Hindawi Publishing Corporation
EURASIP Journal on Advances in Signal Processing
Volume 2008, Article ID 356546, 3 pages
doi:10.1155/2008/356546

Editorial

Signal Processing for Location Estimation and Tracking in Wireless Environments

Richard J. Barton,[1] Rong Zheng,[2] Sinan Gezici,[3] and Venugopal V. Veeravalli[4]

[1] *ERC, Inc., NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058, USA*
[2] *Department of Computer Science, University of Houston, Houston, TX 77204, USA*
[3] *Department of Electrical and Electronics Engineering, Bilkent University, Bilkent, Ankara 06800, Turkey*
[4] *Department of Electrical and Computer Engineering, University of Illinois, Urbana, IL 61801, USA*

Correspondence should be addressed to Richard J. Barton, richard.j.barton@nasa.gov

Received 4 February 2008; Accepted 4 February 2008

In wireless systems, accurate location estimation facilitates a variety of applications such as emergency localization, intelligent transport systems, inventory tracking, intruder detection, tracking of fire-fighters and miners, and home automation [1, 2]. In addition, location information can help optimize resource allocation and improve cooperation in wireless networks. Recent efforts for incorporating location estimation into wireless systems include the Federal Communications Commission requirement for wireless providers to locate mobile users within tens of meters for emergency 911 calls [3], and the IEEE 802.15.4a Task Group's amendment to the IEEE 802.15.4-2006 standard, which defines an ultra-wideband (UWB) physical layer for low data rate communications combined with positioning capabilities [4].

In order to realize the potential applications of wireless positioning, location must be estimated with sufficient accuracy in both simple line-of-sight (LOS) propagation environments as well as in challenging wireless environments with multipath and non-line-of-sight (NLOS) propagation [5, 6]. Theoretical limits for location estimation provide lower bounds on the mean squared error of location estimators [7–10], which can be used as guidelines for designing positioning systems. However, in many practical scenarios, advanced signal processing techniques must be applied in order to obtain location estimators with performance that approaches the theoretical limits.

Location estimation techniques can be classified loosely into two broad categories depending on the use of a reference database. *Mapping* (or *fingerprinting*) techniques are based on comparison of local measurements of signal parameters to a database containing previously estimated values of the signal parameters at known locations within the environment [11–15]. On the other hand, *geometric* and *statistical* techniques do not use such a database, and directly estimate the location based on position-related signal parameters by means of geometric relationships and statistical approaches, respectively [2, 16]. Localization with geometric and statistical approaches performs best in strong LOS environments and is complicated by the presence of NLOS signal components. In mapping approaches, estimation accuracy is generally limited by the accuracy of the reference database.

The papers in this special issue discuss localization approaches that fall into both the mapping and geometric/statistical categories as well as hybrid techniques. The papers explore a broad spectrum of issues in location estimation and tracking in wireless environments and present, we believe, an excellent overview of the current state of the art. The issue contains 14 papers, which are organized as follows.

The first three papers are in the mapping category. The paper by O. Turkyilmaz et al. considers localization based on received signal strength (RSS) measurements in complex propagation environments. The authors propose incorporating an estimate of the radio environment of the mobile user (e.g., urban, suburban, or rural) into the location decision using machine learning techniques. The resulting environment aware RSS-based location estimation (EARBALE) system constructs an artificial neural network to identify a parametric model of the site, which is then used in triangulation for localization. The paper by H. Li et al. considers a combination of proximity-based and triangulation techniques in determining office- and cube-level locations using sensor nodes. A position confidence indicator is derived to measure the quality of location results. The paper by M. Khalaf-Allah evaluates mobile-based wireless location estimation, position tracking, and global localization algorithms in an outdoor GSM environment using RSS measurements from multiple base stations. All approaches use a Bayesian approach to compute an estimate of a mobile position based on an RSS map derived from a propagation simulation within the chosen outdoor environment. Location estimation uses no filtering (no motion model), and computes the maximum a posteriori (MAP) estimate, the conditional mean estimate, and a conditional trimmed-mean estimate based on one-shot network measurements. Position tracking incorporates a motion model and utilizes recursive Bayesian filtering (RBF) to update an assumed initial position. Global localization employs RBF with a nondegenerate prior on the localization until convergence to a stable distribution, and then propagates the conditional mean estimate using position tracking. The authors propose and evaluate particular implementations of each of the three positioning techniques.

