A Compact 3D-microwave holographic pointer system using a size reduced microstrip planar array

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Abstract

A compact system for a three dimensional (3D) pointer (mouse) is possible by combining microwave holography with microstrip antenna arrays to enter 3D coordinates of a point in space into computer memory. To reach the practical reduced size system, new solutions are proposed in both, the receiving planar array antenna for constructing the point hologram image and the holographic algorithms for reconstructing the microwave hologram.

Key words

Microwave holography, 3D pointer (mouse), planar microstrip array antenna, antenna size reduction, slit insertion.

1 Introduction

More than forty years have passed since the first microwave hologram was done at Bell laboratories in 1950. Microwave hologram proves that it has several advantages over the optical one that was invented by Gabor 1948[1].

We utilize this idea to design an interactive system for a 3D pointer. Using this new pointer, the operator can create and draw, point by point or in a multipoint basis, any 3D object that exists physically or even virtually and save it in computer memory. Afterwards this can be used in information reduction, scaling, interpolation, image compression, and 3D data acquisition, generating a body fitted grid system for computer simulation, data animation or pattern recognition of objects in 3D space. We can imagine applying this 3D image processing in many fields of applications such as computer-aided design in medicine and robotics where true spatial information renders important assistance.

For practical purposes an investigation volume of 1m x 1m x 1m is defined, and the different electrical and geometrical system parameters are considered. As a working frequency, we propose S-band or C-band operation as a good compromise between positioning accuracy and antenna array number of elements. Using a conventional planar imaging system with FFT technique, a holographic plate surface of about 2m x 2m had to be considered, making the system size unsuitable practically for many applications [2]. Instead, using the reduced system proposed here, a planar antenna of 0.5m x 0.5m could be used while keeping the system location capabilities of about \(\lambda_0/12\) in accuracy unchanged.

To check the different parameters of the system, a prototype of microstrip planar array with a limited number of elements (2x2) has been fabricated and measured. The prototype has been tested at different frequencies with a reduced holographic plate size of (10cmx10cm) and its positioning capabilities have been investigated in the reconstruction volume of 20cm x 20cm x 20cm. In this paper, we illustrate the results at S-band (2.23GHz). The reconstruction here is done by correlation technique, which is free from \(\lambda_0/2\) hologram’s grid size criterion that exists in conventional FFT technique [2]. Excellent results are reached. Needless to say that the extension of our system represented here has no limitations neither in array surface nor in reconstruction volume.

2 New correlation algorithm for hologram reconstruction

The digital hologram data is retrieved by a new computer simulation model [3] called correlation technique, which is based on the following equation:

\[ \text{correlation} = \text{digital hologram} \times \text{complex conjugate hologram} \]
\[
\phi_i = \sum_{\alpha} \phi_{i\alpha} = \sum_{\alpha} I_{\alpha} \frac{\cos(kR_{i\alpha})}{R_{i\alpha}} \quad (1)
\]

Where \( \phi_i \) is the retrieved image, \( I_{\alpha} \) is the intensity of a grid point on hologram plane and \( R_{i\alpha} \) is the distance between hologram plane’s grid point \( \alpha \) and reconstruction point \( i \). The procedure in equation (1) merely inspects whether the point \( i \) is a part of the original object or not. This is accomplished by using the correlation between the hologram intensity and the factor: \( (P_{\alpha} = \cos(kR_{i\alpha})/R_{i\alpha}) \) which represents the hologram of point source. If the hologram \( I_{\alpha} \) coincides with the pattern \( P_{\alpha} \) generated by the point source at \( i \), the correlation \( \phi_i \) becomes large and hence the point \( i \) has a large probability to be included in the original object. On the contrary, if \( I_{\alpha} \) doesn’t coincide with \( P_{\alpha} \) then \( \phi_i \) becomes very small and hence the point \( i \) is not included in the original object. With changing \( i \) over the 3D space and drawing the structure of \( \phi_i \), it should coincide with the original object pattern. This method doesn’t suffer from the FFT limitations so the hologram sampling grid separation can be less than \( \lambda/2 \) and the number of points doesn’t need to be in the form of \( 2^n \).

