Recent Advances in Indoor Geolocation Techniques

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The integration of location information with day-to-day applications will grow significantly over the next decade as the technology's accuracy evolves. Currently outdoor localization, thanks to the Global Positioning System (GPS), has revolutionized navigation-based applications running on automotive GPS-enabled devices and smart phones. Applications range from guiding drivers to their destinations to providing point-by-point directions to the closest cinema or coffee shop. The success of GPS has been due to the reliability, availability, and practical accuracy that the orbiting satellites covering the globe provide. However, GPS provides limited coverage indoors and poor quality information in urban areas and near buildings which has motivated research in indoor geolocation in the last decade.

A major challenge facing the indoor localization industry is the indoor propagation problem. The indoor environment is not friendly to wireless signals and that is manifested through limited coverage, multipath propagation, and the non-line-of-sight (NLOS) problem. Many research areas developed in the last decade to address those challenges. A fundamental aspect to addressing the challenges is understanding the indoor propagation

mechanisms affecting the accuracy of localization; and efforts to measure, characterize and model the wireless channel from a geolocation perspective have received significant attention. Further algorithms and techniques to mitigate the multipath and NLOS problems have emerged recently for many systems (e.g. WLAN, WSN, UWB, etc.). Another area of research that has evolved around the indoor problem is the inertial measurement unit (IMU) based approaches in navigation and tracking (e.g. Kalman filters, particle filters, etc.) which adds another dimension to indoor location estimation. Finally hybrid technologies and signals of opportunity approaches have gained popularity recently to harness the most available information in order to improve robustness and accuracy of indoor localization systems. Although many approaches have been investigated and proposed, accurate indoor location remains a challenging problem. This special issue aims at attracting research papers focusing on mitigating the indoor geolocation challenges.

The annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) is one of the premier conferences in the wireless research arena and has a long history of bringing together academia, industry and regulatory bodies. Today, it has become one of the IEEE Communication Society's flagship conferences in telecommunications. The 23rd IEEE PIMRC was held successfully in Sydney Australia, from 9 to 12 September 2012, where several hundred researchers met to share their latest research results in wireless technologies. In this special issue, we have compiled the extended versions of the best papers on indoor geolocation techniques from this conference as well as a few invited papers from well-known experts in this field. The invited authors have done an excellent job in substantially extending the conference version of the papers, which significantly improved the

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quality of the manuscripts. The objective of this special issue is to provide the readers a timely perspective on the exciting new developments in the field of indoor geolocation techniques.

The first paper, “Hidden Markov Model Based Localization Using Array Antenna” by Yusuke Inatomi, Jihoon Hong, and Tomoaki Ohtsuki, presents an interesting way to enhance the fingerprinting-based localization technique. In the proposed method, the eigenvectors spanning signal subspace are employed as location dependent feature for location fingerprinting. The eigenvectors does not depend on received signal strength (RSS) but on direction of arrival (DOA) of incident signals. As a result, the eigenvector is robust to fading and noise. In addition, unlike the conventional fingerprinting-based methods, the new method is based on the hidden Markov model and it makes use of the previous state of estimation by comparing the eigenvectors obtained during observation with the one stored in the database. Performance of the proposed method is evaluated using experimental results.

The second paper is “Data Pre-processing in Compressive Sensing Based Indoor Fingerprinting Positioning,” by Jingang Deng, Qimei Cui, and Xuefei Zhang. In this paper, the authors present a compressive sensing (CS)-based location fingerprinting method. In order to effectively apply CS theory to the high precision indoor positioning problem, the authors also designed new data pre-processing algorithms to apply to the location fingerprint signal space, which can mitigate the influence of large measurements noise. In addition, the authors also explored a few location fingerprint signal space filtering algorithms to reduce the computational complexity of the CS recovery algorithm. Both experimental and simulation results demonstrate that remarkable improvements may be achieved using the proposed algorithms.

The third paper, “Localization in Wireless Networks with Post-Improvement Using Estimation of Distances between Unknown Nodes” by Oleksandr Artemenko and Andreas Mitschele-Thiel, presents several refinement algorithms for a posteriori improvement of localization results in wireless networks. The proposed algorithms utilize the distances between unknown-location nodes when such information is available a priori. Performance of the proposed algorithms is evaluated using simulations and experimental studies. The proposed method represents a potential way to further improve localization accuracy in difficult situations where traditional method could not provide adequate performance.

The fourth paper, “Symbol Timing Acquisition for Collaborative OFDM WLAN-based A-GPS” by Mahsa Shafiee, Kyle O’Keefe, and Gérard Lachapelle, presents receiver-level integration of 802.11g OFDM signals and GPS for a WiFi-based Assisted-GPS (A-GPS) acquisition

in a multipath NLOS environment. The A-GPS systems that are currently deployed for commercial operations obtain timing assistance data via cellular networks. In this paper, the authors demonstrate that using WiFi network to provide assistance data for GPS acquisition is a promising approach to enable localization and tracking in the challenging NLOS multipath environments such as indoors.

