Poster Abstract: Material Identification with Commodity Wi-Fi Devices

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ABSTRACT

Target material identification is playing an important role in our everyday life. This paper introduces a device-free target material identification system, implemented on ubiquitous and cheap commercial off-the-shelf (COTS) Wi-Fi devices. The intuition is that different materials produce different amounts of phase and amplitude changes when a target appears on the line-of-sight (LoS) of a radio frequency (RF) link. However, due to multipath and hardware imperfection, the measured phase and amplitude of the channel state information (CSI) are very noisy. We thus present novel CSI pre-processing schemes to address the multipath and hardware noise issues before they can be used for accurate material sensing. Comprehensive real-life experiments demonstrate that we can identify 10 commonly seen liquids at an overall accuracy higher than 95% with strong multipath indoors.

CCS CONCEPTS

• **Computer systems organization** → **Sensors and actuators**;

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1 INTRODUCTION

Target material identification plays an important role in many IoT applications. At the airport, explosive detection is critical at the security checkpoint [3]. With material identification, a robot can smartly reduce its strength when picking up a fragile item such as an egg [2]. Fine-grained material identification can even be applied to differentiate very similar items such as Pepsi and Coke without a taste [4]. With fine-grained material sensing, expired liquid such as milk can be detected without requiring to open the bottle or taste it. Recently, work [4] and work [1] explored the possibility of employing RFID and UWB signals for material identification. It was a plausible step in this direction, but we still believe Wi-Fi is the most promising candidate as it is ubiquitous and no any dedicated infrastructure is needed. Therefore, in this work, we ask the question: *can we accurately identify a target's material with cheap commodity Wi-Fi devices*?

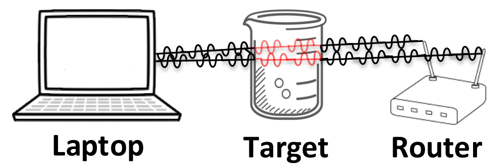

Figure 1: Example application of Our system.

In this paper, we introduce a commodity Wi-Fi based device-free target material identification system, as shown in Fig. 1. To identify the target material, the key observation is that different materials cause different amounts of phase and amplitude changes [4]. However, different from the previous method which employs directional RFID transmissions for material identification, commodity Wi-Fi employs omni-directional antennas and thus multipath effect is much more severe. Furthermore, both signal phase and amplitude readings from commodity Wi-Fi devices are very coarse and noisy, which make them not suitable for fine-grained material identification. We propose methods to address this challenge and evaluate the method performance in real-world environment. The experiments demonstrate that our system is able to identify 10 commonly seen liquid materials at a higher than 95% average accuracy in a lab environments.

2 SYSTEM DESIGN

2.1 The CSI Change through Target

The *CSI phase change* is the difference between two phase readings, which are measured before and after a target appears at the LoS link. Let ϕ_{tar} and ϕ_{free} be the phase readings when there is a target and when there is no target, the

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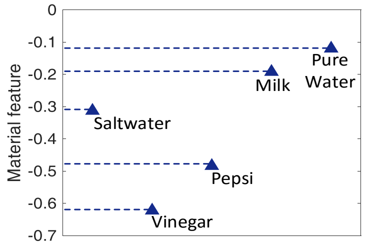

Figure 2: The material features for five different materials.

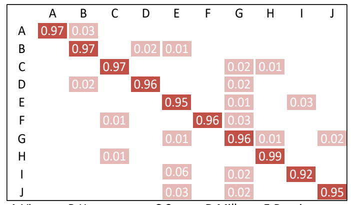

Figure 3: Identification performance for 10 liquids.

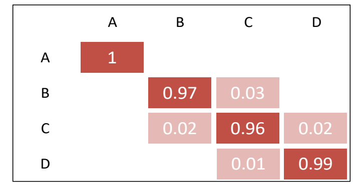

Figure 4: Identification performance with different concentrations of brine.

phase change $\Delta\phi$ can now be calculated as:

$$\Delta\phi = \phi_{\text{tar}} - \phi_{free} = \left[2\pi \cdot \frac{(L-D)}{\lambda_{free}} + 2\pi \cdot \frac{D}{\lambda_{tar}} - 2\pi \cdot \frac{L}{\lambda_{free}}\right] = D \cdot 2\pi\left(\frac{1}{\lambda_{tar}} - \frac{1}{\lambda_{free}}\right) \quad (1)$$

where λ_{tar} and λ_{free} are the wavelengths in the target and in the air, respectively. L is the distance between the transmitter and the receiver and D is the path length inside the target.

For different target materials, the *CSI amplitude change* are also different. Generally, the amplitude has an $e^{-\alpha}$ attenuation over a unit prorogation distance inside the target, where α is the attenuation constant related to the target material. We define the measured signal amplitudes before and after the target appears on the RF link as A_{free} and A_{tar}, we can obtain the RSS change (ratio) in dB as:

$$\Delta R = 20 \times \log \frac{A_{tar}}{A_{free}} = 20 \times \log \frac{A_s e^{-\alpha_{free}(L-D)} e^{-\alpha_{tar} D}}{A_s e^{-\alpha_{free} L}} = 20 \times \log e^{-D\left(\alpha_{tar} - \alpha_{free}\right)} \quad (2)$$

where A_s denotes the amplitude of the original transmitted signal. α_{tar} and α_{free} represent the signal attenuation constants in the target and in the air, respectively.

2.2 Target Material Identification

We design a new material identification feature for the commodity Wi-Fi systems. We consider a two-antenna AP communicates with a single antenna Wi-Fi device. D_1 and D_2 respectively represent the propagation distances inside the target for antenna1 and antenna2.

Thus, based on Equation (1) and (2),we calculate the phase difference and amplitude ratio between the two antennas to obtain the following equations:

$$\Delta\theta = \Delta\tilde{\phi}_1 - \Delta\tilde{\phi}_2 \quad (3)$$

and

$$\Delta\Psi = \frac{\Delta A_1}{\Delta A_2} \quad (4)$$

Thus, based on Equation (1) and (2),we calculate the phase difference and amplitude ratio between the two antennas.

Inspired by [4], we design a parameter $\bar{\Omega}$ which can be calculated with just the amplitude ratio and phase changes.Based on Equation (3) and (4),we can calculate the parameter $\bar{\Omega} = \frac{-\ln\Delta\Psi}{\Delta\Theta + 2\gamma\pi}$ where γ is a integer.

Further, we conduct a group of benchmark experiments to demonstrate the availability of the material feature $\overline{\Omega}$ in the lab environment. The results in Fig.2 illustrates that the material features $\overline{\Omega}$ can be taken as an effective reference to identify the target material. Finally, our system incorporates the material database and uses the SVM classifier to identify the target material.

3 PERFORMANCE EVALUATION

Hardware setup: The system setup is shown in Fig. 1. Our system using a commodity Wi-Fi device TP-link WR890N router as transmitter and a laptop with an Intel 5300 Wi-Fi NIC as receiver. The laptop is placed 2 m from the router, and the tested target is placed at the LoS RF link. The plastic beaker has a diameter of 14.3 cm and a height of 23 cm.

Evaluation: We evaluate the material identification performance in the lab environment. Fig. 3 presents the identification results for ten different liquids. Our system achieves an average accuracy of 96%. Furthermore, we pour three different concentrations of saline water (1.2g/100ml, 2.7g/100ml and 5.9g/100ml) into the same glass container. The identification results are shown in Fig. 4 and we can see that the system can still achieve higher than 95% accuracy.

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