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Research Article

Radar range profile processing using Green's function

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ABSTRACT

In this study, a useful method for synthesizing range profiles to be used in ultra-wideband radar operations is discussed. One-dimensional transmission-reflection geometry of the radar scenario, which consists of a single receiver and single transmitter, is formulated by using the Green's function. A one-dimensional time domain Green's function is employed in the formulation and the impulsive characteristic of this function, which provides focus on the target position, has been determined. This characteristic represents the impulse response of the propagating medium to the electromagnetic wave. The resulting derivation offers a framework that can also be used in higher dimensional and complex radar problems by taking the advantage of its flexibility. Proposed method has been detailed and tested on an exemplary implementation and successful results that provide good focus on the target positions are shown in the conclusions. Finally, outcomes and benefits are discussed.

1. Introduction

If we determine a starting point for any scenario that is desired to be realized with radar, target ranging would be one of the most fundamental problem. Easiest way to range a target cluster is observing a range profile that has sufficient spatial resolution. Range profiles allow all targets likely to be existed throughout the line of sight of the active sensor to be observed at varying amplitudes as determined by the reflectivity variable. According to information theory, the information content of a signal received from a sensor depends on the absolute bandwidth of the signal, and information that is not included in the signal cannot be created by any mathematical method In addition, in order to obtain maximum information from a radar data, it is expected that the processing of this data will be supported by methods with low processing noise, independent of data content and better modelling [1-3]. The tolerance of the method to the sensing conditions, namely the change of parameters is another expectation.

With the technical advantages of radar systems necessitating new areas of use, the development of short-range and especially indoor systems has been paved the way. Technical advances, especially on the hardware side, have brought the use of UWB (Ultra-Wide Band) systems to the fore. The main reason for waiting for this development is the need for high range resolution, and for this, time domain methods started to gain importance for UWB systems that need to operate fast by nature [4,5].

To express specifically for UWB radar systems, if it is formulated in the time domain, the expression of the impulse response of the system and the environment in radar equations will be useful in terms of modeling the system correctly. Green's functions are powerful tools that can be used to accomplish this task [6]. Green's functions can be analytically synthesized at any number of dimension and type of coordinate systems both in time and in frequency domains. This will provide a practical framework for solving different problems in a set of equations where this function can be used modularly. Additionally, more complicated scenarios can be handled in the same way, if the Green's function required synthesized mathematically [7].

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This paper studies obtaining range profiles for UWB radars using one dimensional time domain Green's functions on a set of equations defined in the time domain. Following chapters include the expression of the Green's function and the use in the formulation of the problem, an implementation and results with discussions.

2. Formulation of the Problem

Let assume a simple target with the range of r_t from the radar system. Round trip delay of the return echo will be a function of the range, and considered focused point on this scenario will similarly be as follows:

$$\tau(r, r_f) = R/c - |r_f - r|/c \tag{1}$$

where c is the light speed, $\boldsymbol{r}$ is the position vector in cartesian coordinate, r_f is the range of the point that is focused and R is the observation point of the illuminated scene along the line of sight of the radar.

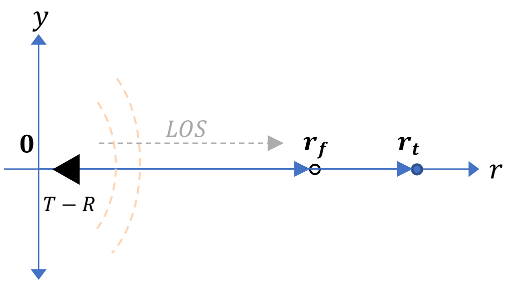

Figure 1. Propagation geometry and representative notation

Green's function mentioned, can be considered as the impulse response of an elementary target function to a two-way propagation system. In the case that the target considered as a dipole, Green's functions' solution provides the impulsive wave front reflected from this dipole. For a two-way radiation problem, the resulting combined Green's function considered as convolution of the individual Green's functions for two ways as follows,

$$G_E\left(r_o, r_f, r, t\right) = G_F\left(\mathrm{r}_f, \mathrm{r}, t\right) * G_p\left(\mathrm{r}_o, \mathrm{r}, t\right) \tag{2}$$

