Location data quality in context: directions and challenges

Maria Luisa Damiani
University of Milan, Italy
E-mail: maria.damiani@unimi.it

1 Real-time location

In the last decade, following the emergence of the mobile application domain, the significance of location information has changed radically. Nowadays, location data not only is a key component of geospatial databases, but also a critical resource for a broad spectrum of applications, including Location-based Services and IOT solutions. This change of perspective has been made possible by the availability of localization technologies providing accurate and reliable location information on moving entities in real time. We refer to real-time location as positioning data. Positioning data has unique characteristics, such as the strong dependency from both the localization technology and the environmental context, which make the specification of standard quality metrics and quality assessment procedures a complex task. In this paper, we elaborate on such an aspect, focusing in particular on indoor positioning data.

Positioning data. In general, positioning data is obtained from the processing of signals - often radio signals - emitted by a transmitting source and typically propagated along a direct path, i.e. line-of-sight, to a (mobile) receiver. The Global Positioning System (GPS) is the first system that has shown the benefits of accurate location information in real time, revolutioning the field of outdoor navigation. The key of the technology is to measure the time elapsed for a radio signal to travel from satellites to a mobile device (called Time-of-Arrival, TOA). The computational mechanism of triangulation is then used to compute the location based on the known position of satellites and TOA-based distance measures [6]. The system, however, lacks coverage indoor and in urban areas where physical obstacles block the signal. Another popular class of positioning systems leverages the Wi-Fi access points (AP) spread across urban/indoor environments through the use of RSS-fingerprinting, a method alternative to TOA. Such a fingerprint is defined by a vector of signal identity information (such as the AP identifier) and a corresponding vector of RSS values [5]. A successful deployment of the technique in the urban/indoor context has been pioneered by Skyhook Wireless and then endorsed by the major players in the
mobile device industry such as Apple and Google. In these systems, the association between Wi-Fi signatures and locations is stored in a database. Hence, upon a location request, the mobile device compares the RSSs measured from the APs nearby to those in the database using a pattern matching technique to detect the best matching [6]. The technique delivers accuracy of tens of meters. However, these systems are dependent on the network infrastructure.

**Positioning data quality.** In general, the quality of positioning data is tightly dependent on the capabilities or *performance* of the localization system used. In fact, the location information is acquired in real-time, upon request, therefore location is consumed as it is computed, without filters in between. To further clarify this aspect, consider, for example, location accuracy, which represents a major characteristic not only of positioning data but also of mapping data [1]. If the location is acquired in real-time, its accuracy is necessarily upper bounded by the accuracy of the localization system used to detect it; conversely, in traditional mapping applications, the accuracy results from a complex and time-consuming map construction process conducted off-line. In this sense, the localization technology can be seen as one of the dimensions of positioning data.

Data quality is also extremely sensitive to the environmental context of the location. Physical objects such as buildings and walls, influence signal propagation causing, in particular, *multi-path* effects (i.e., the reception of multiple copies of the transmitted signal) and *non-line-of-sight*, NLOS, conditions (i.e., obstruction of the direct propagation line between the transmitter and the receiver), which cause signal degradation [6]. For example, in systems based on RSS-fingerprinting, multi-path causes the fluctuation of the signal strength at a location; while NLOS causes the random attenuation of the signal strength at different locations in the same area [6]. As a result, the quality delivered at run-time varies in time, depending on both the characteristics of the signal, the localization technique and the physical space. The impact of the environmental context is especially critical indoor, where the physical space is complex, made of rooms, hallways, floors, and populated by objects obstructing the signal and moving people. The market potential for indoor positioning is however impressive, estimated of several billion dollars by 2022. Application domains include, e.g., retailing and e-marketing, emergency response, assisted living, personal navigation, smart buildings. In a recent report Deloitte includes indoor positioning among the driving technologies for the next 6 years [4]. In such a context, key question is how to define and evaluate the performance of indoor localization systems and thus, indirectly, the quality of positioning data.

# 2 Indoor localization and evaluation metrics

**Localization technologies.** We briefly review major trends. The Wi-Fi (802.11) fingerprinting is currently the most popular indoor localization technique. Nevertheless, the Wi-Fi network infrastructure is not designed for the localization task, moreover the fingerprints can deteriorate in time, because the
network infrastructure evolves, while the level of accuracy may be not sufficient [5]. Complementary technologies, most at early stage of development, are briefly described next. These technologies are based on radio-frequency, sensors and LED lighting.

- **Radio frequency based systems.** Bluetooth Low Energy (BLE) is a new standard developed by Bluetooth Special Interest Group that has attracted the interest of major players e.g. Apple (IBeacon) and Google (Eddystone platform). The signal operates in the same bandwidth used by Wi-Fi, while the signal reachable distance is shorter, because of the low power usage policy [5]. A different class of solutions are those based on ultra-wide-band technology (UWB). UWB-solutions utilizes a large bandwidth which reduces the signal deterioration and thus has the potential for very accurate distance estimation.

- **LED light based systems.** The technology employs the light impulses emitted by a LED source to communicate the source identifier to a receiver. This information is then used along with signal characteristics (e.g. TOA, RSS) to estimate the location [8].

- **Magnetic field mapping.** This is a fingerprint based technique, which exploits the distortion of the magnetic field due to building materials to assign locations a magnetic signature [2].

