RISE RESEARCH INNOVATION SCHOLARSHIP ENTREPRENEURSHIP

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Airport Security: Characterizing Objects Worn on the Limbs

Wideband Analysis of Imaging of Dielectric-Covered Curved Surfaces for Millimeter-Wave Security Scanning

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Opportunity

Background

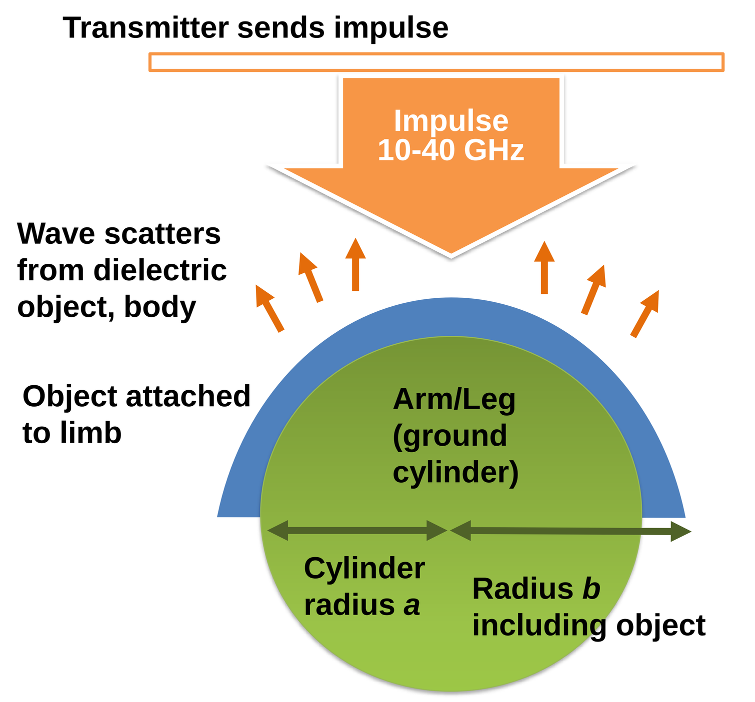
Airport security measures address the threat of terrorist attacks. However, long lines and invasive pat-downs can make airport security an unpleasant, tedious, and labor-intensive experience. Eliminating pat-downs for benign materials would be possible with good object characterization models. Reducing even 50% of false alarm pat-downs–whether from clothing, medical devices, or stray candy wrappers–will cut costs significantly and mean many fewer people have their privacy invaded in airport security.

Introduction

Here, we investigate a model for a dielectric object conforming to person's arm or leg, and see how it reacts to an impulse from a wideband (10 – 40 GHz, with a resolution of 0.5 cm) millimeter-wave radar security scanning system. These results have been validated with data through our lab collaboration with the Pacific Northwest National Lab and the Dept. of Homeland Security.

Goal

Accurately determine the characteristics of objects detected on arms and legs to distinguish between threats and benign objects



Approach

Derive Forward Model

- Forward model found using Maxwell's Equations and boundary conditions
- Waves reflect off multiple interfaces, giving responses that tell us what they hit and when

Create Inverse Model

- Assume the simple inverse model based on flat torso measurements holds for limbs
- Invert forward model for large range of values and observe trends

Validate Inverse Model

- Compare results to ground truth, determine where inverse model falls short of accuracy

