Microstrip Multi-element diversity antenna array for three dimensional microwave holographic input pointer (Holo3D)

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ABSTRACT
We have developed a novel wireless microwave communication input system that allows users to intuitively specify three-dimensional (3D) coordinates in graphics applications. The system depends on combining the microwave holography technique with an appropriate microstrip antenna array system to create the hologram of any desired point in 3D space. A new established software driver called Correlation executes the retrieval of the 3D point coordinates. The new holographic mouse (Holo3D) has reached a high accuracy of about 1 mm (λ/57) using the 5.2GHz (802.11b WLAN operating frequency standard).

1-INTRODUCTION
Wireless PC communication devices now come with high performance 3D graphics hardware and rendering systems capable of offering truly 3D interactive applications. Virtual Reality (VR) applications are already recognized for their value in specialized domains. However, it is convenient to have VR applications that run on the desktop, so a wide number of users can acknowledge. As the need for electronic security and surveillance increases, there is growing use of remote (non-contact) occupancy and motion detection. Current sensing technologies include mechanical, electric field, optical, inertial, acoustic, and electromagnetic[1].

Working toward this target, we have demonstrated the concept of microwave holograms to design a dynamic system for a wireless electromagnetic 3D input pointer [2]. We have named it Holo3D mouse to acknowledge its original inspiration. Using this new pointer (mouse), the operator can create and draw, point by point or in a multipoint basis, any 3D graph or object that exists physically or even virtually and save it in computer memory. Afterwards this data can be used in image compression, 3D data acquisition, generating a body fitted grid system for computer simulation, data animation or pattern recognition of objects in 3D space. We can invasion applying this 3D image processing in many fields with applications such as computer-aided design in medicine and robotics where true spatial information renders important assistance.

The simulation for the Holo3D system has been developed and the reduced size array of microstrip antenna has been fabricated with 15 mm inter-distance between U-shape slot antennas with multi-layer proximity coupling feed to allow the required accuracy. Needless to say that the extension of our system presented here has no limitations neither in array surface nor in reconstruction volume nor in operating frequency.

2. HOLO3D SYSTEM ALGORITHM
In our previous work [2], we chose the accuracy to be 1 cm. In order to demonstrate more practical applications for our 3D mouse, the accuracy is improved to 1mm in this work and the dimension of the working volume is a cube 60mm x 60mm x 60mm. By inputting these requirements to our established correlation simulation code, we found that the optimum parameters for this system are: wavelength to be 57mm, the distance between hologram points (antenna elements) to be 15mm or less and hologram shape to be square. Figure (1) shows the diagrammatic representation of the apparatus used in the Holo3D mouse system. The three components of Holo3D discussed in this paper are the reflector, illuminator and receiver.

1- The mouse unit itself works as a hand agent that contains a short passive reflecting dipole antenna with a modulating diode at (1kHz) and its power supply feed. This unit is attached to the operator’s hand to locate its movements. The illuminator (transmitter 3D dipole antenna or by other words three dipoles orthogonal to each other transmitting a total power ($P_t$)) is fixed in a certain corner within the reconstruction volume (for example, attached to the monitor). The transmitter is set as 3D dipole to make the received signal -less dependent on the actual mouse orientation or the receiver microstrip antenna polarization direction.
2-The transmitter illuminates the whole volume under investigation. When the user clicks on the hand agent at the desired position in space, the switch is closed allowing the modulation of the illumination signal at the diode marked point at low frequency level. The modulated scattered field is proportional to the local field at the corresponding mouse location.

3-The mouse's pad plate contains the receiver (microstrip antenna array) that receives and stores the MxM points corresponding to the modulated scattering signal at each position of the array. In order to construct the two-dimensional hologram, the complex signal (amplitude and phase) at each receiving element has to be detected and recorded. A complete hologram measurement is performed by sequentially addressing every microstrip antenna of the array using a 1 to (MxM) RF multiplexer formed by a binary tree of diode switches.

4-The object scattered signal is demodulated and then is allowed to interfere with the reference signal (same transmitting signal frequency and phase) to form the interference pattern (hologram).

5-The hologram data is digitized through analog to digital converter. Digital data is then interfaced to computer and retrieved in it through a hologram reconstruction driver (it can be software or hardware for real time operation [3]). Finally, the retrieved point is drawn on the screen, if needed, with any graphics software.

3. MICROSTRIP MULTI-ELEMENT DIVERSITY ARRAY FOR HOLO3D

In the holographic 3D pointer system, diversity reception is one of the significant and effective techniques to increase the system accuracy in positioning since we need to sample the data as accurately as possible without any neighboring interference effects. The array antenna elements can act independently if the mutual scattering coefficients are less than (-15dB) between elements [4]. A Microstrip antenna array is the best candidate that satisfies hologram recording process requirements because of its light weight, small size, low cost, high gain and directive beam that are suited to mono-frequency applications. Its planar or conformal configuration let it has strong capabilities to cover any experimental required area.

