On the Accuracy of Data Sensing in the Presence of Mobility

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***Abstract*—Smart Cities aim to improve living conditions by enabling new intelligent services for citizens. These services typically require environmental awareness obtained from distributed sensing systems. The implementation of such sensing systems on a city-wide scale is challenging, as the number of sensors needed can become unpractical. In this paper, we evaluate the utilization of mobile sensors as a possible approach to cover wider areas with fewer sensors and to use opportunistic communication to solve connectivity issues. In this direction, we propose a mobile sensor network using the public transportation system. To validate the feasibility of our proposal, we start by evaluating the performance of important commercial sensors in a mobile scenario, comparing measurements of static and mobile sensors of temperature, humidity, barometric pressure and luminosity. Our findings suggest that there is no or neglectful speed dependency on the measurements taken.**

I. Introduction

Statistics reveals that the world population is expected to grow near 15% in the next 15 years [1]. In urban centers, this growth can impose sustainability problems, such as lack of natural resources. The Smart City paradigm then emerges in this context as an alternative to address urban problems with Information and Communication Technologies (ICT). The key idea is to build a collective intelligence from the integration of physical, ICT, social, and commercial infrastructure [2]. The intelligence becomes the basis for more sophisticated services designed to improve citizens' living conditions.

The traditional infrastructure of cities operates on a wide range of services: public transportation, waste management, and road maintenance, to cite a few. In such scenario, ICT systems can coordinate the deployment of services by creating a virtual communication infrastructure in the city [2]. The virtual infrastructure supports decision and actions in the real infrastructure. For instance, if the virtual infrastructure detects heavy rain in some area, it can warn citizens about the risk of earth slides. Historical data can also be collected and stored for future use in similar situations. The challenge, however, is to provide enough means to gather and, afterwards, distribute city-wide information in an application-agnostic manner. To suit different applications, data must be as complete and as precise as possible, which would require a large number of static sensors scattered throughout the entire city. This solution faces scalability issues not only in terms of number of sensors, but also in terms of the communication infrastructure required.

A possible solution to improve the sensing system scalability is the utilization of mobile sensors. Liu et al. [3] demonstrate that mobile sensors can cover a wider area than static sensors. In addition, as shown by Ekici et al. [4], sensors can opportunistically communicate to a sink. Costa et al. [5] argue that the use of mobile sensors for data collection is a key component to overcome the complexities of large-scale sensing systems deployment. Using mobile sensors, however, does not come for free. Communication links between the sensors and the sink node must be established for data transmission. This issue has already been tackled in previous works. Seino et al. [6] use mobile sinks along a bus route to collect data from static sensors for weather forecasting. Marjovi et al. [7], on the other hand, anchored ten mobile weather stations to public buses. These sensors send measurements of air quality and geographical position to a database server using a General Packet Radio Service (GPRS) network. Similarly, Vagnoli et al. [8] send, also via a GPRS network, measurements concerning air pollutants and weather conditions collected by sensors on bikes. Although these works bring important insights on data gathering and transmission, none of them tackles the network capacity and the accuracy of sensors measurements as a function of sensors speed.

In this paper, we propose a real-time weather service to publish information acquired from mobile sensors installed on mobile platforms, such as cars or buses [9]. All the data sensed must be transferred to a sink node in order to accomplish the real-time weather information service. As a preliminary study to validate our proposition, we carried out real experiments to evaluate the reliability of the collected data as a function of the mobile platform speed. The data collected are temperature, humidity, light intensity, and atmospheric pressure. The obtained results show that temperature and relative humidity measurements can be seriously compromised due to greenhouse effect caused by inappropriate sensor assembling.

This paper is organized as follows. Section II presents the proposed sensing system and all the rationale behind. Section III describes our experimental evaluation, while Section IV presents the obtained results. Finally, Section V concludes this work and indicates future directions.

II. PROPOSED SENSING SYSTEM

The capacity of recognizing the city current state, informing the decision makers about it, and enabling actions upon is what we call the intelligence of the city. A city intelligence is created by the aggregation of sensors, communication networks, data processing, and control mechanisms. Besides improving the management and the operation of the city infrastructure, the intelligence can also enable new services.

