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Extended summary

Vital parameter detection through the usage of UWB radars

Curriculum: INGEGNERIA ELETTRONICA, ELETTROTECNICA E DELLE TELECOMUNICAZIONI

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Abstract. The main purpose of this thesis work was the construction and developing of an elaboration algorithm that can extract from the received UWB antennas signal the breath and heart frequency and to estimate the amplitude of chest displacement. The algorithm should perform fast and make an accurate estimation of these parameters. It needs to eliminate the clutter that in our schemes of realization is static and to cope well with the background noise present and introduced from the different devices. For elimination of the clutter were deployed different methods like the MS, RPS, LTS and SVD. We applied and studied the case with only one antenna in transmission and receiving. The distances of measurements between the antenna and the person are not longer than 2m as this project was developed and meant for the monitoring of the astronauts in the space capsule. The background noise were as well simulated with the varying of value set for the absolute system temperature. Beside the static clutter stimulated we studied and introduce into the signal received the distortion that comes from the multiple reflections of human tissues. This brought a characterization of the impulse response of human body with the usage and approximation done with the line of transmission equation. The reconstruction of the chest displacement was another aim of the work and it was done with the convolution approach. The algorithm were developed into the reconstruction also of the person movement in order to subtract it from the breath activity. This new approach developed and brought by us was a novice finding with such scheme of realization and it should allow us to compensate the movement and to estimate the breath of the person even when he moves.

Keywords. Gaussian pulse, body impulse response, FCC mask, movement compensation, static clutter.

1 Problem statement and objectives

UWB antennas have been used for many years now for monitoring of the person in intensive care rooms of hospitals. Due to their special features like no invasiveness, high resolution and the low power level of the signal used in transmissions, they have succeeded in an increasing usage and interest compared to similar other technologies. Different schemes of realization with monostatic scheme of UWB system realization are developed within this work: UWB antenna transmitting toward the person [1, 2, 3] when he stands still, antenna on the human chest in contact with his skin [4] or attached to his cloths and the last one when the antenna stands in front of the person that keeps moving around the room of simulation [5, 6]. The goals set for this system are the estimation of breath and heart rate[2, 3], compensation of the person movement in case of the third system realization [5], reconstruction of the chest displacement and the extraction from it of the amplitude of this displacement. For the estimation of vital parameters is needed to study the distortion of the signal after the reflection from the human body[4]. A modeling of the human body and the writing of its transfer function with the line of transmission equation was done, giving as result the pulse distorted. Another problem that we have to deal with it was the elimination of the other objects contributions known with a generic term as static clutter. Different methods were tried for the filtering [7] such as:

- Mean Subtraction,
- Range Profile Subtraction,
- Linear Trend Subtraction,
- SVD method.

With these filtering method was observed the elimination of the static clutter but as well of the background noise. For instance the performance of RPS method was not successful as it increased the power of background noise. With the SVD [8] it was seen an accurate estimation of breath frequency even in high level of background noise and in long distances. Even though this last method of filtering was unpredictable about the accuracy of the value estimated, because it sometimes estimate a wrong value as breath frequency.
For estimation of the tidal volume another biomarker should be estimated and it is the amplitude of the chest displacement. For making its estimation we need to reconstruct the chest displacement from the received signal. The approach most used is the convolution of the received waveform with a reference signal. As reference signal we can choose between:

- Transmitted pulse,
- Wavelets,
- Received signal,
- Some part of received signal.

Another one tried by us was the Peak Detection [9] algorithm with the finding of the global maximums and minimums of the received signal.
With the developing and extending of our algorithm with the case when the person under observation with UWB moves around [5, 6] we need to estimate beforehand his movement. The situation simulated were with three kind of movements:

- Performing small movement in long time as 0.05m in 30s with a sinusoidal form of the path,
- Covering a larger distance of 0.5m in 30s with a sinusoidal form,
- Covering short distance with a random form for 30s.

After estimating the path that he covers we need to compensate it so to isolate the respiration activity. We applied the ófitting toolô of Matlab to realign all the received waveforms and to have again the matrix of received waveforms like the case of the standing person.

