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Simulation study of the effect of certain types of noises on the quality of ground penetrating radar (GPR) data

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Abstract

Ground penetrating radar (GPR) is a valuable measuring tool and its fields of use are multiple (civil engineering, space exploration, mine clearance, etc.). During the inspection of the terrain, by the GPR radar, 'noises' can appear on the image and mask the desired information. These parasitic signals (noise) can come from internal sources (such as direct coupling between antennas, system rings) or external sources generated outside the system (such as: reinforced concrete bridges, building pillars). This work presents a simulation study of the influence of two types of noise on the quality of GPR data. These noises are the white Gaussian noise which resembles the background noise during GPR measurements and the noise caused by the direct coupling between the GPR antennas. The influence of the latter was studied with different distances between the antennas, using the operating mode of the common GPR receiver. The results obtained showed that Gaussian noise causes a complete overlap of the GPR images, while the direct coupling between the antennas causes the appearance of a direct wave, of variable depth depending on the distance between the antennas. This led to the masking of certain parts of the hyperbolas showing the presence of the targets.

Keywords: GPR, Distance between antennas, Direct wave, Gaussian noise, FDTD method.

1. Introduction

Ground Penetrating Radar (GPR) is a fast, non-destructive method of investigation and geophysical prospection of the shallow subsoil, based on the propagation and reflection of electromagnetic waves [1-2]. It is widely used in many different areas of research such as concrete reinforcement testing landmine detection, shallow depth geological investigation, hydro geophysical studies, criminal science sector where they can find corpses or buried weapons. GPR can be very useful in the case of natural disasters such as earthquakes, landslides, other typical GPR applications include public transportation infrastructure construction and maintenance sites in urban environments with the purpose of controlling the quality and the condition of the structures [3-6].

GPR waves penetrate through the subsurface when objects with dielectric properties different are encountered a portion of the energy reflected back to the receiving antenna which is moved along the surface at the same time as the transmitting antenna. This signal is recorded over time necessary for the return trip of the waves reflecting on the heterogeneity. The receiver processes the signal using software and displays a sectional view of the subsurface and target [7-8].

The depth of penetration of these waves depends on the electrical conductivity of the soils in the survey area and antenna frequency, in general, a low center frequency leads to a high penetration depth but with low resolution. While a high center frequency leads to a small depth of penetration with a good resolution [9].

The GPR may use a single antenna transmitting and receiving signals (monostatic) or two separate antennas, a transmitter and a receiver (bistatic). The use of bistatic radar antennas makes it possible to perform GPR recordings in different antenna configurations. Depending on the orientation and the relative position of the antennas, it is possible to define several acquisition modes like common offset, common source point, common receiver point and common midpoint [10-11].

During the inspection of the terrain, by the GPR radar, 'noises' can appear on the image and mask the desired information. These noises can come from internal sources (such as direct coupling between antennas, system rings) or external sources generated outside the system (such as: reinforced concrete bridges, building pillars). This work presents a simulation study of the influence of two types of noise on the operation of the GPR radar: the white Gaussian noise which resembles the background noise during GPR measurements and the noise caused by the direct coupling between the GPR antennas. The influence of the latter was studied for the common receiver GPR operating mode where the receiver is fixed but the transmitter moves along the direction of the survey. The simulations were carried out using the GprMax software which is based on the FDTD method.

2. GPR operating principle

The GPR systems consist of a transmitter and receiver antennas, control unit and display unit [12]. During the investigation, the transmitting antenna emits an electromagnetic pulse into the ground, when a certain interface or object changes the conductivity or dielectric constant, a partial radar wave is reflected the ground surface and captures by the receiver antenna (Figure 1). Antennas are moved simultaneously after each measurement point then a GPR profile can be constructed by plotting the amplitude of the received signals as a function of time and position, representing a sectional view of the subsurface and target [13-16]. The operational principle of a GPR system is shown in Figure 1.

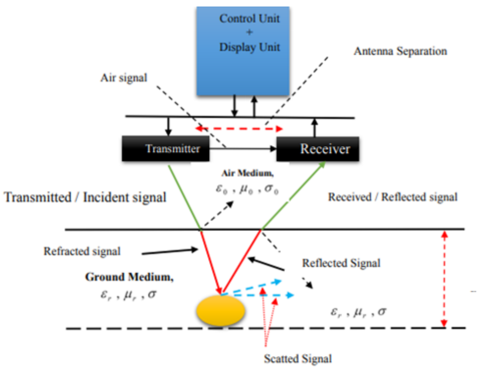


Fig.1. GPR Operational Principles showing antenna separation, air, transmitted, refracted, reflected

3. Results and discussion

3.1 The effect of Gaussian noise

In this part we simulated the GPR response by adding Gaussian noise by taking different values of its mean and variance. Figure 2. a shows the object to be simulated: it is a conductor buried in a medium which is dry sand. The simulation was carried out using the GprMax 2D software (we recall, here, that this software is based on the resolution of Maxwell's equations based on the finite difference time domain (FDTD) technique).