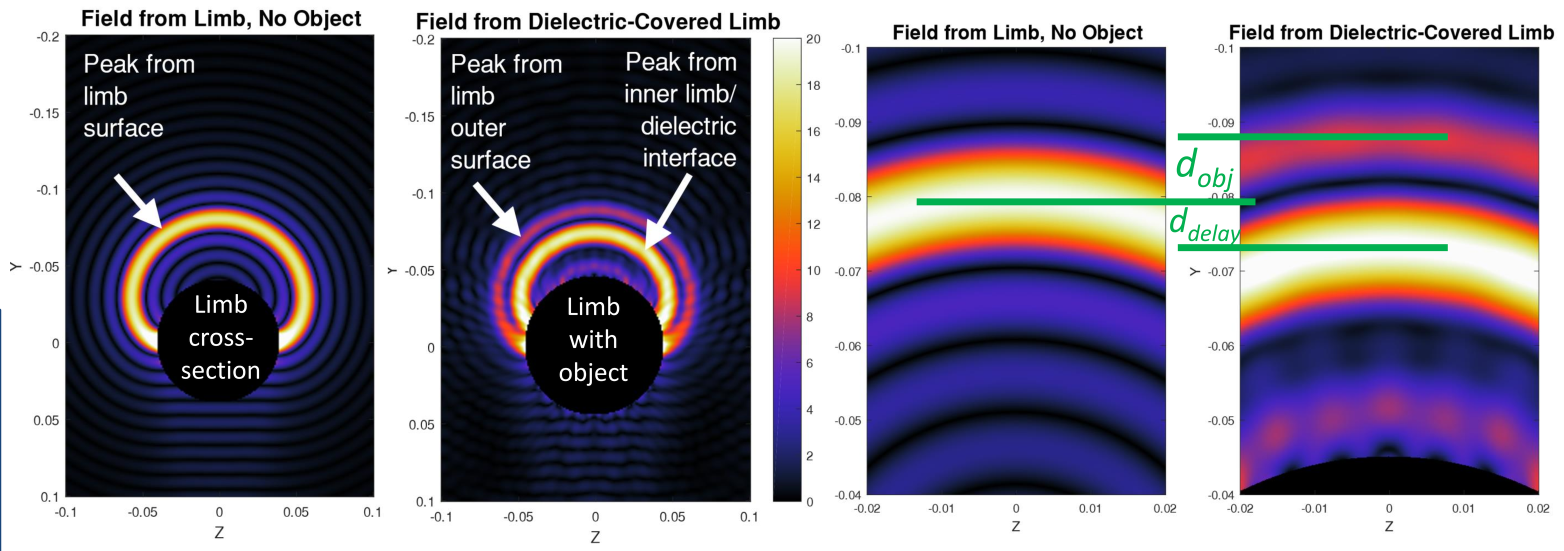


Figure 2. Response of limb without object in it vs. with dielectric object. Wearing a dielectric on the limb creates two reflection peaks, from the inner and outer surfaces, rather than the one from a bare limb. Measuring the distance between the reflection peaks allows us to find the thickness and dielectric constant of the body-worn object

Forward Model: Key Equation

$$E_{scattered} = E_0 \sum_{n=-\infty}^{\infty} j^n A_n H_n^1(n, k_1, \rho) e^{jn\theta}$$

- $E_{scattered}$: Scattered electric field: what's displayed in Fig. 2
- E_0: Initial field value
- A_n: Complex set of Bessel functions based on boundary conditions (below)
- H_n^1: Hankel function: changes with distance from cylinder center
- $e^{jn\theta}$: Angular dependence

$$A_n = \frac{k_2 J_n(k_1 b)\left[H_n^{(1)}(k_2 b)H_n^{(2)}(k_2 a) - H_n^{(2)\prime}(k_2 b)H_n^{(1)}(k_2 a)\right] - k_1 J_n'(k_1 b)\left[H_n^{(1)}(k_2 b)H_n^{(2)}(k_2 a) - H_n^{(2)}(k_2 b)H_n^{(1)}(k_2 a)\right]}{-k_2 H_n^{(1)}(k_1 b)\left[H_n^{(1)}(k_2 b)H_n^{(2)}(k_2 a) - H_n^{(2)\prime}(k_2 b)H_n^{(1)}(k_2 a)\right] + k_1 H_n^{(1)\prime}(k_1 b)\left[H_n^{(1)}(k_2 b)H_n^{(2)}(k_2 a) - H_n^{(2)}(k_2 b)H_n^{(1)}(k_2 a)\right]}$$

Inverse Model: Key Equation

$$\epsilon' = \left(1 + \frac{d_{delay}}{d_{obj}}\right)^2$$

- ϵ': Relative Permittivity: Important characteristic, can indicate if material is explosive
- d_{delay}, d_{obj}: Distances found from Fig. 2, right