2 Research planning and activities

PhD activity started and followed the steps as listed in the state of art of the research main topic. At the beginning was studied the theoretical approach of the existing algorithms, looking more inside the mathematical part of it and then applying such algorithms in Matlab. This program was developed and enriched with the different scenarios realized with monostatic UWB radars, but as well with the different elaboration techniques applied. An user interface window was constructed with the GUIDE of Matlab for making it easier to set the different parameters but to have also a more visible and comprehensive results of simulations shown.
The topic included as well some knowledge regarding the power signal limitation levels set by international organizations and the kind of antennas used in these ranges of frequencies. For these purposes we took part in meetings with the Biomedical group of research that are as well part of our university. We discuss with them about the form of presentation of the signal received from simulation done by them, the measuring unit that we use for defining a mask.

3 Analysis and discussion of main results

This work copes with different issues concerning the elaboration of UWB signal for estimating the breath frequency from this signal. The main concerns are the elimination of static clutter and the background noise. The different filtering methods applied to eliminate the clutter brings distortion to the signal filtered and as result it makes more difficult the reconstruction of chest displacement [5].

3.1 System parameters definition

The type of the signal we use for transmission are the odd order of Gaussian function derivatives. It is more suitable to use the higher odd order of derivative of this function. The idea behind this choice was dictated by the mask that our signal power has to comply with. The first order of derivative did not comply and overpass the border values set by the FCC for the different frequencies that these pulses include. Instead the higher odd orders of Gaussian pulse, their central frequency is shifted into higher frequencies as it is shown in Fig. 1.1, where the limit values are higher.

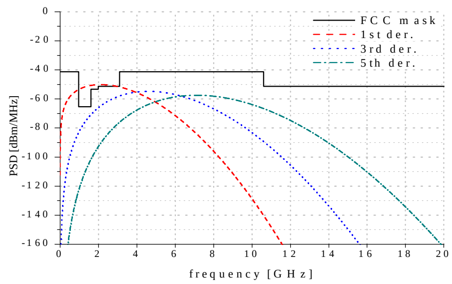

Fig. 1.1 Pulse PSD and FCC mask for indoor transmissions

After setting the parameters for the signal, we have projected the distortion and attenuation that this signal will suffer during the transmission of it in the air. To estimate the distortion was thought to make a modeling of the human body where each tissue is represented by a layer. This modeling bring an approximation of the form of signal distorted after that it is reflected from the human body. We take count in the distortion of all the multiple reflections from the inner tissues. The pulse distorted is taken by making the multiplication of Fourier transform of the pulse with the transfer function of the human body that is in frequency.

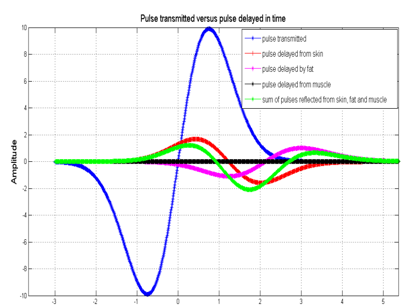

Fig. 1.2 Pulse reflected from different human tissues

We will give a more deep insight about the simulation and the matrix of received waveforms saved into a matrix. In the room of simulation are present other objects around and the antennas transmit as well toward them. The waves reflected by these objects create the static clutter. All these components are represented firstly with Dirac deltas standing in different columns of the matrix of received waveforms. The graphic representation of these Dirac deltas function representing the echo coming from the different objects is shown in Fig. 1.3.