Figure 2.b shows the radargram of the object considered before adding noise to it, while figures 3.a,b, c and d present the radargram of the same object tainted, this time, by the added noise, for certain mean values and variances (successively): 0-5, 0-10, 1-5 and 2-5. In Figure 2.b we note the presence of hyperbolas which show the presence of the object, while in Figures 3 a, b, c and d we note that the noise completely hides these hyperbolas.

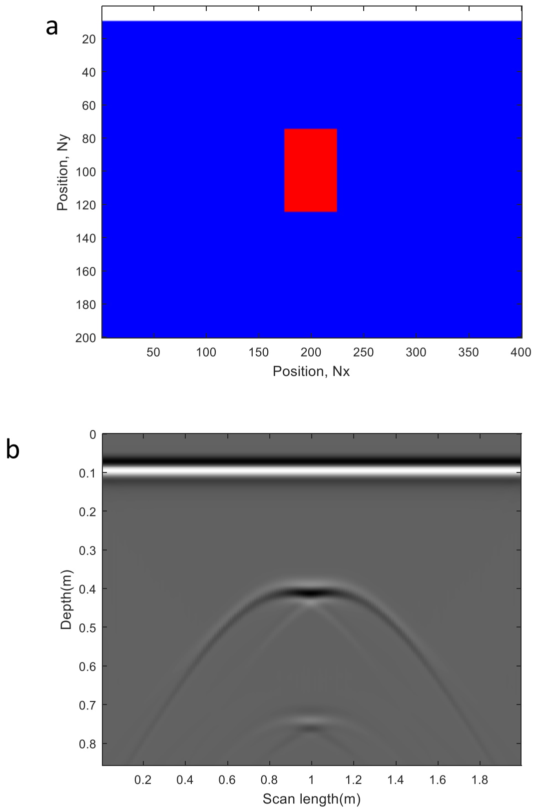
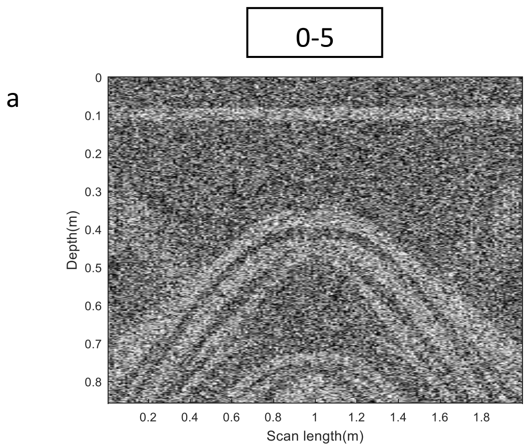


Fig.2. (a) Model of a conductive object buried in a sandy medium, (b) radargram of object detection.



