Investigation of the Continuous Wavelet Transform Method for Use with Late Time Response Analysis of Concealed on Body Threat Objects

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ملخص البحث

الهدف الرئيسي للبحث يتمحور حول إيجاد طرق بديلة للكشف على الجسام الخطرة المخفية بدلا عن الطرق التقليدية المستخدمة حاليا في اغلب نقاط التفتيش مثل مداخل المباني الحكومية، والمصارف، والمطارات، وغيرها. حيث تم اختبار مدى امكانية استخدام الموجات الكهرومغناطيسية في الكشف على الاجسام المخفية وذلك من خلال استخدام تقنيات التحويل المستمر للموجات (continuous wavelet transform CWT) حيث يتم تعريض الاجسام للموجات الكهرومغناطيسية باستخدام هوائي مخفي في الحائط فينتج عن ذلك استجابة عكسية مبكرة و متأخرة (early time response and late time response). الاستجابة المبكرة يمكن استخدامها في تحديد مكان الجسم المراد اكتشافة او الكشف عن نوعيته بينما الاستجابة المتأخرة تحدد نوعية هذا الجسم حيث ان لكل جسم استجابة متأخرة خاصة (unique signature) وباستخدام تقنية التحويل المستمر للموجات (CWT) يمكن تحديد نوعية الجسم . ان استخدام تمثيل الإشارة الكهربائية باستخدام نطاق التردد الزمني يوفر الكثير من خصائص الإشارة التي يمكن استخدامها في مجال الكشف على الاجسام المخفية. ومن خلال هذا البحث أجريت عدة تجارب على بعض الاجسام المختلفة في الخصائص الفيزيائية لاختبار مدى نجاح التقنية المقترحة حيث بينت التجارب انه باستخدام تقنية (CWT) يمكن استخراج خصائص الجسم المخفي والتي يمكن استخدامها في التعرف على نوعية هذا الجسم وذلك من خلال الاستجابة العكسية المتأخرة بعد تعريض الجسم لسلسة من الموجات الكهرومغناطيسية.

Abstract- investigation of the use of continues wavelet transform (CWT) method to late time response analysis for detecting on body concealed threat objects proposed in this paper. The transient backscattered mechanisms of on body concealed weapons target signatures are studied using the wavelet analysis technique in which signal processing algorithm is developed and the Morlet wavelet applied to extract and analyses the re-radiated transient response of concealed targets. Experimental work was done by using simple and complex objects such as wire and handgun, Wavelet analyses of backscattered data from various objects are presented, the results show that the Continues wavelet transform (CWT) has the ability to detect and discriminate between the hidden-on body objects.