Nevertheless, the knowledge about the city must be built upon the most recent city state [2], using the following dimensions:

- **Instrumented**: This dimension is responsible for gathering and incorporating data into the Smart City. This includes all data-acquisition system, e.g., sensors, that can measure directly or calculate values from other measurements;
- **Interconnected**: This dimension integrates the data collected by the instrumented dimension. It enables the communication between data producers and data consumers, e.g., a network between sensors or the whole Internet;
- **Intelligent**: This dimension consists of the raw data analysis. The final goal can be knowledge acquisition or action planning.

The present work acts on the *instrumented* and *interconnected* dimensions by gathering data about the city current state and delivering it to a server.

A. Quality of Information

Our goal is to provide enough means for developers to build services relying on information obtained from our sensing system. To achieve that, it is important to gather, distribute, and present information in a satisfactory fashion even to services yet unknown. In our system, we follow the Quality of Information principle proposed by Bisdikian et al. [10]. In their work, they state that a strategy to gather information perceived as fit-to-use must embed into the data the 5WH principle: *Why*, *When*, *Where*, *What*, *Who*, and *How*. The principles refer to, respectively, the objectives of the measurement, the time of the measurement, the place where the measurement occurred, the measurement itself, the node that performed the measurement, and the sensors implied.

In our sensing system, particular importance is given to the principles *Where* and *When*, that define the spatiotemporal position of a measurement. Since the mobility of urban transportation is not deterministic, these principles are important for data characterization. Consequently, service developers can decide whether a given measurement should be considered.

B. System Architecture

The Instrumented dimension of our sensing system follows the smart object concept [11] requirements: low energy consumption, small physical size, and low cost.

At the node level, these three requirements must be satisfied to assure the project viability, considering the diversity of mobile platforms. Fig. 1 shows the node-level block diagram of our data acquisition module. The controller, the main unit, coordinates all system functions and interacts with other devices.

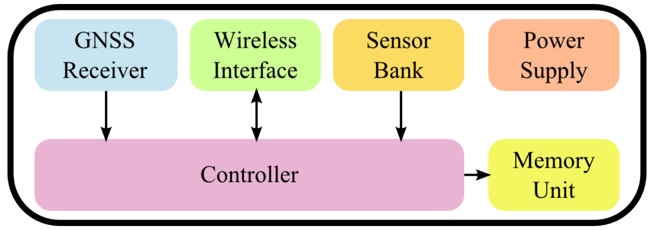


Fig. 1: The node-level architecture of the proposed sensing system.

The Sensor Bank is composed of basic environmental sensors that measure the temperature, humidity, barometric pressure, light, pollution level, or detect rain. The generated data is sampled by the controller at a specific rate, according to the capabilities of each sensor analog and digital input ports. The Global Navigation Satellite System (GNSS) is based on a constellation of satellites that sends their orbital positions to receivers on Earth, providing geo-spatial positioning and high-precision time reference. The GNSS receiver used in our sensing system is capable to receive Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) signals [12]. There is also a memory unit, capable of persisting the data gathered. The latitude, longitude, time, and the sensors measurements are encoded by the controller and, if there is an active link to a sink, sent over the wireless network interface to the sink server. If there is no active link, data is persisted into the memory unit and sent on the next time there is a connection with a sink. It is worth mentioning that, in our implementation, the controller executes a power saving algorithm to reduce energy consumption from the power supply without compromising the data transfer timing requirements. This is important as the dynamic characteristic of the system compel sensors and the GNSS receiver to be awake almost continuously.

The Interconnected dimension of our sensing system, i.e., the network level, is responsible for delivering encoded data from the node level to the sink server. In order to take advantage of already existing devices, our network does not rely on a single connection technology. In our system, the controller can use cellular network or wireless LAN as Internet gateway. Additionally, it is also possible that a node use Bluetooth, Wi-Fi, LoRa or ZigBee to perform routing between nodes to reach Internet (Fig. 2).

