrics imaging

UWB radar in this application area has many advantages over current ultrasound based fetal monitoring system. These new features include; no contact with patient, unimpaired mother and childcare, remote operation, no cleaning and easier use.

UWB radar could replace presently used fetal monitors which use ultrasound (to detect planetary blood flow) and pressure sensors (to detect uterine contractions): the UWB radar signal contains data about maternal heart rate, maternal breath rate, fetal heart rate, fetal movements, and uterine contractions. Furthermore, the remote, non-contact, non-invasive operation permits conventional, uninterrupted mother and childcare [9].

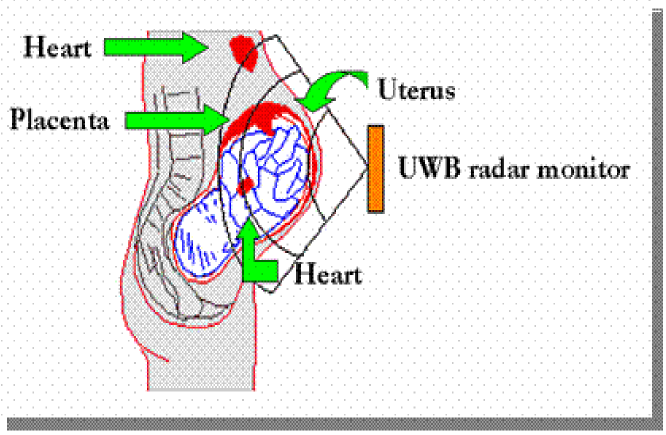


Figure 1.3: Imaging.

1.2.3.3 Guarding systems and security systems

Detection of crossing of a guarded perimeter line and detection of people in a forest is another application of UWB radars. In this application, the UWB radar can detect a person signal when cross the forbidden line. Below figure, show the sample of these applications [10, 11].

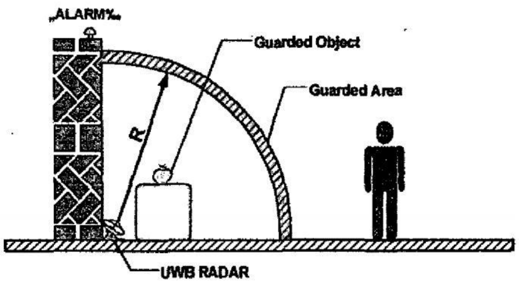


Figure 1.4.1 : Security.

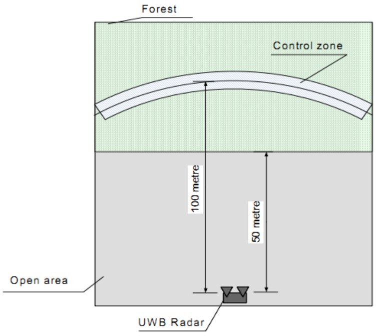


Figure 1.4.2 : Guarding.

1.2.3.4 Rescue systems for sensing buried people

Radar is considered to be a solution to the problem of efficiently, accurately and reliably detecting and locating victims buried under rubble. Since time is a crucial factor, the priority during such trapped-victim detection is given to detect living victims. The operational mode of a search-and-rescue radar is to generate and radiate electromagnetic energy into the rubble and from the received backscattered radiation extract any motion produced by the victim [12]. A typical radar-based trapped-victim detection scenario is depicted in Figure 1.5.

1.2.3.5 Other medical application areas of UWB

The University of Iowa's National Center working on speech sensors using UWB radar technology. The correlations were found between UWB radar signature and other conventional tracings while recording the movements of lips, tongues, glottis and tracheal wall.

1.2.3.6 Other possible medical application areas of UWB include

- Underwater medicine measurements.
- Space medicine measurements.
- Sport medicine measurements.
- Military medicine.
- Emergency medicine: Rubble Rescue Radar

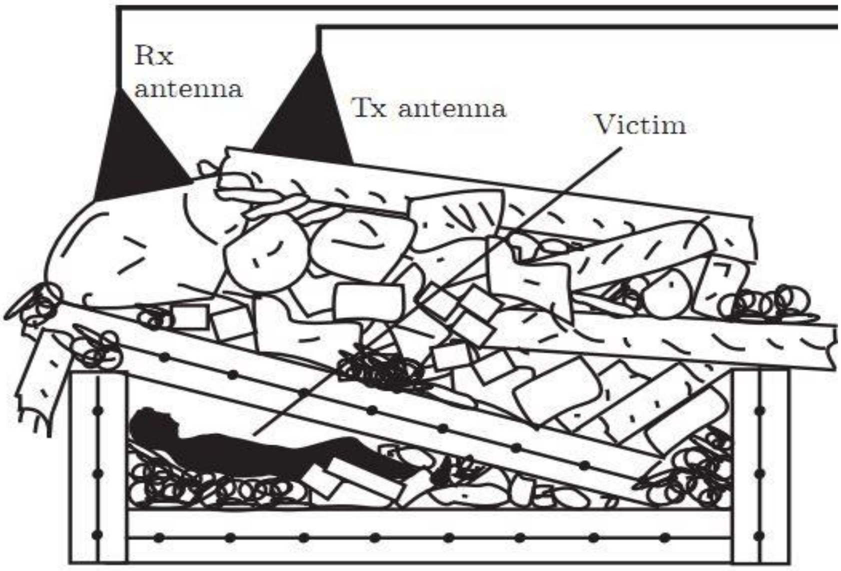


Figure 1.5: Tramping victim detection.

2. UWB RADAR SYSTEM IN HIDDEN HUMAN DETECTION

2.1 Purpose

In this thesis, UWB radar used for hidden human behind a wall. For this reason, appropriate antenna in transmitter and recievierand proper transmitted signal will be discussed. For extract favorable information about target, wavelet transforms, as the best signal processing method will be introduce. Below figure shows the general scheme about this system without wall.

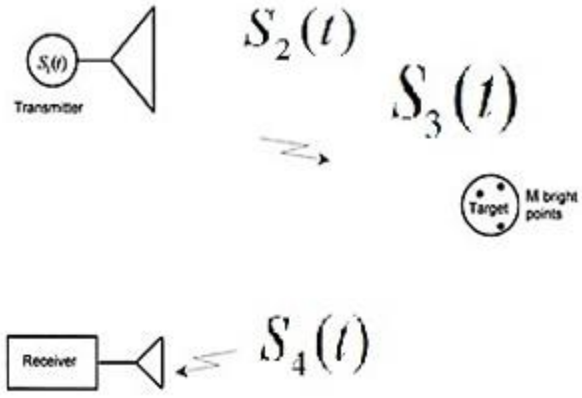


Figure 2.1 : Signal changes during forward and backward path to radar.

The signal changing during the scattering state that can be expressed as in equation (2).

$$S_2(t)=\frac{dS_1(t)}{dt},S_3(t)=\frac{dS_1(t+\tau)}{dt},S_4(t)=\int\frac{dS_1(t+\tau)}{dt}\times h(t-\tau)dt \qquad \textbf{(2)}$$

In this figure $S_1(t)$ is the transmitted signal, τ is the time delay and h is the channel function indicating the reflection model of the target.

2.2 Antenna

The most proper antennas used in UWB radars are Horn and Vivaldi antennas. These antennas have been used as both the transmitter and the receiver antenna.

2.2.1 Horn antennas

There is no doubt that horn antennas are the simplest and one of the most widely used forms of microwave antenna – the antenna is nicely integrated with the feed line (waveguide) and the performance can be controlled easily. They are mainly used for standard antenna gain and field measurements, feed elements for reflector antennas and microwave communications. The horn can take many different forms: pyramidal horns (shown in Figure 2.1) and conical horns are the most popular types – the former is most suitable for linear polarization and the latter for circular polarization. Since the basic theory is covered in the previous section, the focus of this section is on design and performance estimation. The Horn Antenna can be used as a transmit antenna, receive antenna or as a gain standard with gains from 9.5 to 22.0 dBi. It's wide bandwidth and predictability is ideal for many broadband applications. Various mounting hardware and accessories available to meet our specific needs
Specialty Horns covering different frequency bands with various beam width and gain options are also available [13].

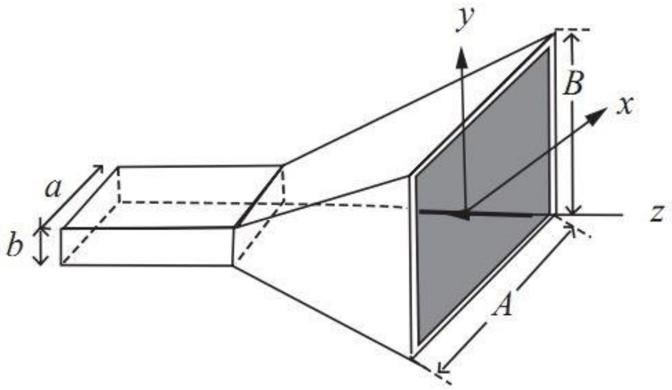


Figure 2.2 : Pyramidal horn.

2.2.2 Vivaldi antenna

Vivaldi antennas are simple planar antennas that are very broadband. This type of antennas can be made for linear polarized waves or - using two devices arranged in orthogonal direction - for transmitting / receiving both polarization orientations.

Vivaldi antennas are useful for many frequency band. Printed circuit technology makes this type antenna cost effective at microwave frequencies exceeding 1 GHz. Advantages of Vivaldi antennas are their broadband characteristics (suitable for ultra-wideband signals), their easy manufacturing process using common methods for PCB production, and their easy impedance matching to the feeding line using microstrip line modeling methods. We can inspect S11 parameter from 1 GHz up to 20 GHz in this type of antenna.

Microwave Engineering Europe's (MWEE) EM simulation benchmark has become quite a tradition over the last few years, enticing some of the best-known software providers to put their diverse simulation methods to the test. The results are always eagerly awaited as they represent the current statue of simulation technology and permit revealing comparisons between individual methods and software packets.

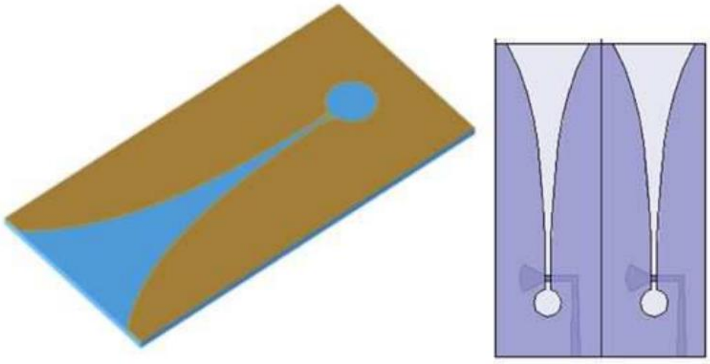


Figure 2.3 : A sample of Vivaldi antenna.

2.3 Transmitted Signal

The optimal duration of the reference pulse having Gaussian envelope. Gaussian signal and its derivatives are the usual choice for modeling UWB impulses. Since the Gaussian function is perfectly local in both time and frequency domains and is indefinitely derivable. Below figures, show the sample of Gaussian signal that used as a transmitted signal in many works [14].

