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Received signal consideration for the through the earth radio-based underground object detection

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Abstract. Underground object detections usually employ ground penetration radar (GPR). However, GPR produces data taken only from the earth's surface. This paper proposes radio through the earth (TTE) propagation path or received signal profile for three-dimensional detection. The propagation model and the three-dimensional propagation line equation are employed. Collections of transmission paths are classified into two-part, blocked and unblocked signals. Both classified signals are compared for signal processing. The study reveals that a number of the transmission path is a function of vertical edge to probe n , the deep of edge l , and transmitter step s . It is suggested the blocked signal paths are used for signal processing analysis as the volume is usually smaller than the evaluated space.

1. Introduction

Underground object detection is an interesting subject for many reasons such as dangerous material detection finding precious materials or searching archeological objects [1]. The object detection was initially performed by using automatic sorting system [15] or the electromagnetic induction (EMI) method [2] which mainly works only for metallic materials. The method relies on the radiated electromagnetic field and is sensitive to temporary magnetic induction. The most popular method is by receiving the reflected signal from the radio transmitter. This method is employed generally for radar. Underground object detection uses special radar which is called ground penetration radar (GPR) [3]. GPR is not only able to detect metallic materials, but also other non-conductive materials. Another technique is by using a time-domain reflectometer (TDR) [4] and capacitance measurement [5] which are mainly to explore land properties like mineral content.

GPR as the most popular device for underground object detection works just like normal radar or sonar. GPR measured electromagnetic reflection on the subsurface environment. GPR is able to detect any objects as long as the reflected wave strong enough to be received and analyzed. Even though, GPR sensitivity changes over the earth's characteristics and depending upon signal processing. Torrione et al. [6] divide GPR research into three types: model inversion, explicit hyperbola detection, dan statistical feature-based techniques. GPR is now widely used for ground and surface explorations.

This paper proposes the use of through the earth radio (TTE) submerged into the earth to determine the underground object by analyzing the propagation paths and received signals. TTE uses low frequency to develop a link between the earth's surface and underground site [7]. TTE is able to develop communication up to 300 m for voice communication and 600 m for text transmission. TTE usually used a frequency of 3150 Hz to 4820 Hz [8] employing single-sideband (SSB) or frequency shift keying (FSK). Some radios are equipped with higher facilities such as noise cancelation [9].



Commercialized TTE radios were mentioned in [10]. This paper focuses on examining radio propagation paths that are considered in signal processing to model underground object detection.

2. Research method

This paper models the underground object detection by using TTE radio by employing the underground propagation model, describing the mathematical model for the propagation line, and comparing the two types of propagation paths for signal processing. The following subsections discuss the propagation model, mathematical expression of propagation path, and strategy in obtaining the compared propagation paths.

2.1. Model for predicting underground propagation

The approximated underground propagation model uses received power prediction by using Friis equation which considered transmit power, antenna gain and propagation loss [11]:

$$P_r(\text{dBm}) = P_t(\text{dBm}) + G_r(\text{dB}) + G_t(\text{dB}) - L_0(\text{dB}) \quad (1)$$

This propagation loss is approximated based on distance (d in km) and frequency (f in MHz) as in Equation 2 [11]:

$$L_0(\text{dB}) = 32.4 + 20 \log(d) + 20 \log(f) \quad (2)$$

Since Equation 2 is generally used for line of sight propagation, the additional factor (L_p) should correct the Friis equation which is taken by considering the ground properties, so that the received power level is then approximated by:

$$P_r = P_t + G_r + G_t - L_p \quad (3)$$

The corrected loss factor L_p is a combination of space loss L_0 and the ground loss L_s . L_s should consider underground signal speed, scattering, and distortion which differ from air propagation. L_s is reconstructed by L_α and L_β . The α is attenuation constant ((in 1/m) that changes over different ground characteristics, β (in radian/m) is a phase shift caused by the ground. L_s is formulated as in Equation 4 [11].