Our system supports three well-established mobility platforms used in most cities. The mobile platforms can directly connect the Internet or use a network gateway. Taxi driver's cellphone can establish Bluetooth connection with node controller and plays the role of LTE/GPRS Internet gateway. An analogous approach is accomplished by train and bus mobile platform where node controller can use an IEEE 802.11 or IEEE 802.15.1 network interface to forward the acquired sensor data. An infrastructure network based on Wi-Fi or Bluetooth provides a border router to the Internet at every train

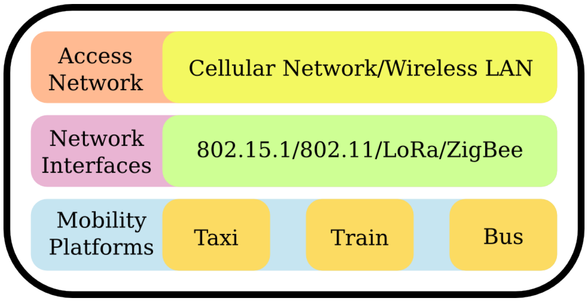


Fig. 2: The network-level architecture of the proposed sensing system.

and bus station. Alternately, buses and trains can have a direct Internet connection using GPRS to perform vertical Machine to Machine (M2M) Communication offered by mobile network providers. This novel service, tailored for Internet of Things (IoT) environment, has limited bandwidth and low cost per byte transferred [13].

III. Experimental Evaluation

(a) Static Node. (b) Mobile Node.

Fig. 3: Node-level prototypes.

We evaluate sensor measurements reliability under real metropolitan traffic conditions. Two node-level prototypes (Fig. 1) were built to perform this task: one playing the role of mobile sensor and another playing the role of static sensor. Table I shows the hardware modules used for data acquisition and their descriptions. All sensors were assembled in a crystal-clear acrylic box as shown in Fig. 3. The Controller Board, the GNSS receiver, the M2M Communicator, and the Wireless Interface were assembled separately.

Two sessions of experiments were carried out inside the campus of the Universidade Federal do Rio de Janeiro, in Brazil. In the first one, named “Mobile Effect Experiment”, the static node was positioned aside an internal street (Fig. 3a), while the mobile node was attached to the car window (Fig. 3b). The car performed a circular trajectory close to the static node. The nodes were synchronized to acquire data simultaneously. This procedure allows the comparison between the sensed data collected under distinct mobility conditions. As a consequence, we can evaluate possible factors that may affect measurements accuracy during mobile platform

TABLE I: Data Acquisition Module Hardware.

Device	Description	Manufacturer
Node Controller	Arduino UNO R3	Arduino
GNSS Receiver	GS-96U7	Guangzhou Xintu
SD Card Interface	GS-96U7	Guangzhou Xintu
Wireless Interface	ESP8266	Espressif
M2M Communicator	EFCom SIM900	SIMCom
Humidity Sensor	DHT11	DFRobot
Barometric Pressure	BMP180	Sparkfun
Temperature Sensor	BMP180	Sparkfun
Light Intensity Sensor	GL5528	GBK Robotics

Fig. 4: Trajectory followed in Casing Effect Experiment (Source: Google Earth).

circulation on metropolitan areas. This experiment was carried out in a sunny day between ten and twelve AM.

The second session of experiments, named “Casing Effect Experiment”, took into account measurements behavior regarding sensors bank casing. As one can observe in Fig. 3, the four sensors are protected by the acrylic box, which has a series of holes on the bottom face to perform air inlet and outlet. Besides this assembling be weatherproof, and indeed protects the sensors against bad weather conditions, we must check if the data acquired are reliable regardless the mobility. To accomplish this task, we attached two node-level prototypes side by side on the car window. One of the prototypes with the sensors inside the box and the other with the sensors outside the box. The vehicle moved along the trajectory shown in Fig. 4 to acquire campus environmental data. This experiment session was performed in cloudy day between three and four PM.

