Landmine Localization Using the Electromagnetic Time Reversal-MUSIC Method

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Abstract

We present an electromagnetic Time Reversal MUltiple SIgnal Classification (TR-MUSIC) method to localize landmines. The performance of TR-MUSIC is investigated using numerical simulations of a two-dimensional configuration considering the effect of noise. The performance of the TR-MUSIC is also evaluated experimentally in free-space.

1 Introduction

Around 110 million mines contaminate over 20 million square miles in more than 64 countries, according to the United Nations [1]. Although a large spectrum of methods has been investigated to detect landmines, only enhanced metal detectors and ground penetrating radars have been used in the field. The performance of these methods is still far from the desired levels due to the complexity of the environmental and field conditions. Here, the Time Reversal MUltiple SIgnal Classification (TR-MUSIC) method is applied to localize landmines [2], [3]. The performance of TR-MUSIC is evaluated both numerically and experimentally.

2 TR-MUSIC Theory

There are three steps to implement TR-MUSIC. a) The transfer matrix $H(\omega)$ is obtained at a single frequency or multiple frequencies [2], [3]; b) The singular value decomposition (SVD) of the transfer matrix is evaluated $H(\omega) = U(\omega)S(\omega)V^H(\omega)$. In the TR-MUSIC the null-space is needed; c) The TR-MUSIC pseudospectrum criterion

$$P_{TR-MUSIC} = 1/a^H E_N E_N^H a. \tag{1}$$

is used to locate the targets. In (1), *a* and E_N are steering vector and noise eigenvectors [4], respectively. The superscript *H* denotes the conjugate transpose operation.

3 Numerical Simulations

A 5-mm radius circular metallic landmine is buried in a horizontally stratified soil (see Figure 1). Five identical antennas are used as transmitters. The horizontal distance between adjacent antennas is $\lambda/2$ and their height above the ground is $\lambda/4$, where λ is the wavelength. The depth of the first ground layer is $\lambda/2$. The depth of the landmine is $\lambda/4$. The relative dielectric constants of the first and second soil layers are 4 and 10, respectively.

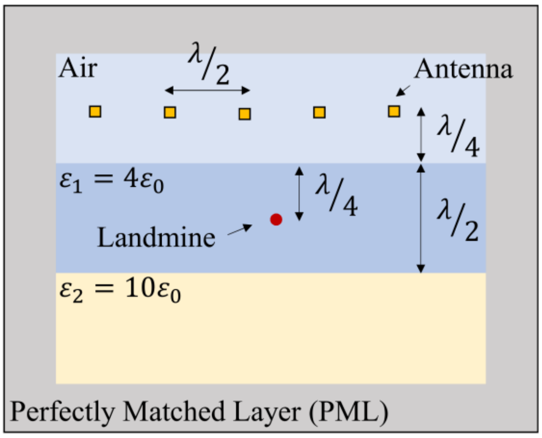

Figure 1: The considered geometry.

The TR-MUSIC method was implemented using COMSOL. The frequency of the sources was set to 300 MHz. Figure 2 shows the TR-MUSIC pseudo-spectrum in presence of noise (signal-to-noise ratio (SNR) = 10 dB). In this figure, the red circle and the black cross show the actual and estimated location of the target, respectively.

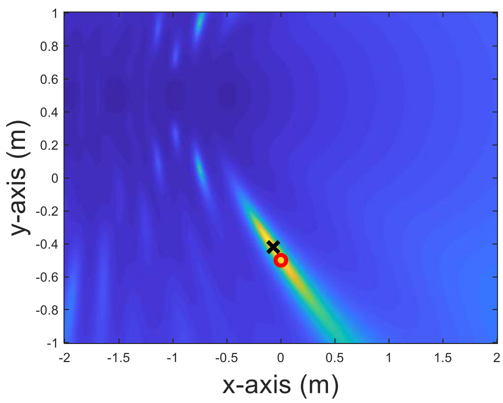

Figure 2: 2D view of the TR-MUSIC pseudospectrum for the geometry of the problem shown in Fig. 1 in presence of noise (SNR = 10 dB). *f* = 300 MHz.

The 2D localization error (distance between the actual and estimated target location) is shown in Table 1 for different SNRs. It can be seen that for values of SNR greater than 20 dB, TR-MUSIC can estimate the object location with an error of less than 4 cm.

