Physical Optics Modeling for the Optimization of Millimetre-Wave Personnel Scanners

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Abstract— **Recent advances in mm-wave imaging show promise for the enhanced detection of threats hidden under clothes. This is particularly important for airport security. This paper focuses on a methodology, based on a comprehensive simulation of the physics of an imaging system, that aims to assess the potential of various modifications to the current systems. This offers low-cost and rapid exploration of the effects of various system parameters, such as imager polarization manipulation, frequency, coherence parameters etc. We report here on the effect of frequency on scene contrast.**

I. Introduction

Recent years have witnessed an increased interest in short-range mm-wave imaging for to enhanced detection of threats hidden under clothes. QinetiQ has developed a real-time 35 GHz imager which produces head-to-toe images [1]. We are interested here in how the operating parameters of the imager can be modified so as to optimize the discrimination of materials within the recorded images. To assess the potential of the possible modifications to current systems, a comprehensive, mm-wave physical optics simulator has been developed. This paper is then divided into three sections: (1) the simulator, (2) the variation of frequency in the imager and (3) the results.

II. Simulation of Millimetre-Wave Images

The mm-wave imager employs active illumination that increases image contrast for indoor imaging. The circularly polarized illumination [2] has an apparent temperature of 800K and, although being spatially and temporally decohered, exhibits some residual coherence. The mm-wave radiation reflected and emitted by the scene are captured by the imager, which employs a conical scan of a linear array of detectors [3]. Physical optics modeling incorporates the following components:

1. Radiometry: the scene is ray-traced using Zemax and the intensity distribution at the detector is calculated according to:

$$T_{rec} = R(\varepsilon)\, T_{ill} + t(\varepsilon)\, T_{back} + \epsilon(\varepsilon)\, T_{obj} \qquad (1)$$

where ε is the permissivity of the material, R the reflectivity, t the transmissivity, ϵ the emissivity, T_{rec} the received temperature, T_{ill} the illumination temperature, T_{back} the background temperature and T_{obj} the object temperature.

2. Optical system: the amplitude impulse response is evaluated and convolved with the radiometric image, and thermal and speckle noise components are added.

3. Rasterisation: the image is sampled and interpolated, yielding the synthetic mm-wave images.

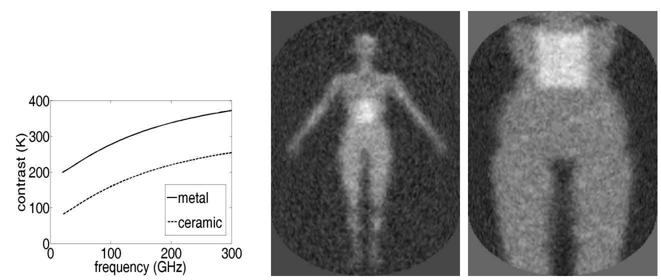
III. Experiment

As an example variable we report here on the effect of frequency:

- Radiometry: the received temperature is modified according to the spectral variation of the dielectric constant of scene components. In practice, the variations of for ceramic and metals is almost constant across the mm-wave range, but the body, modeled as salted water, varies significantly with frequency.
- The transverse dimension of the amplitude impulse response (for the coherent components) and point-spread function (for the incoherent component) decrease with increasing the frequency.
- Speckle noise characteristics and thermal noise magnitude vary with frequency.

IV. Results

The contrast between received temperatures of body and other materials increases with frequency, mainly due to spectral variations in dielectric constant of flesh. Fig. 1 presents the variation of received temperature with frequency for metal and ceramic at normal incidence and the resulting synthetic images in the particular case of a metal patch.



(a) Frequency vs. contrast (b) at 35 GHz (c) at 94 GHz

Fig. 1. Variation of contrast with frequency: (a) frequency vs. received temperature for metal and ceramic at normal incidence, (b) synthetic image including body and metal at 35 GHz and (c) at 94 GHz

V. Conclusion

We have discussed briefly the factors involved in modeling the effects of mm-wave frequency on the image quality. Material contrast improves with increasing frequency, although effects such as noise, coherence and spatial resolution should be also taken into consideration in determining the effect on the detection of materials.

References

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