IV. Results

The Mobile Effect Experiment reveals a relevant difference between static and mobile sensors measurements. Fig. 5a shows the temperature variation of both static and mobile

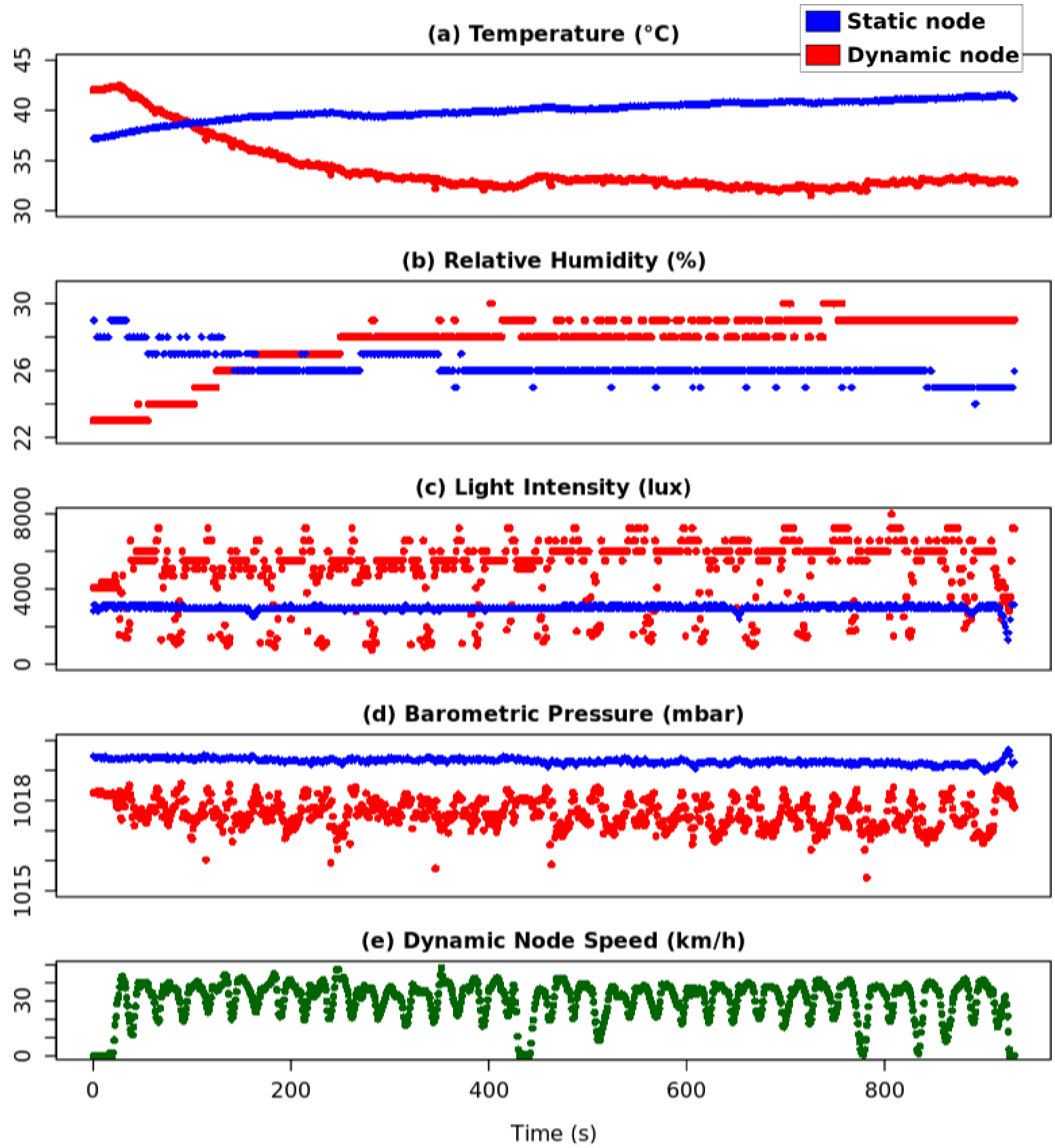
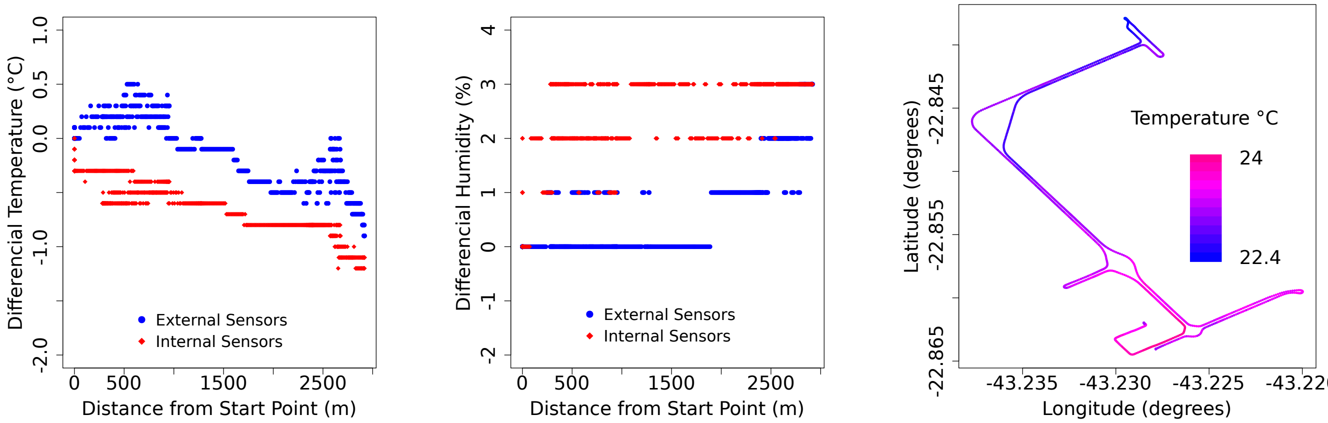