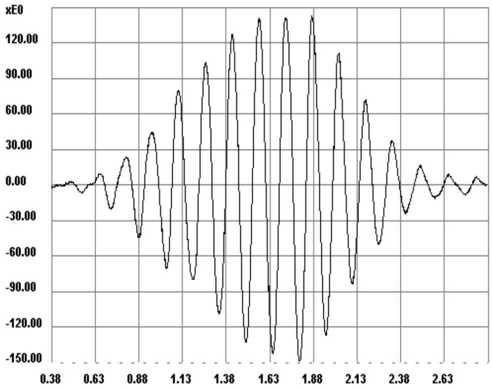


Figure 2.4 : The sample of Gaussian signal.

Antennas on the transmitter and receiver act as differentiation operation on the signal, meaning that the signal at the receiving end will be of higher derivative order than the generated pulse. For this reason, discussing about Gaussian signal and derivatives of Gaussian signal will be proper.

When we take derivatives to *x* (*spatial derivatives*) of the Gaussian function repetitively, we see a pattern emerging of a polynomial of increasing order, multiplied with the original (normalized) Gaussian function again. The equation of Gaussian signal and some derivatives of Gaussian signal could be express as below:

$$\{\frac{e^{-\frac{x^2}{2\sigma^2}}}{\sqrt{2\pi}\sigma}, \frac{e^{-\frac{x^2}{2\sigma^2}}x}{\sqrt{2\pi}\sigma^3}, \frac{e^{-\frac{x^2}{2\sigma^2}}(x-\sigma)(x+\sigma)}{\sqrt{2\pi}\sigma^5}, \frac{e^{-\frac{x^2}{2\sigma^2}}x(x^2-3\sigma^2)}{\sqrt{2\pi}\sigma^7}, \frac{e^{-\frac{x^2}{2\sigma^2}}(x^4-6x^2\sigma^2+3\sigma^4)}{\sqrt{2\pi}\sigma^9}\} \qquad \textbf{(3)}$$

Figure 2.5 shows Gaussian signal waveform and some derivatives of this signal.

The Gaussian function itself is a common element of all higher order derivatives. We extract the polynomials by dividing by the Gaussian function: These polynomials are the Hermite polynomials, called after Charles Hermite, a brilliant French mathematician. Gaussian derivative functions start to look more and more alike for higher order (according to the Hermite polynomials, Charles Hermite (1822-1901)). Here the graphs are shown for the 20th and 24th order of differentiation in Figure 2.6.

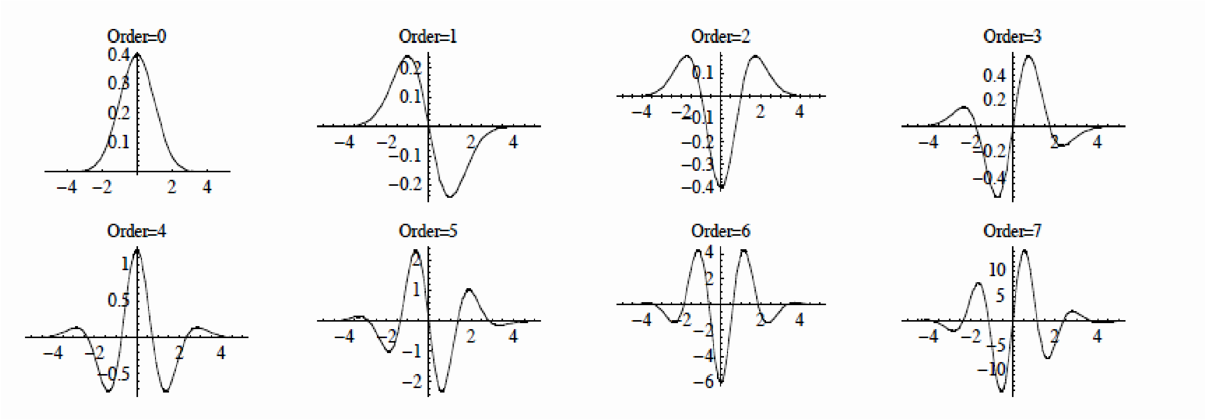


Figure 2.5 : Gaussian signal and some derivatives of Gaussian signal.

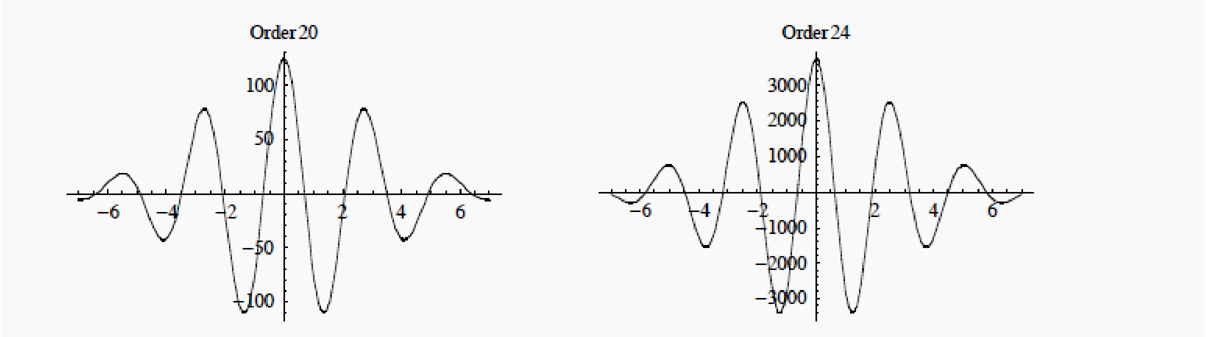


Figure 2.6 : The 20th and 24th derivatives of Gaussian signal.

Moreover, we can show the correlation in matrix and 3-D like in blow:

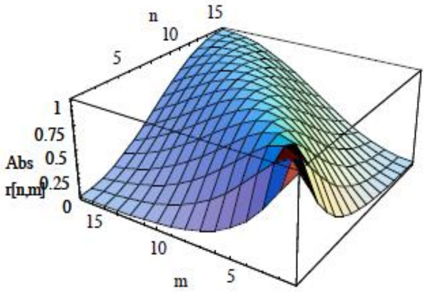


Figure 2.7 : The Gaussian signals and derivatives correlation.

2.4 Wavelet Transform

Wavelet transform can work with non-stationary signals. Therefore, in this thesis it is preferred in signal processing part. Wavelet transform also provides multi resolution analysis with dilated windows, which makes it possible to check different resolutions in various frequencies. Therefore, wavelet transform would be a good choice for processing the received signals that change during passing different layers like air and wall. Like the Fourier transform, the *continuous wavelet transform* (CWT) uses inner products to measure the similarity between a signal and an analyzing function. In the Fourier transform, the analyzing functions are complex exponentials $\exp(j\omega t)$. The resulting transform is a function of a single variable, ω. In the short-time Fourier transform, the analyzing functions are windowed complex exponentials, and the result in a function of two variables. The STFT, $f(\omega,\tau)$ coefficients, represent the match between the signal and a sinusoid with angular frequency ω in an interval of a specified length centered at τ. In the CWT, the analyzing function is a wavelet, ψ. The CWT compares the signal to shifted and compressed or stretched versions of a wavelet. Stretching or compressing a function is collectively referred to as dilation or scaling and corresponds to the physical notion of scale. By comparing the signal to the wavelet at various scales and positions, you obtain a function of two variables. The two-dimensional representation of a one-dimensional signal is redundant. If the wavelet is complex-valued, the CWT is a complex-valued function of scale and position. If the signal is real-valued, the CWT is a real-valued function of scale and position. For a scale parameter, a> 0, and position, b, the CWT is:

$$C(a,b;f(t),\psi(t))=\int_{-\infty}^{+\infty} f(t)(1/\sqrt{a})\psi^*(\frac{t-b}{a})dt \qquad \textbf{(4)}$$

Where * denotes the complex conjugate. Not only do the values of scale and position affect the CWT coefficients, the choice of wavelet also affects the values of the coefficients. By continuously varying the values of the scale parameter, *a,* and the position parameter, *b,* you obtain the *cwt coefficients C (a, b)*. Note that for convenience, the dependence of the CWT coefficients on the function and analyzing wavelet has been suppressed. Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelets of the original signal.

There are many different admissible wavelets, which can be used in the CWT. While it may seem confusing that there are so many choices for the analyzing wavelet, it is actually a strength of wavelet analysis. Depending on what signal features you are trying to detect, you are free to select a wavelet that facilitates your detection of that feature. For example, if you are trying to detect abrupt discontinuities in your signal, you may choose one wavelet. On the other hand, if you are interesting in finding oscillations with smooth onsets and offsets, you are free to choose a wavelet that more closely matches that behavior [15, 16].

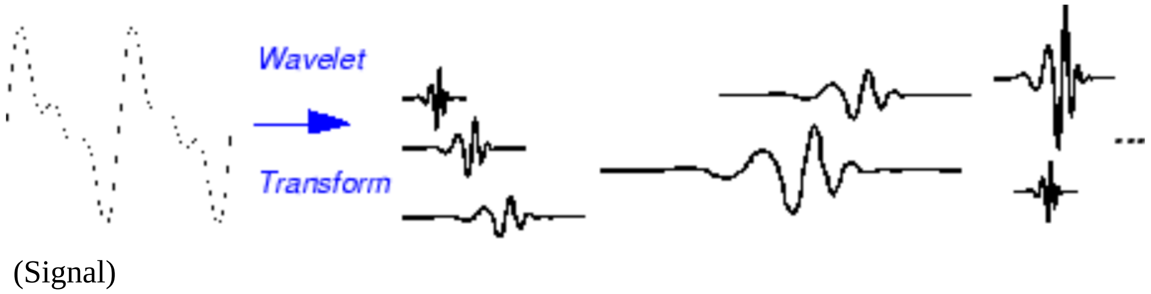


Figure 2.8 : Continuous Wavelet of different scales and positions.

2.5 Dielectric Constant

Another subject matter in hidden human detection is the dielectric constant. For design the system in simulation stage, we have to modeling the human body and wall. For the human body modeling with current dielectric constant, we will mention some research about different subject that relate with human body dielectric.

In fallow, there is a good modeling for the human body dielectric that have been modeling in Lawrence Livermore National Laboratory (LLNL). In this modeling the impedance of the cardiac muscle is in the order of 60 ohms and the impedance of blood is about 50 ohms it can be expected a roughly 10% reflection magnitude of the radio frequency energy at the heart muscle/blood boundary. The reflection coefficient, defined as (Y-1)/(Y+1) where Y=Z (heart)/Z (blood), gives a 9.9% return fraction of the radiated pulse. In blew, we have table of Electromagnetic and anatomical properties of tissue layers in the thorax and figure of modeling Figure 2.9 and Figure 2.10. Model predicted attenuation of pulse-echo intensity travelling from the transmitting antenna to the receiving antenna. Each step accounts for echo at the boundary. Decreasing of the curve accounts for linear attenuation in the tissue (imaginary part of reflection coefficient and multiple reflections are ignored). The Figure 2.11 shows the one application of LLNL research.

