MILLIMETER-WAVE IMAGING USING NEURAL NETWORKS FOR OBJECT RECOGNITION

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ABSTRACT

An active-mode mm-wave (60 GHz) imaging system with Yagi antenna has been developed. The optics for the system was designed with the ray tracing method to reduce aberration. A signal processing using a neural network has been successfully introduced to recognize objects distorted with coherent mm-wave illumination. With 10 x 10 sampling points the recognition rate of 98 % has been obtained for the objects of 10 alphabetical letters and the 5 teaching trials.

INTRODUCTION

Imaging in the millimeter-wave region has up to now been made by scanning the optics mechanically using a single detector. Conversely this, by using a imaging array real time imaging is possible. The imaging system is applicable in the fields of plasma measurement, remote sensing, collision avoidance car radars, etc [1], [2].

We have developed a 60 GHz mm-wave active imaging radar with a one-dimensional (1-D) sensor array. We used the ray tracing method to design the mm-wave optics for the system. A neural network signal processing has been successfully introduced to recognize the objects which were distorted by speckle and/or glint through coherent illumination.

MM-WAVE IMAGING SYSTEM

Fig. 1 shows our experimental arrangements for the mm wave imaging. Coherent mm-waves at 60 GHz, amplitude-modulated for phase-locking detection, is illuminated on an object by a horn antenna. The objects used in our experiments were 26 alphabetical letters (A - Z) made of aluminum foil. Irregular forms in the order of $\lambda/4$ were made on the surface of the objects to reduce specular reflection. The scattered mm waves from the object is focussed through dielectric lenses to construct an image on a plane. The optics consists of an objective lens (TPX, ε_r=2.13, 98mm diameter) and a hemispherical substrate lens (100mm diameter). The distance between the object and the objective lens is 45cm for our bench-top experiment. The image plane is the backside of the substrate lens and on the plane there is an imaging array which consists of a 1-D 10 sensors on a thin di-

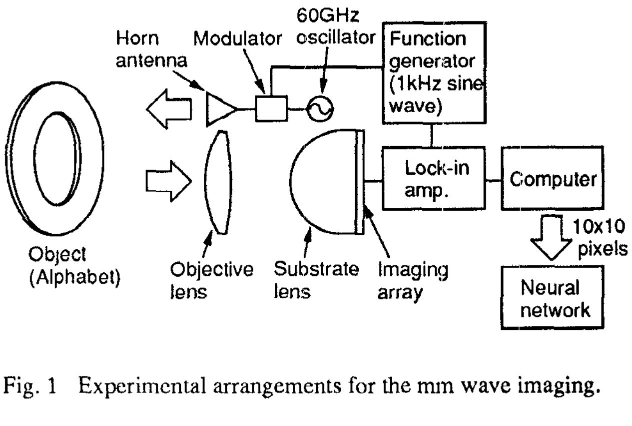

Fig. 1 Experimental arrangements for the mm wave imaging.

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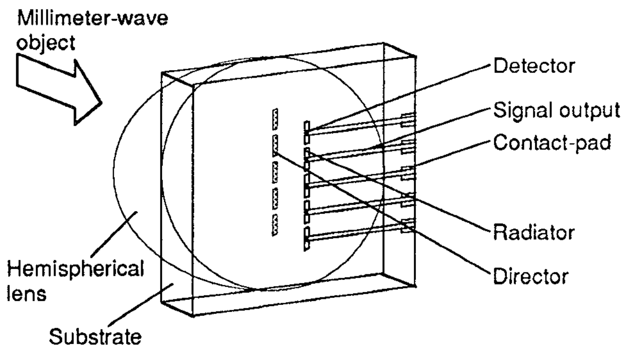

Fig. 2 Yagi-antenna imaging array.

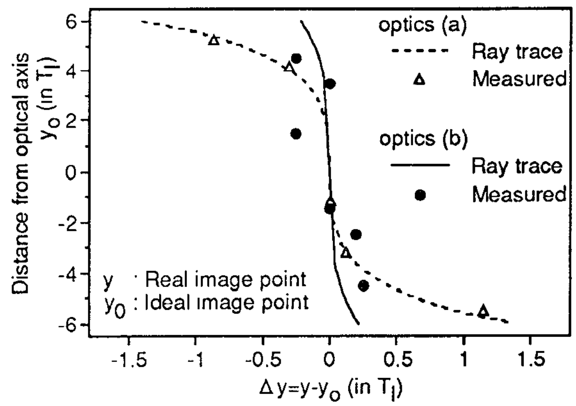

Fig. 3 Distortion for two different types of optics as a function of a distance from the optical axis.

electric plate which forms a part of the substrate lens (Fig. 2) [3]. Since the sensors are arranged in a line, two-dimensional images of 10 x 10 pixels was composed by mechanical scanning the array in another direction. The dimension of the objects corresponds to about 8 x 8 pixels on the image plane.

