A Non-Cooperative Fast Millimeter-Wave Imaging Method by Using MIMO Linear Array

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***Abstract*—A non-cooperative fast Millimeter-Wave imaging method based on multiple-input–multiple-output(MIMO) linear array is presented. The MIMO linear array here cooperating with a dielectric lens realizes a fast fan-beam scanning in vertical direction, and the images of horizontal direction can be obtained by non-cooperative moving of human without motion blur. Simulations are performed by using FEKO and the results demonstrate the performance of the imaging method.**

I. INTRODUCTION

DUE to the advantages of safety, high spatial resolution, and good penetrability, Millimeter-wave(MMW) imaging devices have been widely designed for nondestructive material detection and human security inspection [1][2]. The crucial factors in millimeter-wave imaging systems include imaging speed, spatial resolution, and system cost. Also, we should pay attention to the feel of the person under screening. The security processing time should be short and people could be screened with a comfortable position. However, most MMW imaging systems require the person being screened stand still and hold a specific position. Besides, among existing MMW imaging approaches, the focal plane array technique can get real-time images [3], but the cost is expensive. The synthetic aperture technique can acquire high-revolution images [4], but the imaging speed is limited by scanning aperture. The usage of quasi-optics focusing can improve the frame rate [5], but spatial resolution is limited by the size of reflectors and lens.

This paper presents a non-cooperative fast MMW imaging method based on multiple-input–multiple-output(MIMO) linear array. The prototype imager is shown on Fig. 1. Compared to the existing MMW imaging approaches, the imaging scheme gets a balance of system cost, imaging speed and spatial resolution. Using MIMO liner array can improve imaging speed and reduce system cost, and high revolution is obtained on the narrow side of the fan-beam. More importantly, person under screening can hold a relaxed posture and don't need to keep still.

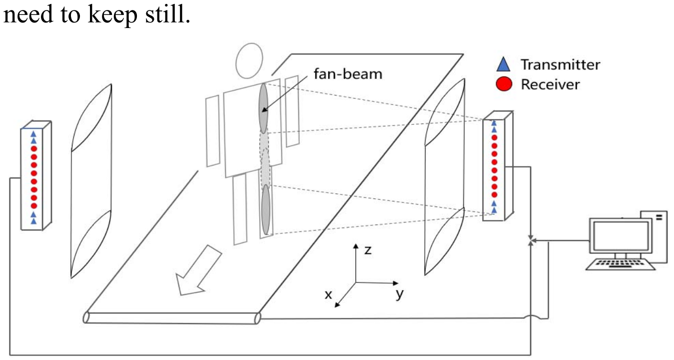


Fig. 1. Prototype imager based on MIMO linear array

II. IMAGING SYSTEM DESIGN AND DATA PROCESSING

We design a MIMO liner array with four transmitters and eight receivers by using the theory of equivalent array [6]. According to the theory, an observation channel formed by the combination of transmitter T and receiver R can be replaced by the transceiver E located at the midpoint of them, which can be expressed as

$$r_E = (r_T + r_R)/2 \tag{1}$$

therefore, a MIMO array with M transmitters and N receivers is equal to an array with M×N transceivers. And the array is called equivalent array.

The design process starts from a uniform equivalent array that meets the requirements of imaging. Specifically, the number of transceivers is derived from the required ideal sidelobe level (ISL) defined as [7]

$$\text{ISL} = 20log_{10}\frac{1}{N_E} \tag{2}$$

and then the required cross-range resolution δ_x determines the equivalent array size relative to wavelength via

$$\text{L} = 2\text{y}\tan[\arcsin(\lambda/4\delta_x)] \tag{3}$$

where y represents the distance of target. The next step in design process is factorization of uniform equivalent array into topology of MIMO array. In general, a uniform equivalent array can be factorized to different MIMO array. Thus, the last step is to choose the best MIMO array by comparing the number of transmitters and receivers, array size, and imaging quality.

The dielectric lens antenna is designed to produce fan-beam based on Gaussian quasi-optics method and optimized with FEKO. The simulated E-and H-plane radiation pattern located on focal plane are presented in Fig. 2. Simulation result shows that the 3dB bandwidth in narrow side of fan-beam is 9mm with a 70 GHz work frequency.

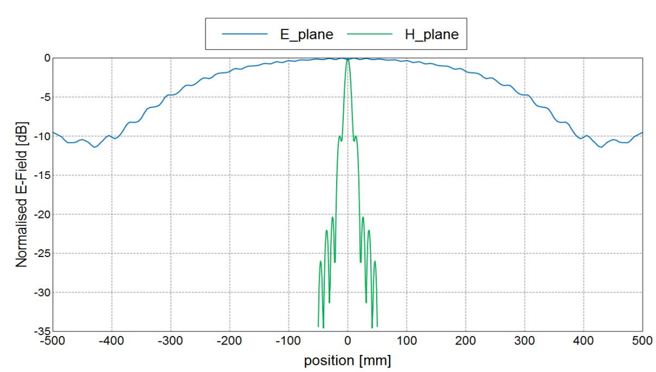


Fig. 2. Simulated E-and H-plane of the dielectric lens antenna at 70 GHz

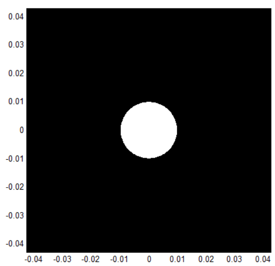
The acquired scattering data $E_{scatt}(x_R, z_R)$ is processed by the well-known backpropagation imaging equation [8]

$$\rho(x,z) = \iint E_{scatt}(x_R, z_R) \exp(jkr_1) \exp(jkr_2)\ dxdz \quad (4)$$

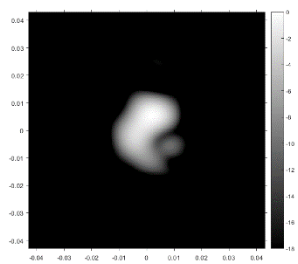
where $\rho(x,z)$ is the reflectivity function of an object, r_1 is the distance from transmitter to the object, and r_2 represents the distance from receiver to the object.

III. RESULTS

To demonstrate the performance of the proposed imaging method, the prototype imager is simulated with a single frequency in FEKO. The work frequency is 70GHz and the imaging plane located at y=2.2 m. A 1-cm-radius metal rotundity is used as the point scatterer whose position is illustrated in Fig.3(a). After 2-D reconstructing, a well focus image is generated in Fig.3(b). The image validates the effectiveness of the proposed imaging method.



(a)



(b)

Fig. 3. (a) Ideal 1-cm-radius metal rotundity. (b)70GHz single-frequency reconstructed image based on simulated data.

IV. CONCLUSION

This paper proposes a MMW imaging method that uses MIMO linear array for non-cooperative fast personnel security screening. Unlike the current methods, the images can be created without people keep still. Preliminary results demonstrate the performance of the imaging method. In the future, wideband imaging will be developed to get MMW holographic images.

ACKNOWLEDGEMENTS

The work was supported by the joint funding project of Natural Science Foundation of China and the China Civil Aviation Administration (U1633202).

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