$$L_s = 8.69\alpha d + 154 - 20 \log(f)(\text{Hz}) + 20 \log(\beta) \quad (6)$$

Constant α and β are approximated as [4]:

$$\alpha = \omega \sqrt{\frac{\mu \epsilon''}{2} \left[\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} - 1 \right]} \quad (7)$$

$$\beta = \omega \sqrt{\frac{\mu \epsilon''}{2} \left[\sqrt{1 + \left(\frac{\epsilon''}{\epsilon'}\right)^2} + 1 \right]} \quad (8)$$

where $\omega = 2\pi f$, μ is magnetic permeability and ϵ' and ϵ'' are the real and the imaginary value of permittivity. Most ground permeability is assumed as free space: $\mu = \mu_0$ and $\mu_0 = 1$ [12].

2.2. Model for propagation line

This paper considers line mathematical model in three-dimensional space described by [13]. The line L through the point $P(x_0, y_0, z_0)$ and is parallel to the vector $\mathbf{v} = \langle a, b, c \rangle$, consists of all points $Q = (x, y, z)$ for which the vector \mathbf{PQ} is parallel to \mathbf{v} can be analyzed as follows (Figure 2). Line connecting points P and Q is PQ has vector $\mathbf{PQ} = \langle x-x_0, y-y_0, z-z_0 \rangle$. Since \mathbf{PQ} parallel to \mathbf{v} , then, $\mathbf{PQ} = t \mathbf{v}$, where t is a scalar. Therefore $\mathbf{PQ} = \langle x-x_0, y-y_0, z-z_0 \rangle = t \mathbf{v} = \langle t a, t b, t c \rangle$. The solution of this equation reveals line equation as:

$$\langle x, y, z \rangle = \langle x_0 + ta, y_0 + tb, z_0 + tc \rangle \quad (9)$$

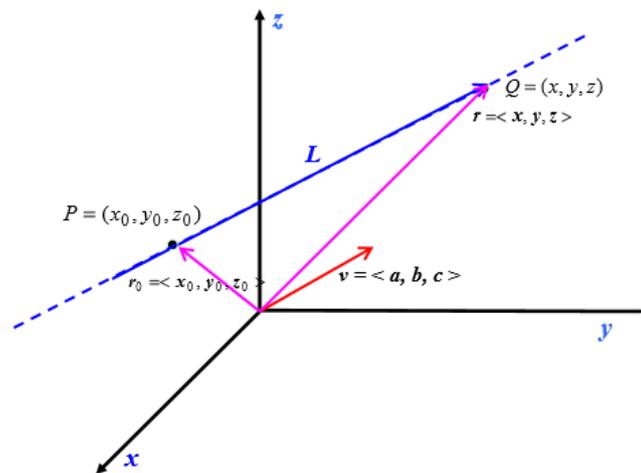


Figure 1. Three-dimensional line model [13].

2.3. The 3D model for separated transmitter and receiver

In order to describe the received signal graphically, some consideration is taken into account. The three-dimensional room which is evaluated is assumed to have a cubical shape with edge size of l . Transmitter and receiver are sequentially put on the different n vertical edge. Transmitter and receiver positions are changed in the step of size s so that the signal flows in various paths.

The ground material is assumed to be homogenous. Signal level consideration for directly received level is initially considered up to 90% of the maximum signal level, otherwise, the signal is assumed to be blocked. Other percentages are also given. The detected underground object is the shape formed by the intersection points of the transmission paths. Figure 2 shows the construction of the model. The evaluated space/room size is 5m x 5m x 5 m ($l = 5$ m). The step size $s = 10$ cm. A number of vertical edges, $n = 4$. Previous work [14] showed that the closest value of the propagation model to experimental measurement was when the real part of permittivity (\mathcal{E}') is 2.

The radio is set to use 109.8 MHz as propagation is more direct with 17 dBm transmit power, antenna gain 2.2 dB for both transmitter and receiver. The object is a cubical box size of 0.5 m x 0.5 m x 0.5 m put in the middle of the room. The simulation set up using python and matplotlib is shown in Figure 2.