SNR (dB)	***2D Localization error obtained in the single frequency TR-MUSIC (cm)***
10	10.6
20	3.6
30	2.2

Table 1: 2D Localization error obtained in the single frequency TR-MUSIC versus the SNR value.

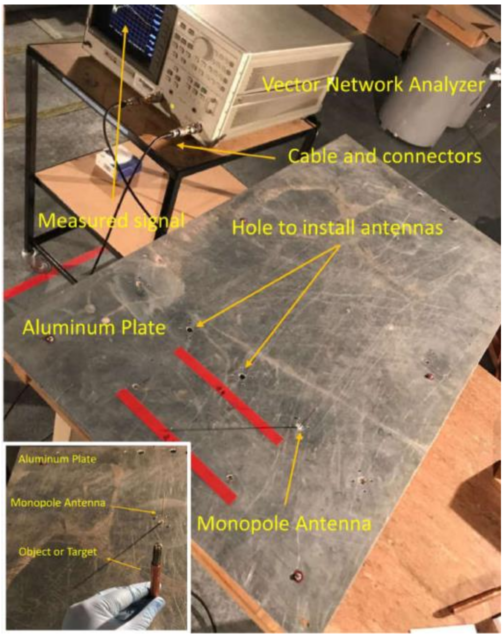

Figure 3: Experimental test setup.

3 Experimental Validation in Free-Space

A preliminary experimental validation of the TR-MUSIC method was performed in free-space using an aluminium plate above a wooden table in the EMC laboratory of the EPFL (see Figure 3). The dimensions of the aluminium plate are 90 cm x 50 cm. Its thickness is about 3 mm. Identical monopole antennas are used with length 5.26 cm and radius 1 mm. Each antenna is soldered to the core of an N-type connector and placed on the aluminium plate. The experimental setup with one monopole antenna is shown in Figure ٣. The object to be located in this case study is a copper cylinder of length 13.5 cm and diameter 9 mm shown in the inset of Figure 3. The geometry of the problem modelled in the CST-MWS software can be seen in Figure 4. The monopole antennas are separated by a distance of 10 cm. After applying the TR-MUSIC, the pseudospectrum is shown in Figure 5. In Figure 5, the position of the three monopole antennas (used to probe the medium), the actual location of the object, and the maximum electric-field are identified by red-circles, a blue star, and a black cross, respectively. The estimated target location estimated by the TR-MUSIC method can be seen by the yellow color in the figure. The localization error, defined as the distance between the actual and estimated location of the object, is about 10 cm.

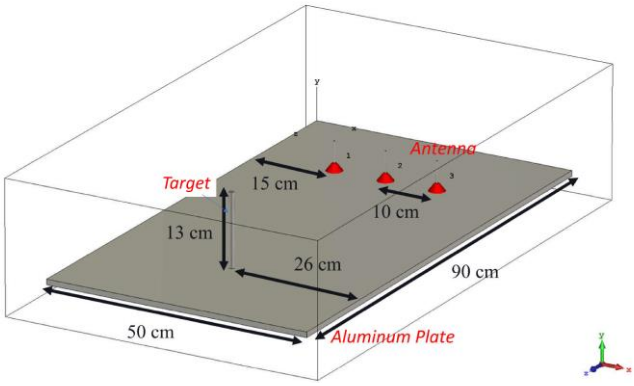

Figure 4: CST-MWS model of the experimental setup.

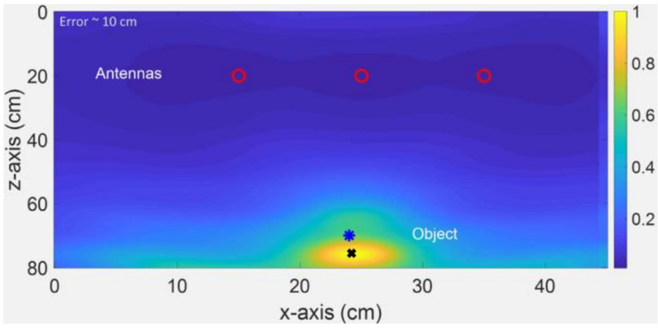

Figure 5: 2D view of the TR-MUSIC pseudospectrum.

4 Conclusion

The TR-MUSIC method was applied to localize landmines. The presented results show acceptable accuracy considering also the effect of the noise. A preliminary experimental validation of the method in free space was also presented.

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