Fig. 5: Comparison Between Static and Mobile Measurements.

nodes along the time at one sample per second rate. The blue points plot the air temperature in Celsius measured by the static node sensor, whereas the red points plot the mobile node sensor measurements. As one can observe, while the static node register a temperature increase around 4 degrees, the mobile node register a decrease around 10 degrees. A reverse behavior can be observed for the relative humidity, at smaller proportions. The static node value (blue points) decreases 4%, whereas the mobile node value (red points) increases 7% (Fig. 5b). Light intensity has no speed dependency and a comparison between the mobile and static values reveals high sensor directionality (Fig. 5c). Although the barometric pressure shows fluctuations during the experiment (Fig. 5d), the speed dependency can be assigned to Venturi effect caused by the air flow through the box bottom face holes [14].

The Casing Effect Experiment was performed after the analysis of the mobile effect that showed a temperature variation up to ten degrees between the mobile and the static node measurements. Fig. 6 shows the differential temperature and relative humidity between the start point and points along the trajectory. Temperature variation, as shown in Fig. 6a, during the vehicle trajectory, reveals that the small difference between internal assembled sensors (red points) and external assembled sensors (blue points) suggests a minor casing effect. On the other hand, the chosen trajectory (Fig. 4) has some local micro-climates not detected by internal sensors, but detected



(a) Temperature. (b) Relative Humidity. (c) External Temperature.

Fig. 6: Comparison Between Internal and External Measurements.

by the external ones. These micro-climate areas can be easily identified analyzing the heat map of the Fig. 6c. Regarding to relative humidity, the casing effect is more visible due to low values of internal sensor measurements compared with the external ones. Similar to the temperature behavior, taking a look at Fig. 6b, one can verify that internal sensors show almost no fluctuations, whereas the external sensors show relative humidity measurements more compatible with the environmental conditions.

V. Conclusion

In this paper, we present preliminary studies about urban sensing using mobile nodes. The idea is to verify the impact of node mobility on sensed data. Results show that the Mobile Effect Experiment, performed at temperatures around 40^{o}C, reveals relevant differences between the static and the mobile nodes. The Casing Effect Experiment shows, however, that the speed has little influence in temperature reliability and relative humidity measurements. Thus, we can deduce that the sensor case causes a greenhouse effect responsible for the increase in temperature, decrease in relative humidity and slow response to environment condition changes.

