Beam Width Robustness of a 670 GHz Imaging Radar

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Abstract – **Detection of a replica bomb belt concealed on a mannequin at 4 m standoff range is achieved using a 670 GHz imaging radar. At a somewhat larger standoff range of 4.6 m, the radar's beam width increases substantially, but the through-shirt image quality remains good. This suggests that a relatively modest increase in aperture size over the current design will be sufficient to detect person-borne concealed weapons at ranges exceeding 25 meters.**

1 INTRODUCTION

A THz imaging radar being developed at the Jet Propulsion Laboratory, California Institute of Technology, utilizes the extremely wide coherent bandwidth of harmonically generated submillimeter-wave signals to achieve cm-scale resolution in three dimensions at a standoff range of 4 m [1]. One potential application for this technology is the detection of weapons or contraband concealed by clothing or other material that is largely transparent to the non-ionizing THz radiation. For weapons detection, long standoff range is a key system goal in order to reduce the threat to the system operator, and therefore standoff ranges exceeding 25 m are desirable.

One important system trade-off for scaling the THz radar to longer ranges involves the aperture size and image resolution. For example, the two-way diffraction-limited cross-range resolution (i.e., the half-power widths of the transmit and receive beams' product) is 0.4 cm at a 4 m standoff range when using a 0.4 m diameter aperture. Maintaining this resolution at 25 m standoff would require increasing the main reflector's size to 2.5 m diameter. Such a large-diameter THz reflector would be extremely costly to fabricate and cumbersome to use in a field environment.

However, a direct multiplicative scaling of aperture diameter, based on the 0.4 m aperture at 4 m standoff, is not necessarily appropriate. As an illustration, in this paper we show that even after increasing the on-target radar beam width by a factor of about 3.2, the system's through-shirt image quality of a mock bomb belt remains robust despite some loss of detail. This implies that a much more manageable reflector diameter of only 0.8 m will be sufficient for important threat detection scenarios at standoff ranges near 25 m.

2 670 GHZ IMAGING RADAR OVERVIEW

JPL's 600 GHz imaging radar has been described previously [1], and the 670 GHz system used for the measurements presented here is based on an identical architecture, with differences only in the microwave backend operating frequencies and bandwidths. The frequency-modulated, continuous-wave (FMCW) radar beam generated and detected with all-solid-state Schottky diode technology spans 659-688 GHz and is focused by an off-axis ellipsoidal aluminum reflector with a diameter of 0.4 m and a distant focus range of 4 m. This results in a diffraction-limited two-way half-power beam width of about 0.4 cm.

The 29 GHz operating bandwidth allows distinct targets to be resolved to within 1 cm of each other in range. This ultra-high resolution permits a three-dimensional digital reconstruction of concealed objects to be made by scanning the radar beam over a target, and then plotting the spatial point cloud of all scattering returns except those coming from the outer layer of clothing.

3 EFFECT OF BEAM WIDTH ON IMAGING

To assess the impact of a larger beam spot size on the THz imaging radar, three-dimensional imagery were obtained at two different ranges: 4.0 m and 4.6 m. At 4.0 m standoff, the beam spot size is essentially diffraction-limited in size, as indicated in Figure 1a, where a THz radar image of a 3 mm diameter gold bead is shown. The bead is suspended at 4 m standoff range by a single cotton thread. In Fig. 1a the range-gated power (spanning 40 cm in range) is plotted, and both the bead and thread are visible. The 3 dB width of the bead image is about 0.4 cm. Owing to the finite bead diameter, these values are upper-limits of the actual two-way beam diameter at 4 m standoff.

At the somewhat longer range of 4.6 cm, the beam diameter increases by a factor of about 3.2, as indicated in Fig. 1b. The 3 dB bead image width is now 1.15±0.25 cm, with the uncertainty representing the apparent elliptical distortion probably resulting from slightly misaligned optics.

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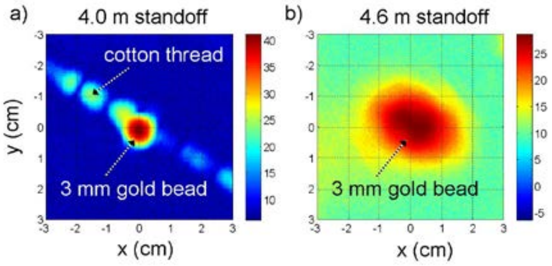

Figure 1: THz radar image of a 3 mm diameter gold bead suspended by a cotton thread. Standoff range is 4 m in (a) and 4.6 m in (b). Color scale in dB.

