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OPTIMAL SIGNAL PROCESSING METHODS IN GPR

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Abstract

In the past three decades, a lot of various applications of Ground Penetrating Radar (GPR) took place in real life. There are important challenges of this radar in civil applications and also in military applications. In this paper, the fundamentals of GPR systems will be covered and three important signal processing methods (Wavelet Transform, Matched Filter and Hilbert Huang) will be compared to each other in order to get most accurate information about objects which are in subsurface or behind the wall.

Keywords-*Ground Penetrating Radar, Wavelet Transform, Hilbert Huang Transform, Matched Filter, Signal Processing*

1. INTRODUCTION

Thanks to the constantly improving technology and science, it is possible to have information about a distant object's location, range, altitude, direction or speed. The system which is used for making this possible is called Radar. Radar is the synonym of Radio Detecting and Ranging. Radar is a way in order to get information about an object using detection and tracking. At first radio waves were used in radar systems, microwave and very High Infrared segments of electromagnetic spectrum are preferred to operate in modern world [1]. Radars are commonly used in meteorology, tracking an object and military [2], [3].

GPR applies the behavior of electromagnetic waves to get information about buried objects [4]. The most common application fields in GPR are civil and military. In military it is mainly used for finding unexploded bombs, underground warehouses, bomb shelters, discovering enemy communication channels, secret rooms [5]. In civil life GPR is commonly applied for finding undetected voids, buried pipes, respiratory movement detection of hidden human [6], [7] and [8].

2. GROUND PENETRATING RADAR

The transmitting antenna emits an electromagnetic wave then this wave scatters and goes until an object appears in the way. The speed of this wave depends on the permittivity of the object. The wave which spreads out of object is detected by receiving antennas (Figure1) [4].

The signal, which is used in the different mediums for various targets, should be localized in the time and frequency domain. For this purpose Gaussian signal is one of the convenient signals to use in the GPR applications [8].

Some results shows that horn and Vivaldi antennas are proper to use in GPR. Horn antennas are very popular because they have broadband frequency up to 18 GHz but costs are much expensive [9], [10] and [7]. Vivaldi antennas frequency range between 1-12 GHz and also easy to manufacture with PCB Technology [11]. As well as, circular polarised antenna like [26] would be appropriate for these types of applications.

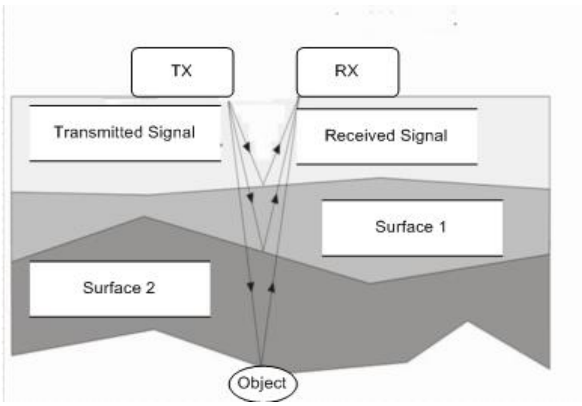

Figure 1. General System of GPR

3. SIGNAL PROCESSING METHODS

When the receiver antenna detects the signal which is emitted because of hitting an object, signal processing methods should be applied to acquire information about this object [4].

In the next step three main signal processing methods that used in the GPR applications in literature will be presented.

3.1 Wavelet Transform

Before mentioning wavelet transform, it is necessary to talk about wavelets. Wavelets can be classified as the waveform which have average value of zero and mostly are irregular and asymmetric. Wavelets can be expressed with mathematical functions. All wavelets are created by dilating or translating the "mother wavelet" function. There are several wavelet types such as haar wavelet, Gaussian wavelet and etc [12].
Continuous Wavelet Transform can be expressed as;

$$\Psi_{WT(\tau,s)} = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{\infty} x(t)\Psi\left(\frac{t-\tau}{a}\right)$$

Multi resolution analysis is a method for analyzing signals. This analysis emphasizes that it is possible to get good time resolution and poor frequency resolution at high frequencies and at low frequencies vice versa is correct [13].

The term scale in wavelet transform basically express dilating or compressing a signal. In the case of $s>1$, signal is dilated but when $s<1$ corresponds a compressed signal. τ is called translation parameter [14].

