Indoor Location Estimation in NLoS Environment Based on ToA Method with Particle Filter

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Abstract — **We study the location estimation in the indoor environment. We use ToA (Time-of-Arrival) information obtained from AN (an anchor node) and TN (a target node). The ToA method measures the distance between AN and TN. However, since the distance by the method often includes a positive error due to the NLoS (Non-Line-of-Sight) environment, it is difficult to estimate the position of TN from ToA information directly. Therefore, we propose a method to localize TN based on particle filter with the correction of the error.**

Keyword: *Indoor Location Estimation; Time-of-Arrival (ToA); Non-Line-of-Sight (NLoS); Auxiliary Particle Filter.*

1 Introduction

We aim at the improvement of the accuracy on indoor position estimation through the statistical approach. Since there is the prospect of utilizations in the fields of such as marketing science and location-based service, the study on indoor localization is important. As the applications, in case of the former, it is considered as the use to get an interesting product shelf information for a customer and to analysis the behavior in the store. In the latter case, we may become able to receive the navigation service anywhere in a shopping mall or a museum (Chong, Watanabe, and Inamura, 2006; Sahinoglu, Gezici and Guvenc, 2008).

Global Positioning System (GPS) is well known as a typical localization method. However its accuracy is within about 1 to 5 meter even if it is outside, it will not be anticipated the further accuracy in urban area and the indoor environment. Hence, a method in Wireless Sensor Network (WSN) is widely used for indoor localization. The localization method in WSN is mainly classified as either the *range-free* method or the *range-based* method. The *range-free* method estimates a position from a network-like view with many devices, and provides a much lower accurate position than the *range-based* method that uses ranges between each device. Therefore, we use the latter in this study.

Using the *range-based* method, we need to prepare for several devices as anchor node (AN) and target node (TN) and handle the distances between them. In addition, there are some kinds of radio signal information to measure a distance, such as Received Signal Strength (RSS) (Okusa and Kamakura, 2015), Time-of-Arrival (ToA) (Kamakura and Okusa, 2013; Venkatraman, Caffery and You, 2004; Watabe and Kamakura, 2010), and Angle-of-Arrival (AoA). We have to select or combine the information to estimate the position of TN. In thsis study, we propose the position estimation method based on ToA.

ToA is the information to estimate the distance between AN and TN based on time. When we call a measurement method using the ToA information as ToA method, this method measures the radio signal's travel time between AN and TN that are completely synchronized, and estimates the distance. For instance, when a radio signal is transmitted from TN at time t_0 and it is received by AN at time t_1, the distance R is calculated as follows:

$$R = C(t_1 - t_0), \tag{1.1}$$

where C is the speed of light. Thus, if the distance was measured correctly, we could estimate the position of TN using trilateration.

However, since the distance often includes not also random error but positive systematic error in the actual environment, it is difficult to estimate the accurate position of TN. It is said that the cause of

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the systematic error has Non-Line-of-Sight (NLoS) conditions, multipath and clock off (Go and Chong, 2015; Sahinoglu, *et al.*, 2008). Especially, the error in NLoS environment, where a radio signal path between devices is partially obstructed, seriously affects the accuracy (Go and Chong, 2015). Therefore, we focus on the error which we call *NLoS error*.

Yoshida, Sakumura and Kamakura (2016) proposed the equation to correct with Gamma regression model. However, the method is not practical because several measurements are regarded as one measurement at same time. Therefore, we propose a more practical method to sequentially estimate the position of TN by modeling the state space model with the new correction equation in this paper.

2 The proposed method

The following model is typically assumed in ToA-based location estimation (Sahinoglu, *et al.*, 2008).

$$\ell = \begin{cases} R + \varepsilon & (\text{if } LoS) \quad (2.1) \\ R + b + \varepsilon & (\text{if } NLoS), \quad (2.2) \end{cases}$$

where ℓ is a measured distance, R is an actual distance, b is a NLoS error, and ε is a random error which follows a normal distribution $N(0, \sigma^2)$. We show the equation to correct NLoS error.

$$\log b = \beta_0 + \beta_1 R. \tag{2.3}$$

Eq. (2.3) is devised using the characteristic of the correction equation by Yoshida *et al.* (2016). We formulated Eq. (2.3) based on the conditions as follows:

- NLoS error is a positive value.
- The larger actual distance is, the larger NLoS error is.
- The smaller actual distance is, the smaller NLoS error is.

