Hindawi
Journal of Sensors
Volume 2018, Article ID 5971752, 3 pages
https://doi.org/10.1155/2018/5971752

Editorial

Indoor Tracking, Mapping, and Navigation: Algorithms, Technologies, and Applications

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Received 18 December 2017; Accepted 24 December 2017; Published 17 April 2018

The necessity for an accurate, precise, and quick positioning capability is growing in modern societies. This feature is needed on the one side by actively moving objects like people, vehicles, and robots. On the other side, passively moving objects may also need to be continuously located and tracked, such as merchandise and transported goods, kids, and people with disabilities. Some examples include (1) finding the nearest exit during emergency events by taking into consideration the obstacles on the ground, (2) continuous georeferencing both in outdoor and indoor environments to receive location-based information, (3) tracking people and goods for surveillance purposes, and (4) monitoring of people's physical activities to encourage an active lifestyle or to facilitate medical rehabilitation.

Notwithstanding the big progresses of outdoor positioning technologies developed in the last decades, which have already influenced our lifestyle, new solutions are continuously in demand. Navigation systems should be able to operate ubiquitously in challenging conditions, including the possibility of indoor tracking. This function requires the integration of multiple positioning systems to facilitate seamless and robust navigation. In indoor environments, the support from *Global Navigation Satellite Systems* (GNSSs, see [1]) cannot be exploited and alternative solutions have to be explored. For instance, great attention is focused on low-cost technologies that may be widely used in a sustainable way. Concurrently, the exploitation of those devices that are already commonly carried by people (such as smartphones) gives the opportunity to develop solutions prone to be quickly adopted by a large number of users.

On the other side, the development of technology for indoor positioning should be complemented by the accurate knowledge of the environment's geometry and semantics, which are both needed to make intelligent decisions and plan optimal actions. Spatial 3D information is crucial in understanding the scene and context to make technologies truly autonomous. In the case of modern newly designed buildings, the use of existing Building Information Models (BIMs) may provide extensive data sources for indoor geometry to support real-time positioning and navigation [2, 3]. Unfortunately, in most existing buildings, the planimetric information is not available in digital form. Thus, indoor maps and 3D models should be collected on purpose. Even though technologies for indoor mapping [4] have reached a high degree of maturity, due to factors such as scene obstructions, movement variations, sensor limitations, and model uncertainty, indoor mapping remains to be a highly challenging problem. Popular techniques for indoor 3D surveying based on integrated photogrammetric [5] and computer vision [6] methods, as well as static [7] and mobile [8] 3D scanning systems, may quickly provide dense and accurate point clouds. On the other hand, discrete point clouds might not be directly suitable to support indoor navigation, but they require a complex modelling stage to obtain 3D vector models, whose derivation is not yet a fully automated process [9]. While public and important buildings with high human traffic may be worthwhile to organize specific projects for 3D indoor modeling, the large majority of indoor spaces require other solutions, such as crowdsourced mapping [10]. Last but not least, standards for sharing 3D indoor digital mapping data have to consolidate and be widely used [11]. Beyond the necessity of such information for indoor positioning and navigation, the integration of indoor 3D models georeferenced in the geodetic coordinate systems and topologically connected to the outdoor maps is one of the major challenges to be resolved in order to support the emerging technology implemented in smart cities. It is also noteworthy to mention the establishment of a benchmarking on indoor modelling by the *International Society of Photogrammetry and Remote Sensing* (ISPRS); see more details in [12].

In this special issue, seven papers that illustrate advances in indoor tracking, mapping, and navigation are published. Three papers deal with different aspects related to the localization of nodes in *wireless sensor networks* (WSNs, [13]), two papers discuss the state-of-the-art methods for navigation estimation, and two papers are focused on mapping using optical instruments.

In "Sequential Monte Carlo Localization Methods in Mobile Wireless Sensor Networks: A Review," the authors first propose a new classification of localization schemes in mobile WSNs, where the chance of changing spatial position allows to expand coverage using a smaller number of sensors while reducing power consumption. In the three suggested categories, the range-free scheme exploits network connectivity to work out the position, without the need of an external device such as an antenna. The paper specifically provides a survey of the *sequential Monte Carlo* method to estimate the location of nodes in range-free WSNs [14]. Three metrics are used for classifying these methods, that is, localization accuracy, computational cost, and communication cost.