INTRODUCTION

The transient scattering returns of a radar target in free space was first studied by singularity expansion method (SEM), by which the late-time phenomena of the target response were obtained as a sum of damped exponentials convolved with resonant frequencies and noise. This beneficial characteristic allows the resonances to be used for target identification. Extensive discussions took place in the mid-1980s to develop a model of the transient scattering behaviour and modelling for early time response, (Dudly,1985),(Felsen, 1985) SEM model has neither been a true reflective nor their a nearby solution to this problem due to the intricate nature of the process itself, Prony's method suggests target resonance extraction to be directed upon the interval of late time response, if the nearby objects are included in the extraction, fairly accurate CNR extraction is achieved. Prony's method thus needs accurate starting late time commencement evaluation is critical for the overall accuracy of target resonance extraction. Late time responses are target dependent and theoretically independent of polarization state and target orientations. However, practically the late time period cannot correctly extract in some cases. Knowledge of the model order is critical in the extraction process and in the subsequent calculations for poles and residues algorithms. If the model order is underestimated this can cause loss of poles in the calculations. Similarly, resonant modes are unlikely to be excited or weakly excited in all incident aspects and states of polarization due to a dependency on residues. It is apparent from the complexity of the methods and algorithms involved that another method is required for the extraction of the resonant modes. To increase further the physical insight of the problems connected to the authentic transient electromagnetic scattering procedure, one feasible approach is to examine the scattering phenomena analytically using electromagnetic theory. This has been extensively studied by (Heyman& Felsen, 1985), (Heyman, 2002), (Shirai & Felsen, 2002). It is well recognized fact that analytical solutions to transient electromagnetic problem involve huge mathematical calculations and they are imperfect for some canonical problems. An alternative, stemming from a signal processing perspective is to apply Joint TF analysis. The joint time-frequency analysis has been commonly applied in many engineering applications such as signal processing in bio-medical data, speech processing, wireless communication, radar imaging and sonar applications, with radar applications substantial work has been carried out on stationary targets using frequencies in the low GHz frequency region i.e. up to 2 GHz. For UWB radar a substantial amount work on feature extraction has been done by (Ling 1992, pp 140-142), on TF analysis of backscattered signals including the range of the profiles for the stationary targets, this later applications frequency of operation is in the quasi-optional regions. GTD in the electromagnetic context describes that quasi-optional regions lie outside the essential resonant modes and high frequency scattering portents such as edges and corners diffraction, (Balanis, 19890. The focusing in this paper is on the late-time resonant that are observed in the SEM and to study the scattering phenomena of the objects using TFDs. The Wavelet transform is introduced as alterative approach to overcome the STFT resolution limitation, a detailed explanation of the wavelet theory could be found in (Rioul&Vetterli, 1991, pp. 14-38). Particularly, the wavelet transform utilizes the wavelet as a 'window' and also as a fundamental for the analysis of multi resolution (Kaiser, 1994, pp. 60-64). To provide good time resolution (small scales) at high frequencies the 'mother' wavelet is compressed so that the wavelet of the time response provides effective resolution in detecting the presence of high frequencies. To have a good frequency resolution at low frequencies the mother wavelet is expanded (large scales), by which the wavelet transform has effective resolution in frequency domain in detecting the appearance of the low frequencies. In fact, in this research the CWT approach is proposed to extract the target signature and represent the LTR in time frequency domain. A Morlet wavelet is used as the mother wavelet within the CWT algorithm because it is simple and well suited for time frequency localization and resolution for concealed weapon application. The CWT provides coefficients in which the degree of correlation is proportional to the peaks or amplitude. Another perspective is that the analysed signal decomposes into a superposition of scaled mother wavelets by the wavelet transform. The aim of this study is to examine TFDs to represents electromagnetic scattering though extracting the LTR which is very useful for object identification and classification. Different simple and complex targets signatures are studied. Instead of new approaches of extracting resonance parameters directly or development of existing methods, the role of the study is for novel development of object recognition algorithms using the CWT.

THEORY

In the application of detecting the response of concealed on body weapons, powerful signal processing algorithms that accurately extract the target signature is needed. In this section CWT time frequency analysis method is used for analysis and extracts the target signature from the backscattering response. Hence the wavelet transform is a powerful TF analysis and it has a multi resolution capability which is not available in WVD and STFT. The basic variable of Fourier Transforms, the frequency, is not possible directly with wavelet transforms instead a new term called “scale” is used and the wavelet transform introduces time-scale representation (Young, 1992, pp. 13-20). Many mother-wavelets are utilized for varies implementation and applications. The best known are Morlet, Daubechies and Haar wavelets. Also, of great importance are the coiflet, symlet, Mexican Hat and biorthogonal wavelets. It is very common to use Fourier transform characteristics for analysis applications when the time domain transformation has no time-frequency localization features. The theory of wavelet transformation has been considered for the first time in the field of multiple resolution analysis, it has been applied to the processing of images and signals. A CWT can analyse a signal in a set of limited basic functions that can reveal transient characteristics in the signal. Wavelet analysis is the violation of a signal in an extended and translated version of the original wavelet. The wavelets must be oscillating, have amplitudes that quickly reduce their decay and have at least one moment of disappearance. In wavelet theory, many of the principal functions of wavelets have been considered, each of which has its proper application. In this work, the selected mother, Morlet-Wavelet, because of its advantages and characteristics, (Fine tuning of the desired frequency band, good resolution and location in the time and frequency domain, recognition capability and extraction-oriented characteristics). Morlet wavelet is a sinusoidal signal modulated by a Gaussian wave. Its offers higher spectral resolution compared with Mexican Hat, this is because of the narrow frequency response. This wavelet is particularly useful for filtering out the background noise of the target response. The CWT is the member of the linear class of TFDs. The prime definition of the CWT is,

$$\mathrm{CWT_x}(t, \alpha, h) = \frac{1}{\sqrt{\alpha}} \int_{-\infty}^{+\infty} x(\tau) h\left(\frac{t-\tau}{\alpha}\right) d\tau \qquad (1)$$

h(t) is the mother wavelet, a is variable scaling parameter. The CWT can be known as a member of Time-Scale distribution (TSD) series. If we compare the STFT with the CWT, then CWT is different from STFT as it can longer be adapted to modulation or frequency shifts as it now created by scaling factor a though the price paid is that the CWT gives a time-scale representation of the signal rather than a time- frequency representation. if $\alpha = \frac{f_o}{f}$ where f_o centre frequency of $h(t)$, for the TF analysis application, the consequent distribution can be given as, [11][12]

$$\mathrm{CWT_x}(t, f, h) = \sqrt{\frac{f}{f_0}} \int_{-\infty}^{\infty} x(t) h\left(\frac{t-\tau}{f_0}\right) d\tau \qquad (2)$$

