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Range Enhancement of Nulling Angle in FN-PMMW Imaging Using Cooling Dielectric Tube Array

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1. Introduction

In order to improve the detection performance of concealed objects in clothes by using the passive millimeter wave imaging technique, a forward-nulling passive millimeter wave (FN-PMMW) imaging method forwarding a null in the direction of human body and objects has been proposed by the authors [1]. The contrast between human body and conducting objects is improved using a developed nulling source composed of a cooling dielectric tube and a parabolic cylinder, however, range of the nulling angle is narrow and the size of a parabolic cylinder is too large for a practical use.

In this paper, a nulling source composed of a cooling dielectric tube array with narrow-width parabolic cylinders is developed to enhance the range of the nulling angle with geometry suitable for the flow of people at the airport security check.

2. Theory

Fig. 1 shows a lens system of the PMMW imaging device in a room surrounded by the wall. The imaging sensor array is located on the image plane $z = z_{im}$. Considering the case without body on the object plane $z = z_{ob}$, the central imaging sensor located on a lens axis will observe brightness temperature distribution of the wall T_{wall} in the range of the solid angle of Ω_{L1}. When a human body having a conducting plate with angle θ from the lens axis stands on the object plane $z = z_{ob}$, the sensor will observe the brightness temperature distribution of the wall T_{wall} placed in a solid angle of Ω_{L2}. The apparent temperature of a human body T'_h is given by $T'_h = T_h + (1 - \varepsilon_h)\, T_{wall}$, where T_h and ε_h are the brightness temperature and the emissivity of the human body, respectively. Therefore, the apparent temperature contrast between a human body and a conducting plate is given by $\Delta T_{wall} = T'_h - T_{wall}$.

When the temperature in the solid angle Ω_{L2} decreases by the presence of the incoherent nulling source with brightness temperature of T_{null}, the apparent temperature contrast between human body and the area of conducting plate is given by $\Delta T_{null} = T'_h - T_{null}$ and becomes large compared with ΔT_{wall} when $T_{null} < T_{wall}$.

The angle θ depends on the curvature of a human body and the range enhancement of the nulling angle is required to detect concealed objects for various angles.

3. Cooling dielectric tube array

Geometry of the cooling dielectric tube array with narrow-width parabolic cylinders are shown in Fig. 2. Dielectric tube array is made of polyvinyl chloride (PVC) with outer diameter of 30 mm, which is often used in the plumbing, and surface temperature of the dielectric tube is kept at 7.5 °C by circulating cooling water through a series of six tubes using a water cooling device. The parabolic cylinders made of a conducting stainless plate with a focal length of $f = 18$ mm were fabricated and the position of the cooling dielectric tube is selected as $p = 23$ mm.

The cooling dielectric tube array was placed along a line parallel to direction of the flow of people at the airport security and the normal direction of each aperture of parabolic cylinders are adjusted to a human body so as to decrease the brightness temperature T_{null} corresponding to the increase of contrast ΔT_{null}.

4. FN-PMMW imaging

The FN-PMMW imaging of a human body and a circular conducting plate (CD-ROM, diameter of 120 mm) located in front of human body with changing the angle θ from 0 to 60 degrees was performed using developed imaging systems [2]. PMMW images using the developed cooling tube array were compared with the cases using a nulling source developed in [1]. Fig. 3 shows the lens system with the cooling tube array with narrow-width parabolic cylinders. Fig. 4 shows the lens system used in [1] having wide-width parabolic cylinder. Parameters of each lens systems are also shown in each figure. Magnitudes of the received voltages of each imaging sensor array are offset by output voltages of the surrounding environment [2], this means that zero of the received voltage is corresponding to the brightness temperature of surrounding environment T_{wall}.

Fig. 5 (a) shows the PMMW images in the cases with the cooling tube with wide-width parabolic cylinder. The contrast between human body and CD-ROM was improved by the presence of a cooling tube with wide-width parabolic cylinder in the case when the angle θ of $36° \leqq \theta \leqq 48°$ and the nulling range of only 12° is obtained. The PMMW images in cases of $\theta < 32°$ are almost the same to the case of $\theta = 32°$ and are omitted.

Fig. 5 (b) shows the PMMW images in the case with the cooling tube array with narrow-width parabolic cylinders. High contrast between human body and CD-ROM is observed in the case when the angle θ of $12° \leqq \theta \leqq 44°$ and larger range of the nulling angle of 32° is achieved compared with the case of Fig. 5 (a).

5. Conclusion

A nulling source with the cooling dielectric tube with narrow-width parabolic cylinders was developed to enhance range of the nulling angle in the FN-PMMW Imaging. High contrast PMMW images is obtained using proposed FN-PMMW imaging method with wide nulling angle range of up to 32°. Also the geometry will be suitable for the flow of people at the airport security check. Although one side of the nulling source is developed, the configuration of multi-side nulling source will be useful to increase the contrast.