Results

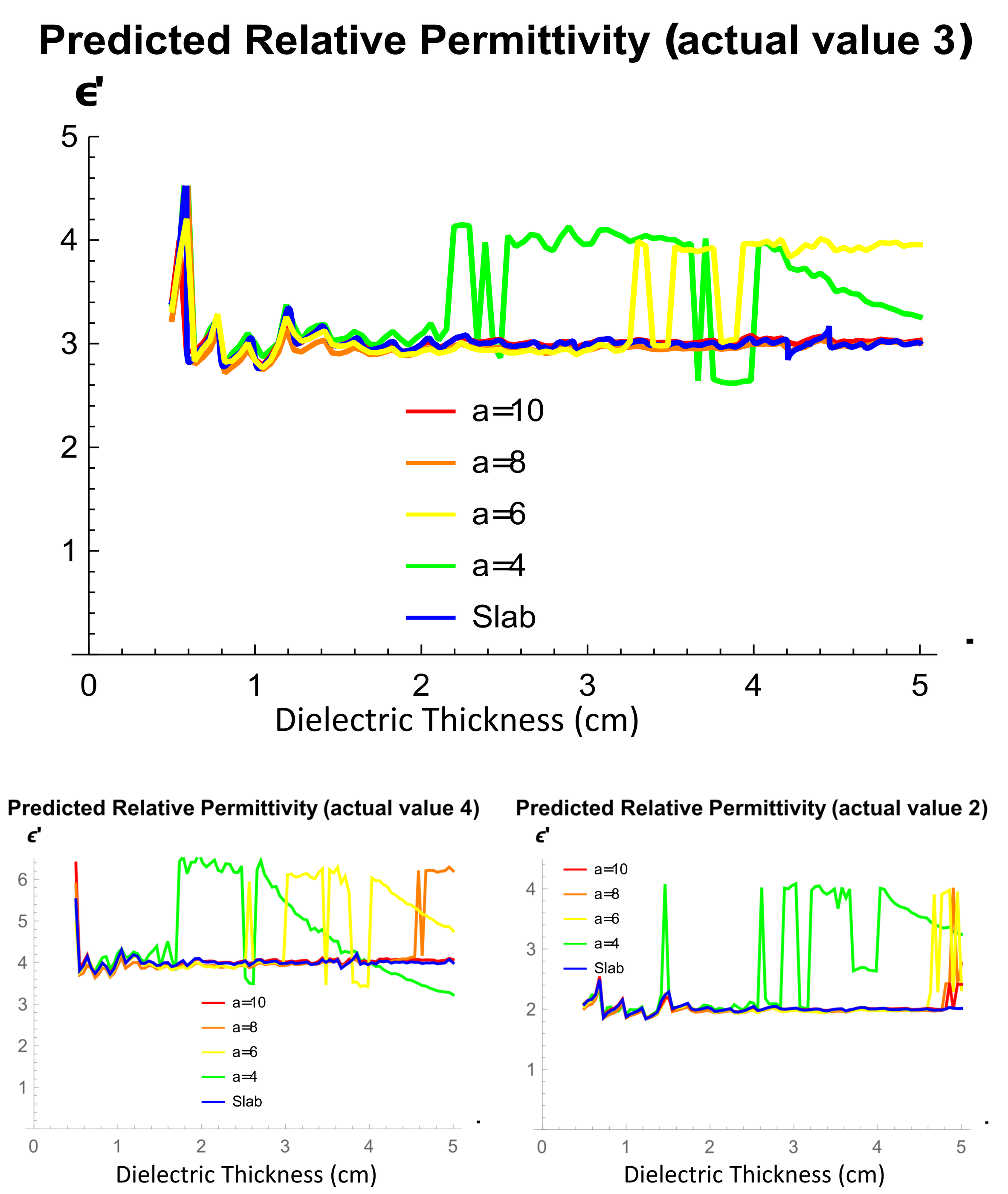


Figure 3. Result of the inverse model – run forward model for many different relative permittivity, dielectric thickness, and cylinder radius a values. Compare to the actual value of the relative permittivity (2, 3, or 4). A perfect result is a horizontal line at the actual permittivity.

- Graphs, left, are plotted for different values of relative permittivity ϵ'
- The **predicted** relative permittivity, found from the basic inverse model equation, is plotted against object thickness, from 0.5 to 5 cm.
- A **perfect result** would be a horizontal line at the actual value (e.g. 2, 3, 4).
- A more realistic "good" result is in blue ("Slab" case for a non-curved surface).
- Larger limb radius yields better results.
- Smaller radii (e.g. 4 cm) prone to **errors with thicker objects**
  - i.e. objects for which the electrical path length in dielectric is half the limb radius or larger
- $\epsilon' \approx 3$ is common for **explosives** and **drugs**. Getting this value right means **fewer pat-downs** and **better explosives detection**
- **This model is highly effective for characterizing dielectric objects concealed on limbs**

Impact

The unique feature about my research is
a complex mathematical model which quickly finds material properties of objects worn on the limbs.
The impact of this presentation is
more efficient, less invasive airport security with fewer pat-downs!

References

1. M. Sadeghi, E. Wig and C. Rappaport, "Determining the Dielectric Permittivity and Thickness of a Penetrable Slab Affixed to the Human Body Using Focused CW mm-Wave Sensing," *2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, Boston, MA, 2018, pp. 621-622.
2. D. H. Staelin, J. A. Kong, and A. W. Morgenthaler, *Electromagnetic waves*. Englewood Cliffs, NJ: Prentice Hall, 1998.
3. C. C. H. Tang, "Backscattering from Dielectric-Coated Infinite Cylindrical Obstacles," *Journal of Applied Physics*, vol. 28, no. 5, pp. 628–633, 1957.

Acknowledgements

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