We combine Eq.(2.2) and Eq.(2.3) and construct the following state space model. Our method performs sequential estimation using Auxiliary Particle Filter (Pitt and Shephard, 1999) based on the model.

$$\begin{pmatrix} x_t \\ v_{x,t} \\ y_t \\ v_{y,t} \end{pmatrix} = \begin{pmatrix} 1 & \Delta T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \Delta T \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_{t-1} \\ v_{x,t-1} \\ y_{t-1} \\ v_{y,t-1} \end{pmatrix} + \boldsymbol{w}_t, \quad \boldsymbol{w}_t \sim N(0, \Sigma_{1,t}), \tag{2.4}$$

$$\begin{pmatrix} \ell_1 \\ \vdots \\ \ell_K \end{pmatrix} = \begin{pmatrix} d(x_t, y_t, \boldsymbol{a}_1) \\ \vdots \\ d(x_t, y_t, \boldsymbol{a}_K) \end{pmatrix} + \begin{pmatrix} exp(\beta_{0,t} + \beta_{1,t} d(x_t, y_t, \boldsymbol{a}_1)) \\ \vdots \\ exp(\beta_{0,t} + \beta_{1,t} d(x_t, y_t, \boldsymbol{a}_K)) \end{pmatrix} + \boldsymbol{v}_t, \quad \boldsymbol{v}_t \sim N(0, \Sigma_{2,t}), \tag{2.5}$$

where x_t, y_t are the coordinate of the position of TN, $v_{x,t}, v_{y,t}$ are the velocity of TN, ΔT is a time interval, $d(x_t, y_t, \boldsymbol{a}_k) = \sqrt{(x_t - a_{x,k})^2 + (y_t - a_{y,k})^2}$, $\boldsymbol{a}_k = (a_{x,k}, a_{y,k})^T$, and $\beta_{0,k}, \beta_{1,k}, \Sigma_{1,t}, \Sigma_{2,t}$ are unknown parameters. These parameters are estimated by the simultaneous estimation method of the unknown parameter by Liu and West (2001).

References

[1] Caffery J. Jr. (2000). A New Approach to the Geometry of TOA Location. *52nd IEEE Vehicular Technology Conference*, **4**, 1943-1949.

[2] Chong, C., Watanabe, F. and Inamura, H. (2006). Potential of UWB Technology for the Next Generation Wireless Communications. *Proc. 9th IEEE International Symposium on Spread Spectrum Techniques and Applications*, 422-429.

[3] Kamakura, T. and Okusa, K. (2013). Estimates for the spatial locations of the indoor objects by radial distributions. *Proc. 59th ISI World Statistics Congress 2013 (ISI2013)*, 4827-4832.

[4] Liu, J. and West, M. (2001). Combined Parameter and State Estimation in Simulation-Based Filtering. *Sequential Monte Carlo Methods in Practice*, New York: Springer.

[5] Okusa, K. and Kamakura, T. (2015). Indoor Location Estimation based on the RSS method using Radial Log-normal Distribution. *16th IEEE International Symposium on Computational Intelligence and Informatics (CINTI2015)*, 25-34.

[6] Patwari, N., Joshua, N. A., Spyros, K., Alfred, O. H., Randolph, L. M. and Neiyer, S. C. (2005). Locating the nodes: Cooperative localization in wireless sensor networks. *IEEE Signal Processing Magazine*, **22**(4), 54-69.

[7] Pitt, M. and Shephard, N. (1999). Filtering via Simulation: Auxiliary Particle Filters. *Journal of the American Statistical Association*, **94**(446), 590-599.

[8] Sahinoglu, Z., Gezici, S. and Guvenc, I. (2008). *Ultra-wideband Positioning Systems. Cambridge*, New York: Cambridge University Press.

[9] Go, S. and Chong, J. (2015). Improved TOA-Based Localization Method with BS Selection Scheme for Wireless Sensor Network. *Electronics and Telecommunications Research Institute (ETRI) Journal*, **37**(4), 707-716.

[10] Venkatraman, S., Caffery, J. and You, H. (2004). A Novel ToA Location Algorithm Using LoS Range Estimation for NLoS Environment. *IEEE Transactions on Vehicular Technology*, **53**(5), 1515-1524.

[11] Watabe, T. and Kamakura, T. (2010). Localization algorithm in the indoor environment based on the ToA data, *Australian Statistical Conference 2010 Program and Abstracts*, 243.

[12] Yoshida, A., Sakumura, T. and Kamakura, T. (2016). Indoor Location Estimation Based on ToA Data and Bias Estimation with Gamma Regression. *Journal of Japan Society of Computational Statistics*, submitted.