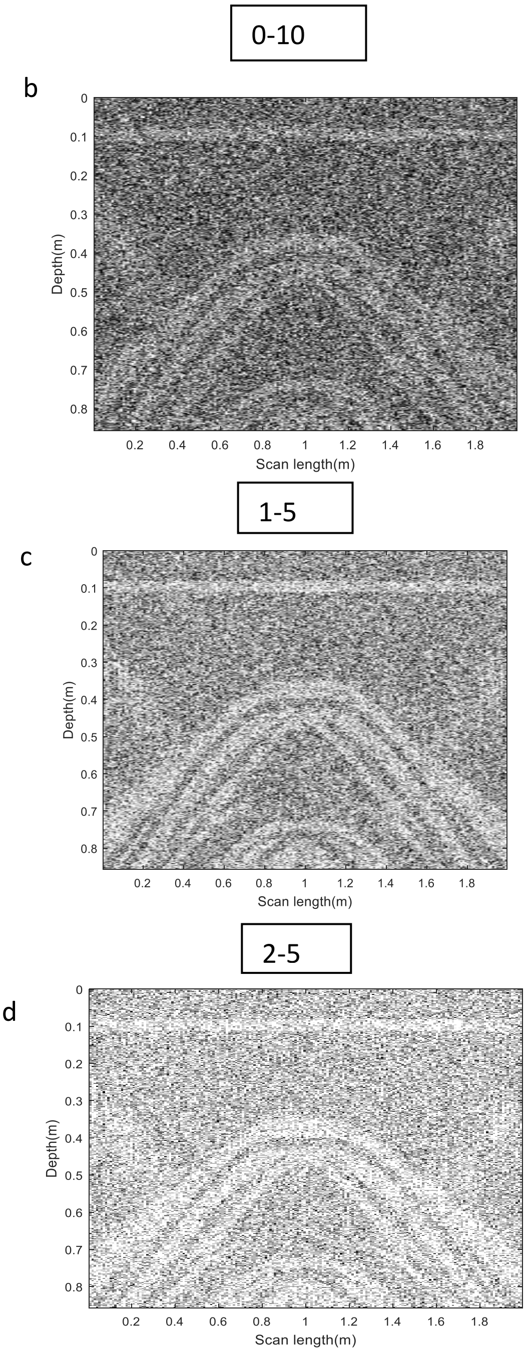


Fig.3. Object detection radargrams after adding noise.

3.2 The effect of coupling between GPR antennas

In this part we have simulated the detection of some iron rebars buried in a concrete slab using common receiver mode for different values of the distance between the antennas (10, 20, 30 and 40cm).

- **Offset 10cm**

In this case, we have simulated the detection of the rebars where the distance between transmitter and receiver is 10 cm. The resulting radargram and radar wave evolution over time are shown in Figure 4. On the obtained radargram we note the presence of hyperbolas indicate the presence of objects in addition to the lines that refer to the direct wave resulting from the transmitter in the direction of the receiver what we indicate by the arrow as shown in Figure 4a. This wave is composed of the direct wave in the air and the direct wave in the ground.

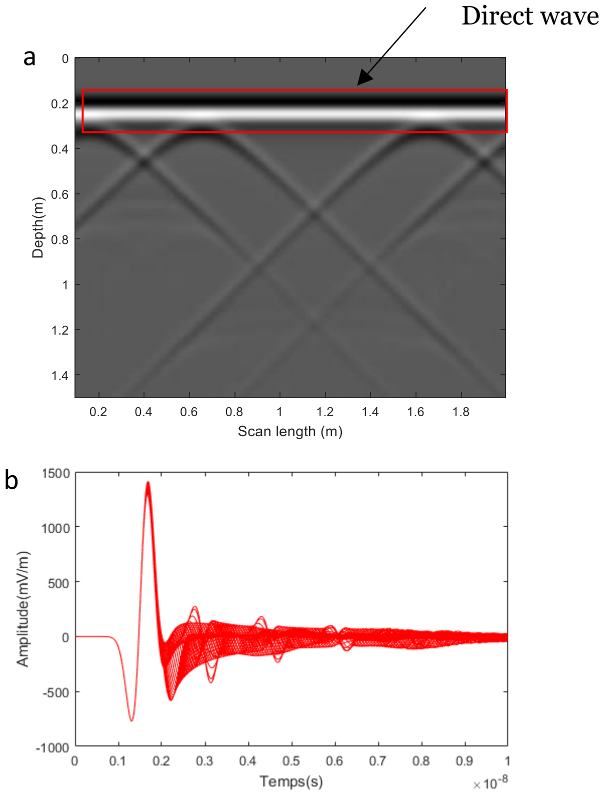


Fig. 4. (a) Radargram of detection of some iron rebars buried in a concrete slab for distance between antennas of 10cm (b) evolution of the GPR wave over time.

- **Distance between antennas: 20cm**

For this case, the separation between the antennas is 20 cm, we can see that the amplitude of the direct wave is less important in this case, but in the radargramm its find on a depth more important than for the previous case.

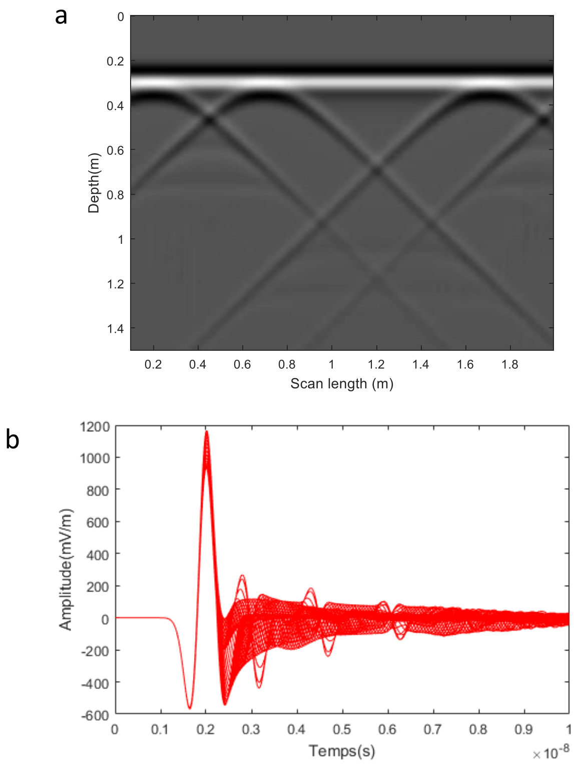
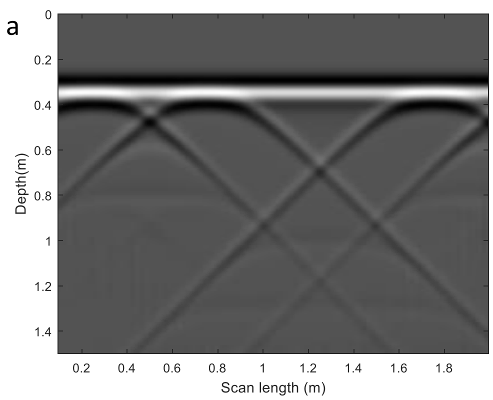