Discrete wavelet transform is the case when wavelets are discretely sampled. Analyzing signals, the DWT provides multi-resolution of these signals. Basically a multi-resolution description means that obtaining a continuous signal by DWT. This means getting approximation and detail coefficient series after a process. Approximation coefficient series can be obtained using low pass filter during the series conversion. Whereas Details coefficient series can be obtained using high pass during the conversion of series. Each series have a length of m/2 [15].

It is much likely to see wavelet transform in GPR applications. Such as; in the detection of underground water pipe application with GPR, wavelet transform has an important role. When wavelet transform is applied, the target image displayed by the wavelet is more clear and more smooth, there can be very little signal interference at the same time, but the water pipe can be seen very prominently in that image [16].

According to the image wavelet coped image, identification of underground water pipe and its approximate location is more accurate [16].

Not only but also wavelet transform can be used in the depth estimation of buried object. For this purpose discrete wavelet transform is used in the step before processing. This step includes throwing out the ground bounce and other interferences in the received GPR signal. In this application wavelet-based denoising technique is used. This method applies converting the data into wavelet domain and eliminates the coefficients that correspond disordered signatures [17].

3.2 Hilbert Huang Transform

The combination of Hilbert Spectral Analysis (HSA) Empirical Mode Decomposition are presented as

Hilbert Hung Transform since 1998 by NASA and applied for nonstationary and nonlinear data analysis [19]. HHT has been used in geophysical studies, measuring heartbeats recently [18], [19].

3.2.1 Hilbert Spectral Analysis

HSA is a method that demonstrate the relationship between time-frequency-energy components. Also this method identify nonstationary data locally, and evaluate instantaneous frequencies, amplitudes [20].

$$H[x(t)] \equiv \check{y}(t) = \frac{1}{\pi} PV \int_{-\infty}^{+\infty} \frac{X(\tau)}{t-\tau} d\tau$$

In HSA, every functions cannot be applied. Because some of them produce physical instantaneous frequencies such as non-zero functions which give negative frequency components when HSA is used [21], [22].

3.2.2 Empirical Mode Decomposition

EMD attempts to decompose any complex signal into a finite set of functions which are called intrinsic mode functions (IMF). An intrinsic mode function (IMF) is a component of EMD that must provide two conditions:

a) In all data set, the number of extreme and the number of zero crossings must equal or differences are at most by one.
b) At any given point, the mean value of the envelope identified by the local maxima and when local minima is zero, the envelope calculated [21].

EMD has simple assumption that says at any given time complex data dissociates many basic signals in different frequencies. The algorithm creates a shifting process which serves two purposes , purifies background of IMFs and generate waves more symmetric[19].This process is repeated until the signal meets the desired function , it is known as IMF(Intrinsic Mode Function).

3.3 Matched Filter

The basic concept of matched filter is to maximize the signal noise ratio in the presence of additive random noise. The complex conjugate transmitted signal corresponds matched filters frequency response. If transmitted signal is reversed in time and shifted, the impulse response obtain [23].

In the case of discrete time systems replica correlator is one of implementation methods of matched filter. Transmitted signals shifted time reversed version is mutualized with the received waveform by the replica correlator, to get likelihood ratio function. Indicating discrete-time sequence x (n), to compute likelihood ratio function of the replica correlator, this formula is used [24];

$$L(n) = \exp\{-\frac{1}{2\sigma^2}\left(\sum_{m=0}^{M-1} s^2(m) - 2\sum_{m=0}^{M-1} x(n-m)s(m)\right)\}$$

Sample number is showed with n, whereas s(m) corresponds the computing of the transmitted signal whose length is M received signal is x(n) and noise variance symbolizes as σ^2. When the likelihood ratio value is bigger than the threshold of detector an existence of an object can but taught. While threshold is determined too low, the result will be false alarm coming out of clutter. On the other hand, threshold is determined to high which are result of noise and clutter will not show any existence, but at the same time identifying weak target will get harder [25].

4. DISCUSSION

The consequences below is observed after a deep literature research.

Matched filter is better at removing environmental noise. However in more complex environments, the design of matched filter is getting harder because of high noise ratio. For this reason in these kinds of environments, other signal processing methods are preferable. For instance; in the case of respiratory detection of a human, if our antenna is placed in front of the human, matched filter will be the best way to apply.

