Towards *Pactive* (Passive + Active) Sensing for Security Applications

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***Abstract*—This report summarizes the progress of the project proposed for the 2019 IEEE MTT-S graduate fellowship. The project aims to demonstrate a new technique, called *pactive* (passive + active) sensing, to better identify and classify concealed items for security screening of human beings. Efforts made to improve the accuracy of the passive and active subsystems are reported. Calibration techniques are developed to achieve range resolution of 2.5 cm and temperature resolution less than 0.5 K. Electromagnetic models of concealed items that are approximated as stratified dielectric layers are developed. As the project progresses, these models will be used to extract the complex permittivity and thickness of the concealed item.**

***Index Terms*—*Pactive* sensing, radar, radiometer, security sensing, electromagnetic modeling.**

I. INTRODUCTION

INCREASING threats of terrorism and contraband smuggling have led to a growing interest in millimeter wave/ THz active and passive security sensors. This work aims to contribute to security sensing by developing a *pactive* sensor that combines active and passive modes into one system where multi-mode measurements will be used in a complementary fashion to predict the material properties and thickness of concealed objects. *Pactive* sensing reduces measurement ambiguity in stand-off measurement scenarios (Fig. 1 (a)) [1]. Items that are unresolved by one mode can potentially be detected by the other. For example, consider Fig. 1 (b) where the same material with different thicknesses backed by skin is measured. If the measurement consisted only of passive sensing, the two situations would appear identical. This ambiguity is resolved using the active measurement. In practice, extracting the permittivity and thickness of the material from the *pactive* data in Fig. 1(b) requires highly accurate sensors. This report summarizes the efforts made towards building such highly accurate sensors for the *pactive* sensing.

II. PACTIVE SENSOR: DESIGN AND CALIBRATION

Passive and active subsystems for the *pactive* sensor are designed in the K-band of the frequency spectrum using commercially available off-the-shelf components. Calibration techniques to improve the performance of these systems are developed and implemented.

A. Active Sensor

The active sensor is a frequency modulated continuous wave (FMCW) radar operating in the 18 – 26 GHz frequency range [SPIE, WAMICON 2018]. The block diagram of the prototype radar is shown in Fig. 2 (a). The waveform transmitted by the radar is linear chirp with 8 GHz of bandwidth resulting in a theoretical resolution of 2 cm. However, imperfections in the RF front-end such as non-linear phase response of filters, gain ripple in amplifiers, etc., distort the chirp resulting in degraded resolution. To correct system-induced distortions, a Hilbert transform based calibration technique is implemented [2]. The uncalibrated and calibration range profiles (received signal amplitude vs depth) for a metallic object placed at approximately 2.5 m away from the radar is plotted in Fig. 2(c).

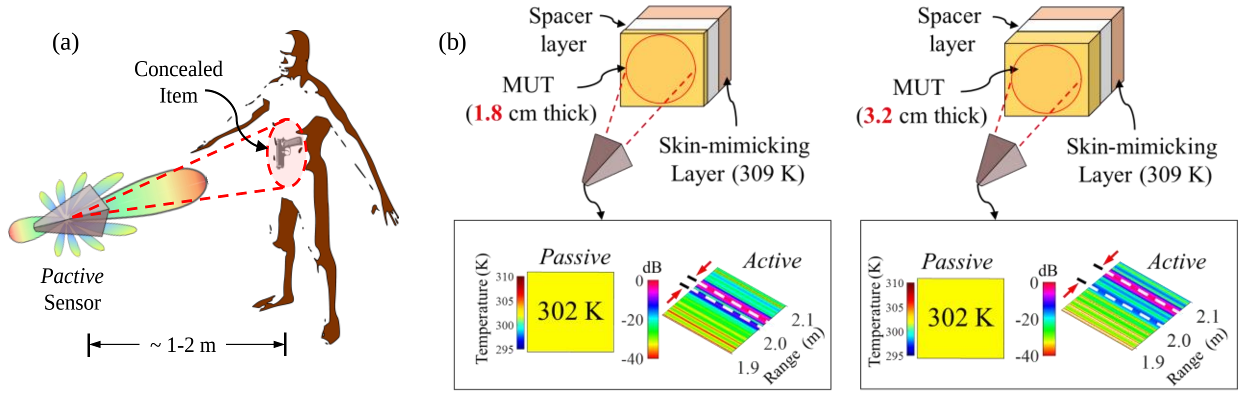

Fig. 1. (a) A typical sensing scenario in security screening of human beings (b) The region observed by the *pactive* sensor is modeled as a stratified dielectric layer along with the passive and active responses in the corresponding inset. The two structures are indistinguishable using the passive sensor alone, but the active sensor is able to differentiate the two.

