Near Field Millimeter Wave Imaging Based on Range Migration Algorithm

[I]Guoping Chen, [II]Bowen Sun, [III]Tianzhen Wang, [IV]Jie Chen, [V]Bing Chen
[I,IV,V]College of Optoelectronic Engineering, Chongqing University of Posts and Telecommunications, Chongqing, China
[II,III]College of Communication and Information Engineering, Chongqing University of Posts and Telecommunications, Chongqing, China

Abstract
At present, terrorist attacks occur frequentlyall over the world, it is particularly important to carry out security inspection in public places. The near-field millimeter wave imaging technology in detecting human body concealed weaponssignificantly, has attracted more and more attention. This paperdescribes the range migration algorithmsystematically, and carry out the three-dimensional imaging of active millimeter wave in near field based on RMA. In thesimulation software of MATLAB, using the frequency of 37.5GHz millimeter wave, simulation imaging and experimental data imaging are all feasible, verifying the validity of the millimeter wave algorithm, but also embodies the millimeter wave imaging has certain application prospect and valuein the security inspection.

Keywords
Near-Field Millimeter Wave Imaging; Concealed Weapons; Three-Dimensional

I. Introduction

In recent years, the growing threat of terrorism, especially in public places, terrorist attacks occur frequently, causing heavy casualties and serious property loss. It needs to carry out security checks on personquicklyat the airport, train station, bus station, and large public traffic, it can reduce casualtiesand the loss of property[1]. The "9.11" terrorist attacks, Paris terrorist attacks, knock the alarm to the people to strengthen security inspection. Actually, the detection of hidden objects on human bodies has alwaysbeenadifficult problem. The requirement of human security inspection is that distinguishing different concealed weaponsquickly under the premise of harmless to people. There are different degrees of defects in some traditional detection methods[2]. For example, high-energy rays candetectthe baggage effectively,but it is harmful to the human body , it can not use for people's daily inspection. Infrared detection depends on the temperature of the object, the ability to distinguish between different objects is not strong, and can only get the image of the human body surface, unable to find concealed weapons. Metal detectors are helpless with plastic and other non-metallic items.

Millimeter wave is usually refers to the frequency of electromagnetic waves between 30-300GHz, corresponding to the wavelength of 10 to 1 millimeter, between microwave and far infrared waves, have the characteristics of microwave and infrared waves[3]. Millimeter wave detection technology combines the advantages of microwave and infrared waves, retains the more ideal image resolutionin a certain penetrating ability, at the same time, millimeter wave is non ionizing, will not affect human healthunder appropriate radiation power.Because the millimeter wave imaging system has many advantages, such as quickness, safety, stability and so on, has become the mainstream technology of security imaging [4].

II. Range Migration Algorithm

In this paper, it will use an algorithm. Range migration algorithm is a kind of improved algorithmofSARimaging, and it applies to the near field millimeter wavesecurityimaging system. The imaging precision is high, and it can use FFT to reconstruct the image, the speed of imaging is also fast. Fig.1 is the block diagram of the 3-D RMA.

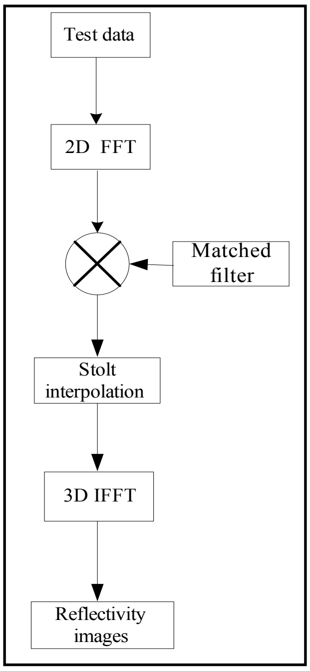

Fig.1: Block diagram of the 3-D RMA

The three-dimensionalimaging system through mechanicalscanning to form aperture plane($x'z'$ plane)and the aperture plane as the antennaarray. The $x'z'$ plane parallel to the x plane, the vertical distance between two planes is R0. $x-$ axis direction is defined as a azimuth, $z-$ axis direction is defined as the elevation.Fig.2 is the Millimeter wave imaging system.

