PerfLoc: A Comprehensive Repository of Experimental Data for Evaluation of Smartphone Indoor Localization Apps

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***Abstract*—Smartphones are an important target platform for research and development of indoor localization solutions. Due to the large diversity of smartphone hardware and OS services, making general statements about the performance of indoor localization algorithms in different environments remains very challenging. In this work we present a comprehensive repository of measurement data which can be used for indoor localization, collected with four Android phones. It contains time-stamped traces of the values of all built-in sensors that are available on these phones, along with RF signal strength data from Wi-Fi and cellular networks and GPS fixes, whenever available. The data collection took place in four different buildings and according to a diverse set of mobility scenarios. After a quality assurance step through post-analysis and validation, the collected data is made available to the R&D community through a dedicated web portal. In the near future, the same portal will also be used for remote evaluation of indoor localization apps in accordance to the ISO/IEC 18305 standard.**

I. Introduction

Location awareness is an integral function of many modern systems and Location Based Services (LBS) is a growing market with multi-billion dollar potential. Outdoors, Global Positioning System (GPS) has proven its effectiveness in a wide range of domains but it does not work inside buildings. As a result, indoor localization has attracted significant attention in research and development in recent years. Prominent usage scenarios are found in search and rescue operations, equipment and personnel tracking in hospitals and mines, and increasingly in different Internet of Things (IoT) applications. Due to the rich sensing and processing capabilities and their rapid proliferation, many of these solutions are being developed using smartphones as their main target platform. The fair evaluation of smartphone-based Localization and Tracking System (LTS), however, remains very challenging, hampering their wider adaptation. The performance of such systems is affected by a wide range of factors, such as building construction material or different mobility scenario of the node to be localized (walking, running, crawling, etc.). Despite the existence of a standardized evaluation methodology, as defined by the upcoming ISO/IEC 18305 standard, many developers of indoor localization apps lack access to hardware and testing environments necessary to cover the broad mix of conditions that their system might be exposed to. In the presented work, we aim to address this problem by (i) making available to the R&D community a rich repository of smartphone sensor data, RF signal strength data, and GPS fixes collected in accordance to the procedures outlined in the ISO/IEC 18305 standard and (ii) by developing a web portal that can be used for automated remote evaluation of indoor localization apps operating on the collected datasets.

II. Data Collection

We utilized four buildings for the data collection: an office building, two industrial shop- and warehouse-type buildings and a subterranean structure. These buildings were instrumented with more than 900 test points (further called dots) that are installed on the floors. The precise locations of these dots are known to NIST. To capture some of the diversity in available smartphone hardware like built-in sensors and RF circuitry, in our data collection we used four Android phones: LG G4 (LG), Motorola Nexus 6 (NX), OnePlus 2 (OP) and Samsung Galaxy S6 (SG). To facilitate fair comparison, we performed the measurements on all phones concurrently, wiring the devices in parallel to a mechanism for simultaneous timestamping of the measurements. Armbands were used to attach the four phones to the two arms of the test person, as shown in Figure 1.

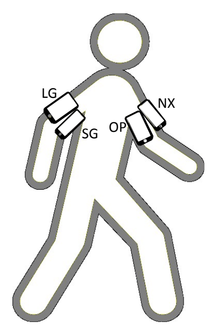

Figure 1: Device placement on the test subject's body

Two types of datasets were collected, one for training and one for testing. In addition to the timestamped data traces, the training dataset provides the ground-truth locations of the dots during a measurements run and will allow app developers to develop and configure their systems. For the testing datasets, the ground-truth locations will not be publicly provided. Instead, the developers will be asked to upload their location estimates to the PerfLoc web portal for a given time instance, and will be automatically evaluated with the help of the ground-truth data that has been held back.

A subset of the 14 Test & Evaluation (T&E) scenarios described in ISO/IEC 18305 were used because some scenarios did not apply to our data collection campaign. Including the training data, we collected data over 38 T&E scenarios in the four buildings.

For each scenario in each building we generated six categories of data on each smartphone: Wi-Fi, Cellular, GPS, Dots, Sensors and Metadata. This data is stored as one or more Google's Protocol Buffer Messages in a separate file for each data category.

1) **Wi-Fi data:** Signal strengths measured from Wi-Fi access points (APs) in range and other information provided by the APs operating at 2.4 and 5 GHz channels.
2) **Cellular data:** Identity information and signal strengths measured from cellular network signals.
3) **GPS data:** GPS location fixes.
4) **Dots:** Timestamps at dots visited during a scenario.
5) **Sensors:** Values from the built-in environmental, position, and motion sensors.
6) **Metadata:** Context information like building ID, scenario ID, device's manufacturer, model, ID, brand, etc. and initial barometer value (if the smartphone has one).

