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A Prony Technique for Prediction of Ground Multipath Parameters in LOS Radio Links Using Field-height Data

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1. Introduction:

Multipath propagation is a major cause of impairment in LOS link performance. With the advent of high capacity digital radio and development of high level modulation schemes both a high bit rate and wide bandwidth are required to accommodate the transmitted signal**.** Such requirements are highly affected by the frequency selective fading, which is a typical characteristic of multipath propagation. Therefore it is desirable to identify multipath components like, number of rays, their relative amplitude and delay with respect to the direct ray, and their angle of arrival, so that counter measures can be taken.

The estimation of multipath parameters has received much attention in the last three decades. The received field variations with height, range, time and frequency have been used in the estimation [1-5]. Holographic approaches have been utilized where the received field variation with height is Fourier transformed to produce field distribution at the transmitting end [6-9]. The Prony algorithm had also been applied in the estimation process where the variation of received signal with frequency was utilized [4, 10]. The Prony technique showed ability for time delay estimation that is better than half the Fourier limit [4]. The Prony algorithm is utilized here for the estimation of multipath ray parameters from record of received field variation with height. The performance of the technique is studied and compared with that of using the Fourier transform.

2. Principle of the proposed technique:

Figure 1 shows the geometry of propagation where a flat earth model is assumed for which the separation between transmitter and receiver is not too large. When h_1, h_2, << Z then a number of approximations can be performed so that the field at the receiving antenna can be given by:-

$$E = \frac{E_o}{Z}\left[\exp -j\beta(Z + (h_2 - h_1)^2/2Z)+\Gamma \exp(j\psi) \exp(-j\beta(Z+(h_2+h_1)^2/2Z)\right] \quad [1]$$

Where E_o is constant, β is the phase constant and $\Gamma\, e^{j\psi}$ is the reflection coefficient at point of reflection.

Now if the received field is recorded at the receiving end and sampled by N samples along the vertical range $h_2 = h_o + k\sigma$, ($k=1 \rightarrow N$), then Eq.1 can be rearranged in the form:-

$$E_K \exp(j\beta(Z+(h_o+k\sigma)^2/2Z)) = \frac{E_o}{Z}\Big[(\exp(-j\beta(h_1^2 - 2h_1h_o)/2Z) \exp(j\beta h_1 k\sigma/Z)$$
$$+ \Gamma \exp(-j(\psi+\beta(h_1^2-2h_1h_o)/2Z)) \exp(-j\beta h_1 k\sigma/Z)\Big] \quad [2]$$

The equation of Prony for order 2 can have the form as:-

$$X_k = \sum_{i=1}^{2} C_i\, \mu_i^k \quad [3]$$

Comparison between Eqs. 2 & 3 shows that:-

$$C_1 = \frac{E_o}{Z}\, (\exp(-j\beta(h_1^2 - h_1h_o)/2Z) \quad [4.a]$$

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$$C_2 = \frac{\Gamma E_o}{Z} \exp(-j(\psi+\beta(h_1^2+h_1h_o)/2Z)) \quad [4.b]$$

$$\mu_1 = \mu_2^* = \exp(j\beta h_1\sigma/Z) \quad [4.c]$$

$$x_k = E_k \exp(j\beta(Z+(h_o+k\sigma)^2 / 2Z)) \quad [4.d]$$

If N samples of received signal with height are recorded at σ sampling interval then the data samples are multiplied by the factor $\exp(j\beta(Z+(h_o+k\sigma) / 2Z))$; the result is equivalent to the left side of Eq.2. The Prony algorithm is then applied by comparing right sides of Eq.2 and Eq.3 and using Eqs.4. The transmitter height and ground reflection coefficient can be predicted, and found to be:-

$$h_1 = |Z \ln(\mu_1)/\beta\sigma| = |Z \ln(\mu_2)/\beta\sigma| \quad [5]$$

$$\Gamma = |C_2| / |C_1| \quad [6]$$

After determining transmitter height, the relative time delay between direct and reflected rays and the angle-of-arrival (AOA) of each ray can then be calculated.

In the Fourier transform method the field samples are recorded along the vertical direction at receiving end (Eq.1). The recorded samples are then multiplied by the factor $\exp(j\beta(Z+(h_o+k\sigma)^2/2Z))$ and Fourier transformed using the FFT algorithm. The obtained result will show two SINC functions representing direct and reflected rays. Form the positions of the SINC functions the transmitter height is estimated. The relative magnitude of the SINC representing the reflected ray will give the value of the reflection coefficient.