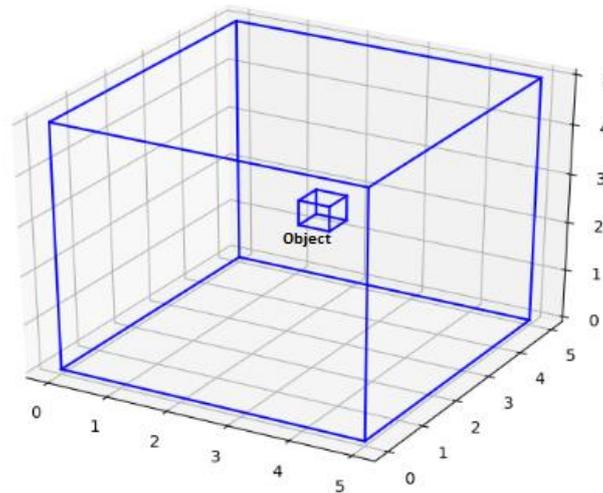


Figure 2. Underground space and object.

3. Modeling results and discussion

Figure 3a shows the propagation model in the form of propagation loss in dB changes to the distance in meter. Loss increases rapidly in near field area up to 1 m, then grows steadily, even almost linearly. The graph shows distances only up to 10 m. The received signal is calculated and depicted in Figure 3b.

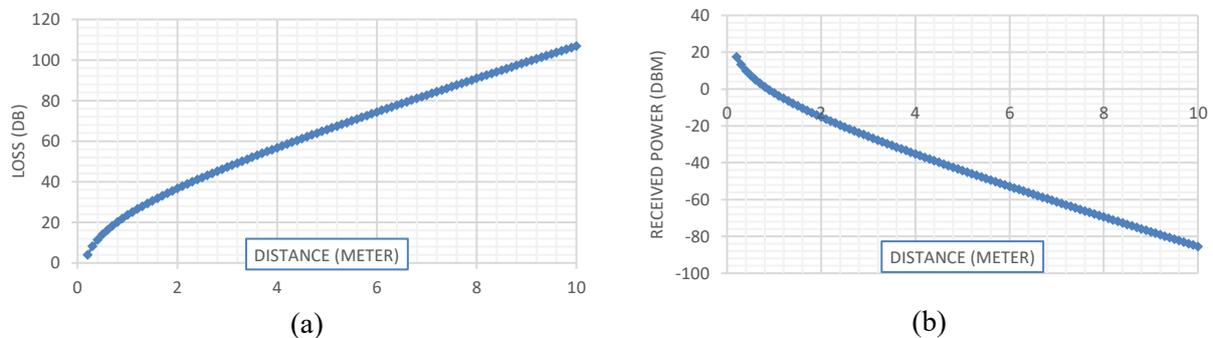


Figure 3. Propagation loss to distance.

Figure 4 shows simulation 2 transmitter and receiver positions for evaluated space/room edge $l = 5$ m, number of vertical edge $n=2$, steps $s = 1$ m. There will be 6 positions for transmitters and 6 positions for the receiver. The signal propagation path is 36 transmission paths. Therefore, a number of transmitter-receiver position can be calculated as:

$$pos = \left(\frac{l}{s} + 1\right) \cdot n \quad (10)$$

A number of the transmission path, p , can be approximated as the unrepeated two-combination of vertical edge multiplied by the square of the number of positions in every edge by using Equation 11:

$$p = \binom{n}{2} \cdot \left(\frac{l}{s} + 1\right)^2 \quad (11)$$

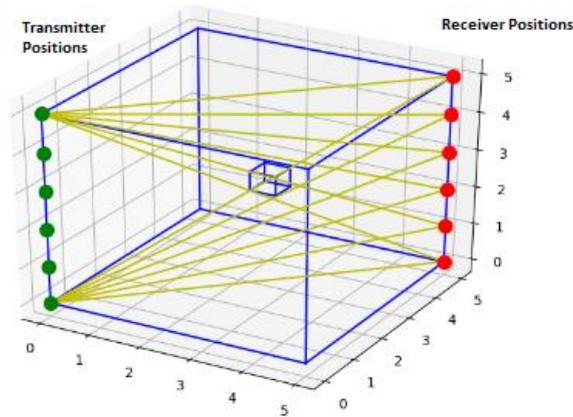


Figure 4. Sample signal propagations from transmitter to receiver.