Several analyses for different elements and 2x2 sub-arrays have been done. Table (1) is the summery of the results. The antenna elements and arrays are analyzed by the finite element method (HFSS software package) and fabricated with a photolithographic technique. Scattering parameters have been measured using a network analyzer (HP8510c). From the table, the optimum structure that fulfills the hologram generation requirements is the U-slot element with O-plane orientation. The O-plane coupling technique is to feed each adjacent element in the array orthogonally. This reduces the mutual coupling significantly as compared to the parallel H-plane or E-plane feed. The array element is designed to work at the second resonant mode for obtaining broader impedance bandwidth [4]. The strip conductor is connected through the dielectric substrate to the edge of the slot while the matched 50Ω microstrip line is center fed to excite the 2nd resonance and etched on the other side of the dielectric as a proximity coupling feed. The bandwidth of the antenna (12% centered at 5.2GHz) is broader enough to compensate for any manufacturing tolerances. A 16-element array is fabricated with inter-element spacing as in table 1. The array is used as the hologram receiver plate for a reconstruction volume of 60mm x 60mm x 60mm in x, y and z directions respectively.

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4. RESULTS

To verify our idea, the Holo3D system is simulated at different points within the operator's hand reconstruction volume. Figure (3) shows, as examples, the 3D representation of the retrieved image of points at positions (15mm, 15mm, 30mm) and (45mm,45mm,10mm) respectively. From the figure, it is seen that we can identify 3D coordinates of a point within the object reconstruction volume with absolutely no error. We have used a software filter to clarify the point position accurately.

References

Fig. 1: Holo3D mouse system.

Fig. 2: Experimental measurements of the 4x4 O-plane U-shape slot antenna array at 5.2 GHz, dielectric constant $\varepsilon_r = 2.2$, dielectric thickness $h=62$ mil, element size=12 mm x 6.9 mm, feed line width=4.2 mm and inter-element distance (center-to-center)=15 mm ($0.26 \lambda_0$) in x and y directions.

Fig. 3: Retrieved image of one point with hologram size of (60 mm x 60 mm) and grid sampling $\lambda_0/4$ with point position at (15 mm, 15 mm, 30 mm) for left figure and (45 mm, 45 mm, 10 mm) for right figure.
Table (1): Comparison between different required characteristics for different holographic plate antenna single element unit.

<table>
<thead>
<tr>
<th>Element</th>
<th>Shape</th>
<th>Design technique</th>
<th>Bandwidth</th>
<th>Element size</th>
<th>Inter-element in 2x2 sub-array</th>
<th>Mutual coupling</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference rectangular patch</td>
<td><img src="image1" alt="Reference rectangular patch" /></td>
<td>Aperture proximity coupling feed</td>
<td>1.5%</td>
<td>0.28λ x 0.29λ</td>
<td>λ/2 in x λ/2 in y</td>
<td>H=-33dB</td>
<td>Not practical size</td>
</tr>
<tr>
<td>Reduced size rectangular patch</td>
<td><img src="image2" alt="Reduced size rectangular patch" /></td>
<td>Inverted H slit for size reduction</td>
<td>0.55%</td>
<td>0.15λ x 0.18λ (75% reduction)</td>
<td>λ/5 in x 0.4λ in y</td>
<td>H=-21dB</td>
<td>Reduced BW</td>
</tr>
<tr>
<td>Stacked reduced size patch</td>
<td><img src="image3" alt="Stacked reduced size patch" /></td>
<td>Additional Stacking patch with vias between 2 patches for BW enhancement</td>
<td>1.7%</td>
<td>0.24λ x 0.1λ</td>
<td>λ/4 in x 0.4λ in y</td>
<td></td>
<td>Difficult Fabrication</td>
</tr>
<tr>
<td>Coplanar Waveguide antenna</td>
<td><img src="image4" alt="Coplanar Waveguide antenna" /></td>
<td>Cpw line feed</td>
<td>3%</td>
<td>0.24λ x 0.16λ</td>
<td>λ/5 in x 0.4λ in y</td>
<td>H=-16dB</td>
<td>Large mutual coupling in array case</td>
</tr>
<tr>
<td>U-shape slot antenna</td>
<td><img src="image5" alt="U-shape slot antenna" /></td>
<td>microstrip line feed through multiplayer proximity coupling</td>
<td>12%</td>
<td>(0.2λ x 0.12λ)</td>
<td>0.24λ in x 0.24λ in y</td>
<td>E=-14dB</td>
<td>Bi-directional radiation (solved by using λ/4 reflector plate under the slot)</td>
</tr>
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