Table 2.1 : Electromagnetic and anatomical properties of tissue layers in the thorax.

	İmpedance	attenuation	speed	thinkness
	Ω	m^{-1}	m/s	M
Air	376.7	0.00	$2.998\ 10^{8}$	$1.00\ 10^{-28.96}$
Fat	112.6	8.96	$8.958\ 10^{7}$	$0.96\ 10^{-2}$
Muscle	49.99	31.67	$3.978\ 10^{7}$	$1.35\ 10^{-2}$
cartilage	58.16	31.93	$4.628\ 10^{7}$	$1.16\ 10^{-2}$
Lunge	52.86	29.62	$4.206\ 10^{7}$	$5.78\ 10^{-3}$
Heart	49.17	38.71	$3.912\ 10^{7}$	

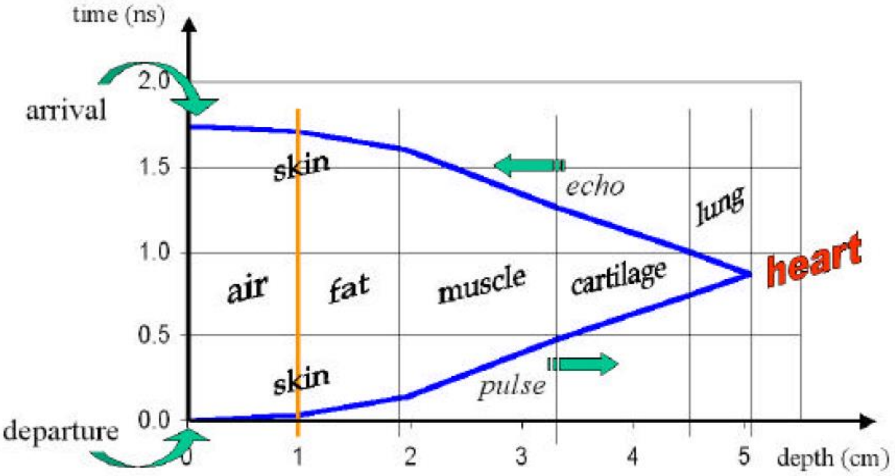


Figure 2.9 : UWB pulse-echo delay times in the thorax as predicted by the model.

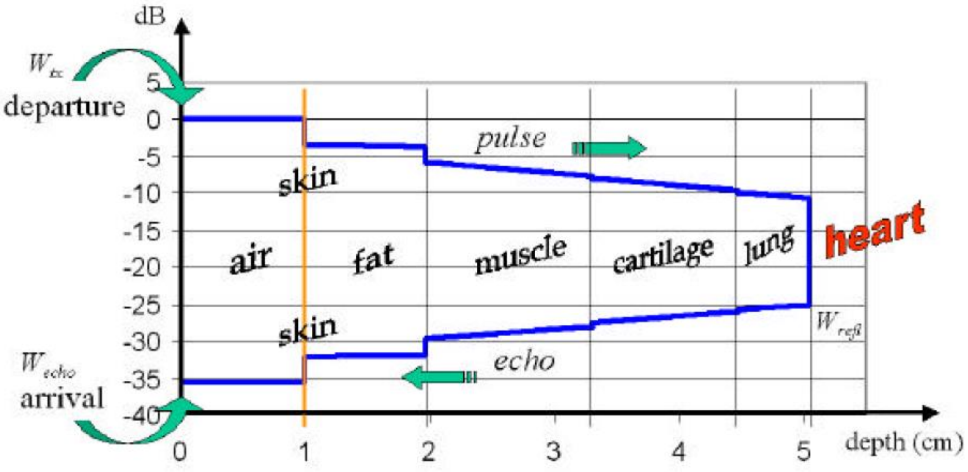


Figure 2.10 : Model predicted attenuation of pulse-echo intensity travelling from the transmitting antenna to the receiving antenna.

Actual slice of the thorax from the Visible Human Project. Chest is on the low part of the image; U-shaped left ventricle section is at center right. The layers of living tissues are seen from the chest to the heart: skin and fat (yellowish), muscle (red), cartilage (reddish), lung (red) and the heart wall (red). Pericardium is visible at lung/heart boundary.

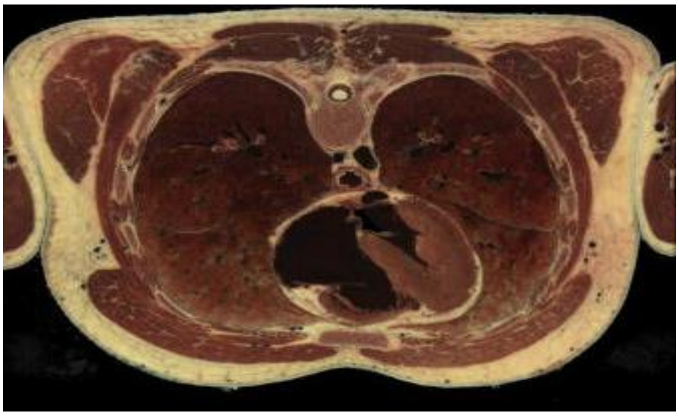


Figure 2.11 : The heart imaging using UWB in the "Visible Human Project''.

The specific absorption rate (SAR) is another research for obtaining the information about human body dielectrics [17].

In this type of research, the effect of mobile on human brain have been studied. There are, figure of head geometry and antenna placement in figure of dielectric and permittivity of materials inside human head in different frequency in below.

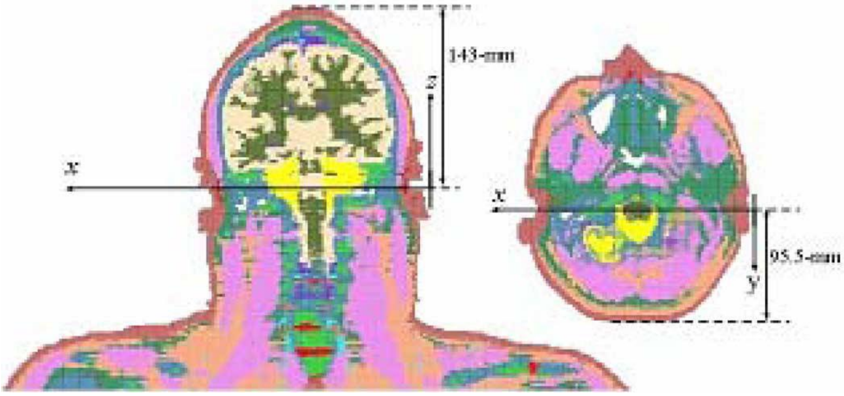
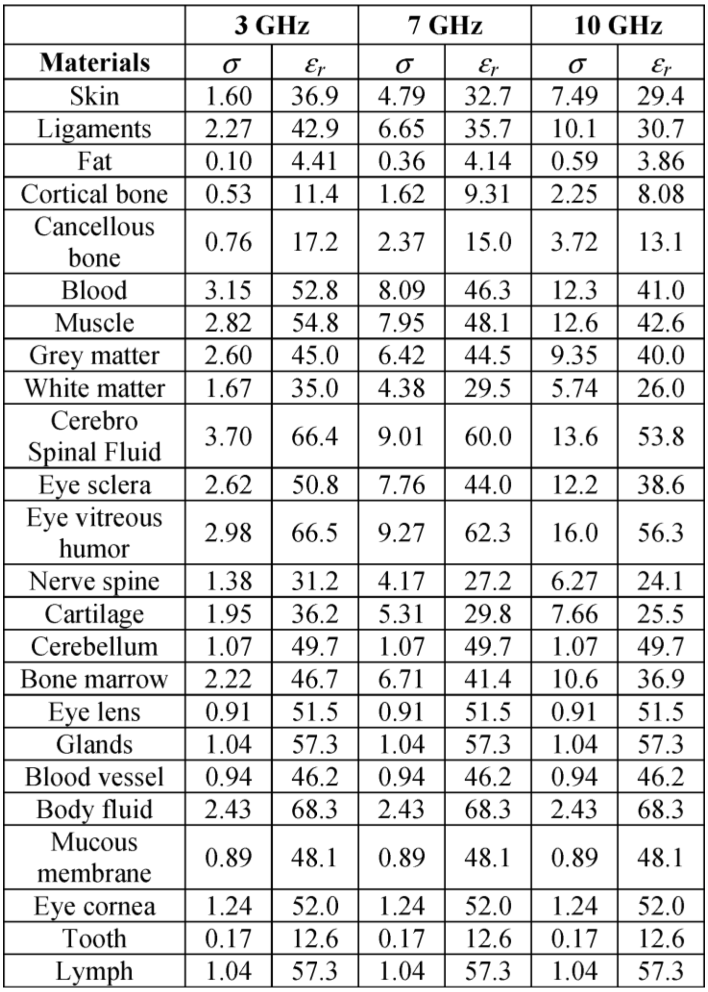


Figure 2.12 : Head geometry and antenna placement.



	3 GHz		7 GHz		10 GHz	
Materials	σ	ε_r	σ	ε_r	σ	ε_r
Skin	1.60	36.9	4.79	32.7	7.49	29.4
Ligaments	2.27	42.9	6.65	35.7	10.1	30.7
Fat	0.10	4.41	0.36	4.14	0.59	3.86
Cortical bone	0.53	11.4	1.62	9.31	2.25	8.08
Cancellous bone	0.76	17.2	2.37	15.0	3.72	13.1
Blood	3.15	52.8	8.09	46.3	12.3	41.0
Muscle	2.82	54.8	7.95	48.1	12.6	42.6
Grey matter	2.60	45.0	6.42	44.5	9.35	40.0
White matter	1.67	35.0	4.38	29.5	5.74	26.0
Cerebro Spinal Fluid	3.70	66.4	9.01	60.0	13.6	53.8
Eye sclera	2.62	50.8	7.76	44.0	12.2	38.6
Eye vitreous humor	2.98	66.5	9.27	62.3	16.0	56.3
Nerve spine	1.38	31.2	4.17	27.2	6.27	24.1
Cartilage	1.95	36.2	5.31	29.8	7.66	25.5
Cerebellum	1.07	49.7	1.07	49.7	1.07	49.7
Bone marrow	2.22	46.7	6.71	41.4	10.6	36.9
Eye lens	0.91	51.5	0.91	51.5	0.91	51.5
Glands	1.04	57.3	1.04	57.3	1.04	57.3
Blood vessel	0.94	46.2	0.94	46.2	0.94	46.2
Body fluid	2.43	68.3	2.43	68.3	2.43	68.3
Mucous membrane	0.89	48.1	0.89	48.1	0.89	48.1
Eye cornea	1.24	52.0	1.24	52.0	1.24	52.0
Tooth	0.17	12.6	0.17	12.6	0.17	12.6
Lymph	1.04	57.3	1.04	57.3	1.04	57.3

Figure 2.13 : Table of Conductivity and permittivity of materials inside human head at 3, 7 , and 10 GHz.

