Demo: Mobile Device Identification via Wireless Charging Fingerprints

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Abstract

Recent years have witnessed the increasing penetration of wireless charging base stations in the workplace and public areas, such as airports and cafeteria, to allow users to charge their mobile devices. Such an emerging wireless charging infrastructure has presented opportunities for developing new indoor localization and identification services for mobile users. In this demo, we present QID, the first system that can identify a Qi-compliant device during wireless charging in real-time using features extracted from the clock oscillator and control scheme of the power receiver. QID employs 2-dimensional motion unit to regulate the inductive coupling between the power transmitting and receiving coils, which allows for fine-grained device fingerprinting.

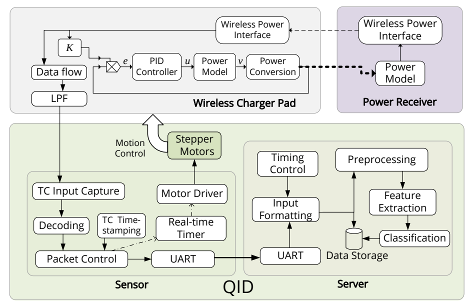

Figure 1. System diagram

1 Introduction

Recent years have witnessed the increasing penetration of wireless charging base stations in public areas like office buildings, restaurants, and airports, etc. [6]. These is also a trend to embed wireless charging base stations in furnitures like desks and tables [1, 4]. This emerging wireless charging infrastructure has presented new opportunities for precise user localization, where the base station learns the location and identification of the mobile device being charged. For instance, a coffee shop may recognize its customers when they charge their phones on the coffee table and provides customized services or location-based advertisements. Such ability to provide high localization accuracy, high reliability at low deployment cost enables a wide range of applications such as smart buildings, customer behavior tracking, and personalized advertisements.

To leverage the wireless charging infrastructure for user identification, a key challenge is to reliably identify the wireless charging unit of mobile devices. Unfortunately, unlike network interfaces such as Wi-Fi and Bluetooth that have unique and fixed hardware addresses, the wireless charging unit of commercial off-the-shelf (COTS) mobile devices typically does not have a fixed hardware ID. For instance, according to the Qi standard [5], the identity of a power receiver (PRx) is defined by a Basic Device ID, which can be a software-generated random sequence that may change each time the PRx is booted.

In this demo, we present QID – the first practical system that reliably identifies Qi-compliant mobile devices based on the hardware fingerprints. Specifically, QID augments the standard-compliant wireless charging base station to extract features from the oscillator, coil, and controller of a Qi-compliant PRx, while requiring no retrofitting or modification to the mobile devices. QID employs a 2-D motion controller to regulate the inductive coupling between the power transmitter (PTx) and PRx coils, which allows for fine-grained fingerprinting of the PRx while optimizing the efficiency of power transfer. Experimental results on 52 devices show that QID achieves an accuracy of up to 89.1%.

2 System Design

It's challenging to recognize a mobile device from the Qi charger due to the intrinsic characteristics of wireless charging environment:

- The wireless power transfer introduces noise in the hardware-level features, resulting in overlapping feature values among different devices.
- The wireless power transfer process is usually stabilized at an operating point within hundreds of milliseconds,

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which does not cover enough data points in the feature space and eventually raises the recognition error rate.

- The feature values depends on the phone placement. If the user alters the position of the mobile device, the feature values can change dramatically.

It is difficult, if not impossible, to identify a mobile device under wireless charging using hardware-level features without addressing these challenges.

2.1 System Overview

We now provide an overview of the QID system. The system architecture is shown in Figure 1. It consists of 3 components, namely a COTS Qi wireless charger, the QID sensor, and the QID server. The QID sensor is responsible for collecting a selected set of features from wireless charging and uploading the data to the server, while the QID server is responsible for the feature extraction and device classification. The QID server can connect to the QID sensor directly (e.g., through UART) or resides on the cloud and communicates with multiple QID sensors through the Internet, enabling tracking the target device at different charging locations.