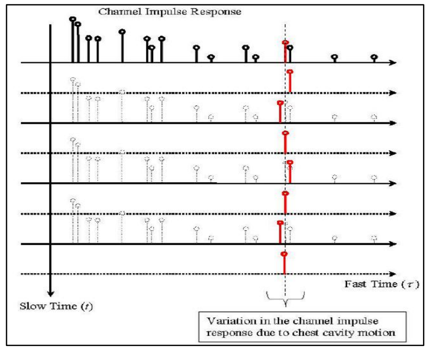

Fig. 1.3 Channel impulse response with the body impulse response included

The received waveform are the rows of the matrix of the input signal. In the direction of columns we have the fast-time and it is of the order of nanoseconds. We transmit different pulses with a pulse repetition frequency of 10Hz. The received waveforms create the rows of the matrix, and in this direction we have the slow-time axes, it is of the order of some seconds. The person echo moves position following a sinusoidal low as shown in Fig.1.3. It is represented by a Dirac delta that moves along the slow-time direction with a sinusoidal form and is denoted with red colored element. This sinusoidal move is a complex sinusoidal movement as result of the sum of two sinusoids. The harmonics of the signal of the sum of two sinusoids are that of breath and heart frequency. Later on we have substituted this movement with the real chest displacement reconstructed from a medical study. It was very similar in form with the sinusoidal movement that we used to simulate as chest displacement. With the Dirac deltas standing in different instants of fast-time we designed the transfer function of the channel that in our case is air. To reach to the matrix of received waveform we perform another convolution this time of the channel transfer function with the pulse transmitted. To have the matrix of received waveforms we need to make the sum of the matrix that holds the static clutter or better the received waveforms reflected from the different objects that are around in the room of simulation with the pulse reflected from the human body. This last component will be a moving pulse that varies position in fast-time instants range included within the amplitude of chest displacement from the breath activity.

3.2 Elimination of static clutter

The algorithm follows with the elimination of the echo coming from the objects in scheme of simulation. The filtering method more useful and successful in elimination of static clutter resulted Mean Subtraction. From every received waveform is subtracted the mean value of all the waveforms along the slow-time direction. Another method that resulted successful in discrimination of the breath activity from the background noise was Singular Value Decomposition. The decomposition allows to have the person echo apart from the static clutter and the background noise. The parameters set through the GUI window are shown in Fig. 1.4. In Fig.1.5 we will show a presentation of the matrix of received waveforms, where are evident the clutter and person echo. The decomposition with the method of SVD and the Eigen images that we calculate by making the product of the columns of left and right Eigen vectors matrixes with the respective Eigen value of the diagonal matrix. The Eigen images obtained are shown in Fig. 1.6 and Fig. 1.7.

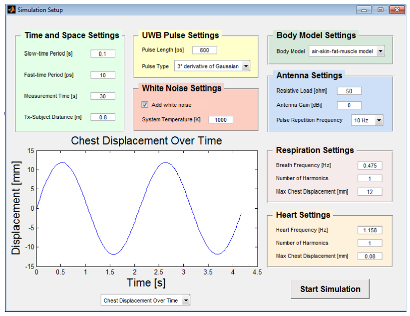

Fig. 1.4 Parameters setting through GUI

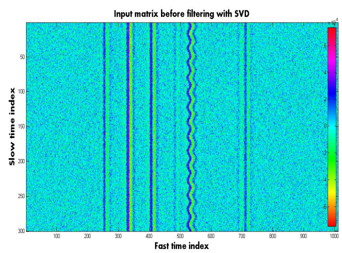

Fig. 1.5 Matrix of received waveform

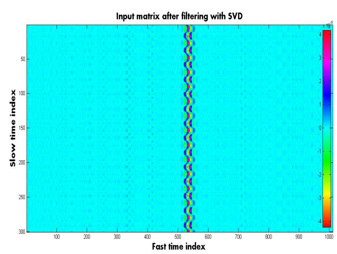

Fig.1.6 Person echo estimated with sum of second and third Eigen image

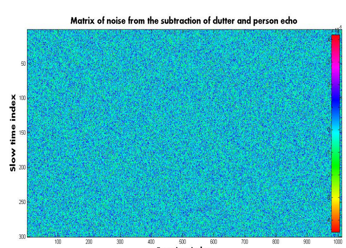

Fig. 1.7 Background noise estimated with SVD

3.3 Chest displacement reconstruction

Another important issue for the monitoring with UWB radar of certain patients is the chest displacement amplitude that serves to calculate the tidal volume . The most used approach is by doing the convolution between the received signal and a reference signal. As reference signal we choose a part of received signal. The part of signal that we subtract to take as reference signal should include the range of columns with fast-time instants that are within the chest displacement amplitude. By following the maximum of correlation between these two waveforms we can reconstruct fairly the chest displacement and estimate as well its frequency.