The fifth paper, “Heterogeneous Cooperative Localization for Social Networks” by Ruijun Fu, Guanqun Bao, Yunxing Ye, and Kaveh Pahlavan, offers another interesting development in the field of indoor geolocation. Traditional cooperative localization methods are mostly based on ranging techniques, so that they are highly dependent on the distance interpreted from the RSS or time of arrival (TOA) from anchors. However, a precise ranging procedure demands high performance hardware which would increase the cost to the current mobile devices. In this paper, the authors describe four ranging-free probabilistic cooperative localization algorithms that can be used to improve the accuracy for indoor geolocation using mobile devices.

The sixth paper, “Modeling the effect of human body on TOA based indoor human tracking” by Yishuang Geng, Jie Hey, and Kaveh Pahlavan, studies the impact of human body on system performance when wireless geolocation sensors are carried by or mounted on human body. Such a study is especially relevant to typical indoor geolocation applications where geolocation sensors are commonly integrated into electronic name tags or smart phones or some other miniature electronic devices carried by users. To quantitatively describe the TOA ranging error caused by human body, the authors propose a statistical ranging error model for body mounted sensors based on measurement results. The model separates ranging error into multipath error and NLOS error caused by multipath radio propagation phenomenon, and it is demonstrated that the distribution of multipath errors is only related to the bandwidth of the system while the distribution of NLOS error is related to the angle between human facing direction and the direction of transmitter–receiver, signal to noise ratio (SNR), and bandwidth of the system.

The seventh paper, “Position Tracking for Passive UHF RFID Tags with the Aid of a Scanned Array” by Antonios (Anthony) Bouzakis and Ludger Overmeyer, presents a RFID tag positioning system that utilizes an active electronically-steered array in the same way as the modern radar systems. With the wide-spread adoption of RFID in many industrial and commercial sectors, it is becoming an important candidate wireless system to implement indoor geolocation techniques. In this paper, the authors describe and study the main attributes of the proposed system using a finite element method (FEM) simulation model and investigate the system performance with far-field tests. The

demonstrated positioning precision is under 1 cm laterally for a range of a few meters, which certainly opens up a wide spectrum of possibilities in mobile robot localization, automated handling of packaged goods, and many other indoor geolocation applications.

The last paper collected in this special issue, “A Model for Spatial Behavior of Multipath Components Pertinent to Indoor Geolocation Using Ray Optics,” by Ferit Ozan Akgul and Kaveh Pahlavan, presents a novel model for the spatial behavior of multipath components in indoor environments. Most of the existing multipath radio propagation channel models were designed for communication applications without specific attention to the unique characteristics and requirements of indoor geolocation applications. Therefore, such models are not useful in the design and analysis of indoor geolocation techniques. In this paper, the authors use the principles of ray optics to explain the spatial evolution of path gains, TOA, and angle-of-arrival of multipath components observed by a mobile terminal operating in an indoor environment. Such a model is particularly important for indoor geolocation applications utilizing ultra-wideband (UWB) signal and multipath diversity to achieve high precision in localization and tracking.

We would like to thank all of the authors of the special issue papers for their exceptional work in extending and improving their conference version papers to high-quality archival journal articles. We are also grateful to the anonymous reviewers for their thoughtful, constructive comments, which have helped authors to improve the quality of the papers significantly. Last but not least, we would like to express our sincere gratitude to the publishing editors and staff of Springer for their prompt assistance throughout the preparation of this special issue. We hope our readers enjoy reading this special issue.

Author Biographies

Xinrong Li received BE degree from the University of Science and Technology of China, Hefei, China, in 1995, ME degree from the National University of Singapore in 1999, and PhD degree from Worcester Polytechnic Institute (WPI), Worcester, MA, in 2003, all in Electrical Engineering. From 2003 to 2004, he was a Post-doc Research Fellow at the Center for Wireless Information Network Studies, WPI. He joined the Department of Electrical Engineering, University of North Texas, Denton, Texas, as an Assistant Professor in 2004, and then he was promoted to Associate Professor in 2010. His recent research has been focused on statistical signal processing, geolocation, and wireless sensor network systems.

Nayef Alsindi received his PhD in Electrical and Computer Engineering from Worcester Polytechnic Institute (WPI), Massachusetts, USA in 2008. While at WPI he conducted research at the Center for Wireless Information Network Studies (CWINS) where he worked on research projects on indoor geolocation. He holds a bachelor's degree in Electrical Engineering from the University of Michigan, Ann Arbor and a Master's degree in Electrical and Computer Engineering from WPI. Dr. Alsindi is a Fulbright Scholar (2002–2004). Currently he is a Senior Researcher at Etisalat BT Innovation Center (EBTIC), Abu Dhabi, UAE. He is a member of IEEE and the Scientific Research Society Sigma Xi. His research interests are focused on indoor geolocation and time/frequency synchronization over packet and wireless networks.