YAGI-ANTENNA IMAGING ARRAY

The imaging array consisted 2-element Yagi antennas with beam-lead Schottky diodes (SANYO SBL-804) as shown in Fig. 2 [4], [5]. The interval between the sensors was determined by the sampling theorem to obtain the diffraction-limited image. The radiator elements are half-wave dipoles on the thin plate of PTFE/glass of ε_r=2.17 which is almost the same as that of TPX, and the diodes are integrated as detection elements at a feed point of each radiator. The detector elements are on the other side of the plate. For optimization of the antenna configuration, the element dimensions are determined by the following two conditions : impedance matching with the diodes and beam pattern matching with the optics. The optimized dimensions for our experiments are that the radiator length $2l_1$ is 0.5 λ_e, the director length $2l_2$ is 0.462 λ_d, and the spacing d is 0.093λ_d, where λ_e and λ_d are the effective wavelength at the air-dielectric interface and the wavelength in the dielectric, respectively.

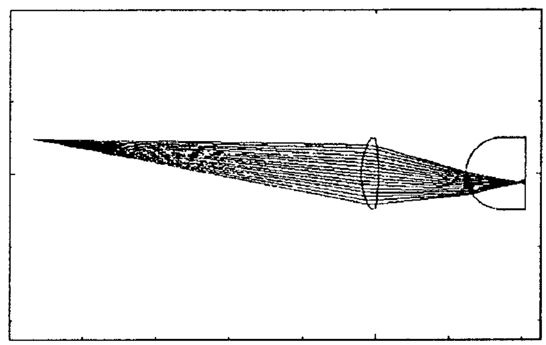

Fig. 4 The ray tracing for the optics (b).

MM-WAVE OPTICS

The hemispherical substrate lens was used in the optics to eliminate substrate modes or cross-talk between the sensors. The optics was designed to minimize the spherical aberration. The curvatures of the objective lens (f = 163 mm) was designed to obtain the optimum shape factor of 0.5. The substrate lens (f = 109 mm) is an aplanatic lens to eliminate spherical aberration and coma at the paraxial region. The effective F-number of the optics of 1.68 was determined by the sensor interval.

The design of the optics was checked by the ray tracing method. Fig. 3 compares distortion measured experimentally with that obtained by the ray tracing. The distortion are normalized by the sensor interval

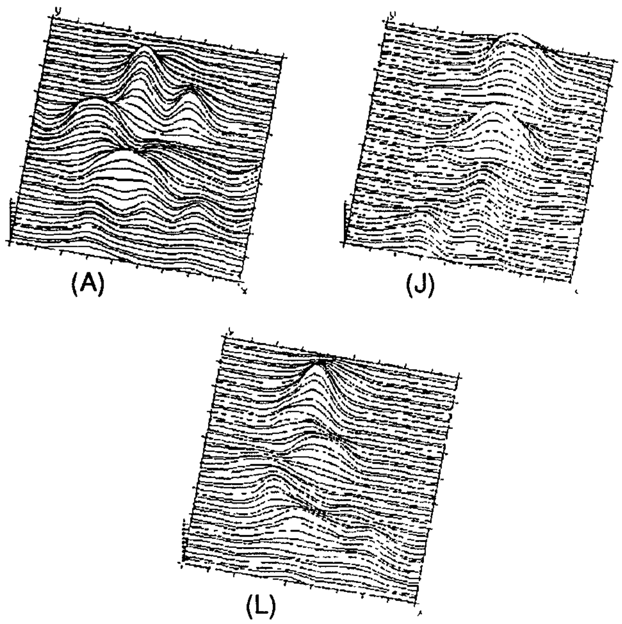

Fig. 5 Samples of image data.

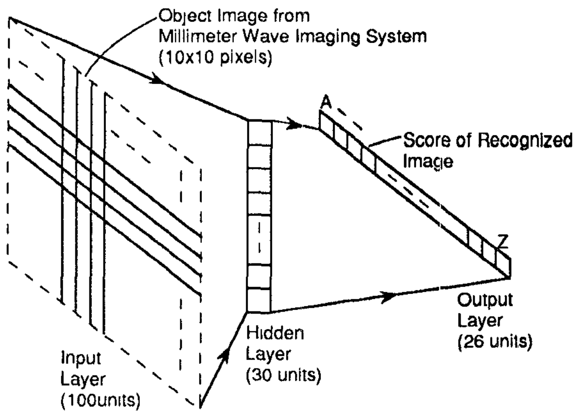

Fig. 6 A neural network for image recognition.