One of the popular research subject, than involve in dielectric constant of human body, is breast cancer detection. Researcher in this subject work with human chest dielectric for detection and imaging the foreign dielectric in chest that named breast cancer. Another source for acquiring the human body dielectric especially human chest dielectric is research that involve breast cancer [18].

Figure 2.14 and 2.15 show the breast cancer image and result of detection and imaging.

In this way, online dielectric calculator table were be so useful too. In Figure 2.16, there is a figure of online site that show calculation of the dielectric properties of body tissues [19].

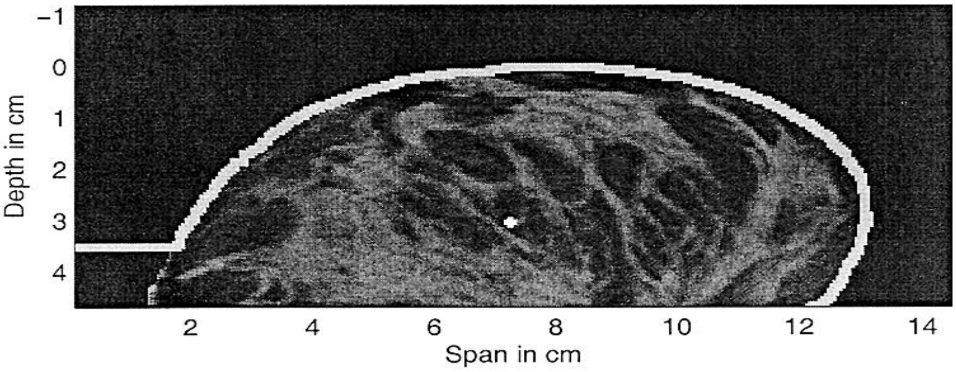


Figure 2.14 : Two-dimensional dielectric-properties breast model derived from an MRI scan. A 2-mm diameter malignant tumor has been inserted at a depth of 3.1 cm.

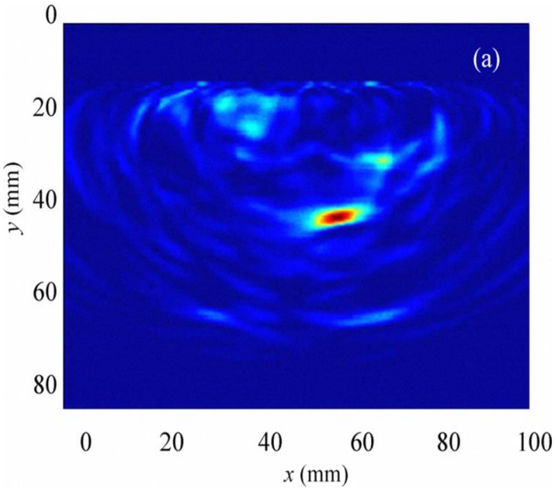


Figure 2.15 (a): Reconstructed breast image resulted from the confocal algorism shows the coincident tumor information with the assumed case,

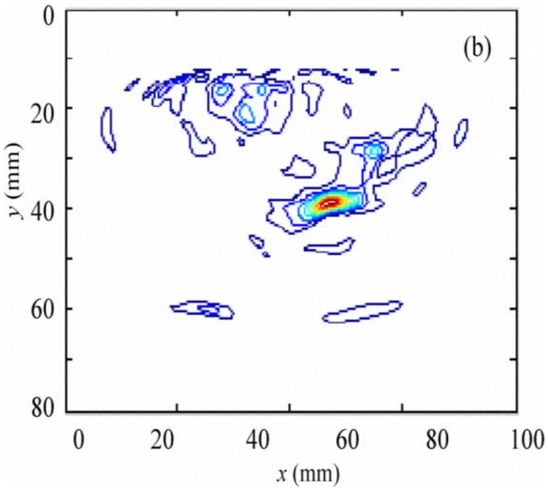
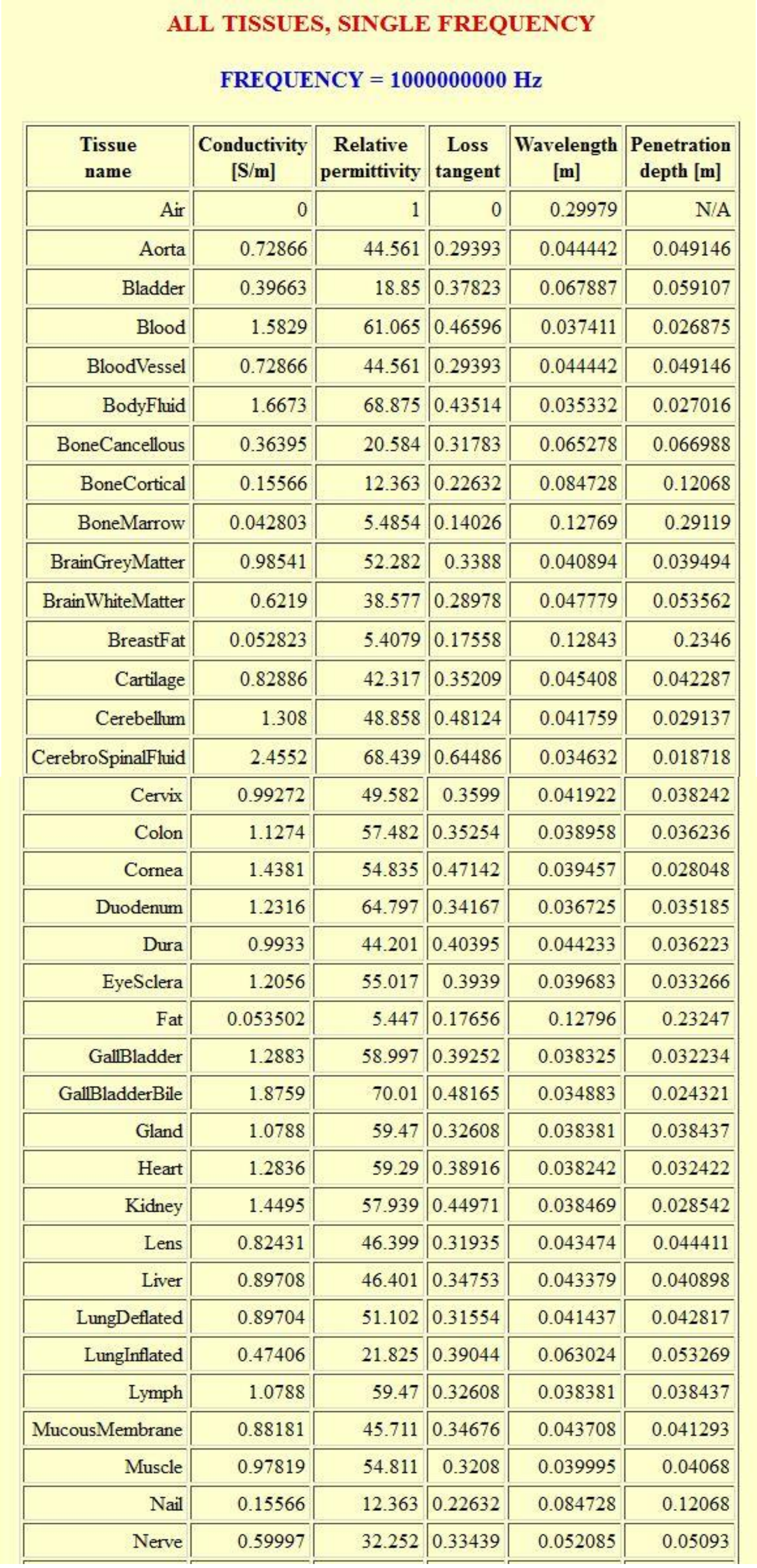


Figure 2.15 : (b). The contour map of the reconstructed breast image.