Figure 2 presents an example of how the increase in radar beam width affects the radar's ability to detect a potential concealed threat. The threat is a mock bomb belt made from a cotton pouch containing rubber sheets and tightly packed ball bearings, with a total thickness of about 2.5 cm. As shown in Fig. 2a, the belt is strapped to a mannequin and concealed by a T-shirt. (To mimic human skin, the mannequin is made opaque to THz radiation by wrapping it first with a damp shirt).

For the smaller beam width at 4 m standoff, Fig. 2b shows both the power-only imagery and the three-dimensional back-surface reconstruction. The power image hints at a possible rectangular anomaly, whereas the back-surface reconstruction very clearly reveals that a wide belt of some kind is being concealed underneath the mannequin's shirt.

Imagery of the same target scenario at 4.6 m standoff, where the radar beam width is 3.2× larger, is shown in Fig. 2c. The power-only imagery indicates a very weak increase in scattering from the belt, but its distinctiveness is even less than in Fig. 2b. The three-dimensional back-surface imagery, on the other hand, still exposes the hidden mock bomb belt with good fidelity. The belt's edges are more jagged than in Fig. 2b, but there is still enough contrast against the mannequin to be detected. In part, this is because the range resolution in the longitudinal direction does not change with the target standoff distance – it is determined only by the radar bandwidth – so that the 2.5 cm thickness of the belt is sufficient to make a reliable detection nonetheless.

3 CONCLUSIONS

The results presented here are important for calculating the necessary aperture size to achieve imagery comparable to in Fig. 2c but at a much longer standoff range. Because the radar beam used for Fig. 2c was purposefully defocused by a factor of 3.2 compared to that of Fig. 2b, the image quality in Fig. 2c would be equivalent to that obtained at a 4 m standoff and an aperture diameter of (0.4 m)/3.2 = 0.13 m. Scaling to 25 m, therefore, implies that an aperture diameter of (0.13 m)×(25/4) = 0.8 m would is sufficient at this much greater distance. This is a very manageable size for a THz imaging radar system meant for realistic threat environments, and efforts are underway at JPL to scale up THz imaging to these longer standoff ranges.

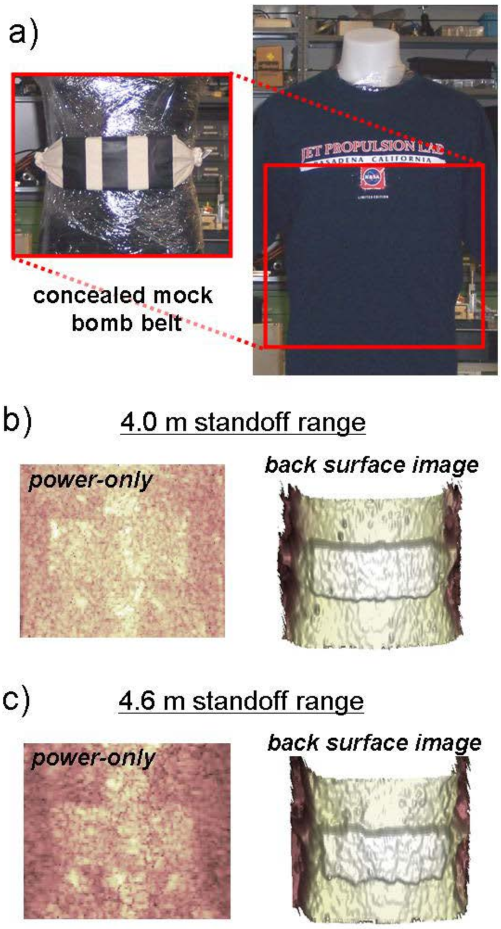

Figure 2: a) Target scenario consisting of a mock bomb belt strapped to a mannequin and hidden by a T-shirt. b) At 4 m range, the belt is very clearly revealed by the THz imaging radar. c) At 4.6 m range, the belt is still evident despite the larger radar beam width.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

[1] K. B. Cooper, *et al.*, "Penetrating 3D Imaging at 4 and 25 Meter Range Using a Submillimeter-Wave Radar", IEEE Trans. Microw. Theory Tech., vol. **56**, pp. 2771-2778, Dec. 2008.