Here, the G_F and G_p shows the Green's function components for propagation and the focusing, and the notations shown by $\boldsymbol{r}$ refers to the position vector along the line of sight. The Green's function for focusing is a delta Dirac function on the proper delay as shown in (3),

$$G_F\left(\mathrm{r}_f, \mathrm{r}, t\right) = \delta\left(t - \tau\left(r, r_f\right)\right) \tag{3}$$

on the other way, for a single transceiver system, one dimensional time domain Green's function is identified for the propagation between antenna position vector r and vectoral denotation of the observed point r_o as follows [6],

$$G_p\left(\mathrm{r}_o, \mathrm{r}, t\right) = \frac{Sgn(|r_o + \mathrm{r}|/c) - Sgn(|r_o - \mathrm{r}|/c)}{4\pi} \tag{4}$$

where $Sgn(\cdot)$ notation represents Signum function. Here, if the impulsive characteristic of the Green's functions is determined, this will give good results in terms of the simplicity of the final equation. Let analyze the limits of the Green's function given in (4), where r is short enough, theoretically close to zero, by taking advantage of the fact that UWB systems work with pulse signals of very short duration. For a fixed focusing point of r_o, these properties can be written for a hypothetical fixed-point target on the range of r_t,

$$\lim_{r\to 0} G_p(\mathrm{r}_o, \mathrm{r}, t) = \begin{cases} 1/2\pi & , \quad r_t \in (r_o - r, r_o + r) \\ 0 & , \quad r_t \notin (r_o - r, r_o + r) \end{cases} \tag{5}$$

In the lights of the pair of expressions given in (5), an example plot for the Green's function given, for a focusing range of $t = |r_f - r|/c = 0.1\ ns$ delay time is given in Figure 2.

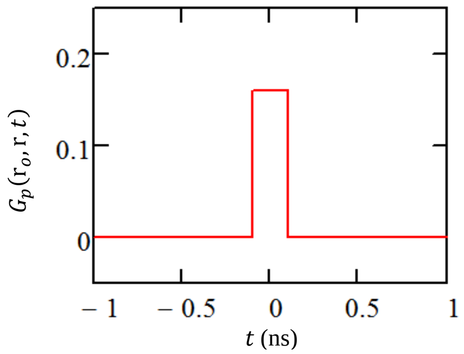

Figure 2. An example plot for one dimensional time domain Green's function for propagation

This enables one to represent the Green's function as a range independent scaled version of the delta Dirac function as shown below, in (6).

$$\lim_{r\to 0} G_p(\mathrm{r}_o, \mathrm{r}, t) = \frac{\delta(|\mathrm{r}_o - \mathrm{r}|/c)}{2\pi} \tag{6}$$

Thus, by using (2), it can be shown the resulting Green's function in combined form as,

$$G_E(r_t, r, t) = \delta\left(t - \tau\left(r, r_f\right)\right) * \frac{\delta(|\mathrm{r}_o - \mathrm{r}|/c)}{2\pi} \tag{7}$$

$$G_E(r_t, r, t) = \frac{1}{2\pi}\delta\left(t - |r_f - r|/c - |\mathrm{r}_o - \mathrm{r}|/c\right) \tag{8}$$

Now, let shape the radar scatter function by using the synthesized Green's function. For a transmitted signal $s(t)$, for example a Gaussian pulse, radar return $u(\cdot)$ can be written as superposition of all the echoes from individual scatterers [7,8]. By noting the target density function as $\rho(r_t, t)$ and vectoral range of the target point as r_t, total radar return u can be expressed in linear form as follows [9-11].

$$u(r, t) = G_E(r_t, r, t) \cdot \rho(r_t, t) * s(t) \tag{9}$$

By placing the focusing rule to the resulting function, integration of the distribution along the r axis yields the one-dimensional target density $P(\cdot)$ in multiplicative form as below [12,13],

$$P(\mathrm{r}_o, t) = \int_r \alpha(r) \cdot u\left(r, \tau_f(\mathrm{r}_o, \mathrm{r}, t)\right) dt \qquad (10)$$

Thus, in the presence of the target, the Green's function will bound and reflect the high amplitude response of the target trace over the focused point in the time domain. This can be achieved by reconsidering the Green's function for all the observation points along the r space.

In this equation, $\alpha(r)$ is the antenna function and can be omitted for simplicity and τ_f rule function should be defined to focus on the right point. Considering a roundtrip propagation for a pulse radiated and received by a transceiver at the position $r = 0$, the relation between focusing rule and observed point should be,

$$\tau_f(\mathrm{r}_o, \mathrm{r}, t) = t + 2|r_o|/c \qquad (11)$$

3. Implementation and Results

In this section an implementation is set up to show the outputs of the proposed method. The formulation in previous section is considered under the general frame. Signal processing in time domain has some challenges like processual cost despite it has theoretical and mathematical simplifications. At this point, we face the first trade-off between bandwidth and processual load. The selected bandwidth should be right enough to accommodate the required resolution, but not too large to make the process unwieldy. Here, the transmitted pulse is a gaussian pulse has a bandwidth of 500 Mhz with a center frequency of f_c =1.25 GHz. The plot of the designed ultra-wideband waveform, a high order Gaussian pulse which has properties close to the impulse function can be seen in Figure 3. With this properties, radar system's range resolution becomes as in (12). Here, c is the speed of the propagation, i.e. lightspeed and B is the signal bandwidth.