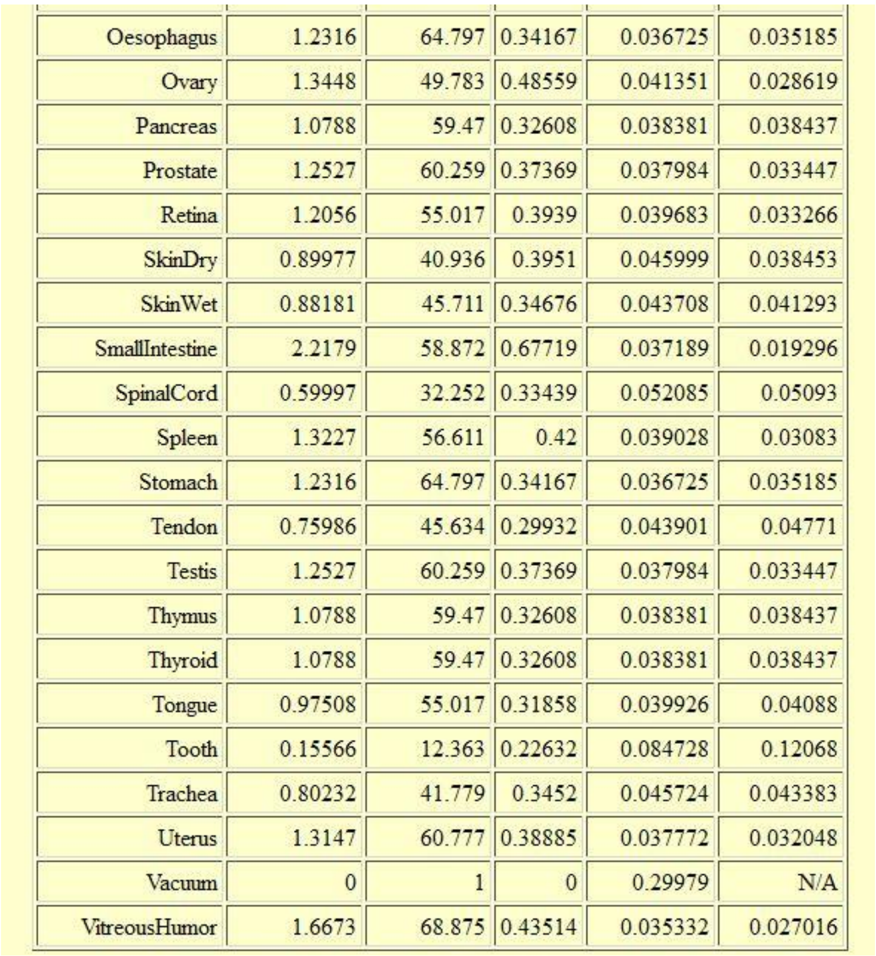


ALL TISSUES, SINGLE FREQUENCY

FREQUENCY = 1000000000 Hz

Tissue name	Conductivity [S/m]	Relative permittivity	Loss tangent	Wavelength [m]	Penetration depth [m]
Air	0	1	0	0.29979	N/A
Aorta	0.72866	44.561	0.29393	0.044442	0.049146
Bladder	0.39663	18.85	0.37823	0.067887	0.059107
Blood	1.5829	61.065	0.46596	0.037411	0.026875
BloodVessel	0.72866	44.561	0.29393	0.044442	0.049146
BodyFluid	1.6673	68.875	0.43514	0.035332	0.027016
BoneCancellous	0.36395	20.584	0.31783	0.065278	0.066988
BoneCortical	0.15566	12.363	0.22632	0.084728	0.12068
BoneMarrow	0.042803	5.4854	0.14026	0.12769	0.29119
BrainGreyMatter	0.98541	52.282	0.3388	0.040894	0.039494
BrainWhiteMatter	0.6219	38.577	0.28978	0.047779	0.053562
BreastFat	0.052823	5.4079	0.17558	0.12843	0.2346
Cartilage	0.82886	42.317	0.35209	0.045408	0.042287
Cerebellum	1.308	48.858	0.48124	0.041759	0.029137
CerebroSpinalFluid	2.4552	68.439	0.64486	0.034632	0.018718
Cervix	0.99272	49.582	0.3599	0.041922	0.038242
Colon	1.1274	57.482	0.35254	0.038958	0.036236
Cornea	1.4381	54.835	0.47142	0.039457	0.028048
Duodenum	1.2316	64.797	0.34167	0.036725	0.035185
Dura	0.9933	44.201	0.40395	0.044233	0.036223
EyeSclera	1.2056	55.017	0.3939	0.039683	0.033266
Fat	0.053502	5.447	0.17656	0.12796	0.23247
GallBladder	1.2883	58.997	0.39252	0.038325	0.032234
GallBladderBile	1.8759	70.01	0.48165	0.034883	0.024321
Gland	1.0788	59.47	0.32608	0.038381	0.038437
Heart	1.2836	59.29	0.38916	0.038242	0.032422
Kidney	1.4495	57.939	0.44971	0.038469	0.028542
Lens	0.82431	46.399	0.31935	0.043474	0.044411
Liver	0.89708	46.401	0.34753	0.043379	0.040898
LungDeflated	0.89704	51.102	0.31554	0.041437	0.042817
LungInflated	0.47406	21.825	0.39044	0.063024	0.053269
Lymph	1.0788	59.47	0.32608	0.038381	0.038437
MucousMembrane	0.88181	45.711	0.34676	0.043708	0.041293
Muscle	0.97819	54.811	0.3208	0.039995	0.04068
Nail	0.15566	12.363	0.22632	0.084728	0.12068
Nerve	0.59997	32.252	0.33439	0.052085	0.05093

Figure 2.16 : Calculation of the dielectric properties of body tissues



Oesophagus	1.2316	64.797	0.34167	0.036725	0.035185
Ovary	1.3448	49.783	0.48559	0.041351	0.028619
Pancreas	1.0788	59.47	0.32608	0.038381	0.038437
Prostate	1.2527	60.259	0.37369	0.037984	0.033447
Retina	1.2056	55.017	0.3939	0.039683	0.033266
SkinDry	0.89977	40.936	0.3951	0.045999	0.038453
SkinWet	0.88181	45.711	0.34676	0.043708	0.041293
SmallIntestine	2.2179	58.872	0.67719	0.037189	0.019296
SpinalCord	0.59997	32.252	0.33439	0.052085	0.05093
Spleen	1.3227	56.611	0.42	0.039028	0.03083
Stomach	1.2316	64.797	0.34167	0.036725	0.035185
Tendon	0.75986	45.634	0.29932	0.043901	0.04771
Testis	1.2527	60.259	0.37369	0.037984	0.033447
Thymus	1.0788	59.47	0.32608	0.038381	0.038437
Thyroid	1.0788	59.47	0.32608	0.038381	0.038437
Tongue	0.97508	55.017	0.31858	0.039926	0.04088
Tooth	0.15566	12.363	0.22632	0.084728	0.12068
Trachea	0.80232	41.779	0.3452	0.045724	0.043383
Uterus	1.3147	60.777	0.38885	0.037772	0.032048
Vacuum	0	1	0	0.29979	N/A
VitreousHumor	1.6673	68.875	0.43514	0.035332	0.027016

Figure 2.16 : Calculation of the dielectric properties of body tissues(continue).

3. APPLICATION

In this part of thesis, the hidden human detection simulation with CST program will be presented. The optimal transmitted signal will be introduce and the wavelet transform as the best signal processing will be discuss.

3.1 CST Simulation

During thesis, two type of antenna had been tested for hidden human detection. Firstly, we test Vivaldi antenna in the presence of a wall. Figure (3.1) shows this experiment. After that, we used Horn antenna for human detection behind a wall. Figure (3.2) shows the CST simulation stage. In this experiments Horn antenna had a better result therefore are preferred for the next steps. Figure (3.3) shows the farfield characteristic of Horn antenna in 1 GHz.

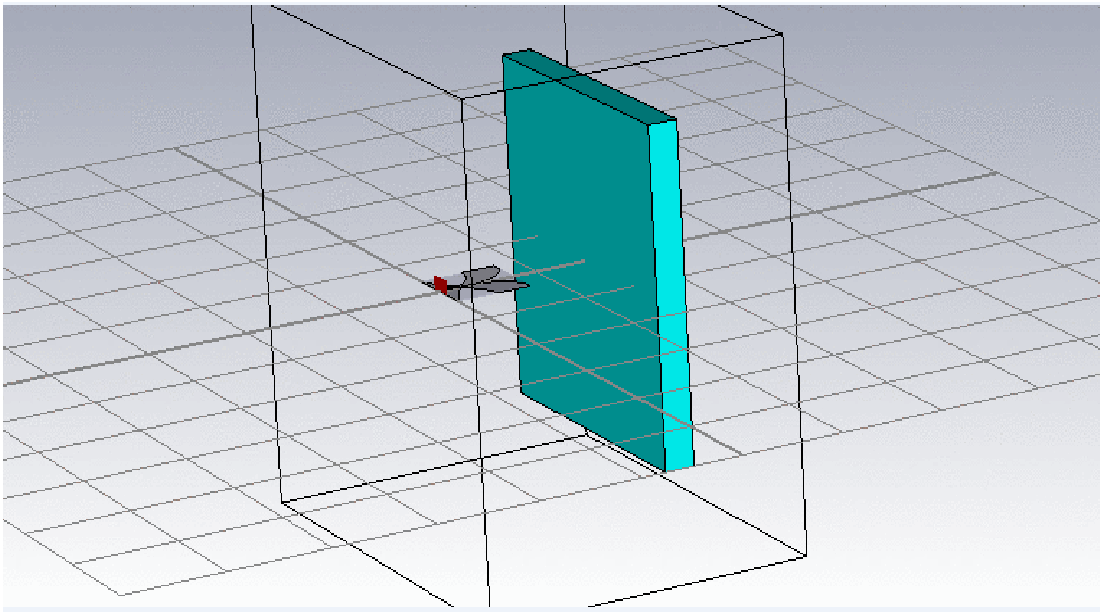


Figure 3.1 : The Vivaldi antenna in the presence of a wall.

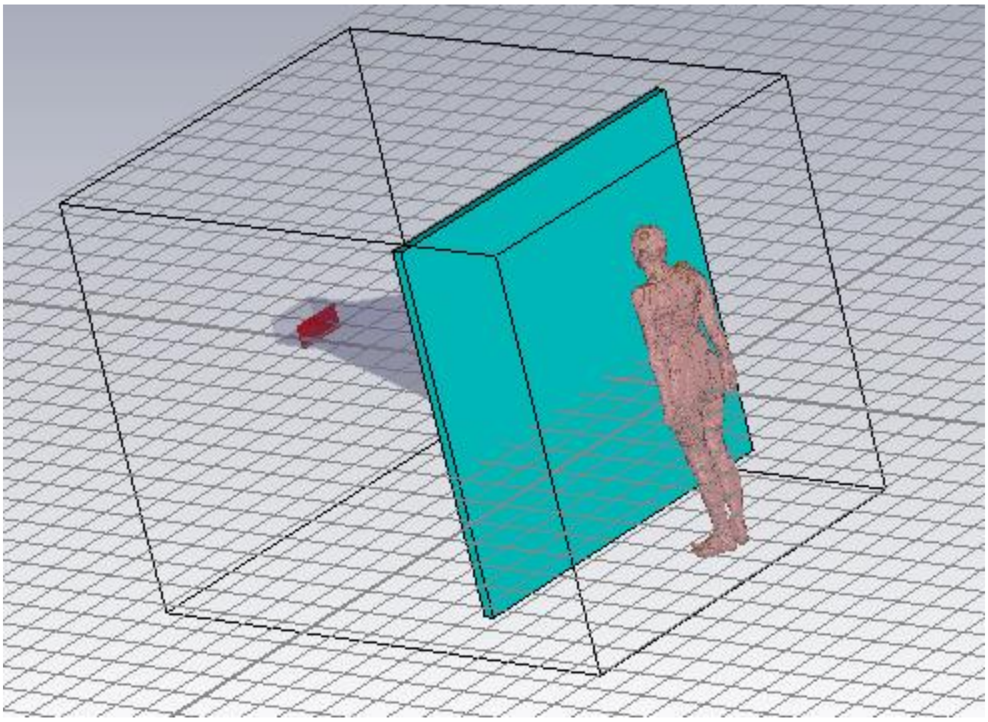
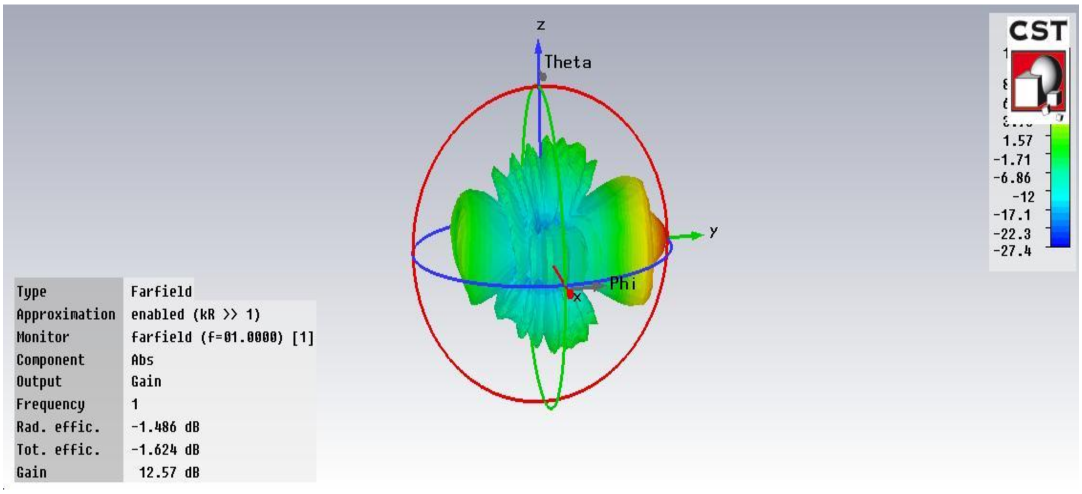


Figure 3.2: Human body behind a wall in the presence of Horn antenna.