3. Results of computer simulations

To verify the theoretical analysis of previous section computer simulations were performed. The simulated system considered the following parameters as one of the examples:

Range (Z) = 7.5 km, Frequency (f) = 11 GHz, Ground reflection coefficient $|\Gamma|$=0.5
Transmitter height (h_1) = 24 m, Minimum receiver height (h_o) = 20 m

The number of data samples calculated at receiving end was N = 30. Figure 2 shows an example of images reconstructed by Fourier and Prony techniques. It is obvious that the image reconstructed by Prony technique has two delta functions, one due to direct ray and other due to reflected ray. However, the image reconstructed by Fourier technique shows two SINC functions instead of the delta functions. The transmitter antenna height estimated from the image obtained by the Fourier technique will not be as accurate as that obtained by the Prony technique due to the interference with the sidelobes of the other SINC function. The estimated parameters are shown in Table 1, which shows that better performance is obtained from the Prony technique.

The performance of Prony and Fourier techniques was examined under noisy conditions. Received field data where generated and a zero mean Gausian white noise was added to the data to simulate real recording conditions. A signal to noise ratio of SNR = 20dB was assumed. Images were obtained from the recorded data for various window lengths representing various recording lengths. The order of the Prony technique used was 10 so that better estimation can be obtained under noisy conditions [11]. From the obtained images the reflection coefficient and transmitting antenna height where estimated and the results where compared to the actual assumed ones. Figure 3 shows the percentage error in prediction of ground reflection coefficient and transmitter height encountered in both Prony and Fourier techniques. The errors decrease as the record length is higher. However the Prony technique performance is much better than the Fourier technique especially at smaller record lengths. The Fourier method failed to produce reasonable results for record lengths smaller than 4 m. The Prony technique has much better resolution. Such result has been noticed for this technique in the estimation of time delay from frequency swept data [4].

4. Conclusions

The application of the Prony technique to the problem of reconstructing field distribution at transmitting end from field variation with height at sending end has been demonstrated. The proposed technique has performance that is superior to Fourier technique and it needs shorter data record.

5. References

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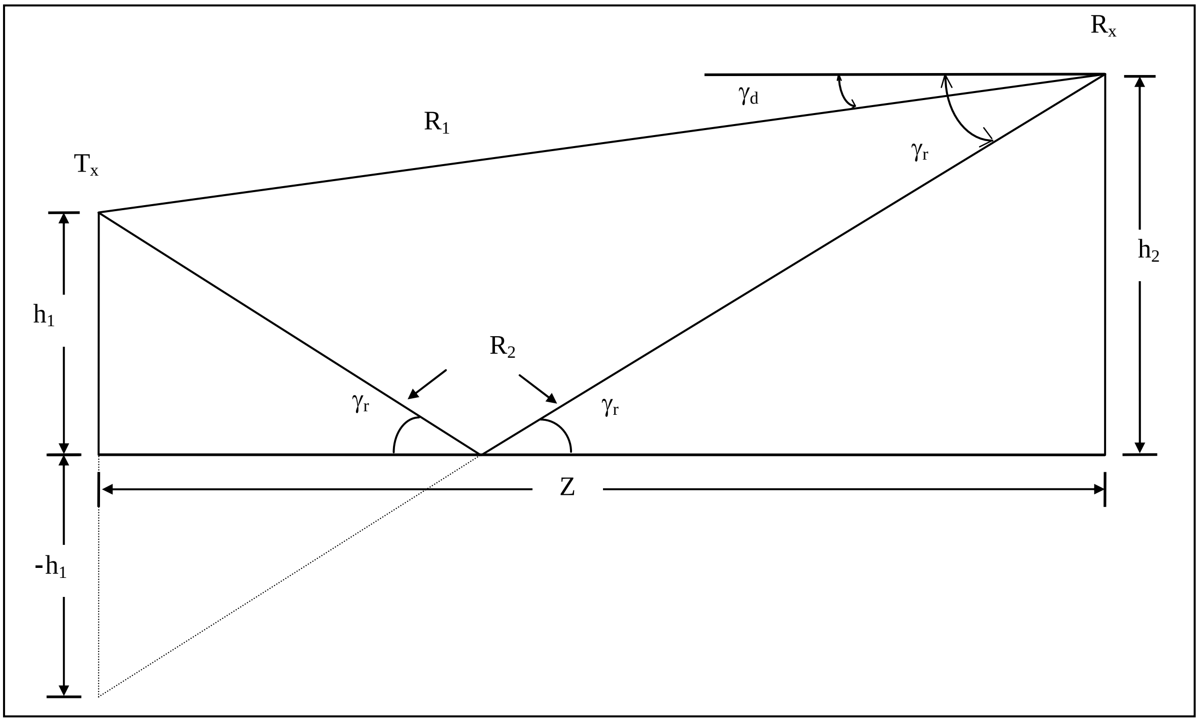

Figure 1 Geometry of multipath propagation over flat earth

Table 1 Estimated values of antenna height and ground reflection coefficient obtained from Fourier and Prony techniques

Parameter	Actual value	Estimated by Fourier	% Error	Estimated by Prony	% Error
Antenna height	24	21.5	-10.4	23.9	-0.4
Reflection coefficient	0.5	0.452	-9.6	0.485	-3