Acknowledgement

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References

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[2] H. Sato, K. Sawaya, K. Mizuno, J. Uemura, M. Takeda, J. Takahashi, K. Yamada, K. Morichika, T. Hasegawa, H. Hirai, H. Niikura, T. Matsuzaki, S. Kato and J. Nakada, “Passive millimeter-wave imaging for security and safety applications,” SPIE Proceedings, vol. 7671, Orlando, USA, 2010.

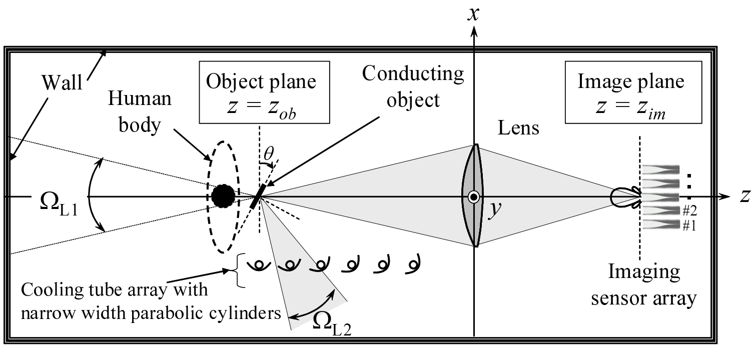
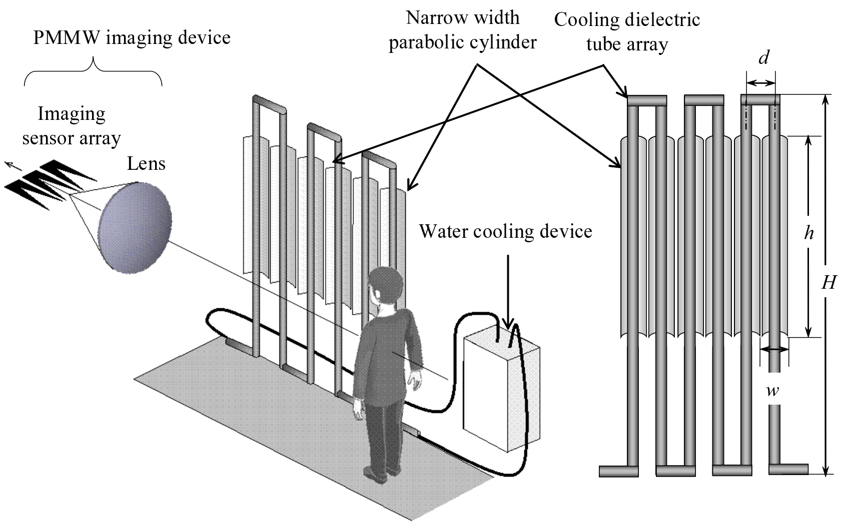


Figure 1: Lens system in room (top view).



Parameters of narrow width parabolic cylinder [mm]	
Height H	1700
Pitch d	126
Height h	1000
Focal length f	18
Length p	23
Width w	96
Depth D	32

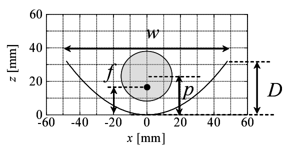
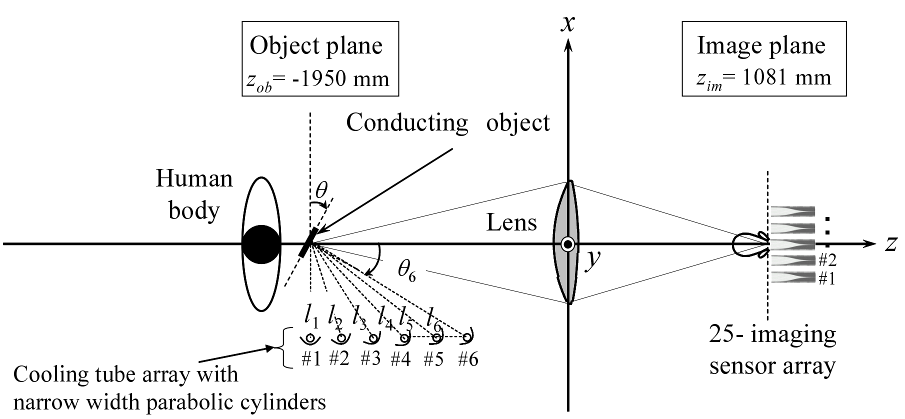
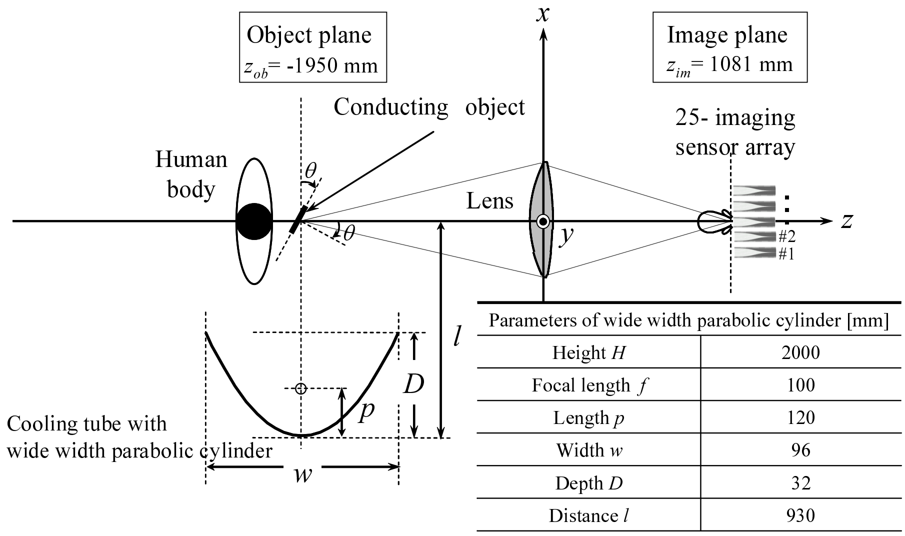