Scalogram (SC) is known as the magnitude of the CWT.

$$|\mathrm{CWT_X}(T, F, H)|^2$$

The mother wavelet requests to achieve certain mathematical principles. A complex or real- value function h(t) is defined as a wavelet if,

$$\int_{-\infty}^{\infty} h(t) dt = 0 \qquad (3)$$

Which means that a wavelet should has a zero-dc component (zero average value in the time domain), which also specifies that signal must be oscillatory in the frequency domain. It can be shown that the signal $x(t)$ can be recovered from the following equation (Rioul & Flandrin, 2002, pp. 1746-1757).

$$x(t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \mathrm{CWT}(\tau, \alpha, h) h\left(\frac{t-\tau}{a}\right) d\tau \frac{da}{a^2} \qquad (4)$$

Many wavelets meet the Admission Condition, only if $h(t)$ satisfies the Admission Condition. The Morlet wavelet is one of the most frequent used wavelets that does this and is given by (Sadiku & Garcia, 2005, pp. 21-67) as

$$h(t) = e^{jw_0 t} e^{-t^2/2} \qquad (5)$$

It must be appreciated that individual wavelets have different characteristics, so they are appropriate for different applications. To discover whether the multi-resolution property of the CWT is appropriate for investigating transient scattering consequently, it is necessary to decide which mother wavelet is selected. Expecting the result somewhat, in this paper the multi-resolutions characteristics of the Morlet CWT that are examined to determine whether the CWT is a convenient method extracting the LTR of concealed weapons. TSD in the signal processing literature was first introduces with respect to the CWT and then later applied to TF analysis by [11]. CWT produces a fixed time and frequency resolution throughout the 2-D plot The CWT gives a good time resolution but poor frequency resolution when a is small (high frequency as $a = f_o / f$), but good frequency and poor time resolution when a is large i.e. low frequency (Debanth, 2003). successful work on TF analysis for electromagnetic scattering using the SP and CWT has been reported in (Ling & Kim, 1992, pp. 140-142). In the following sections, practical experiments will be carried out by using two types of targets. Initially, we will test a simple target of a wire with 20cm length and 5mm width, followed by another experiment using a hand gun, which is more complicated than the simple wire. The purpose of this study is to know the limits and determine the ability of the CWT technology to analyse the LTR backscattering target response signal.

METHOD

Two identical transmitting and receiving tapered slot antennas, designed and fabricated as part of this research, with cut off frequency around 0.25 -3.0 GHz, the transmitting antenna was oriented in the direction of the illuminating radiation and the receiving antenna at 90o (cro ss-polarized) to give better discrimination between the early and late frequency time response. a sweep frequency of bandwidth 0.25-3.0 GHz generated by the vector network analyser VNA E8363B to excite the target. A Gaussian shaped window was used throughout, and the frequency target response were subjected to signal processing to subtract the background signal and antenna response deconvolutions followed by time domain transformer by using the Inverse Fourier Transform. The start of the LTR was determined using the Equation (6), (Baum, 1976, pp. 129-179).

$$y(t) = \sum_{t=1}^{M} A_m \cos(\omega_m t + \varphi_m) \exp(-\alpha_m t), \qquad t > T_L \qquad (6)$$

SIMPLE WIRE

A huge amount of research was done to analyse the LTR backscattering response using simple wire in order to understand its behaviour in time domain. Moreover, the wire backscattering response were studied deeply in the SEM context (Baum, 1976, pp. 129-179). a wire with length L = 21 cm and diameter d = 4 mm with incident target orientation angle $\varphi = 45^{o}$ is considered. Firstly, the Target response is subject to the mentioned signal processing. Beginning of late time response (LTR) signal is measured by using the equation (6), (Baum, 1976, pp. 129-179). In this experiment the forced ETR target response starting at 3 ns and thus $Tb = 3$ ns with $Tp = 14$ ns, $\varphi = 45^{o}$.

$$T_{tr} = \frac{L \sin \varphi}{c} = 0.59 \text{ ns}$$

This means LTR life time to be around 10ns. The resonance of LTR modes are extracted by using the GPOF,[16]. Figure 1 illustrate the scattering poles of this target; model order was estimated M = 6. GPOF is very sensitive to the target model order, any falls or wrong estimation of target model will lead to fake poles and increase the error of target detection and identification.