Hilbert Huang Transform gives better results for nonstationary and nonlinear signals. In our researches we have observed when GPR is used in more complex areas, frequency of transmitted signal changes in time. Therefore Hilbert Huang Transform is a very convenient method for compound signals in order to obtain information about target.
For Wavelet Transform, same features are applicable. Mother wavelet can be adjusted according to conditions of the environment. Thus even though Wavelet transform is more difficult mathematically, with the right mother wavelet and right signal, more accurate results can be obtained in the more complex environments.
In the below application, GPR is used to detect respiration of a human behind the wall. Gaussian signal and its derivatives is tested as transmitted signal. In the received signal, background subtraction method is applied and wavelet transform is applied to obtain respiration signal.

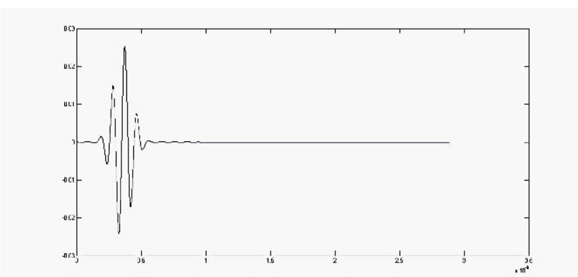

Figure 2. Transmitted Gaussian signal

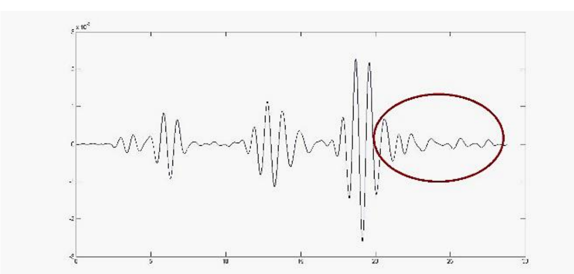

Figure 3. Received signal in the first position

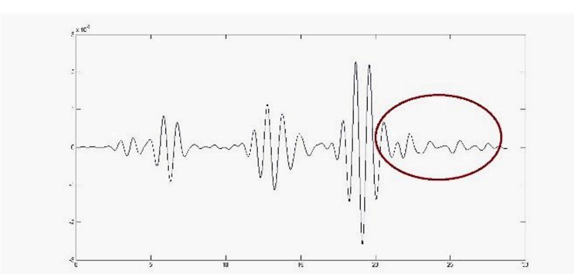

Figure 4. Received signal in the second position

In the Figure 2, Gaussian signal as transmitted signal can be seen and in the Figure 3 and Figure 4 there are two received signals according to the position of the human (in the inspiratory and expiratory positions), is showed. Signals pieces with lower amplitudes belong to the signal reflected from human respiratory (shown by the red line), whereas the piece with the highest amplitude represents the wall between the GPR and human and other background noise. If we subtract these two signals, then the result of this subtraction will be ready to apply wavelet transform. The signal which will be obtained after this wavelet transform, will stand for respiration signal of a human.

5. CONCLUSION

In this paper, firstly a brief information about radar and GPR has been introduced. Afterwards, three main signal processing methods for GPR applications in literature have been compared and presented. Respiration detection of a human with GPR, by using wavelet transform has explained.

6. REFERANCES

[1] M.I.,Skolnik ,*Radar Handbook* McGraw Hill , New York Chiago San Francisco London Madrid Mexico City Milan New Delhi San Juan Seoul Singapore Sydney Toronto , 2008
[2] X. He,‘*’Weather Radar Based Quantitive Precipitation Estimation in Modeling of Catchment Hydrology’’*, Department of Geography and Geology Faculty of Science University of Copenhagen ,,2011
[3] P. Hofmann , *‘’Object Detection and Tracking with Side Cameras and RADAR in an Automative Contex’’*, Freie University of Berlin ,2013
[4] J.J., Daniels, *‘’Ground Penetrating Radar Fundamentals ‘’*, Department of Geological Sciences The Ohio State University, 2000.
[5] T. H., Bee,*’’ Detection Leakages in Underground Buried Pipe’’*, Department of Mechanical Engineering National University in Singapore, 2009-2010
[6] S. Karamzadeh, M. Kartal “*Detection Improvement of Hidden Human’s Respiratory Using Remote measurement methods with UWB Radar’’,* International Conference on Telecommunication and Remote Sensing, Netherland, pp.(104-108), July 2013.