Figure 2: Geometry of cooling tube array with narrow-width parabolic cylinders.



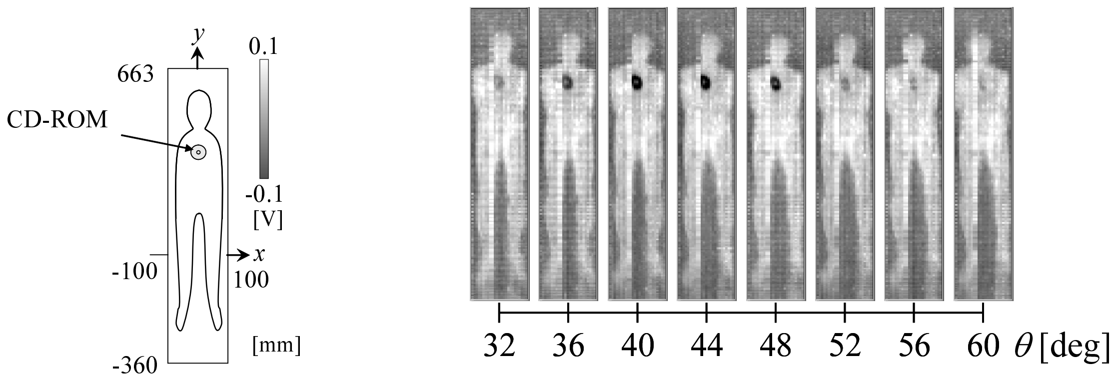
Parameters of cooling tube array						
No. n	#1	#2	#3	#4	#5	#6
l_n	400	419	473	551	643	747
$90\text{-}\theta_n$	0	17.5	32.2	43.4	51.6	57.6

Figure 3: Lens system with cooling tube array and narrow-width parabolic cylinders.

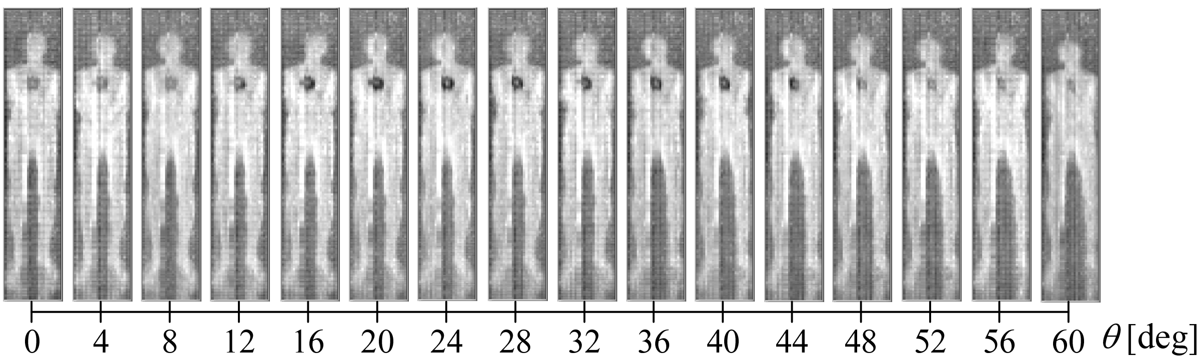


Parameters of wide width parabolic cylinder [mm]	
Height H	2000
Focal length f	100
Length p	120
Width w	96
Depth D	32
Distance l	930

Figure 4: Lens system used in [1] having wide-width parabolic cylinder.



(a) Cooling tube with wide width parabolic cylinder.



(b) Cooling tube array with narrow width parabolic cylinders.

Figure 5: FN-PMMW imaging of human body and CD-ROM located in front of human body with angle θ from 0 to 60 degrees.