We can overcome the problem by increasing the air flow inside the acrylic box to reduce the greenhouse effect or using some other strategy to protect electronic sensors from water, dust and other environmental threats. Those ideas are left as future work along with more experimental evaluation. Also, we plan to increase the number of weather measurements to better capture the reliability of mobile sensors.

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References

[1] United Nations, "World population projected to reach 9.7 billion by 2050," Accessed online at http://www.un.org/en/development/desa/news/population/2015-report.html, Jul. 2015.

[2] C. Harrison, B. Eckman, R. Hamilton, P. Hartswick, J. Kalagnanam, J. Paraszczak, and P. Williams, "Foundations for smarter cities," *IBM Journal of Research and Development*, vol. 54, no. 4, pp. 1 – 16, 7 2010.

[3] B. Liu, P. Brass, O. Dousse, P. Nain, and D. Towsley, "Mobility improves coverage of sensor networks," in *Proceedings of the 6th ACM international symposium on Mobile ad hoc networking and computing*. MobiHoc, 2005.

[4] E. Ekici, Y. Gu, and D. Bozdag, "Mobility-based communication in wireless sensor networks," *IEEE Communications Magazine*, vol. 44, no. 7, pp. 56 – 62, 2006.

[5] R. Costa, R. Resende, and S. Fernandes, "Urban data collectors: A pragmatic approach to leveraging urban sensing," in *IFIP/IEEE International Symposium on Integrated Network Management (IM)*, May 2015, pp. 886 – 889.

[6] W. Seino, T. Yoshihisa, T. Hara, and S. Nishio, "A sensor data collection method with a mobile sink for communication traffic reduction by delivering predicted values," in *26th International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, March 2012, pp. 613 – 618.

[7] A. Marjovi, A. Arfire, and A. Martinoli, "High resolution air pollution maps in urban environments using mobile sensor networks," in *2015 International Conference on Distributed Computing in Sensor Systems*. IEEE, 2015, pp. 11 – 20.

[8] C. Vagnoli, F. Martelli, T. D. Filippis, S. D. Lonardo, B. Gioli, G. Gualtieri, A. Matese, L. Rocchi, P. Toscano, and A. Zaldei, "The sensorwebbike for air quality monitoring in a smart city," in *IET Conference on Future Intelligent Cities*, Dec 2014, pp. 1 – 4.

[9] N. Castell, H.Liu, F. R. Dauge, M. Kobernus, A. J. Berre, J. Noll, E. Cagatay, and R. Gangdal, *"Supporting Sustainable Mobility Using Mobile Technologies and Personalized Environmental Information: The Citi-Sense-MOB Approach in Oslo, Norway"*. Cham: Springer International Publishing, 2016, pp. 199 – 218.

[10] C. Bisdikian, J. Branch, K. K. Leung, and R. I. Young, "A letter soup for the quality of information in sensor networks," in *Pervasive Computing and Communications*. IEEE PerCom, 2009.

[11] J. Vasseur and A. Dunkels, *Interconnecting Smart Objects with IP: The Next Internet*. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc., 2010.

[12] C. J. Hegarty, "Gnss signals — an overview," in *2012 IEEE International Frequency Control Symposium Proceedings*, May 2012, pp. 1 – 7.

[13] S. Severi, F. Sottile, G. Abreu, C. Pastrone, M. Spirito, and F. Berens, "M2M technologies: Enablers for a pervasive internet of things," in *European Conference on Networks and Communications (EuCNC)*, June 2014, pp. 1 – 5.

[14] A. Baylar, F. Ozkan, and M. Unsal, "Effect of air inlet hole diameter of venturi tube on air injection rate," *KSCE Journal of Civil Engineering*, vol. 14, no. 4, pp. 489–492, 2010. [Online]. Available: http://dx.doi.org/10.1007/s12205-010-0489-6