The next three papers in the issue all deal with geometric and statistical approaches to localization using UWB impulse radio technology. The paper by R. Barton and D. Rao studies the performance limitations of UWB for long-range location and tracking in an outdoor environment based on time-difference-of-arrival (TDOA) measurements. Performance of weighted-least-squares (WLS), weighted-total-least-squares (WTLS), and maximum-likelihood (ML) algorithms is characterized as a function of signal-to-noise ratio (SNR), range, sensor geometry, and number of sensors. Particular emphasis is given to the effects of algorithm bias and bias resulting from sensor position errors. The paper by İ. Güvenc et al. studies NLOS identification and mitigation for UWB systems. The authors propose using the kurtosis of the channel impulse response (CIR) together with the excess delay and the delay spread of the CIR as the basis for classifying channels at multiple receivers as LOS or NLOS and also to choose weights to be used in a WLS time-of-arrival (TOA) location estimate. Performance of the proposed approach is studied in a simulated environment and compared with conventional WLS location estimates that make no attempt to compensate for NLOS bias. The paper by C. Steiner et al. proposes a course-grained localization (clustering) technique for UWB systems based on sampling the CIR at one or more receivers. The CIR is modeled as a complex Gaussian random vector parameterized by the mean vector and the covariance matrix. The environment is divided into regions and localization is performed using a hypothesis test to identify the maximum-likelihood model corresponding to a received CIR. Performance of the approach is studied using measured as well as modeled data to generate empirical and theoretical probability of error statistics for a binary version of the localization problem.

The following three papers deal with the statistical modeling and mitigation of NLOS propagation. The paper by M. Heidari and K. Pahlavan presents a new methodology and framework for modeling and simulation of random ranging errors observed by a mobile user in an indoor wireless environment. A procedure is developed for deriving a four-state hidden Markov model using ray-tracing software to simulate propagation in an indoor environment. Generalized extremal distributions (GEDs) are used to model the conditional range error distributions. An infrastructure-distance-measurement-based model (IDM) applicable to a generic environment is also provided for determining the state corresponding to a particular location within the environment. The paper by L. Mailaender considers performance of TOA and TDOA location estimation techniques in a total NLOS environment. Cramer-Rao lower bounds (CRLBs) are developed and compared for 2D TOA and TDOA location estimation in NLOS flat-fading conditions both with and without errors in sensor position. Bounds for round-trip TOA systems are also developed. The author shows that the Fisher information matrix on an all NLOS channel is singular with no knowledge of the NLOS bias parameters, so that no CRLB exists under that scenario. If partial knowledge of the NLOS parameters is available (i.e., the distribution of the parameters), then the generalized Fisher information matrix may or may not be singular. The special case of half-Gaussian NLOS parameters is considered as an example. The paper by Y. Park et al. proposes and evaluates a geometric method to estimate the location of a mobile station (MS) in a mobile cellular network when both TOA and angle-of-arrival (AOA) measurements are available at the base station (BS) but corrupted by NLOS errors. Constraints based on the statistical distribution of both the TOA and AOA measurements are placed on the position of the MS. The constraints lead to a closed-form system of equations defining the region containing the MS, which can be solved directly to generate an estimate of the MS location when the AOA errors (angle spread) are sufficiently small. In the general case, the location of the MS within the constraint region is estimated by minimizing a particular objective function using either a Lagrange multiplier solution or an alternative numerical technique.

The final five papers in this special issue deal with various other aspects of geometric and statistical approaches to location estimation. The paper by F. Benbais et al. provides a theoretical characterization of the effect of landmark placement for range-free topology-based location in wireless sensor networks. The authors prove that under certain simplifications and restrictions, it is best to place landmarks at equal distance on the boundary of the area of interest. Furthermore, random placement yields comparative performance as long as the number of landmarks is sufficiently large. Simulation evaluations of landmark placement on routing performance are also presented in the paper. The paper by I. Bergel et al. proposes a probability-controlled interference management mechanism using a random symbol-dropping scheme to reduce multiple-access interference (MAI) and improve TOA location estimation accuracy in a multiuser code-division multiple-access (CDMA) scenario. The paper assumes that symbols that are dropped (not transmitted) can be recovered using an error-correcting code. Average user transmission power is fixed so that peak power for each symbol increases as the probability of transmitting a symbol decreases. The effect is to increase the impulsive nature of the transmission for each user and to reduce the impact of MAI on the estimation accuracy in a TOA system. Interestingly, the results in this paper are reminiscent of previous results in the information theory literature indicating that the capacity-achieving symbol distribution for random channel codes on uncertain fading channels is impulsive [17, 18]. The paper by C. Chen et al. considers the problem of direction-of-arrival (DOA) estimation in the presence of additive sensor noise that is Gaussian, zero-mean, independent from sensor to sensor, but with nonuniform variance. The variance from the uniform noise case makes solving the ML estimation problem much more difficult numerically. The paper presents two new algorithms for finding approximate solutions to the problem in the general case, making no assumptions regarding array geometry, signal waveform, or far-field approximations. The CRLB for the nonuniform case is also derived in the paper. The paper by M. Bhuiyan et al. considers delay-lock loops and related feedback code tracking algorithms, which are used to track LOS delay in global navigation satellite systems. The performance of such algorithms degrades in severe multipath scenarios. The paper analyzes feedback and feedforward code tracking algorithms and proposes peak-tracking methods, which are combinations of both feedback and feedforward structures, as alternatives to improve performance in severe multipath environments. Improvements to other multipath mitigation schemes are also proposed and analyzed by the authors. The main focus of the paper is performance comparison of the new and existing algorithms via simulations in a closely spaced multipath scenario. The paper by T. Haenselmann et al. proposes a positioning scheme for locating nodes with no position information based on distance measurements from previously located nodes within a network. The position estimate is a weighted average of approximate triangulation solutions computed using pairwise combinations of the nodes defining the convex hull of a neighborhood containing the node being located. The weights are computed using a heuristic rule that assigns relatively more weight to position estimates computed from neighboring nodes "close" to the target and relatively less weight to estimates from nodes "far" from the target. The approach is computationally simple and the weights are computed using only pairwise distances between nodes, so the exact geometry of the network is not needed (other than the convex hull requirement). No knowledge of the method used to compute the distance estimates is required.