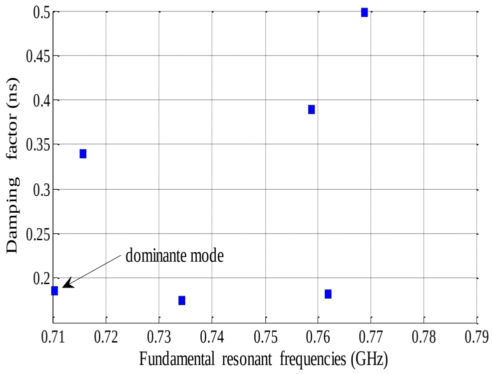

Figure -1 Poles of wire of length 21cm

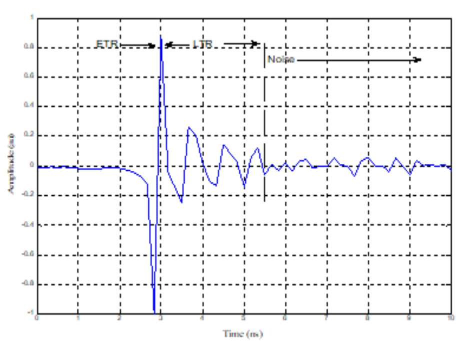

Figure 2 complex resonance frequency CNR

it is quite clear that the dominant mode resonates frequency is near to the theoretical value $f_{res} = \frac{c}{2l} = 0.71\text{GHz}$ where c is speed of light and l is the target length, (Ksienski, 1985, pp. 13-19). The lowest pole of the scattering has a similar resonant frequency of the LTR and can be used to reconstruct it by,

$$f\big((n-1)\Delta t\big) = \sum_{m=1}^{N} c_m \, e^{s_m (n-1)\Delta t} \qquad (7)$$

Where $s_m = \sigma_m + i\,w_m$ are the poles and c_m are the residues, σ_m is the damping factor and w_m is the resonant frequency [20]. the first three resonances values are for the 21cm wire are $1.5 - i2.2500, 3.0000 - i1.5000$ and $-4.5000 + i2.2500$ (imaginary parts in GHz and real parts inns^{-1}). The results of the GPOF will be considered as reference reanalysis results for determining the efficiency of CWT in detection of frequency dominate modes of the target related to its geometry. The frequency bands of interest of the particular target wire determined from the results of GPOF are considered as points of reference for the initial dominant modes of resonance. In this subsection a simple case of an idealized target response using the resonant modes is considered. The construction of these artificial responses is based on. From figure 2 the dominant resonant frequency can be calculated from consecutive peaks – these are about 1.5 ns corresponding to the dominant frequency mode of about 0.7 GHz. The target dominate frequency is presented in figure 3. Results of the CWT analysis of the target response are presented in figure 4, which most of the target signature resonant modes are obvious Crosseponding to their energy levels.

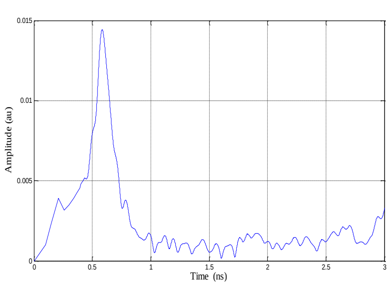

Figure 3 Simple wire Frequency response

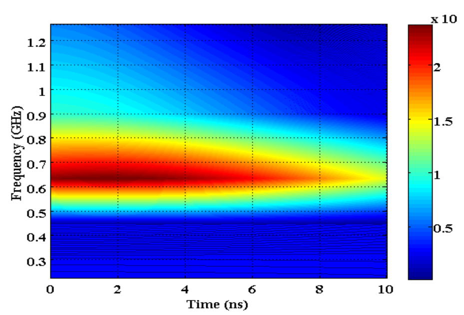

Figure 4 CWT of simple wire

The results of TFDs obtained through the use of CWT indicate the ability of this technique to extract the frequency target signature through the frequency dominate modes related to their energy levels, red colure means high energy level and the blue colour means the lowest energy level (end of late time response life time). These results ensure that the CWT technique is suitable and convenient to extract the LTR target signature as it has good frequency resolution in the LTR period and good time resolution in the ETR period. The observed energy levels indicates the amplitude of each dominate frequency, this leads to general conclusion in the situation where $\sigma \ll \omega$ the relevant energy E of a single mode signal would be given by $E = \frac{Z^2}{\varepsilon}$ where Z is target impedance, ε is the target permittivity properties.