Fig.5. Radargram of detection of iron rebars for distance between antennas of 20cm (b) evolution of the GPR wave over time.

- **Distance between antennas: 30cm**

The detection of the same rebars in the previous case is performed but with a distance between the antennas of 30 cm. On the obtained radargram, we notice the presence of hyperboles indicating the detection of objects, in addition to the direct wave which appears in this case to a depth more than that of the previous case (more than 0.3m) as shown in the figure 6 a. we can note also that in this case this wave hide a part of hyperboles.



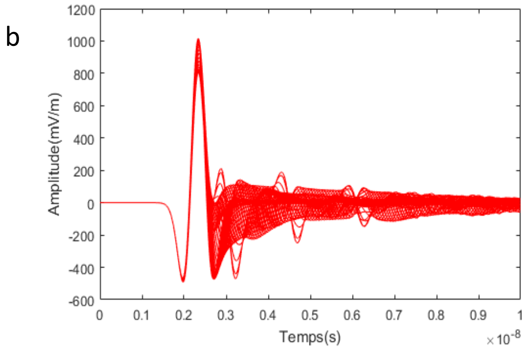


Fig.6. (a) Radargram of detection of rebars for distance between antennas of 30cm (b) evolution of the GPR wave over time.

- **Distance between antennas: 40cm**

In this case, we have simulated the detection of the rebars where the distance between transmitter and receiver is 40 cm. The resulting radargram and radar wave evolution over time are shown in Figure 7. on the radargram we note that the wave is in this case at a greater depth than that of the preceding case which leads to the concealment of a larger part of the hyperbolas.

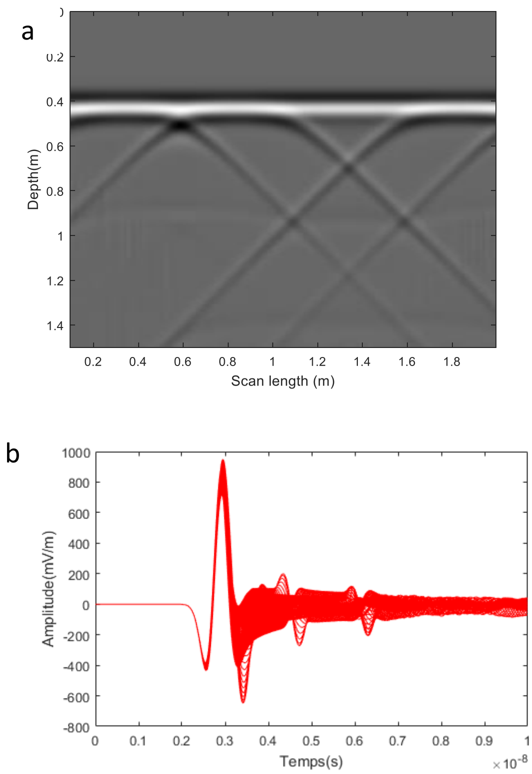


Fig.7. (a) Radargram of detection of rebars for distance between antennas of 40cm (b) evolution of the GPR wave over time.

4. Conclusion

In this work we simulated the influence of two types of noise on the quality of GPR data. The results obtained showed that the effect of this noise differs, depending on its nature it was found that the noise of the Gaussian type causes a complete coverage of the GPR images, while the direct coupling between the antennas causes the appearance of a direct wave on the radargrams in the form of horizontal lines, the depth of these lines varies depending on the distance between the antennas or for certain values of the distances (30cm and 40cm) these lines hide parts of the hyperbolas that indicate the presence of objects.

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