Demo Abstract: E-Eye: mmWave Nonlinear Response for Hidden Electronic Device Recognition

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ABSTRACT

Hidden electronics possess the risk of both security threat and privacy intrusion. We present a wireless hidden electronic recognition system, through electronic components unique mmWave nonlinear responses to identify the threats. We then evaluate E-Eye's performance and robustness with a controlled experiment and a field study using iconic devices and score the system with metrics. Results prove that E-Eye is an accurate and robust hidden electronic recognition system.

1 INTRODUCTION

This demo is based on our published work [4]. Countless security and privacy breaches from hidden electronic devices have caused both financial and sociological problems [1, 2]. From hidden camera and microphone eavesdropping in private zones to remote weapons in camouflage causing deaths and injuries, brutal lessons urge the need to recognize hidden e-devices before more victims are harmed. Current methods utilize security gate at the entrance to detect and eliminate malicious objects such as X-ray detector, metal detector, and Infrared detector are limited in recognition ability, application feasibility, and personal safety [7].

E-Eye is based on electronic devices (e-devices) emitting a unique nonlinear response at the interrogation of mmWave. As shown in Fig. 3, E-Eye starts with transmitting interrogation signal from the Tx terminal of the mmWave probe, as the signal reaches each e-devices, a nonlinear response is generated from each of the devices. Once the nonlinear response is received at the Rx terminal of mmWave probe, recognition of hidden e-devices is performed.

The crux of E-Eye is the nonlinear response of each e-devices, which bases on the unique pattern of electronic components in their printed circuit boards (PCB). Each of the electronic components of the PCB contributes to the nonlinear response by reflecting the interrogation signal, this results in a response signal that describes the pattern in the form of electromagnetic wave. Such reflection property of e-devices serves as their descriptor, which definitively

grants their signal modulation to be unique. The modulated signal is reflected to mmWave probe from the e-devices, allows recognition infer the responding e-devices.

Figure 1: E-Eye's hidden electronic recognition examples.

2 SYSTEM DESIGN

The system accomplishes hidden e-devices recognition through four stages, nonlinear response acquisition, signal-wavelet transform, feature extraction, and device classification.

Nonlinear Response Acquisition: We implement the 24 GHz mmWave radar that accommodates typical trace length of PCB to capture the unique nonlinear response from e-devices. As shown in Fig. 2, the radar probe sends interrogation signal through its Tx port, and collects response signal with its Rx port.

Wavelet Transform: We implement wavelet transform of nonlinear response signal to decompose it into sub-bands for better analysis. The reconstruction of nonlinear response from the collection of wavelet functions is formulated by Eq. (1):

$$\underbrace{y(t)}_{\text{Nonlinear response}} = \underbrace{\frac{1}{C_\phi} \int_{-\infty}^{\infty} F_W(a_0, b) \phi_{a_0, b} \frac{db}{\sqrt{a_0}}}_{\text{The approximation part}} + \underbrace{\frac{1}{C_\psi} \int_{a_1}^{\infty} \int_{-\infty}^{\infty} F_W(a, b) \psi_{a, b} \frac{da}{a^2} \frac{db}{\sqrt{a}}}_{\text{The detail part}}, \quad (1)$$

where t is time, $y(t)$ is the nonlinear response in spectral-temporal domain from electronic device [6]. $F_W(a, b)$ is the time-scale map coefficients, a and b are the scale and translation parameters. $\phi_{a, b}$ and $\psi_{a, b}$ are the mother wavelet functions for approximation part and detailed part that utilizes C_ϕ and C_ψ constants, respectively.

Feature Extraction: We implement 13 scalar features in spectral-temporal domains to characterize each nonlinear response. The spectral features are responsible for spectral-frequency related characteristics of a wavelet, whereas the temporal features are responsible for property in an amplitude-time relationship as shown in Table 1. In addition, we adopt 10 Mel-Frequency Cepstral Coefficients

The video link: "https://youtu.be/apgRH3cDKdQ".

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SenSys '19, November 10–13, 2019, New York, NY, USA

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ACM ISBN 978-1-4503-6950-3/19/11...\$15.00

https://doi.org/10.1145/3356250.3361932

Figure 2: Difference in nonlinear response from three typical e-devices and one 3D printed object in spectral analysis.

Table 1: Feature List for nonlinear response recognition

Domain	Features
Spectral	Flatness, Crest Factor, Skewness, Kurtosis, Mean Value, Standard Deviation (STD), MFCC-10
Temporal	Skewness, Kurtosis, RMS Amplitude, Lowest Value, Mean Value, Highest Value, STD

(MFCC-10) which describes the nonlinear response in auditory field. The total of 46 features, with 23 for approximation part and 23 for detail part enables accurate recognition of hidden e-devices.

Hidden Electronic Recognition: We label each electronic device by their extracting their features and fit the feature data into a Support Vector Machine (SVM) for accurate classification. To train the SVM, we use a Gaussian radial basis function kernel to fit the extracted features. After the model is established, recognition of an electronic device is done within few milliseconds using the prediction function.

3 EVALUATION

Figure 3: Device Setup for sensing.

As the development of 5G network scales, mmWave radar is also used toward identification in many scenarios [3, 5, 8]. We utilize a 24 GHz mmWave radar with industrial, scientific, medical (ISM) band. The electronic devices are placed in cloth sleeves, paper packaging, plastic wrap, or obstructed with 1-inch wood piece for interference. We utilize 40 devices from multiple groups of electronic devices to perform inter-group classification and intra-group classification. We display the recognition result with confusion matrices as shown in Fig. 4. The result collected from the model prediction of 40 devices with 100 samples from each device. The percentage accuracy of the classification was 99.9% for both inter-group and intra-group classification. Result proves that E-Eye's capability in accurately recognizing hidden electronic devices. To display the process of hidden electronic device recognition, we prepared a demo video ([video link attached](#)).

Figure 4: Confusion matrix for prediction result of 40 electronic devices. Deeper color represents higher occurrence.

4 CONCLUSION

Our work examines and confirms the recognition of hidden electronic devices using unique nonlinear response. Our developed system allows hidden device recognition with various occlusion and interference. The technology can be applied widely due to its low-cost and non-human harming nature.

ACKNOWLEDGEMENT

We thank our anonymous reviewers for their insightful feedback. This work was in part supported by the National Science Foundation under grant No. 1718375/1718483.

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