[7] Karamzadeh, S., Kartal, M., Kent, S., & Ashtiyani, A. A. “Optimal Signal Processing Method in UWB Radar for Hidden Human Detection”. In EUSAR 2014; 10th European Conference on Synthetic Aperture Radar; Proceedings of (pp. 1-3). VDE. (2014, June).

[8] Karamzadeh, S., Kartal, M. *“UWB Radar In Hidden Human Detection”* Internatıonal Journal Of Electronics, Mechanıcal And Mechatronics Engineerıng Vol.3 Num 2 pp.(579-583), *2014.*

[9] X. Li, S. C., Hagness, M. K., Choi, and D. W., van der Weide, *“Numerical and experimental investigation of an ultrawideband ridged pyramidal horn antenna with curved launching plane for pulse radiation,”* IEEE Antennas and Wireless Propagation Letters, vol. 2, 259–262, 2003

[10] A. G., Yarovoy, A. D., Schukin, I. V., Kaploun, L. P., Ligthart, *“Theielectric wedge antenna,”* IEEE Transaction on Antennas and Propagation, vol. 50, 1460–1472, 2002.

[11] M. Chiappe , G. L. Gragnani, *“Vivaldi antennas for microwave imaging: Theoretical analysis and design considerations,”* IEEE Transactions on Instrumentation and Measurement, vol. 55, 1885–1891,2006.

[12] I. Waisberg, *SoCo Mathemaics of The Information Age* , 2011

[13] R. Polikar , *‘’The Wavelet Tutorial Part 3 Multiresolution Analysis The Continuous Wavelet Transform’’*

[14]R.J.E., Merry,*’’Wavelet Theory and Applications’’* , A literature study DCT ,2005

[15] R.Madan , S. K., Singh, N. Jain , ‘’International Journal of Recent Trends in Engineering,’’ Vol 2, No. 2009

[16] Q. YANG,*”GPR detection for underground water pipe based on Wavelet Transform and Matching Pursuit Algorithm”*, International Journal of Advancements in Computing Technology(IJACT) Volume5, Number13, School of Information Engineering Departments Nanchang Institute of Technology, China, 2013

[17] A. B., Yoldemir , M. Sezgin*”Depth Estimation Of Buried Objects Using Wavelet Transform And Statistical Hypothesis Testing”*

[18] N.E., Huang Z. Wu , *‘’A Review on Hilbert-Huang Transform:Method And Its Applications To Geopyhsical Studies’’* , 2008

[19] Z. L. Lanbo Liu and Benjamin Barrowes , The Application of the Hilbert-Huang Transform in Through-wall Life Detection with UWB Impulse Radar, School of Engineering, University of Connecticut, Storrs, CT 06269-2037, USA , 05\07\2010

[20] B. L., Barnhart, ‘*’The Hilbert-Huang Transform: Theory, Applications, Development’’* , 2011

[21] N. E. ,Huang, Z. Shen, S. R. Long, M. Wu, H. H., Shih, Q. Zheng, N. Yen, C. C., Tung , H. H., Liu, ‘*’The Empirical Mode Decomposition And The Hilbert Spectrum For Nonlinear And Non-Stationary Time Series Analysis ‘’*, 1996

[22] N.E., Huang , Z. Shen, S.R., Long , *‘’A New View Of Nonlinear Water Waves: The Hilbert Spectrum. Annual Review Of Fluid Mechanics’’*,1999

[23] M. I., Skolnik, *Introduction To Radar Systems*, McGraw-Hill, New York, 2001

[24] S. M., Kay, *Fundamentals of Statistical Signal Processing Vol II: Detection Theory*, Englewood Cliff, NJ: PTR Prentice Hall, 1998

[25] G, D., Borkotoky, S. S., Mahanta, A. Sarma, *‘’K. C: A Matched Filtering Technique for Noninvasive Monitoring of Human Respiration Using IR-UWB Radar’’*, International Journal of Advanced Technology & Engineering Research (IJATER), 2012.

[26] Karamzadeh, S., V. Rafii, M. Kartal, O. N. Ucan, and Bal S. Virdee. "Circularly polarised array antenna with cascade feed network for broadband application in C-band." Electronics Letters 50, no. 17 (2014): 1184-1186.