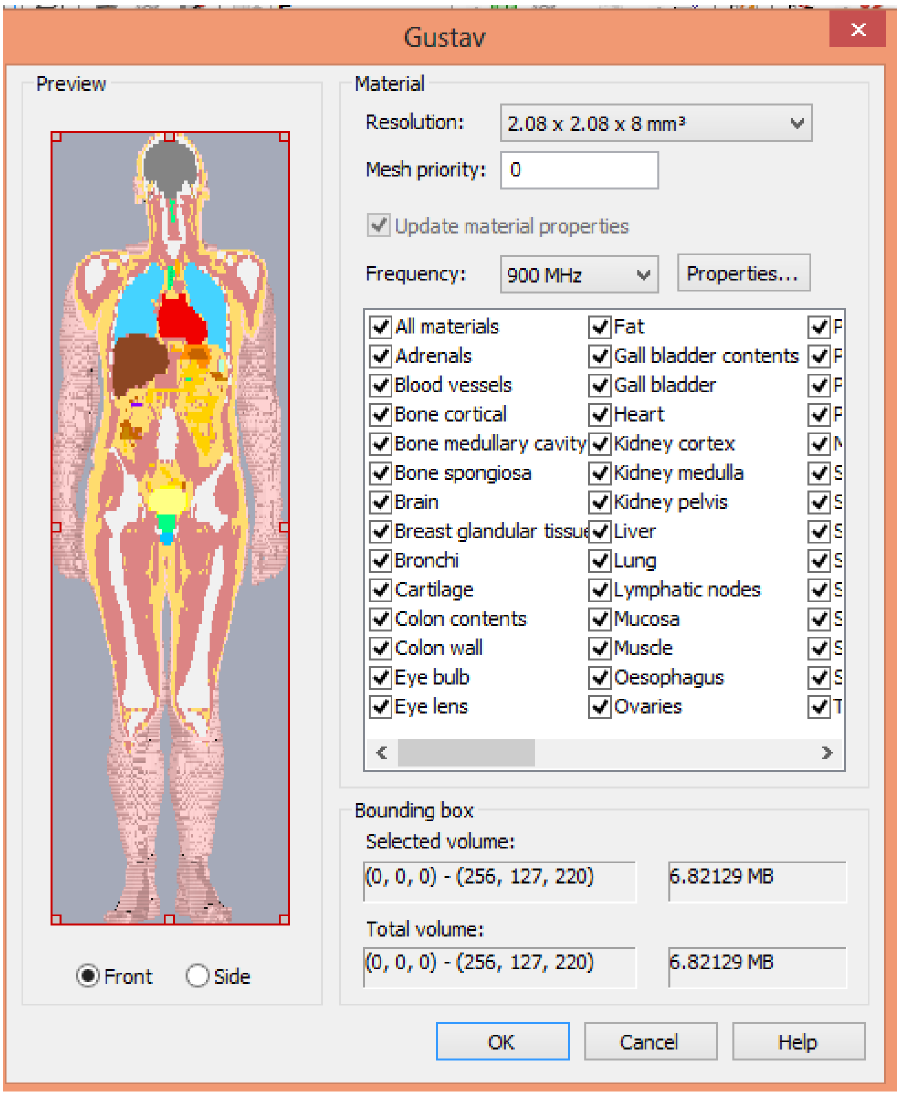


Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=01.0000) [1]
Component	Abs
Output	Gain
Frequency	1
Rad. effic.	-1.486 dB
Tot. effic.	-1.624 dB
Gain	12.57 dB

Figure 3.3 : Horn antennas farfield in 1 GHz.

3.2 Human Body Model

In the simulation part of thesis, Voxel Data used for human body modelling. Voxel data is the prepared modeling of human body that include dielectric constant of all human body tissue. Figure of this model available in Figure 3.4.



Resolution: 2.08 x 2.08 x 8 mm³

Mesh priority: 0

☑ Update material properties

Frequency: 900 MHz

- ☑ All materials
- ☑ Adrenals
- ☑ Blood vessels
- ☑ Bone cortical
- ☑ Bone medullary cavity
- ☑ Bone spongiosa
- ☑ Brain
- ☑ Breast glandular tissue
- ☑ Bronchi
- ☑ Cartilage
- ☑ Colon contents
- ☑ Colon wall
- ☑ Eye bulb
- ☑ Eye lens
- ☑ Fat
- ☑ Gall bladder contents
- ☑ Gall bladder
- ☑ Heart
- ☑ Kidney cortex
- ☑ Kidney medulla
- ☑ Kidney pelvis
- ☑ Liver
- ☑ Lung
- ☑ Lymphatic nodes
- ☑ Mucosa
- ☑ Muscle
- ☑ Oesophagus
- ☑ Ovaries
- ☑ P
- ☑ P
- ☑ P
- ☑ P
- ☑ N
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Selected volume: (0, 0, 0) - (256, 127, 220) 6.82129 MB

Total volume: (0, 0, 0) - (256, 127, 220) 6.82129 MB

Figure 3.4 : The Voxel data of CST program include human body tissue dielectric.

3.3 Transmitted Signal

As mentioned before, The most commonly used signal in UWBs is Gaussian signal and some of its derivatives. In this thesis, Gaussian signal, sinusoidal Gaussian and seven derivative of Gaussian signal is used as transmitted signal . In below there are some example figures of transmitted signal in Figure 3.5 and Figure 3.6 and the uploading state of these signal on CST program in Figure 3.7.

3.4 Received Signal

Transmitted signal, return to the receiver antenna, after crossing the wall and contact to the target. The saving received signals step, repeat for all transmitted signal one by one. Some received signal illustrate in Figure 3.8 and Figure 3.9.

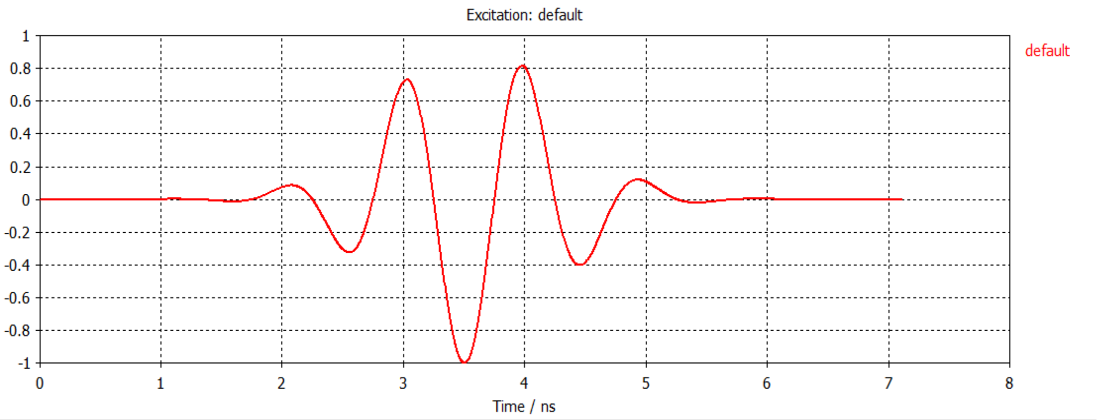


Figure 3.5 : The Gaussian signal used as transmitted signal.

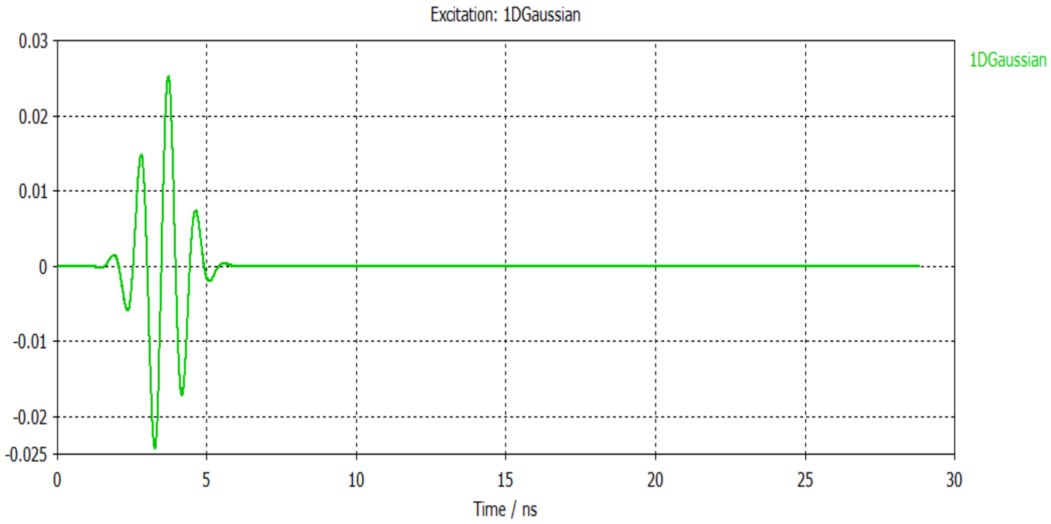
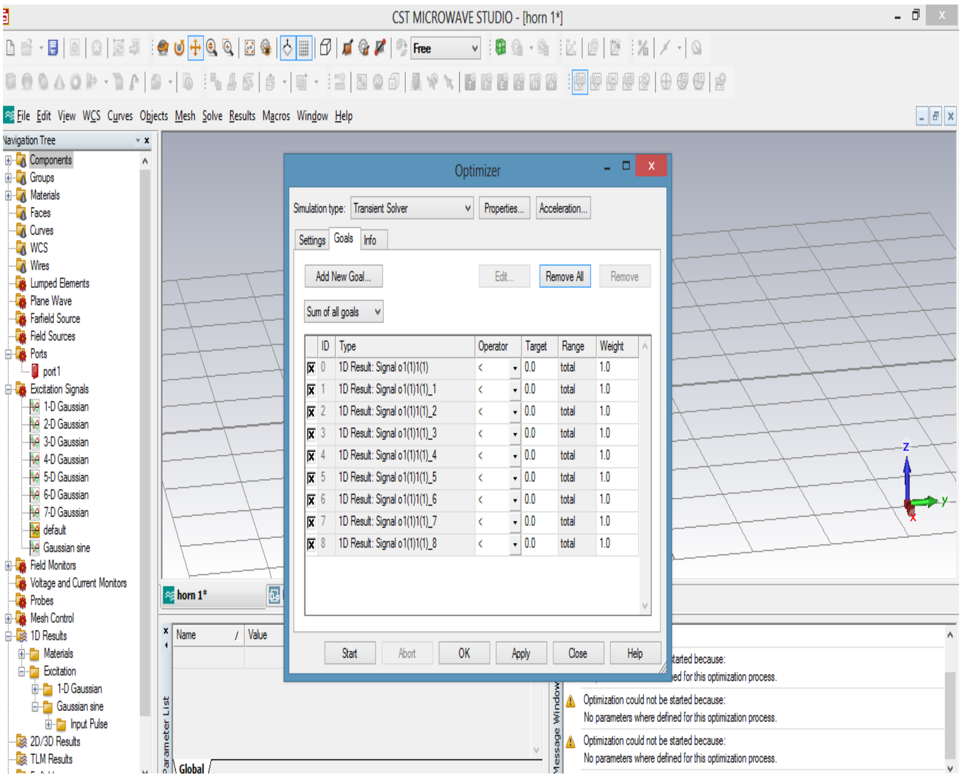


Figure 3.6 : The first derivatives of Gaussian signal used as transmitted signal.