From 2 samples of transmitter and receiver positions, there will be at least two signals blocked by the underground object. If the path is denoted by $p_{i,j}$ where i is transmitter position and j receiver position, the $p_{i,j}$ is defined as in Equation 12 with f is threshold percentage to be considered as a signal through.

$$p_{i,j} = \begin{cases} \text{Blocked, if } P_r < f \cdot P_{rmax\ i,j} \\ \text{Through, if } P_r > f \cdot P_{rmax\ i,j} \end{cases} \quad (12)$$

It is advised that transmission paths that are used for signal processing to determine the detected underground object the signal with the lowest components. If the detected object is large enough compared to the observed space, then the through signal should be used, otherwise, the blocked signal is a better choice. Since it is common that the observed space is much larger than the detected object, it is suggested that blocked transmission paths be used to determine the detected object. Simulation evaluation uses the following pseudocode (Figure 5) for determining the underground object.

```

for (i=0; i<number_of_position; i++)
  for (j=0; j<number_of_position)
    if (i!=j){
      MaxReceivedPower(i,j)=PropagationModel;
      Check Blocking uses Propagation_Line_Mathematic_Expression;
      if(Blocked)
        AddReflectionDifractionPower;
      if (ReceivedPower(i,j)>f*MaximumPower(i,j))
        P(i,j) is through;
      else
        P(i,j) is blocked;
    }

```

Figure 5. Pseudocode for blocked and through signal determination.

Figure 6 shows the three-dimensional figure of the simulated underground object detection uses evaluated space/room edge $l = 5$ m, number of vertical edge $n = 4$, steps $s = 10$ cm. There are 15,606 transmission paths, in which at least 228 transmission paths are blocked. These signals can be used in signal processing to determine the shape of the object.

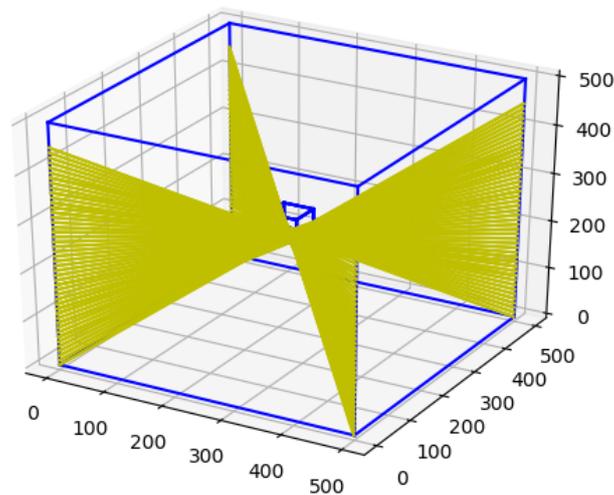


Figure 6. Transmission paths for $l = 5$ m, $n = 4$, and $s = 10$ cm.

The next step is to model object prediction based on the blocked signals so that the underground object is precisely described. However, this topic is covered in future work.

4. Conclusions

This paper has presented propagation path consideration when using TTE to detect an underground object by using the propagation model and some three-dimensional tools, including mathematics and programming language. The study reveals that a number of possible transmission paths to assess object position is a function of vertical edge to probe n , the deep of edge l , and transmitter step s . It is suggested the blocked signal paths are used for signal processing analysis as the number is smaller. Future work will deal with object modeling.

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