Richard J. Barton
Rong Zheng
Sinan Gezici
Venugopal V. Veeravalli

REFERENCES

[1] "IEEE 802.15 WPAN Task Group 4 (TG4)," 2003.

[2] J. J. Caffery, *Wireless Location in CDMA Cellular Radio Systems*, Kluwer Academic Publishers, Boston, Mass, USA, 2000.

[3] "Revision of the Commission's Rules to Ensure Compatibility with Enhanced 911 Emergency Calling Systems," Federal Communications Commission, 1996.

[4] "Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LRWPANS)," IEEE, July 2006.

[5] S. Gezici, Z. Tian, G. B. Giannakis, et al., "Localization via ultra-wideband radios: a look at positioning aspects of future sensor networks," *IEEE Signal Processing Magazine*, vol. 22, no. 4, pp. 70–84, 2005.

[6] Y. Qi, H. Kobayashi, and H. Suda, "On time-of-arrival positioning in a multipath environment," *IEEE Transactions on Vehicular Technology*, vol. 55, no. 5, pp. 1516–1526, 2006.

[7] A. Mallat, J. Louveaux, and L. Vandendorpe, "UWB based positioning in multipath channels: Crbs for AOA and for hybrid TOA-AOA based methods," in *Proceedings of the IEEE International Conference on Communication (ICC '07)*, pp. 5775–5780, Glasgow, Scotland, June 2007.

[8] H. V. Poor, *An Introduction to Signal Detection and Estimation*, Springer, New York, NY, USA, 2nd edition, 1994.

[9] Y. Qi, "Wireless geolocation in a non-line-of-sight environment," Princeton University, Princeton, NJ, USA, 2004.

[10] Y. Qi, H. Kobayashi, and H. Suda, "Analysis of wireless geolocation in a non-line-of-sight environment," *IEEE Transactions on Wireless Communications*, vol. 5, no. 2, pp. 672–681, 2006.

[11] R. O. Duda, P. E. Hart, and D. G. Stork, *Pattern Classification*, Wiley-Interscience, New York, NY, USA, 2nd edition, 2000.

[12] S. Gezici, H. Kobayashi, and H. V. Poor, "A new approach to mobile position tracking," in *Proceedings of the IEEE Sarnoff Symposium on Advances in Wired and Wireless Communications*, pp. 204–207, Ewing, NJ, USA, March 2003.

[13] T.-N. Lin and P.-C. Lin, "Performance comparison of indoor positioning techniques based on location fingerprinting in wireless networks," in *Proceedings of the International Conference on Wireless Networks, Communications and Mobile Computing*, vol. 2, pp. 1569–1574, Maui, Hawaii, USA, June 2005.

[14] M. McGuire, K. N. Plataniotis, and A. N. Venetsanopoulos, "Location of mobile terminals using time measurements and survey points," *IEEE Transactions on Vehicular Technology*, vol. 52, no. 4, pp. 999–1011, 2003.

[15] C. Nerguizian, C. Despins, and S. Affès, "Geolocation in mines with an impulse response fingerprinting technique and neural networks," *IEEE Transactions on Wireless Communications*, vol. 5, no. 2, pp. 603–611, 2006.

[16] S. Gezici, "A survey on wireless position estimation," *Wireless Personal Communications*, vol. 44, no. 3, pp. 263–282, 2008.

[17] M. Mèdard and R. G. Gallager, "Bandwidth scaling for fading multipath channels," *IEEE Transactions on Information Theory*, vol. 48, no. 4, pp. 840–852, 2002.

[18] V. G. Subramanian and B. Hajek, "Broad-band fading channels: signal burstiness and capacity," *IEEE Transactions on Information Theory*, vol. 48, no. 4, pp. 809–827, 2002.