In the paper "An Analysis of Multiple Criteria and Setups for Bluetooth Smartphone-Based Indoor Localization Mechanism," the problem of fading impairments in localization of Bluetooth Low Energy (BLE) 4.0 beacons is addressed. BLE beacons have become a relevant alternative to Wi-Fi-based indoor localization mechanisms [15]. After reviewing the literature about this technology, the paper identifies the main system parameters to be considered during the design of this type of localization sensors: the mean localization error, local prediction accuracy, and global prediction accuracy. A series of experimental tests prove this conclusion.

The integration of strapdown inertial navigation system (SINS) and WSN is the topic of the paper "Integrated SINS/WSN Positioning System for Indoor Mobile Target Using Novel Asynchronous Data Fusion Method." SINS sensors contained in a mobile target can continuously provide ubiquitous positioning without depending on any external interaction with other devices. On the other hand, while the positioning accuracy is very high in the short term, SINS sensors suffer from drift within time [16]. When GNSS signals are available, the integration of both technologies is used to complement the short-term stability of SINS by the long-term stability of GNSS, but this does not work in indoor environments. Some authors have already proposed the integration of SINS and WSN to compensate for the drift [17] and to obtain continuous indoor positioning. In this paper, the authors focus on this method by developing an asynchronous data-fusion technique based on an unscented Kalman filter [18]. Some simulations and experiments with real data show that this method may perform better than traditional techniques for both asynchronous and synchronous data.

A topic that is closely related to the previous article is presented in "Linear Kalman Filter for Attitude Estimation from Angular Rate and a Single Vector Measurement." Indeed, attitude estimation is fundamental in inertial indoor navigation [19]. In the past, several filtering methods have been used, mainly on the basis of different versions of the Kalman filter and complementary filter [20]. In particular, the latter has been used because the former is difficult to apply with relatively low-cost hardware. Here the authors propose the implementation of a Kalman-filtering scheme along with gyroscopic data and a single vector observation. Using quaternion algebra, the attitude is estimated together with its variance-covariance information. The Single Vector Observation Linear Kalman filter (SVO-LKF) features a flexible design that makes its application faster than other filters based on linearization, as also demonstrated in simulations and experiments reported in the paper.

Besides using a variation of the Kalman filter to estimate the navigation solution, for scenarios where the noise is not normally distributed and the mathematical model is nonlinear, a particle filter may be considered. In the article "An Improved Particle Filter Algorithm for Geomagnetic Indoor Positioning," the authors presented an improved navigation solution using the ambient magnetic field processed by a particle filter. They proposed an improved particle filter algorithm based on initial positioning error constraint, inspired by the Hausdorff distance measurement point set matching theory. Since the operating range of the particle filter cannot exceed the magnitude of the initial positioning error, it avoids the adverse effect of sampling particles with the same magnetic intensity but away from the target during the iteration process on the positioning system.

As mentioned before, 3D mapping of indoor environments is one of the aspects strictly related to navigation and tracking. One solution to this problem is to use distributed mapping agents (e.g., people or robots) that move in and out of an indoor environment and concurrently may generate partial maps. In a second stage, independently and partially reconstructed maps need to be unified into a highly accurate global map. This topic is presented in the paper "Distributed Monocular SLAM for Indoor Map Building." Here the *simultaneous localization and mapping* (SLAM) technique is adopted for the acquisition of relatively dense 3D models by using distributed mobile sensors [21]. On the other hand, constructed maps are used to help navigation in an interactive way (tracking and mapping problem). Here the use of monocular visual SLAM is considered for distributed indoor mapping. If an agent moves into an area that has already been mapped, it may use the existing geometric information to support navigation. In the case that an agent enters an area that has not yet been mapped, it starts the local mapping process and localizes itself as a part of the SLAM process. All independently and locally built maps are then merged together to complement each other. In particular, the paper introduces and discusses a distributed framework to compute map overlaps also in the case no prior knowledge of the starting positions of the agents is available.

The problem of mapping the indoor environment is also the final aim of the solution proposed in "Practical In Situ Implementation of a Multicamera Multisystem Calibration." Systems made up of multiple consumer-grade cameras may offer a low-cost and effective solution for image-based indoor mobile mapping. In this paper, first, some methods for the geometric calibration of multicamera systems are reviewed, including the determination of both interior and exterior orientation parameters for each sensor [22]. Then, the authors introduce a novel, versatile methodology for multicamera system geometric calibration, capable of concurrently handling more camera systems as well.

Acknowledgments

We would like to thank all the authors for their valuable contributions and the reviewers for their help. It is everybody's contributions that allowed us to complete this special issue with high-quality papers. Finally, we would like to thank all members of the editorial board for approving this special issue.

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References

[1] B. Hofmann-Wellenhof, H. Lichtenegger, and E. Wasle, *GNSS — Global Navigation Satellite Systems*, Springer Verlag, Vienna, 2008.