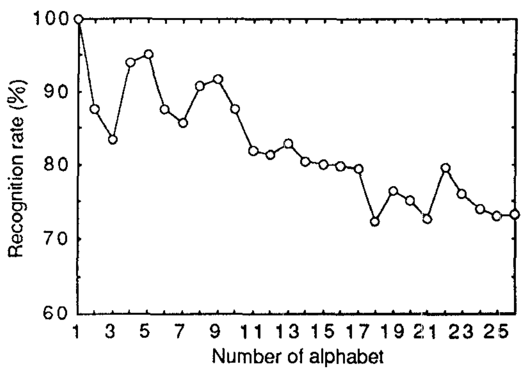

Fig. 7 Recognition rate as a function of the number of alphabets.

(T_I), and shown for two different types of the optics as a function of a distance from the optical axis. The experimental value was obtained by scanning a 60 GHz point source on the object plane. The good agreement between the experiments and the simulations shown in Fig. 3 verifies the validity of our design on the optics. Fig. 4 shows an example of the ray tracing for the optics (b) in Fig. 3. This optics was used in our mm-wave imaging experiments. The optics (a) was to verify the usefulness of the ray tracing method.

MM-WAVE IMAGES AND NEURAL NETWORK PROCESSING

Fig. 5 shows experimentally-obtained mm-wave images for alphabetical letters A, J, L. The images represents power distribution of scattered signals and are strongly distorted mainly because of speckle and/or glint by coherent illumination. To recognize these images, a back-propagation model neural network [6] has been proposed for a signal processor. Fig. 6 shows the network configuration which consists of 10 x 10 input units, 30 hidden units and 26 output units. In our experiments 9 sets of image data were collected for each object letter, and the sets were divided into two groups (5- and 4- sets) : one (5-set) was used for teaching data, and the other of 4-set was for test data. The 5-set was taught to the network, and then the resulting recognition rate for the test 4-set was studied. In Fig. 7 the rates are plotted as a function of the number of object alphabets (horizontal axis). The number increases in alphabetical order, for example, the rate of 87.5 % at 2 of the horizontal axis was obtained when 5-set data for alphabets A and B were taught to the network and 4-set data for the two letters were studied. As the number of alphabets increases, the recognition rate shows a tendency to decrease, since alphabets which are similar to each other increase, for example I and J. The recognition rate of 73.1% has been obtained when the number of alphabet

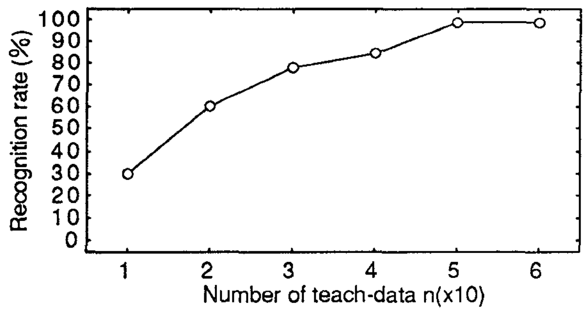

Fig. 8 Recognition of 10 alphabets.

is 26.

When 10 alphabetical letters (A, H, J, L, O, P, S, T, V, and Z) which were not similar to each other were used, the recognition rate was improved. In this case, 11-set of image data were collected for each letter, and among them 5-set of data was used for test data. Although the selection of good teaching data from among many teaching data is important, an arbitrary set of teaching data was, first of all, selected from the remaining data sets and taught to the network. At this stage the resulting recognition rate for the test data was very poor (30 %) as shown in Fig. 8, since varying degrees of distortion were as yet not taught. A set whose recognition result was particularly bad was then used as the next set of teaching data. By repeating this process to select the teaching data and then teach the network, the recognition rate was improved. The recognition rate of 98% has been obtained when the number of teaching data is 5 per letter.

CONCLUSION

A 60 GHz mm-wave imaging systems has been developed. The mm-wave optics for the imaging to minimize aberrations was designed and checked by the ray tracing method. A sensor array with Yagi antennas and Schottky diodes was used for a 1-D imaging array. A neural network was successfully introduced in signal-processing to recognize objects. The recognition rate of 98% has been obtained when 10 alphabetical letters were used as the objects and the number of teaching trials was 5 per letter.

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