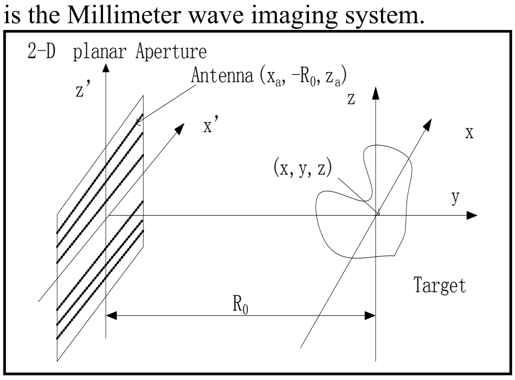

Fig.2: Millimeter wave imaging system

The active millimeter wave security imaging system transmit millimeter wave, detecting the millimeter waves reflected back by the human body, throughtheholographic three-dimensional imaging technology to inverse the body image. Through the figure 1, the process of system imaging can be described as follows. The first step: doing the two-dimensionalFourier transform to the direction of the echo data and the height ofecho data. The second step: the obtained data multiply the matched filter function to achieve the purpose of uniform focusing. The third step: stolt interpolation, the (k_x, k_r, k_z) domain data convert to (k_x, k_y, k_z) domain to achieve the goal of focusing on the purpose. The fourth step: doing three- dimensional inverse Fourier transformto get the target image.

The theoretical analysis is as follows. Assuming the position of any point of the target is (x, y, z), the reflectivity is σ(x,y,z), the measured backscatter data is $d(x_a,k_r,z_a)$.

$$d(x_a,k_r,z_a)=\sigma(x,y,z)\exp[k_rR_0]\exp[-k_rR] \quad (1)$$

The operating frequency can be converted to wave number $k=2\pi f/c$, c is the speed of the light, order $k_r=2k$, the distance from antenna to point (x, y,z) is R.

$$R=\sqrt{(x_a-x)^2+(-R_0-y)^2+(z_a-z)^2} \quad (2)$$

The first exponential term in the equation (1) establishes a reference phase between the origin of coordinate and the synthetic aperture plane, and the second exponential terms only represent the phase history associated with the point scattering. It should be noted that, for the sake of simplicity, the propagation loss of free space and the antenna pattern are not considered here.

Doing Fourier transform of the azimuth and elevation of the equation (1), obtaining $D(k_x,k_r,k_z)$:

$$D(k_x,k_r,k_z)=\sigma(x,y,z)\iint\exp[jk_rR_0]\times \exp[-jk_rR]\exp[-jk_xx_a-jk_zz_a]dx_adz_a \quad (3)$$

Assuming the integrals in equation (3) ,

$$E(k_x,k_z)=\iint\exp[-jk_rR]\exp[-jk_xx_a-jk_zz_a]dx_adz_a \quad (4)$$

Using the method of stationary phase (MSP)[5].

So Equation (3) can be changed to

$$D(k_x,k_r,k_z)=\sigma(x,y,z)\times\exp(-j\sqrt{4k_r^2-k_x^2-k_z^2}R_0)\times \exp(-jk_xx-jk_zz-j\sqrt{4k_r^2-k_x^2-k_z^2}y)\times\exp(jk_rR_0) \quad (5)$$

The following is matched filter. Transposing in equation (5). Getting the equation below.

$$\sigma(x,y,z)=D(k_x,k_r,k_z)\exp[-jk_rR_0]\times \exp[j\sqrt{k_r^2-k_x^2-k_z^2}(y+R_0)+jk_xx+jk_zz] \quad (6)$$

Arranging the equation (6), getting the equation below.

$$\sigma(x,y,z)=D(k_x,k_r,k_z)\exp[jR_0(-k_r+\sqrt{k_r^2-k_x^2-k_z^2})] \quad (7)$$
$$\exp[j(\sqrt{k_r^2-k_x^2-k_z^2}y+k_xx+k_zz)]$$

This is a point of expression, if a lot of points of imaging will need to use the integral formula.From the equation (5), order

$$\Phi_{MF}(k_x,k_r,k_z)=-k_rR_0+\sqrt{k_r^2-k_x^2-k_z^2}R_0 \quad (8)$$

Equation (8) is a matching filter function in the three-dimensional wave number domain algorithm. The introduction of matched filter function is used to compensate for all the wave front curves at the same distance R0. To achieve the purpose of uniform focusing.