3.5 Signal Processing

As explained in the first part, the shape and bandwidth of transmitted signal changes during passing the wall, hitting the target and returning to the receiver antenna. Wall thickness and its substance and distance between the human and antenna also affect the received signal. By using appropriate signal in transmitter, the received signal can be predicted. As derivative of transmitted signal, the bandwidth of the signal changes and appears in receiver. Using wavelet transform, because of predicting the occurred changes like waveform and received signal bandwidth, is helpful in background subtraction and results appropriate output signal. The returned signal from target is received by the receiver antenna and to extract target information, proposed signal processing method is used to analyze. The Wavelet transform, as the best signal processing method for obtaining the respiratory signal of hidden human with background subtraction have used. In this step, the return signal from the target is received in two-time interval of breathing (inhalation and exhalation). The difference between these two signals, illustration the spatial variations of chest during breathing. The result of this change is a sample of breathing signal. Thence, the transmit and receive operation will be repeated. The result in a certain period will be saved. After that, the resulting matrix from the sample signals will be depicted. The resulting figure is the human breathing raw data. Afterward, with using the proper wavelet transform (as mentioned in beginning of this part) required respiratory signal could be obtained.

In Figure 3.10, Figure 3.11 and Figure 3.12 some figure of popular wavelet that used in this thesis is available.



Simulation type: Transient Solver

Sum of all goals

	ID	Type	Operator	Target	Range	Weight
☒	0	1D Result: Signal o1(1)1(1)	<	0.0	total	1.0
☒	1	1D Result: Signal o1(1)1(1)_1	<	0.0	total	1.0
☒	2	1D Result: Signal o1(1)1(1)_2	<	0.0	total	1.0
☒	3	1D Result: Signal o1(1)1(1)_3	<	0.0	total	1.0
☒	4	1D Result: Signal o1(1)1(1)_4	<	0.0	total	1.0
☒	5	1D Result: Signal o1(1)1(1)_5	<	0.0	total	1.0
☒	6	1D Result: Signal o1(1)1(1)_6	<	0.0	total	1.0
☒	7	1D Result: Signal o1(1)1(1)_7	<	0.0	total	1.0
☒	8	1D Result: Signal o1(1)1(1)_8	<	0.0	total	1.0

```
tarted because:
ed for this optimization process.
Optimization could not be started because:
No parameters where defined for this optimization process.
Optimization could not be started because:
No parameters where defined for this optimization process.
```

Figure 3.7 : The uploading signal on CST.

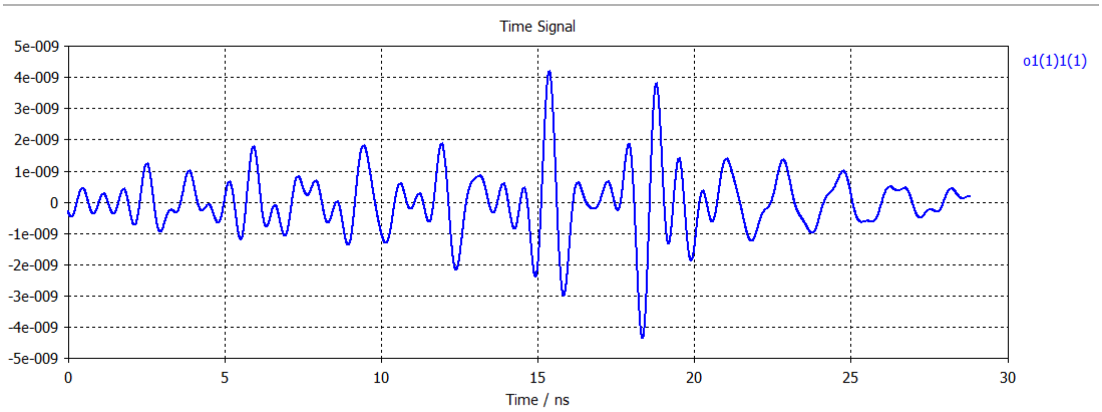


Figure 3.8 : The sample of receives signal (output of the fifth derivative).

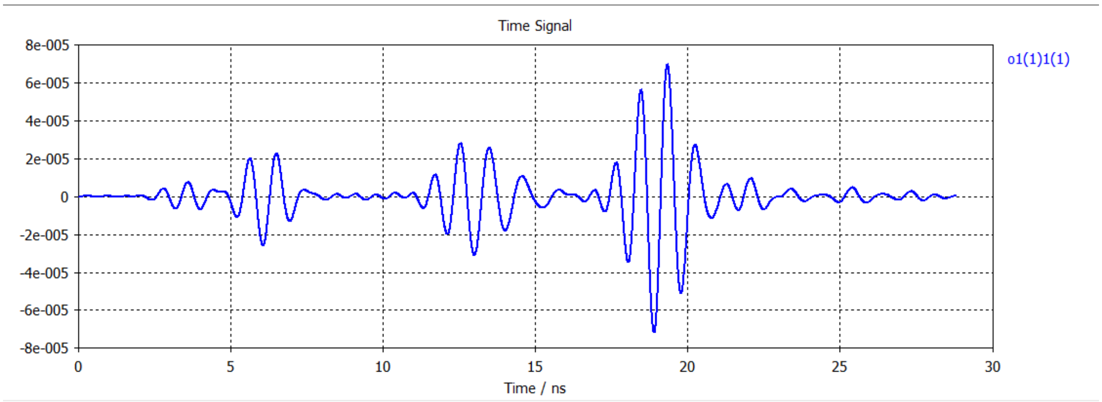


Figure 3.9 : The sample of recived signal (output of the first derivative).

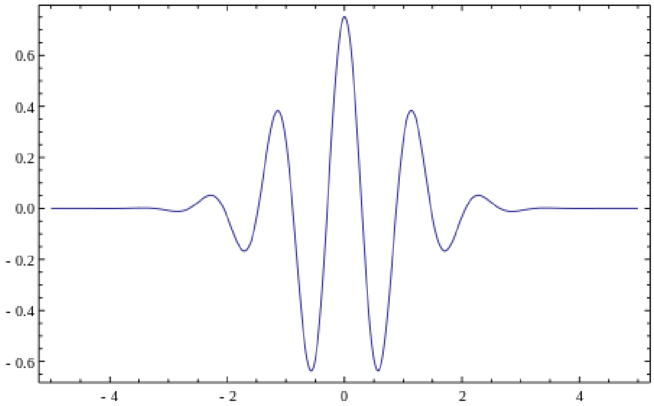


Figure 3.10 : The Morlet Wavelet.

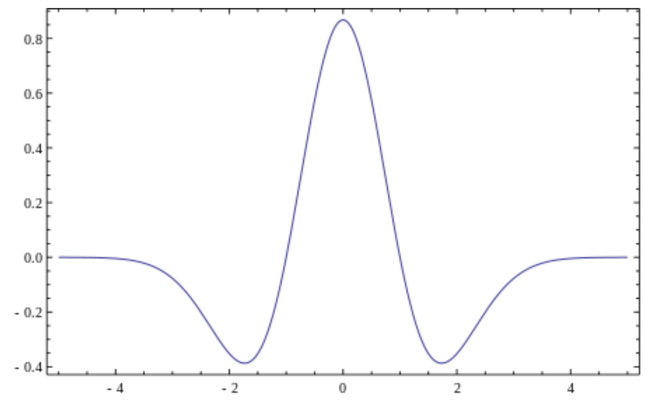


Figure 3.11 : The Mexican hat Wavelet.

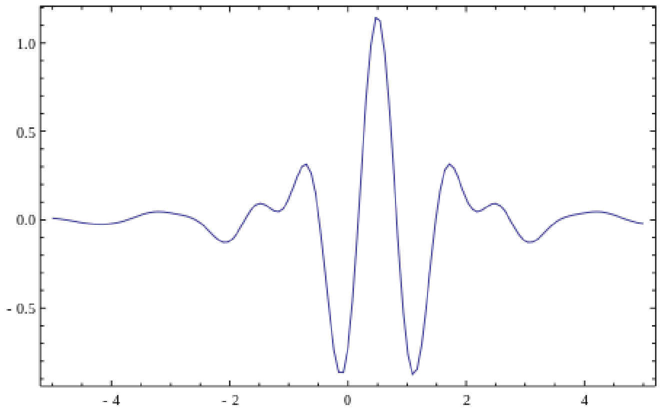


Figure 3.12 : The Meyer Wavelet.

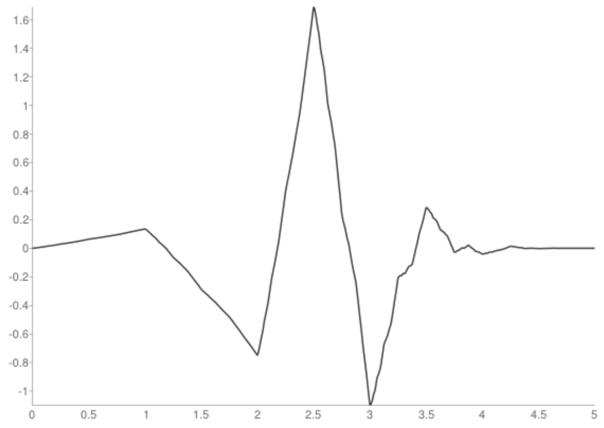


Figure 3.13 : The Symlet Wavelet

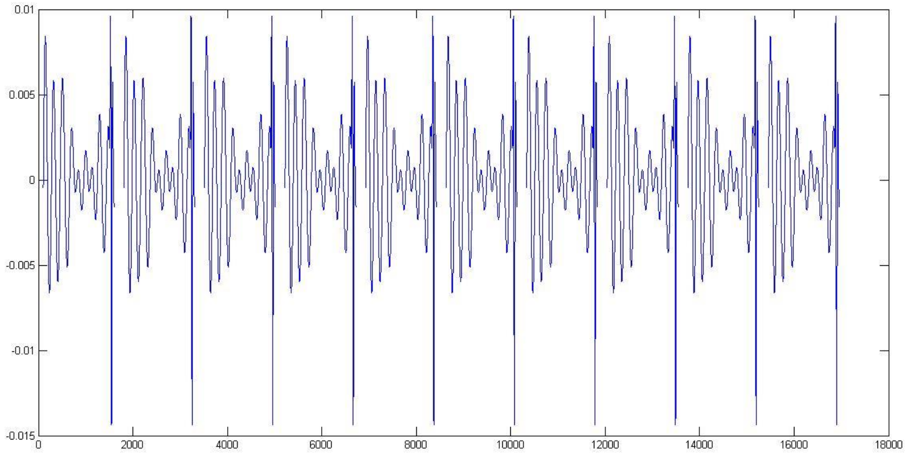
4. RESULTS

As mentioned in part 2.4, because of Wavelet transforms ability in working with non-stationary signals and provide multi resolution analysis with dilated windows, preferred to the other transforms like Fourier. In addition, selection the appropriate wavelet would be so important. In case of choosing wrong method in signal processing part, In other words, selecting the unsuitable wavelet transforms can be cause to the different result. In this situation, the obtained signal, completely affected with the background noise. As well as, the signal processing method will not be helpful for background subtraction and the expected result will not be acquire. The sample of inappropriate wavelet available in Figure 4.1.