3 3D pointer system

The proposed 3D pointer system is illustrated in Fig. 1 [4]. The pointer unit itself works as a hand agent that contains a passive reflecting dipole antenna with a modulating diode at low frequency in range of KHz. This unit is attached to the operator’s hand to locate its movements. The illuminator (transmitter dipole antenna) is fixed in a certain corner within the reconstruction volume. When the user clicks on the hand agent at the required position in space, the switch is closed allowing modulating the illumination signal at the diode marked point at low frequency level. Modulating the diode results in modulating the scattered field which is proportional to the local field at the corresponding pointer location. The pointer’s plate contains the receiver (microstrip antenna array) that measures the modulated object scattered signal (which carries the amplitude and phase information of the point position). The object signal interferes with the reference signal in the panel unit to form the interference pattern (hologram). The hologram data is de-modulated and digitized in the same unit. Digital data is interfaced to computer and retrieved in it through a hologram reconstruction driver (it can be software or hardware [4]) that is called a 3D pointer card. Finally the retrieved point is drawn on the screen, if needed, with any graphics software. Note that the diode modulation step can be replaced by directly connecting the transmitting dipole antenna to the operator’s hand mouse unit, which will be connected to the generator through RF cable with the cost of movable RF connection. In this case, the microstrip antenna receives directly the mouse radiated signal. The selection between the two models depends on the application. Needless to say that our pointer system can work in a single point basis as discussed or in a multi point basis where each point has a modulating diode with different frequency level. This can be utilized in detecting an object movement or in defining different selected properties since each modulating diode can refer to certain property like color, material type, etc.

It is worth here to mention that if we add two illuminating dipoles, one with linear vertical polarization and the other with linear horizontal polarization in the required reconstruction volume, we can detect from the receiving signal not only the point position but also its orientation in space. This could be done if different polarization directions are used for the adjacent elements of the microstrip array antenna. The 3D pointer (mouse) system is illustrated in Fig. 1.
4 Size Reduced Planar Microstrip antenna with slit insertion procedure

We reduce the individual antenna element surface by cutting a slit at an adequate position of the patch surface with adequate length and width. We select an inverted H shape slit because it can effectively minimize the size of the microstrip antenna from a half wavelength to a quarter wavelength, without any overlap with the feed aperture or feed line [5]. The slit decreases the resonant frequency because the current has to flow around the slit so the electrical equivalent length of the current path gets longer. The drawback of adding slits is the decrease in the impedance bandwidth which becomes less than 1%. This is not suitable for practical applications. Stacking technique with short circuit pins (vias) is used to improve the bandwidth up to 3%, which is accepted from most array applications point of view as in our case of hologram recording. Fig. 2 shows the antenna element’s layout and the return loss response for the original rectangular patch, patch with slits and with adding stacking layer and vias to improve the bandwidth.

Fig.2. a) Antenna layout for original rectangular patch with aperture coupled feed, with H shape slit

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and with slit and shorting pins b) return loss value for single patch in the three cases of (a).

The antenna physical surface size is reduced by ratio of 75% from the original rectangular patch as shown in figure 2(a). The main problem of adding the slits with its inductance effect is the difficulty to match with feed. To solve this problem, short tuning stub of appropriate length and width is connected to patch as illustrated in fig. 2(a)[5]. The stub position is on the patch edge with offset from patch center of half feed line width. This perturbed cavity or short tuning stub is used in conjunction with the proximity coupling to oppose the slit effect and provide enhanced element matching. This element is included in a 2x2 array. The array is fabricated and measured. Fig. 3 illustrates the comparison between the simulation and experimental results with inter-element distance (center to center) $\lambda_0/3$.

![Simulation vs Experimental Results](image)

Fig. 3. Comparison between simulation and Experimental results of 2x2 reduced size antenna array at (2.23GHz) S-band.

5 Virtual image reconstruction results

To validate the 3D pointer system capabilities, the hologram is generated at different points within the operator’s hand reconstruction volume. Fig. 4 shows two of these results. We use here software filter to clarify the point position. As discussed before, the holographic system in figure 2 can be used for simultaneously identifying multiple points, colors or materials using different modulating frequency for every selected feature. Figure 5 is a simulation example for two points reconstruction with hologram size of 1mx1m and points positions at (50cm, 50cm, 9cm) and (70cm, 70cm, 9cm) respectively. The resolution (minimum object point separation) is found empirically to be about $\lambda_0$ while the accuracy is related to the number of the array antenna elements.

![Virtual Image Reconstruction](image)

(a)

(b)

Fig 4. Retrieved image of one point holography at frequency of 2.23GHz with hologram size of (10x10) and grid sampling $\lambda_0/3$ with the point position at a) (4,4,12) and b) (9,9,9), 9cm).
Fig.5: Reconstructed image of two points hologram at 2.23GHz with point’s positions at (50cm, 50cm, 9cm), (70cm, 70cm, 9cm) and with hologram size 1mx1m.

6 Conclusion

A special method for investigating 3D mouse or 3D pointer was described. By this method, the hologram is easily established for any point within the designed reconstruction volume at low cost. Reducing the receiving antenna surface does an improvement in the hologram plate size. The image is retrieved by correlation algorithm. Using the reduced size antenna with the correlation technique, the system size can be reduced by about 75% of its original size using original rectangular patch antenna with conventional FFT reconstruction technique. Retrieved images of a point hologram at different 3D positions verify the idea.

References