In the stolt interpolation, transforming (k_x, k_r, k_z) domain data into (k_x, k_y, k_z) domain in order to achieve the goal of focusing. Then k_r,k_x,k_z are evenly distributed in formula of $\sqrt{k_r^2-k_x^2-k_z^2}$,After transforming of the formula $k_r^2-k_x^2-k_z^2$, k_r,k_x,k_z become non-uniform, we will operate the value of Stolt interpolation into a uniform value, that is k_y (note $k_r^2-k_x^2-k_z^2\geq 0$, otherwise it has no sense).

Using three-dimensional inverse Fourier transform to obtain the reconstructed image of the target. After stolt interpolation, k_xx,k_yy,k_zz and target position x,y,z are linear relationship respectively, so it can be used to reconstruct the image of the target by three-dimensional inverse Fourier transform.

III. Simulation

Through theoretical analysis above, then using the simulation test to verify the validity of the algorithm based on the wave number domain, the experimental parameters are shown in table 2.1.

Table 2.1 : imaging system of simulation reference

reference	numerical value
carrier frequency	37.5GH$_Z$
bandwidth	5GH$_Z$
reference distance (R0)	0.9m
the number of antenna element	10000
Sample interval: Δx_a	0.005m
sample interval: Δz_a	0.005m
The number of frequency samples (Nf)	201

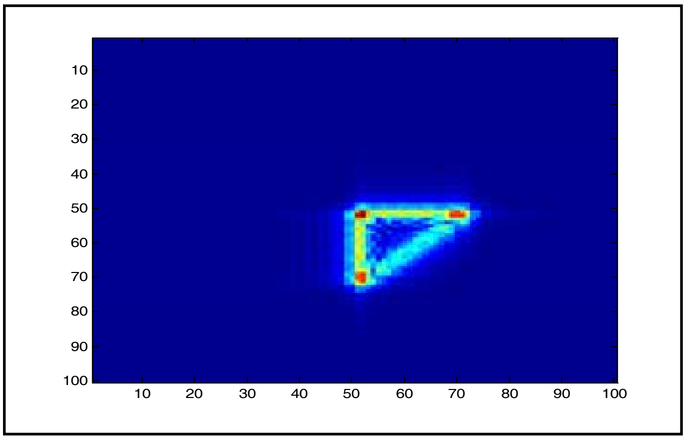

Fig. 3: Simulated image of triangle

In Fig.3, the z direction represents the elevation, the x direction represents the azimuth. The length is 0.1 meter, the width is 0.1 meter.The validity of the millimeter wave algorithm can be judged by the triangle simulation image.

IV. Imaging of Experimental Data

Through correctness of the simulation, the experimental data can be measured by millimeter wave imaging. 3-D RMA algorithm can have accuracy. The experimental data are a ruler and a handgun. Corresponding to it, through Fig.4, the simulated image is also a ruler and a handgun. It shows that the millimeter wave algorithm is effective.

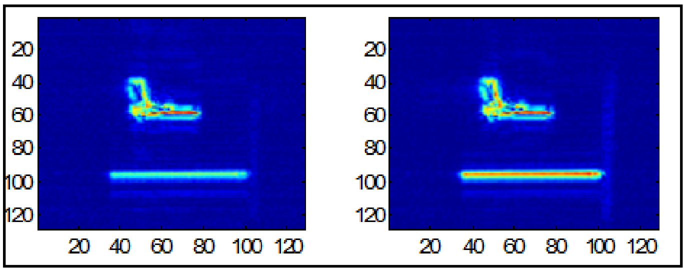

Fig.4:Imaging of the actual data

V. Conclusion

Through the simulation and the imaging of the actual data in this paper, the algorithm of 3D-RMA have validity, the algorithm is feasible, so the millimeter wave algorithm has a certain application prospect in security imaging.

References

[1] *LI Zhihao, WEN Yazhen. Application of active millimeter wave imaging in the field of public safety [J]. infrared, 2014, 35 (7): 29-32.*

[2] *SANG Wei, YUE Shengli. Application of millimeter wave imaging technology in the field of human safety inspection [J]. China security, 2013 (4): 83-87.*

[3] *XIAO Zelong. Millimeter wave radiation imaging of concealed objects in human body[D]. Nanjing: Nanjing University of Science and Technology, 2007.*

[4] *REN Bailing. Research on active millimeter wave security imaging algorithm and system[D].Beijing Institute of Technology, 2014.*

[5] *FEI Peng, Fang Weihai, Wen Xin, et al. Active millimeter wave imaging technology and prospect for personnel security status.*