Article Summary

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Context-Aware Sensing and Implicit Ground Truth Collection: Building a Foundation for Event Triggered Surveys on Autonomous Shuttles

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Abstract
The LINC project aims to study interactions between passengers and autonomous vehicles in natural settings at the campus of Technical University of Denmark. To leverage the potential of IoT-components in smartphone-based surveying, a system to identify specific spatial, temporal and occupancy contexts relevant for passengers’ experience was proposed as a central data collection strategy in the LINC project. Based on predefined contextual triggers specific questionnaires can be distributed to affected passengers.
This work focuses on the discrimination between two fundamental contexts for LINC passengers: be-in and be-out (BIBO) of the vehicle.
We present empirical evidence that Bluetooth-low-energy beacons (BLE) have the potential for BIBO independent classification. We compare BLE with other smartphone onboard sensors, such as the global positioning system (GPS) and the accelerometer through: (i) random-forest (RF); (ii) multi-layer perceptron (MLP); and (iii) smartphone native off-the-shelf classifiers.
We also perform a sensitivity analysis regarding the impact that faulty BIBO ground-truth has on the performance of two supervised classifiers. Results show that BLE and GPS could allow reciprocal validation for BIBO passengers' status. This potential might lift passengers from providing any further validation. We describe the smartphone-sensing platform deployed to gather the dataset used in this work, which involves passengers and autonomous vehicles in a realistic setting.

Background and purpose of the article
A fleet of autonomous shuttles received approval for public operations at the Technical University of Denmark, starting April 2021. The trial is conducted as a part of the UIA funded\textsuperscript{1} LINC project\textsuperscript{2} with the purpose of studying future scenarios involving shared autonomous vehicles and their impact on society. To collect relevant user data and the information necessary to successfully pursue the project goals, LINC deployed a context-aware smartphone-based travel survey (SBTS) integrated with the autonomous vehicles and other Internet of Things (IoT) components—(i.e.) Bus Stops and Buildings—through Bluetooth low energy beacons (BLE) technology \cite{1}.

The implications of introducing context-aware smartphone-based travel surveys (SBTS) in the field of shared autonomous travel are very broad. Detection of spatial and temporal occupancy contexts can be leveraged to submit specific surveys to users who have had specific types of exposure to the service which can potentially reduce known problems with hypothetical bias and status quo bias in user data \cite{2, 3}. Some examples of specific areas where this method provides opportunities to advance understanding of users travel behavior are: (i) the potential of improving public service through responsive time schedule; (ii) the effects of driverless shuttle service on social inclusiveness \cite{4}, perceived safety and security in specific contexts \cite{3, 5} (e.g. darkness, presence of other passengers, unexpected driving patterns, emergency stops); and (iii) the impact on user’s future transportation mode and route choices \cite{3, 6}.

To monitor passengers' presence aboard a vehicle—representing the basic context of interest for LINC common solutions—require users' explicit interactions with a device, e.g., to check-in/check-out (CICO), or the implicit interaction with a device detecting, e.g., walk-in/walk-out (WIWO). This work focuses on the implicit interaction between BLE and passengers' smartphones, which we identify with be-in/be-out (BIBO) \cite{7}.

\textsuperscript{1} Urban Innovative Action. Retrieved from web 01/01/2019 at https://uia-initiative.eu/en
\textsuperscript{2} LINC project. Retrieved from web 01/01/2019 at https://lincproject.dk
The study was conducted during the development phases preceding LINC operations. We describe the architecture of the smartphone sensing platform and the results of the experiments directed to assess BIBO detection with BLE and Global Positioning System (GPS) data, with respect to smartphone native activity recognition based on, e.g., accelerometer. The empirical validation of this architecture involved passengers and vehicles in a semi-controlled environment, set up to approximate a high congested urban area. Passengers were free either to walk or to travel on the autonomous vehicles. The environment included three bus stops and two buses operating on two routes, which intersected in one of the stops.

**Methods, analyzes and procedures used**

This section presents the sensing platform, consisting of the smartphone application used for data collection, and the BIBO sensitivity analysis method.

**Sensing platform Overview**

The data collection platform consists of several major components (see Fig. 1), firstly native smartphone applications handling system driven data collection on a per participant level. Secondly, several web services APIs providing live data from the autonomous shuttles and other sources. Thirdly, overlap between the aforementioned 2 data sources enables simple but context-aware services to prompt users for user driven data to be collected in the form of surveys.

The smartphone platform consists of two native apps for iOS and Android respectively coded in Swift and Java. Each application collects the same data namely, location, sensor data, activity and beacon proximity. The latter serving as a ground truth (GT) validation mechanism for collected data, providing a proximity measure to certain locations such as autonomous shuttles, buildings and public transport nodes (see Fig. 2).
BIBO sensitivity analysis
To assess BLE signal as independent measure for a BIBO system, we trained and evaluated under label-noise conditions two supervised ML classifiers: RF and MLP [9]. The process involved independently BLE received signal strength (RSSI) and GPS signals for both these classifiers. We used Monte Carlo simulations to assess the effect of various levels of noise causing labels' values to flip from BI to BO or vice-versa. Then we compared the performance of classifiers trained without flipped labels, against classifiers trained with flipped labels. As baseline, we referred to the native activity-classifier distributed with Apple and Android operating systems (OS), where BI corresponds to “automotive”, and BO to everything else [8]. As ground truth, we relied on high resolution video-cameras that recorded each user through his or her journey. The dataset consisted of 13,723 data points and high-quality ground.

Results
This work presents a feasibility and sensitivity study about a BIBO system. This system is based on the smartphone onboard sensors including BLE RSSI detected from an external BLE beacons network. The system relies on a full-stack sensing platform deployed for data collection and constitutes the foundation for a context-aware SBTS. Empirical evidence shows that the exclusive use of BLE for BIBO classification is more effective than smartphones’ native classifiers based on inertial sensors such as accelerometer, gyroscope and pedometer. GPS shows higher potential that comes at the cost of high battery consumption for the smartphone. Hence, future research should expose how to leverage available sensors to find the best tradeoff between BIBO accuracy and battery efficiency. As for now, BLE RSSI and GPS signals seem to enable independent BIBO classification, and reciprocal validation. Consequently, this platform could relieve passengers from BIBO ground truth collection and thus allow them to focus on other surveys, possibly BIBO-aware, and relevant for studying other aspects of their interaction with the autonomous vehicles.

Future perspectives on autonomous collective mobility utilizations
The scalability of BLE network involving for example bus and at bus stops only, represents a negligible cost per vehicle in the first case, and seems possible at the scale of metropolitan areas in the second case. Consequently, the combination of BLE, GPS and other sensors through smartphones could allow for practical applications such as implicit and unified ticketing systems in MaaS multimodal transport chains. This could ease the coexistence of different mobility providers on the same platform. At the same time, providing multiple independent measurements of passengers traffic flow, mobility patterns could be measured and validated, allowing for more reliable studies on demand predictions models. These qualities may support a more attractive public transport service and contribute to the reduction of transit time and cost for both the passengers and the system. Challenges such as privacy risks due to the concentration of passengers’ sensitive information under the same domain, or regarding the management of a shared BLE network, should also be addressed in future research.
References