2.2 Fingerprints Acquisition and Classification

The selected fingerprints should be device-specific, time-invariant and discriminative. Specifically, we select the follows:

- **Onboard oscillator**. It is well known that oscillators have distinctive drifts due to factors like hardware manufacturing variations [3, 2]. Specifically, QID sensor timestamps the Control Error Packet (CEP) sent by the PRx and calculates the CEP time interval as features.

- **Receiving coil**. Different Qi-compliant devices may have different coil shapes, diameters, and layouts. In our scenario, the PRx coil diameter can be fingerprinted based on the interacting area between the PTx and PRx.

- **PRx controller**. The PRx controller are vendor-dependent. We observe that the pattern of packet values in the CEPs do differ across devices of different manufacturers, which makes it an auxiliary feature.

To acquire these fingerprints, we design a 2-dimensional movement control unit to adjust the position of the PTx coil with respect to the PRx coil. Such design requires two linear slides powered by a stepper motor individually, as shown in Figure 2. First, the bottom slide is fixed on a surface. Next, the upper slide is placed with its axis direction perpendicular to that of the bottom one. Finally, the charger coil is attached to the slider of the upper linear slide. The movement unit enables fine-grained feature acquisition. It can also record fingerprints from all of the contact area between the PTx and PRx, such that it tackles the aforementioned challenges. In each round, QID sensor moves the PTx coil along a designated trajectory. All the aforementioned PRx fingerprints will be collected along with the movement. The data points collected during one round will be uploaded to the QID server to be further processed and classified.

In QID server, we apply Gaussian Kernel Density Estimation (KDE) to both the CEP time intervals and the CEP packet values, where the values with highest probabilities are chosen as our classification features. We design an ensemble classifier, where a voting system is applied to multiple classifiers to get the final class decision. Figure 3 shows the evaluation results of 52 Qi-compatible mobile devices.

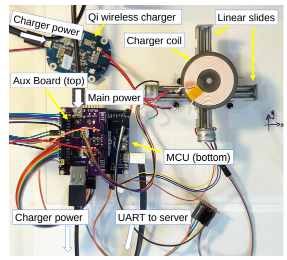

Figure 2. A prototype of QID sensor.

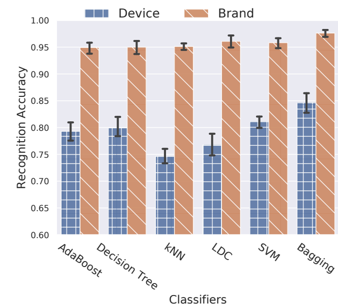

Figure 3. Recognition rate of 52 Qi-compatible devices from 7 brands.

3 Demo Setup

The demo uses the Atmel SAMG53N19 MCU at the center of the QID sensor. It is responsible for decoding and timestamping packets, driving the stepper motors, and sending collected data to the QID server via UART. We choose a COTS GMYLE Mini Qi Charging Pad as the PTx, which is connected to the MCU via a data flow debug pin. At the server side, the `pySerial` UART library and `scikit-learn` library are adopted for communication and classification.

4 Conclusions

In this demo, we present our design and implementation of QID, the first system that recognizes Qi power receiver during wireless charging using fingerprints from the onboard oscillator, coil characteristics, and control scheme of the wireless charging system. Our evaluation results show that QID achieves a high overall accuracy of both device and brand recognition. Therefore, we demonstrate the feasibility of leveraging public wireless charging infrastructure for tracking mobile users and providing ID/location-based services.

5 References

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Appendix: Demo Setup

This page shows the requirement of the demo.

Hardware Used

We use the following hardware to demonstrate QID:

- A laptop that runs the QID server software, performing the feature extraction and device classification task.
- The QID sensor. We have already implement a prototype of QID sensor. We will bring it to the venue if this demo is accepted.
- Qi-compatible devices. We will bring about 10 of these devices for the demo.
- An outlet for power.

Space Needed

A desk with 80 cm $\times$ 50 cm.