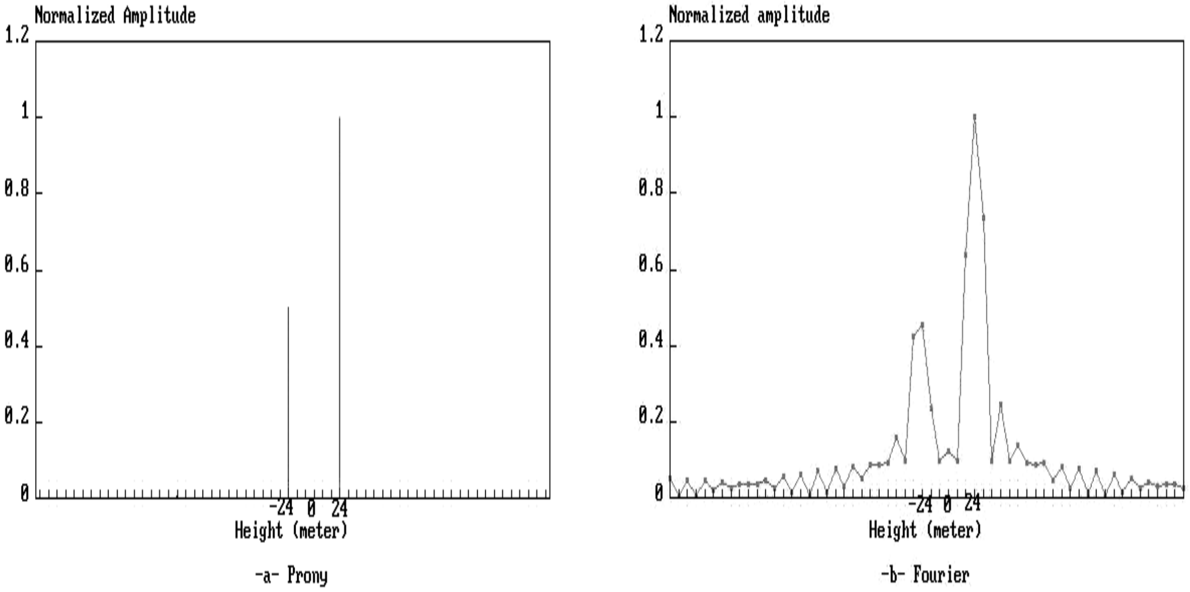

Figure 2 Reconstructed images of field distribution at transmitter side using (a) Prony and (b) Fourier techniques.

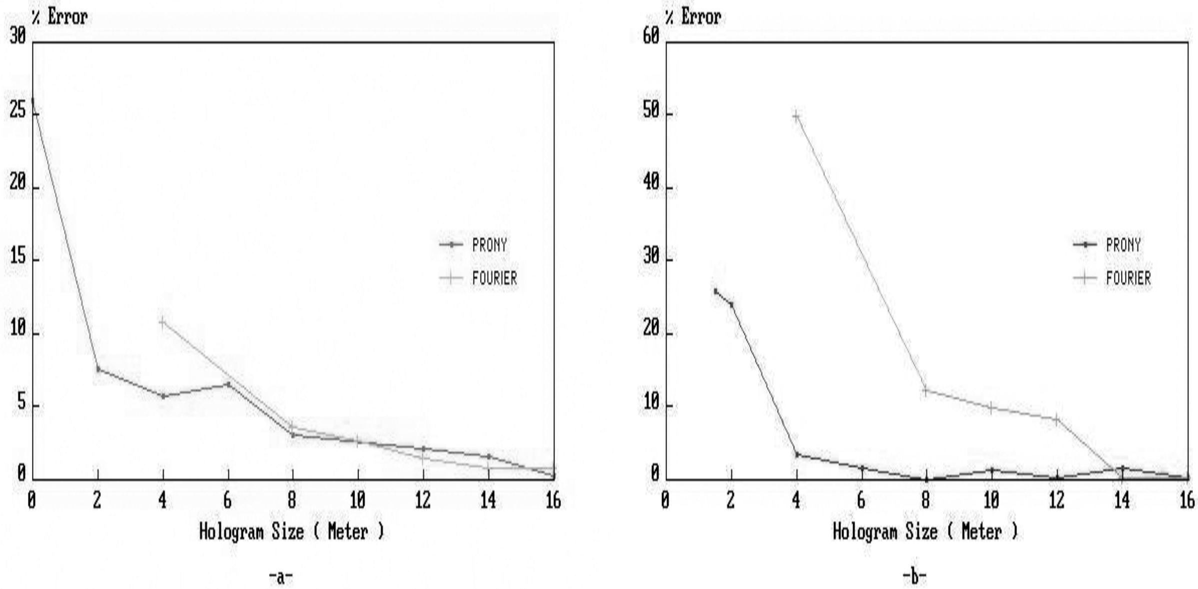

Figure 3 Percentage error in the estimated parameters from Prony and Fourier techniques as a function of record size (hologram):-
(a) Reflection coefficient, (b) Transmitter antenna height.