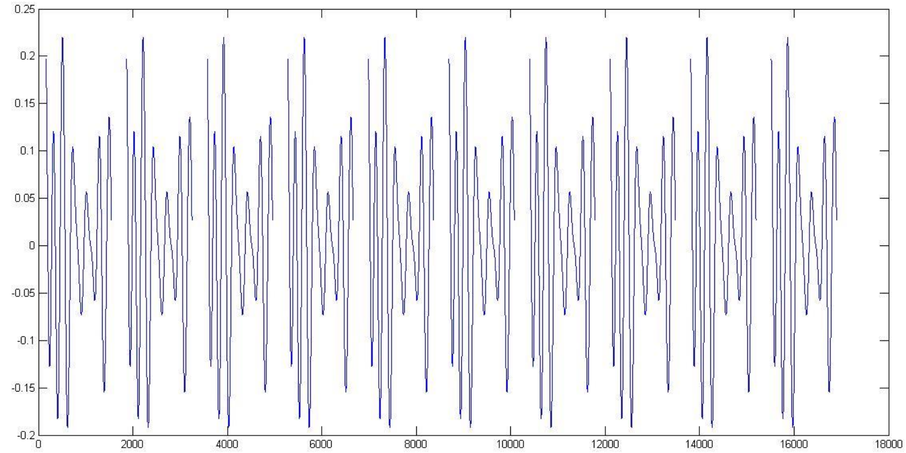
Below figures shows diagrams of final data resulted from signal processing part, which is human respiration periodic signal (Vertical axis show the amplitude of breathing signal and the horizontal axis show the repeat of this signal).

Figure 4.2 shows the sample of received signal after signal processing. The obtained results show that, Mayer and Morlet Wavelets give the best results by sending first derivative of Gaussian signal in transmitter. Also between these two wavelets, Mayer is closer to received signal and has better results. In these results, the background noise is completely omitted and respiration signal with acceptable amplitude can be observed (Figure 4.3). By sending the second derivative of Gaussian signals, Mexican hat wavelet gives better and acceptable output. By the way, Mayer wavelet would be more suitable as the transmitted signal in sending the second derivative of Gaussian signal (Figure 4.4). During simulation process, it could be understood that the forth derivative of Gaussian signal in transmitter would have the best results using Morlet. For other derivatives (5, 6, 7), using Coiflets, Symlets and Daubechies wavelets would have better results which among them. Symlets would be more appropriate for fifth derivative and Daubechies would be more appropriate for sixth derivative of Gaussian signal. It can be concluded from the results that the transmitting antenna forms the transmitted signal and then it can be interpreted as the second derivative of the transmitted signal at the receiver. Considering this, the best results for the target can be obtained by choosing appropriate wavelet.

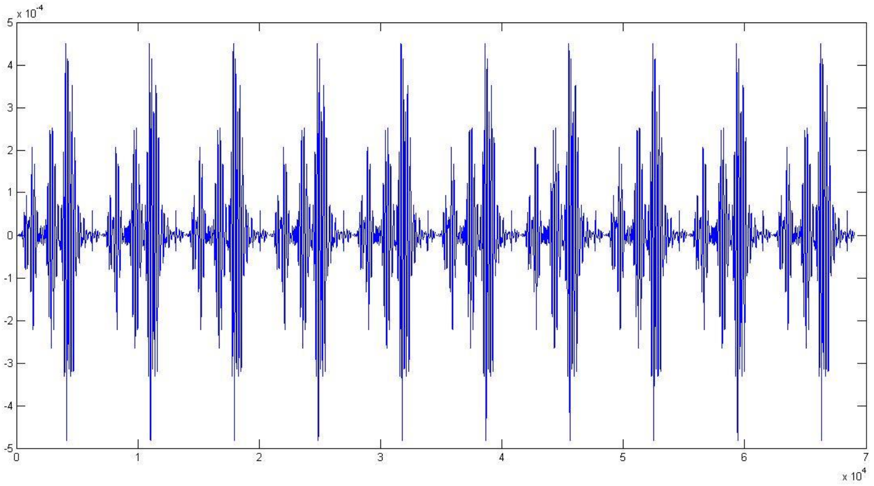
In forward, after different simulations, it could be observed that second derivative of Gaussian signal would be the best choice for similar environments. In addition, if the distance between human and antenna increase, using Daubechies wavelet would be a better choice for extracting desired target specifications. About walls with higher dielectric constant, using second derivative of Gaussian signal with Morlet wavelet would give the best results for target specifications.



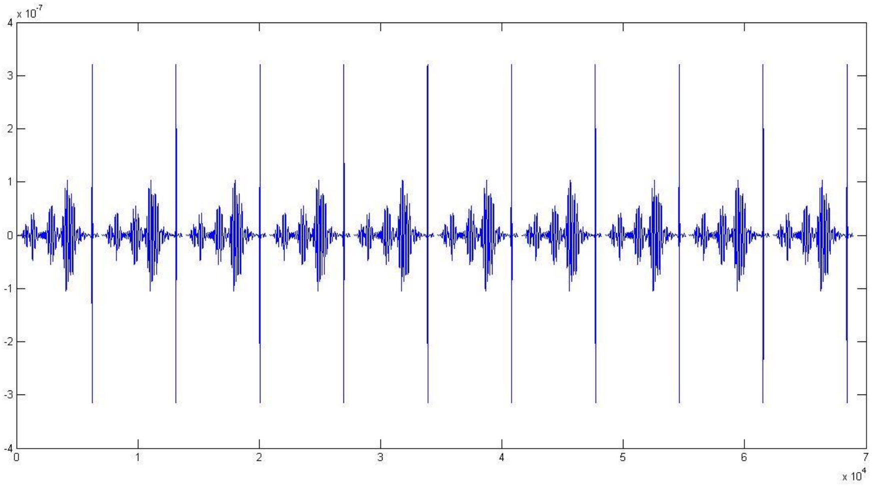
(a)



(b)



(c)



(d)

Figure 4.1: The results of inappropriate wavelet transform.

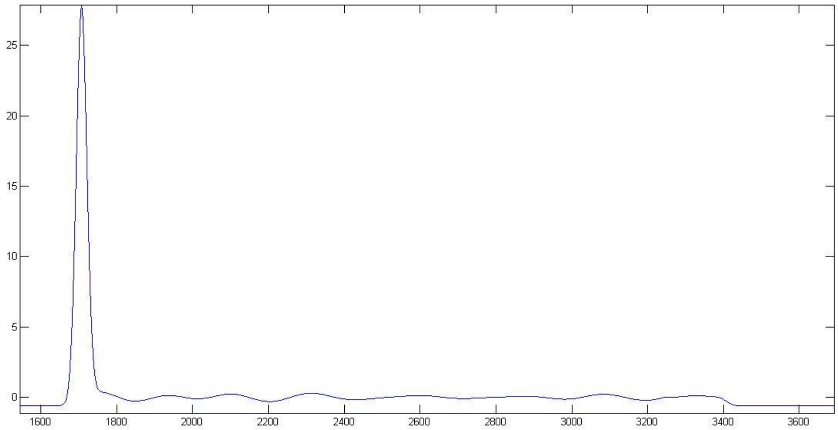


Figure 4.2: one pulse of received signal after using wavelet methods.

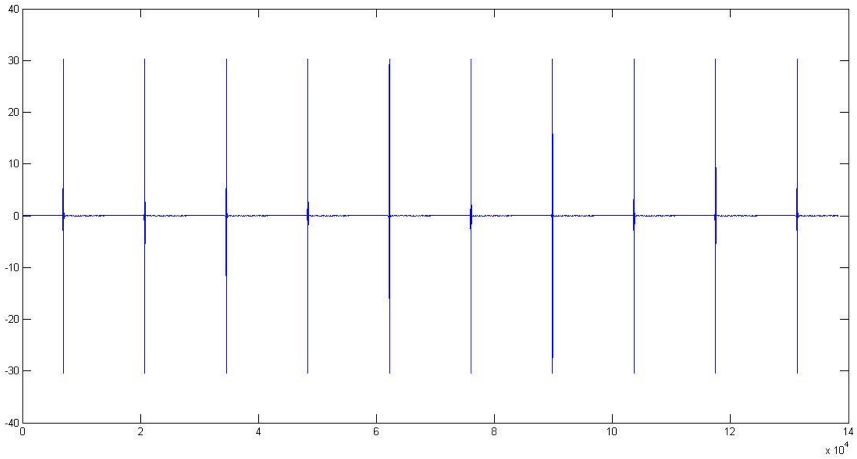


Figure 4.3 : The result of Meyer wavelet when first derivatives of the Gaussian signal used as transmitted signal.

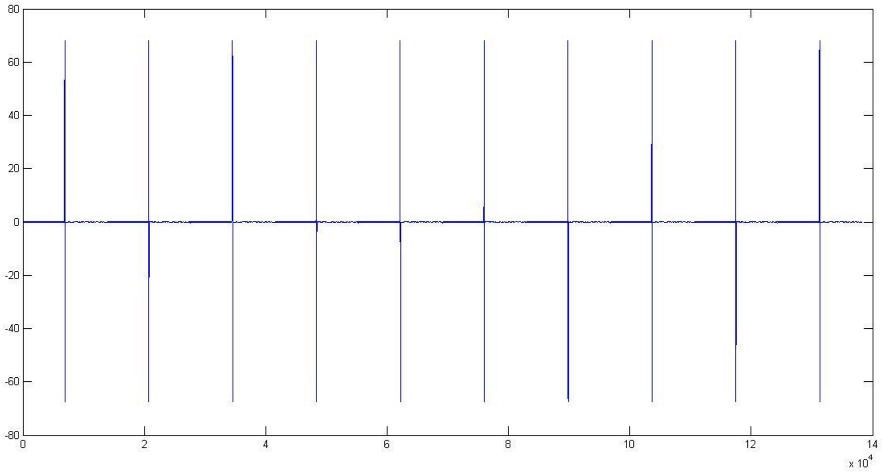


Figure 4.4: The result of Mexican hat wavelet when second derivatives of the Gaussian signal used as transmitted signal.

5. CONCLUSIONS AND RECOMMENDATIONS

In this thesis, human respiration detecting is considered. At first, the general UWB system used in detection is discussed. Then the choice of the antennas used in this work is presented. According to the importance of the transmitted signal form, appropriate transmitting signal for improving detection and obtaining better results are introduced. Finally, the wavelet transform method as the best method for background subtraction is used and simulation results are presented. It is concluded that for different system geometries, appropriate derivative of the transmitted signal and the mother wavelet selection give the best result. Additionally the respiratory signal of more than one hidden humans and moving humans could be consider in next work.

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