3.4 Chest displacement reconstruction for the III-rd scheme of simulations

In the third scheme of simulation with UWB radar the reconstruction of the chest displacement is done after having estimated and subtracted the person movement. First we eliminate the clutter with the MS filter described in the section 3.2. The reconstruction of path that the person covers is done by finding the maximum value of every received waveforms. Then after estimating the distance between the person and the antennas, we do a realignment of all the received waveforms to compensate this movement. After we have realigned every received waveform the algorithm goes on with the estimation of breath. It finds the highest value of the signal and performs a Fourier transformation of the column where stands these maximums along the slow-time direction. The highest peak in the spectrum belongs to the harmonic of breath. A demonstration of the matrix of received waveform in the case when the person performs a sinusoidal trajectory 0.5m in 30s is given in Fig. 1.8:

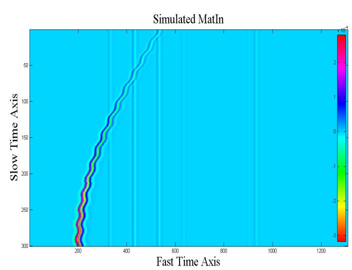

Fig. 1.8 Matrix of received waveforms

The received waveforms realigned will be shown in Fig. 1.9:

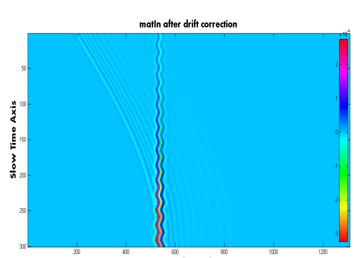

Fig. 1.9 Matrix with realigned waveforms

The reconstructed chest displacement with compensation of the person movement will be shown in Fig. 1.10:

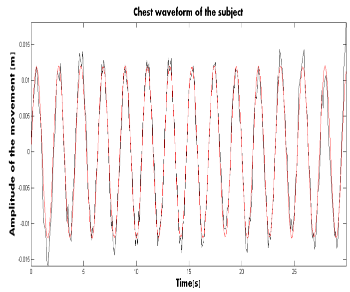

Fig. 1.10 Chest displacement reconstruction after person movement compensation

The estimated frequency of breath with the classical method when we find the column with the highest value of the received signal, after doing the Fourier transform to it and find the harmonic with the highest value of energy that belong to breath frequency is as shown in Fig. 1.11.

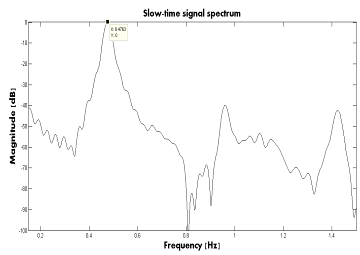

Fig. 1.11 CZT to the column with highest value of received signal

3.5 Results obtained with our algorithm

For controlling the feasibility of our algorithm we have elaborated the data obtained from measurements done with UWB antennas. The choice of system parameters, attenuation and distortion of the signal during the transmission have resulted correct, because we could make quite a correct estimation of breath frequency from the data obtained with real measurements done with UWB radar. We will bring in Fig.1.12 the spirometer data beside so we have another source of information regarding the real value of breath frequency.

In Fig. 1.12 we give the spirometer signal sampled, than on Fig. 1.13 we have the Fourier transform of the spirometer signal and the value of breath frequency is 0.1741Hz .

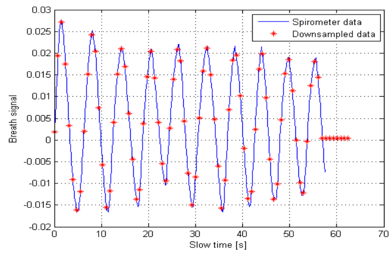

Fig.1.12 Spirometer signal for ů = 20 ps, *d* = 50 cm

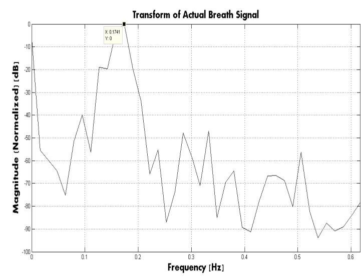

Fig.1.13 Fourier transform of the breath signal

With our algorithm we find the column with the highest value of received signal. By performing FFT to this column and by checking of the peak value of energy we find the breath harmonic as shown in Fig. 1.14, the value estimated is 0.1549Hz.