- **Inertial sensors based systems.** Inertial sensors such as accelerometers and gyroscopes, available on mobile phones, are used to quantify changes in speed or direction. Such information can be used to detect the location based on the starting location and orientation. This technique is often used in conjunction with other localization methods.

**Performance metrics.** The heterogeneity of indoor localization systems and the diversity of application requirements have hindered the development of a common set of concepts and procedures for evaluating the performance of the different localization systems [2]. In fact, evaluation methods are in most cases proposed for specific technologies, e.g. [5, 9]. In general, the capabilities of a system are evaluated with respect to a set of performance metrics. For example, the early framework presented in [11] introduces the following dimensions for the evaluation of indoor localization system performance: accuracy, precision, complexity, scalability, robustness, and cost.

Notably, the recent standard ISO/IEC 18305 'Test and evaluation of localization and tracking systems', promotes the use of common practices for the evaluation of localization systems in the large [10]. The standard introduces detailed metrics primarily for the evaluation of localization accuracy. Location can be specified at two different granularities, either in terms of coordinates or zones/floors. Additional metrics include: coverage, a measure of the space in which the system meets the minimum performance requirements specified by the application; latency, the time elapsed to deliver the location estimate to the ultimate user of the location information: set-up time, the time elapsed to make...
the system operational. Besides, 'optional' performance metrics are specified, such as time availability and resilience for use in mission critical applications. Data security and privacy are included as system requirements.

3 Challenges and directions

We are witnessing a rapid evolution of the indoor localization techniques. For the effective utilization of positioning data a number of challenging issues are to be solved, including:

Increased accuracy. Centimeter-level accuracy, also referred to as micro-location, is the new frontier [1]. This calls for advanced methods capable of mitigating the effect of the environmental context on signal propagation. For example, UWB-based positioning has the potential to match the accuracy requirements, nevertheless such a performance can be typically achieved in environments in which there is no physical obstruction because the signal is sensitive to NLOS problems [6], thus methods are needed to mitigate this effect, e.g. [12]. Another major direction is developing algorithms to fuse sensor data from multiple sources to produce improved localization [6, 13].

Security and privacy. As the location information becomes a critical resource, preserving the integrity, availability and confidentiality of the geolocation system against cyber attacks becomes essential. Attacks can cause the delivery of incorrect positioning data, system operation disruption, unauthorized location and personal identity disclosure to third parties. Location authentication methods are needed to accomplish critical location-dependent tasks such as the enforcement of context-based access control policies [3].

Evaluation practices. The homogenization of performance assessment practices is fundamental to enable the comparison of research results, typically evaluated in different environments using different evaluation criteria [9]. In that respect, the standardization efforts recently put in place for the evaluation of localization techniques is a relevant step ahead. Maintaining the performance metrics and assessment procedures in line with the technological evolution and the application requirements is a major issue.

The work reported in this paper was carried out while visiting the research group of Professor Elisa Bertino at Purdue University CS Department and has been partially supported by the NSF award IIS-1636891.

References

[1] C. Batini and M. Scannapieco. Data and Information Quality, Dimensions, Principles and Techniques. Springer, 2016.

[2] J. Chung, M. Donahoe, C. Schmandt, I. Kim, P. Razavai, and M. Wiseman. Indoor location sensing using geo-magnetism. In Proc. of the 9th
International Conference on Mobile Systems, Applications, and Services, MobiSys ’11, 2011.

[3] M. L. Damiani, E. Bertino, B. Catania, and P. Perlasca. Geo-rbac: A spatially aware rbac. ACM Trans. Inf. Syst. Secur., 10(1), 2007.

[4] Deloitte. The Deloitte Consumer Review. Technical report, 2017.

[5] R. Faragher and R. Harle. An Analysis of the Accuracy of Bluetooth Low Energy for Indoor Positioning Applications. In Proc. International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2014), 2014.

[6] C. Gentile, N. Alsindi, R. Raulefs, and C. Teolis. Geolocation Techniques, Principles and Applications. Springer, 2013.

[7] Y. Gu and A. Lo. A survey of indoor positioning systems for wireless personal networks. IEEE COMMUNICATIONS SURVEYS & TUTORIALS, 11(1), 2009.

[8] N. Hassan, A. Naeem, M. Pasha, T. Jadoon, and C. Yuen. Indoor positioning using visible led lights: A survey. ACM Comput. Surv., 48(2):20:1–20:32, 2015.

[9] T. Haute, E. Poorter, I. Moerman, F. Lemic, V. Handziski, A. Wolisz, N. Wirström, and T. Voigt. Comparability of rf-based indoor localisation solutions in heterogeneous environments: An experimental study. Int. J. Ad Hoc Ubiquitous Comput., 23(1/2):92–114, 2016.

[10] ISO/IEC18305. Information technology, real time locating systems, test and evaluation of localization and tracking systems. https://www.iso.org/standard/62090.html, 2016.

[11] H. Liu, H. Darabi, P. Banerjee, and J. Liu. Survey of wireless indoor positioning techniques and systems. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 37(6):1067 – 1080, 2007.

[12] M. Tabaa, C. Diou, R. Saadane, and A. Dandache. LOS/NLOS Identification based on Stable Distribution Feature Extraction and SVM Classifier for UWB On-body Communications. Procedia Computer Science, 32:882–887, 2014.

[13] F. Zafari, I. Papapanagiotou, and K. Christidis. Microlocation for internet-of-things-equipped smart buildings. IEEE Internet of Things, 3(1):96–112, 2016.