CWT performance of on body concealed weapons

In this section on body concealed objects will be analgised. Firstly, human body response will be investigated followed by the investigation of the backscattering response related to on body concealed weapon. The purpose of that is to verify the interference between the human body backscattering response and the back-scattering response of on body

concealed weapon in order to understand the ability of CWT to detect concealed threat objects. The back-scattering response from the human body show how weak these signals which is due to the human body tissues dielectric properties figure (5). The refraction angle $\emptyset_t^{o}$ and the transmitted pulse phase velocity is frequency dependent and varied subsequently,[17]. The weakness in the backscattering response of the human body since the transmitted pulse suffers from the attenuation as its propagated within the lossy dielectric of the human body as its illustrated in figure 5and figure 6.

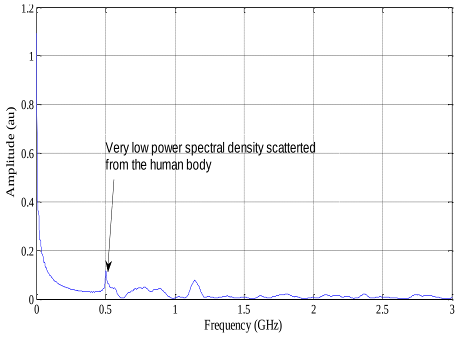

Figure -5 Frequency response of body only.

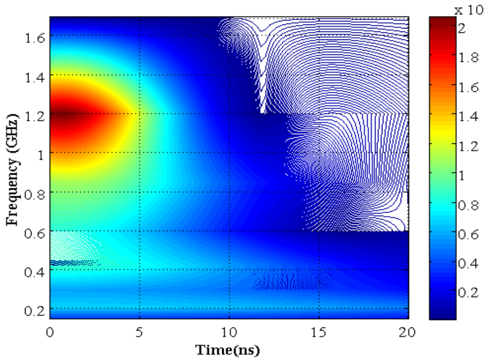

Figure -6 CWT of human body only.

In this subsection the backscattering response of the human body carrying a hidden threat object will be investigated, in comparison with previous section results, it is clear how the target signature is overlapped with the human body response. The CWT results of the on body concealed weapon are given in figures 7, and 8. Throughout these experiments, it is observed backscattered high energy levels corresponding to the signature of the on body concealed objects compared to the low levels when there is no target. These results confirm that the use of the CWT technique could detect the existence or absence of any threat objects concealed on body and it's also capable to discriminate between different objects.

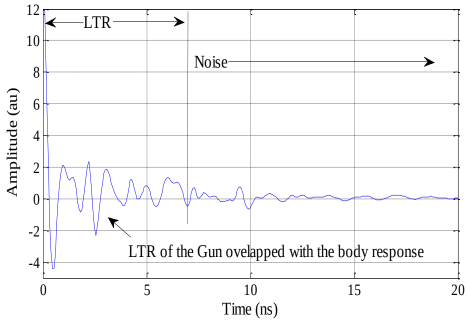

Figure -7 LTR of on body gun

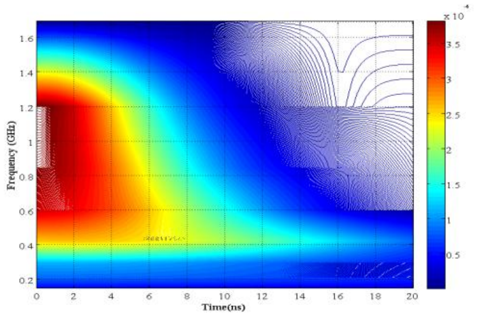

Figure- 8 CWT performance of on body gun.

However further investigation is required. The big difference in the levels of energy emitted, as it was observed that the levels of energy are low when the detection of the human body alone and on the contrary, the levels of energy are high When the detection of the human body carries dangerous objects.

CONCLUSION

CWT performance could detect concealed target signature on both simple and complex objects, the LTR was accurately extracted and illustrated in time frequency domain TF. The promising results confirmed that the CWT performance is directly identifies the response of the unknown concealed target and could be a very powerful tool in the detection of any on body concealed object, however, further research should be done to distinguish between the concealed objects throughout a strong database or and adaptive technology.

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