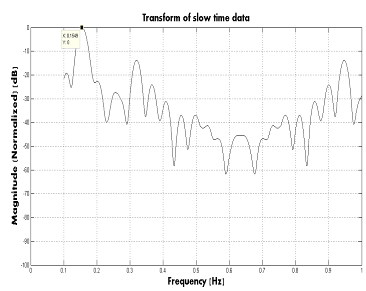

Fig. 1.14 Estimated breath frequency 0.1549Hz

In conclusion we can say that the algorithm developed so far can make a good estimation of the breath frequency and allows also the reconstruction of the chest displacement.

4 Conclusions

Different improvements were brought to the existing algorithm of elaboration of UWB signal within this thesis work, like the different filtering methods applied, the writing of the impulse response of human body based on the line of transmission equation, the detection and reconstruction of the path that the person does in order to compensate it after to detect the breath frequency. These improvements gave good results with the simulations done with different parameters set like distance between antenna and the person, the absolute system temperature, sampling time in fast-time, pulse duration, etc. What is more important is that what so far was designed and done through simulation resulted successful even with the elaboration of the real UWB signals. It makes clear that our parameter setting and training of the program to work in certain conditions have depicted the real situations, allowing a well approximation of values of breath frequency.

References

[1] S. Venkatesh, C. Anderson, N. V. Rivera, and R. M. Buehrer, ***ñ****Implementation and analysis of respiration-rate estimation using impulse-based UWB****ò***, in Proc. Milcom ô05, vol. 5, Atlantic City, NJ, Oct. 2005, pp. 3314ï3320.

[2] A. Lazaro, D. Girbau, and R. Villarino, ***ñ****Analysis of vital signs monitoring using an IR-UWB radar****ò***, Progress in Electromagnetics Research,vol.100, pp.265ï284,2010.

[3] M. Baldi, F. Chiaraluce, B. Zanaj, M. Moretti, ***ñ****Analysis and simulation of algorithms for vital sign detection using UWB radars****ò***, Proc. 2011 IEEE International Conference on Ultra Wideband (ICUWB 2011), pp.341-345, Bologna, Italy, 14-16 September 2011.

[4] M. Baldi, F. Chiaraluce, M. Moretti, F. Venieri, B. Zanaj, ***ñ****Signal modelling and processing for physiological sensing through UWB radars****ò***, Proc. SoftCOM 2011, 19th International Conference on Software, Telecommunications & Computer Networks, Split-Hvar-Dubrovnik, Croatia , September 15-17, 2011.

[5] M. Baldi, F. Appignani, B. Zanaj, F. Chiaraluce, ***ñ****Body movement compensation in UWB radars for respiration monitoring****ò***. Proc. 2012 Estel Conference, 2012 IEEE First AESS European Conference on Satellite Telecommunications, Rome, Italy, October 2-5, 2012.

[6] C. Li and J. Lin, ***ñ****Complex signal demodulation and random body movement cancellation techniques for non-contact vital sign detection****ò***, in 2008 IEEE MTT-S International Microwave Sysmposium Digest, Atlanta, GA, Jun. 2008, pp. 567ï570.

[7] A. Nezirovi´c, A. G. Yarovoy, and L. P. Ligthart, ***ñ****Signal Processing for Improved Detection of Trapped Victims Using UWB Radar****ò***, IEEE Transactions on Geoscience and remote sensing, Vol. 48, No. 4, April 2010.

[8] P. K. Verma, A. N. Gaikwad, D. Singh, and M. J. Nigam, ***ñ****Analysis of clutter reduction techniques for through wall imaging in UWB range****ò***, Progress in Electromagnetics Research B, vol. 17, pp. 29ï48, 2009.

[9] J. C. Y. Lai, Y. Xu, E. Gunawan, E. C.-P. Chua, A. Maskooki, Y. L.Guan, K.-S. Low, C. B. So, and C.-L. Poh, ***ñ****Wireless sensing of human respiratory parameters by low-power ultra- wideband impulse radio radar****ò***, IEEE Trans. Instrum. Measur., vol. 60, no. 3, pp. 928ï938, Mar.2011.