III. Data Validation

Prior to the start of our extensive data collection campaign, we took certain measures to ensure that the data we were getting from the phones was sound. These included sanity checks of the sensor data, like acceleration or gyroscope and environmental sensors. Later we checked the similarity of the measurement readings across different devices. We computed Spearman's correlation coefficient and corresponding p-values for all six pairs of devices and observed reasonably high correlation between sensor readings. The correlation across the readings from different devices is also evident from the raw data plots. For example, Figure 2 shows the RSSI values measured on the four phones from a single Wi-Fi access point (the one with maximal number of observations), with evident cross-correlation of the values. Similarly, Figure 3 shows high correlation for the acceleration magnitude samples (i.e. l_2-norm of the x, y, and z acceleration samples).

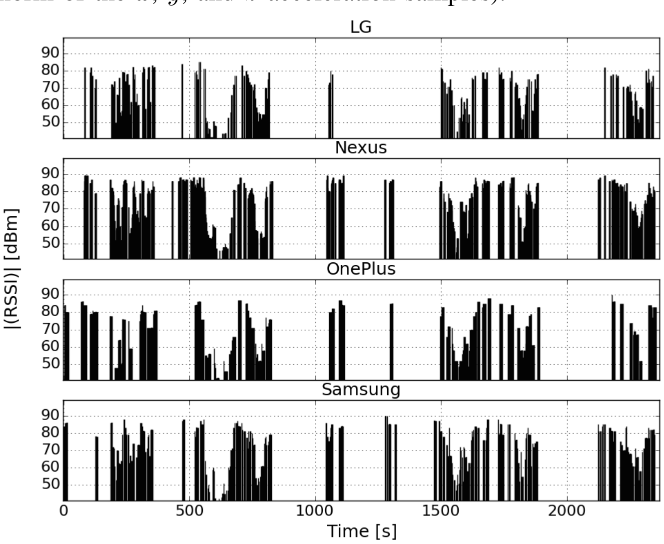

Figure 2: Wi-Fi data trace

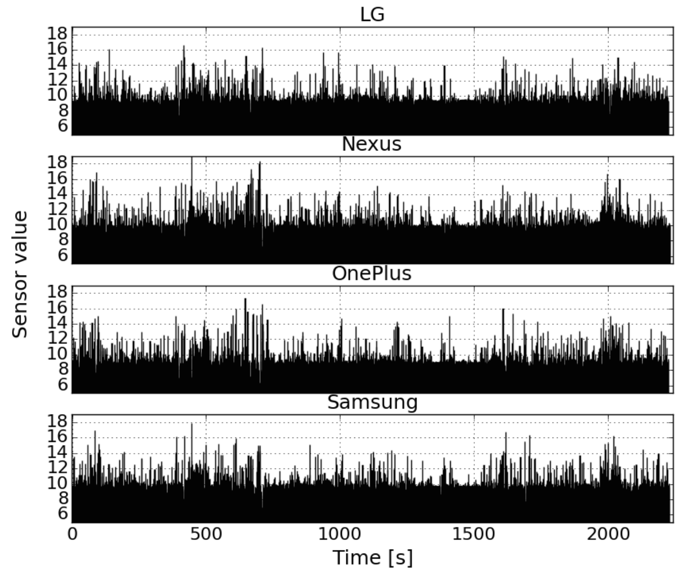

Figure 3: Accelerometer data

IV. Conclusions

This data that we have collected and are making available to the R&D world is truly unique. The dedicated resources were substantial and included instrumenting four large buildings, covering about 30,000 m^2 of space, with 900+ test points, having the locations of the test points professionally surveyed, and spending about 200 man hours on data collection using four Android phones after months of preparation. The collected data has been analyzed and we have confirmed its validity. This data will be soon made publicly available to researchers and developers across the world so it can be used in the development of smartphone-based indoor localization systems. As an ongoing work, we are developing a web portal for comprehensive automatic performance evaluation of indoor localization apps based on the ISO/IEC 18305 standard.

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose. The scenarios involved different modes of mobility: 1) walking to a dot and stopping for 3s before moving to the next dot; 2) walking continuously and without any pause throughout the course; 3) running / walking backwards / sidestepping / crawling part of the course; 4) "transporting" the four phones on a pushcart; 5) using elevators, as opposed to stairs, to change floors; 6) leaving the building a few times during a scenario and then reentering through the same door or another.

The full version of this paper has been accepted for publication in 27th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) on 4-7 September 2016 in Valencia, Spain.