$$\Delta r = \frac{c}{2B} \cong \frac{3 \times 10^8}{2 \times 500 \times 10^6} = 0.3 \quad meters \qquad (12)$$

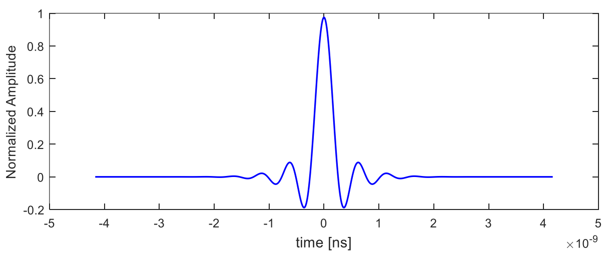

Figure 3. Designed UWB pulse waveform.

The data acquisition scenario shown in Figure 4., consists of two fixed PEC (Perfect Electric Conductor) trihedral corner reflectors placed 5 and 6,5 meters from a fixed ultra-wideband transceiver in a suitable way for indoor sensing. A code script that is using the FDTD (Finite-Difference Time-Domain) algorithm is generated to realize the time-domain electromagnetic backscatter from three-dimensional computer aided visual design of the representative environment. Trihedral corner reflectors, which is a frequently used target model in radar literature, are preferred because they provide maximum efficiency in electrical reflectivity aperture ratio when compared to its physical aperture sizes as formulated in (13). The equation simply consists of the squares of the reflector dimensions as a and b, and wavelength λ to obtain effective cross section σ_{RCS}. With this equation, it can be said that particularly at high frequencies, especially in the reflector with multiple reflectors, the cross-sectional area will increase dramatically with the coefficients (12 in this example) and exponent. Therefore, higher amplitude response can be obtained compared to other reflector types due to these exponents that are 8 for dihedral corner reflectors and 4 for square plane reflectors. Propagation environment's theoretical bounds considered open to avoid possible multipath reflections [14].

$$\sigma_{RCS} = \frac{12\pi a^2 b^2}{\lambda^2} \qquad (13)$$

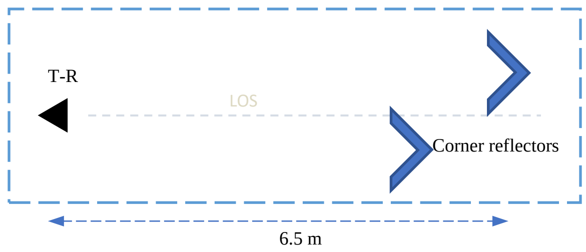

Figure 4. Considered radar data acquisition schematic.

Next figure shows the resulting range profile that evaluated by the method proposed and theoretically concluded in chapter two. High responses of two reflectors can be seen clearly on the correct positions.

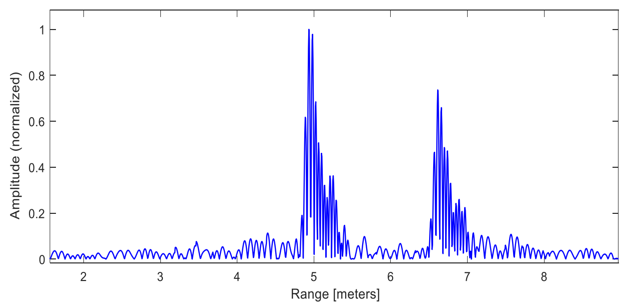

Figure 5. Range profile with target signatures

It should be noted that the resulting image is time gated to suppress the high distorting responses such as crosstalk, bandpass filtered and postprocessed but still has spread target signatures due to the broaden impulse responses of the corner reflectors, designed signal and imperfectness of the data acquisition process. In accordance with the nature of UWB focusing, it was observed that the pulse form used would have a destructive behavior on the sidelobes and a constructive effect on the main lobe.

Differences seen on amplitudes of the target signatures are caused by the attenuation due to the different ranges and different cross sections of the reflectors as stated before in (13).

4. Conclusion

Green's functions offer some useful properties to process ultra-wideband radar data and acquire target info from raw signals. Consistent modelling of the propagation mechanism is the key for the radar signal processing such as radar imaging.

In this paper a range profile processing method for ultra-wideband radars that employs Green's functions is proposed and handled both in theory and the implementation. Results show that the proposed method is able to achieve high resolution radar profiles and the frame can be extended to multi-dimensional requirements.

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