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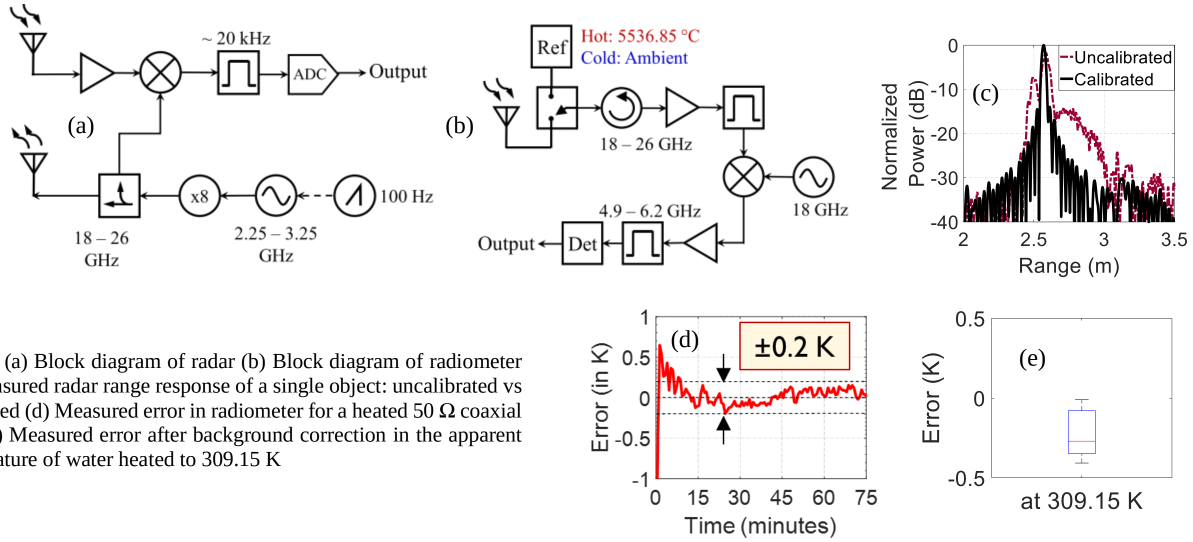

Fig. 2. (a) Block diagram of radar (b) Block diagram of radiometer (c) Measured radar range response of a single object: uncalibrated vs calibrated (d) Measured error in radiometer for a heated 50 Ω coaxial load (e) Measured error after background correction in the apparent temperature of water heated to 309.15 K

The uncalibrated response is spread out in range potentially obfuscating any objects behind it. With calibration, a sharp peak is noticed. Measured range resolution of 2.5 cm is reported using the calibration technique, which is close to the theoretical value.

B. Passive Sensor

The passive sensor is a total power radiometer with a center frequency of 23.55 GHz and bandwidth of 1.3 GHz [3]. The block diagram of the radiometer is shown in Fig. 2 (b). The radiometer estimates noise temperature by measuring noise power. In order to correct for fluctuations in system gain, the radiometer is continuously calibrated using a diode noise source in the ON and OFF states. Additional calibrations are performed to correct systematic as well background-dependent errors as follows:

- *Radiometer System Equation (RSE):* An equation to correct for front-end mismatch and temperature-dependent insertion loss contributions is derived in [3]. Accurate measurement of S-parameters of the front-end components is necessary for this technique. The RSE is validated experimentally using a 50 Ω coaxial load inserted in heated water. The error in the temperature of the load, shown in Fig. 2 (d), is measured and shows that the RSE results in an overall error of only ±0.2 K.
- *Background Correction:* A novel calibration technique to correct for background noise contributions is derived in [4]. This technique is experimentally validated by extracting the temperature of hot water at 309.15 K placed ~ 2 m away from the radiometer. The error measured over different trials is plotted in Fig. 2 (e) and shows that absolute error less than 0.5 K can be achieved.

III. ELECTROMAGNETIC MODELING

With highly accurate passive and active subsystems in place, techniques to extract meaningful data from *pactive* measurements are being explored. Scattering and radiative transfer models for concealed items approximated as a planar dielectric layer backed by a skin-mimicking layer are studied to predict sensor response (Fig. 1 (b)). Experimental validation of the models is currently underway, following which inverse models will be developed to extract the complex permittivity and thickness of the concealed object.

IV. IMPACT OF FELLOWSHIP AND CAREER PLANS

Receiving the 2019 IEEE MTT-S Graduate Fellowship is a true honor. This fellowship directly impacted the publications [3] and [4], and a journal publication consisting of experimental validation of the electromagnetic model is also currently underway. The fellowship provided me with the opportunity to attend the 2019 International Microwave Symposium at Boston, where I was able to connect with other researchers in the field and broaden my professional network. I also had the opportunity to interact with undergraduate students attending the conference as part of Project Connect and share my experience as a graduate student.

Upon completion of my doctoral degree, I intend to pursue an academic career in applied electromagnetics either through a postdoc appointment or a tenure track position at a teaching and research university. I enjoy teaching and I hope to teach both graduate and undergraduate level electromagnetics and microwave circuit design courses.

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