Poster Abstract: USN - an Extremely Large Sensor Network based on Urban Infrastructures for Smart Cities

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ABSTRACT

In this poster, we present an Urban Sensor Network (USN) from a board perspective, i.e., any device in urban infrastructures is considered as a pervasive urban sensor if it generates data about residents' locations. Built upon correlation and divergence among various urban sensors, we aim to provide unseen urban dynamics in fined-grained spatio-temporal resolutions to support novel smart cities services. As opposed to previous ad hoc sensor networks, our approach aims to establish USN in a modular architecture as a middleware with open interfaces to various lower level urban infrastructures, ensuing interoperability and flexibility, which are crucial prerequisites for higher level applications.

1. INTRODUCTION

According to the United Nation, we are in a rapid process of urbanization where 54% of people in the world had moved to urban areas by 2014 and this number is projected to rise to 70% by 2050. The White House announced the Smart Cities Initiative as a national strategic plan to explore new approaches to address urban challenges, e.g., traffic congestion and energy consumption [2]. To address these urban challenges, it is essential to capture real-time dynamic urban phenomena. In this poster, we present an Urban Sensor Network (USN) from a board perspective, i.e., any device in urban infrastructures (e.g., cellular, taxicab, bus and subway networks) is considered as a pervasive urban sensor if it generates data about residents' locations. As opposed to previous monolithic and closed ad hoc sensor networks [1], USN serves as a middleware with open interfaces to various lower level urban infrastructures, ensuing interoperability and flexibility. We implement such an USN in Shenzhen, the most crowded city in China based on its four infrastructures: a 10.4 million user cellular network, a 14 thousand taxicab network, a 13 thousand bus network, and an automatic fare collection system with 17 thousand smartcard readers and 16 million smartcards.

2. ARCHITECTURE

We outline the modular architecture of USN in Figure 2 where it consists of three modules, i.e., (i) Data Fusion, (ii) Data Analysis and (iii) Data Utilization. These three modules span the whole sensor data processing chain: (i) we first

transparentize the heterogeneity in four kinds of raw sensor data in order to obtain *harmonized information*; (ii) we then analyze the obtained information by extracting travel records to study resident spatiotemporal distribution and urban dynamics, which aims to produce *application specific knowledge*; (iii) we finally utilize the produced knowledge to motivate and guide the real-world service designs, e.g., inter-region transit, travel time prediction, etc. As a result, our approach builds an architectural bridge between a domain-independent sensor network and application-specific knowledge output tailored by end users. The details of three modules are given as follows.

(i) **Sensor Data Fusion:** We consider four kinds of devices as sensors in the data fusion module, and each kind of sensors detects urban residents from a unique perspective.

- **Cellphones as Sensors** are used to detect cellphone users' locations on cell tower levels based on call detail records when they use their cellphones.
- **Taxicabs as Sensors** are used to detect taxicab passengers' locations and real-time traffic based on taxicab status (i.e., GPS and occupancy).
- **Buses as Sensors** are used to detect bus passengers' locations by cross-referencing data of onboard smartcard readers for fare payments.
- **Smartcard Readers as Sensors** are used to detect a total of 16 million smartcards used by passengers to pay bus and subway fares at transit stations.

We show the number of active residents tracked by the above sensor data in 5 minute slots in Figure 1.

Figure 1: Active Residents in 24 Hours

Based on these four kinds of data, we introduce our data fusion module, which aims for an integration of multiple sensor data (i.e., cellphone, taxicab, bus and reader sensors) to infer urban dynamics (i.e., resident locations, traffic, etc) through a consistent representation. To this end, we utilize a unified tuple record as a generic abstraction $r = (id, l, t)$ where id is an ID for a cellphone, taxicab, bus or subway user; l is a location; t is a moment. A tuple r gives a generic

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Figure 2: Urban Sensor Network and its Data Processing Chain

travel record that a resident id was at a location l at a moment t . This abstraction produces harmonized information for the following data analysis.

(ii) **Sensor Data Analysis:** Built upon the sensor data fusion, we use two data analyses as examples of producing application specific knowledge in the data analysis module. First, we present a resident spatiotemporal distribution among 216 urban regions of Shenzhen as shown in Figure 3. The size of a vertex indicates the number of residents in an urban region, and the thickness of an edge indicates the volume of traveling. Second, we show the urban dynamic in Figure 4, which gives average traffic speeds during 6PM in 496 Shenzhen regions where a warmer color indicates a slower speed.

Figure 3: Resident Spatiotemporal Distribution

Figure 4: Traffic Speeds in Regions

(iii) **Sensor Data Utilization:** The data utilization module utilizes the application-specific knowledge from the data analysis module to support real-world services. For example, based on the resident spatiotemporal distribution, we

can design novel urban transit services to improve the urban efficiency. Figure 5 shows an implementation of a novel transit service called Inter Region Transit IRT in the TangLang subway station in Shenzhen based on the resident spatiotemporal distribution. IRT is designed to address the urban transit flaw by providing express non-stop transit services among region pairs, between which there is a high resident travel volume (obtained by cellphone sensor data) yet a low public transit volume (obtained by smartcard sensor data), indicating that the residents traveling between these region pairs usually use private vehicles and suffer from insufficient urban transit. IRT is potentially capable of reducing the travel time between these undersupplied region pairs by its non-stop transit service.

Figure 5: IRT Implementation

3. CONCLUSION

In short, the urban sensor network in Figure 2 suggests a novel view of building high-performance applications. We believe this urban sensor network has the potential to point out an interesting research direction by utilizing data from existing urban infrastructures, instead of *ad hoc* sensor networks, to support various real-world urban applications.

4. ACKNOWLEDGMENTS

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5. REFERENCES

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