[2] C. Eastman, P. Teicholz, R. Sacks, and K. Liston, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators*, John Wiley & Sons Inc, Hoboken, NJ, USA, 3rd edition, 2018.

[3] L. Barazzetti, "Parametric as-built model generation of complex shapes from point clouds," *Advanced Engineering Informatics*, vol. 30, no. 3, pp. 298–311, 2016.

[4] J. Kárník and J. Streit, "Summary of available indoor location techniques," *IFAC-PapersOnLine*, vol. 49, no. 25, pp. 311–317, 2016.

[5] G. Forlani, R. Roncella, and C. Nardinocchi, "Where is photogrammetry heading to? State of the art and trends," *Rendiconti Lincei*, vol. 26, Supplment 1, pp. 85–S96, 2015.

[6] R. Hartley and A. Zisserman, *Multiple View Geometry in Computer Vision*, Cambridge University Press, Cambridge, UK, 2006.

[7] G. Vosselman and H.-G. Maas, *Airborne and Terrestrial Laser Scanning*, vol. 318, Taylor and Francis Group, Boca Raton, FL, USA, 2010.

[8] C. Thomson, G. Apostolopoulos, D. Backes, and J. Böhm, "Mobile laser scanning for indoor modelling," in *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. II-5/W2, pp. 289–293, Antalya, Turkey, 2013.

[9] L. Previtali, R. B. Barazzetti, and M. Scaioni, "Towards automatic indoor reconstruction of cluttered building rooms from point clouds," in *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. II-5, pp. 281–288, Riva del Garda, Italy, 2014.

[10] C. Heipke, "Crowdsourcing geospatial data," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 65, no. 6, pp. 550–557, 2010.

[11] G. Gröger, T. Kolbe, C. Nagel, and K. Häfele, *Opengis City Geography Markup Language (CityGML) Encoding Standard v2.0.0*, Open Geospatial Consortium Standard, Open Geospatial Consortium, OGC, 2008.

[12] K. Khoshelham, L. Díaz Vilariño, M. Peter, Z. Kang, and D. Acharya, "The ISPRS benchmark on indoor modelling," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLII-2/W7, pp. 367–372, Wuhan, China, 2017.

[13] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Computer Networks*, vol. 52, no. 12, pp. 2292–2330, 2008.

[14] L. Mihaylova, D. Angelova, and A. Zvikhachevskaya, "Sequential Monte Carlo methods for localization in wireless networks," in *Advances in Intelligent Signal Processing and Data Mining*, p. 354, Springer-Verlag, Berlin Heidelberg, 2013.

[15] Z. Farid, R. Nordin, and M. Ismail, "Recent advances in wireless indoor localization techniques and system," *Journal of Computer Networks and Communications*, vol. 2013, Article ID 185138, 12 pages, 2013.

[16] Q. Yuan and I.-M. Chen, "3-D localization of human based on an inertial capture system," *IEEE Transactions on Robotics*, vol. 29, no. 3, pp. 806–812, 2013.

[17] C. Luo, W. Li, H. Yang, B. Ying, and G. Xin, "Implementation of mobile target positioning technology integrating SINS with WSN measurements," *Journal of Sensors*, vol. 2014, Article ID 673179, 12 pages, 2014.

[18] J. Wang, A. Hu, X. Li, and Y. Wang, "An improved PDR/magnetometer/floor map integration algorithm for ubiquitous positioning using the adaptive unscented Kalman filter," *ISPRS International Journal of Geo-Information*, vol. 4, no. 4, pp. 2638–2659, 2015.

[19] X. Yun, J. Calusdian, E. R. Bachmann, and R. B. McGhee, "Estimation of human foot motion during normal walking using inertial and magnetic sensor measurements," *IEEE Transactions on Instrumentation and Measurement*, vol. 61, no. 7, pp. 2059–2072, 2012.

[20] W. T. Higgins, "A comparison of complementary and Kalman filtering," *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-11, no. 3, pp. 321–325, 1975.

[21] R. Smith, M. Self, and P. Cheeseman, "Estimating uncertain spatial relationships in robotics," in *Autonomous Robot Vehicles*, I. J. Cox and G. T. Wilfong, Eds., pp. 167–193, Springer-Verlag, New York, N.Y., USA, 1990.

[22] T. Luhmann, S. Robson, S. Kyle, and J. Böhm, *Close Range Photogrammetry: 3D Imaging Techniques*, Walter De Gruyter Inc., Germany, 2nd edition, 2014.