JANT 한국항행학회논문지
Journal of Advanced Navigation Technology

기반 기술

J. Adv. Navig. Technol. 24(2): 128-133, Apr. 2020

반복선형회귀를 이용한 수신 신호 세기와 이동성 정보에 기반한 1차원 위치 추정

One-dimensional Positioning using Iterative Linear Regression Based on Received Signal Strength and Mobility Information

이 동 준[1] · 김 다 영[1] · 이 은 혜[2]
[1]한국항공대학교 항공전자정보공학부
[2]퀄컴 코리아

Dong-Jun Lee[1] · Da-Yeong Kim[1] · Eun-Hye Lee[2]
1School of Electronics and Information Engineering, Korea Aerospace University, Gyounggi-do, 10540, Korea
[2]Qualcomm, Korea

[요　　약]

본 연구에서는 위치추정을 하는 경우 선형회귀법을 반복적으로 적용하여 신호의 경로 손실을 추정하는 방법을 제안한다. 제안한 방식에서는 단말이 이동하면서 여러 위치에서 측정한 수신신호세기와 가속도계로 구한 측정 위치들 사이의 거리 정보를 이용하여 전송 비콘부터의 경로 손실을 선형회귀를 이용하여 추정한다. 전송 비콘과 특정 위치사이의 거리에 대하여 여러 잠정값들을 가정하고, 각 잠정값에 대하여 선형회귀식을 구한다. 이 선형회귀식들 중에서, 기준 수신 세기에 가장 가까운 식을 이용하여 송신 비콘와 목표 위치사이 거리를 구한다. 테스트 결과, 제안 방식은 단순 경로 손실 모델보다 훨씬 더 높은 정확도를 보인다.

[Abstract]

In this study, an 1-dimensional positioning method using iterative linear regression for path loss expression is proposed. In the proposed method, received signal strengths (RSS) measured in several locations and distances between the measuring locat ions obtained by dead reckoning are used to derive a linear regression for the path loss from the transmitting beacon. In the proposed method, for the distance between the transmitting beacon and a target measuring location, several tentative values are assumed. For each tentative value, a linear regression is obtained. Among the linear regression expressions, the one closest to the known reference RSS value is selected and used to derive the distance to the target location. Test results show that the proposed method is more accurate than path loss model.

Key words : Dead reckoning, Positioning, Linear Regression, Path Loss Model, Received signal strength.

https://doi.org/10.12673/jant.2020.24.2.128

Received 13 March 2020; **Revised** 14 March 2020
Accepted (Publication) 21 April 2020 (30 April 2020)

***Corresponding Author**

Tel: +82-2-300-0181
E-mail: ldj@kau.ac.kr

www.koni.or.kr　pISSN: 1226-9026　eISSN: 2288-842X

Ⅰ. 서 론

Indoor positioning has been considered as one of main applications of mobile phones. Received signal strength (RSS) has been used widely in indoor positioning, e. g. in trilateration and fingerprinting, etc [1]. In these methods, accurate measurement of distance between transmitting beacons and a moving receiver is important in positioning. Some RSS-based approaches are based on path loss model. When applying path loss model for distance estimation, proper path loss exponent of a path loss model should be known in advance, which is not easy. Path loss exponent in a path loss model depends on environment, and it could also vary depending on time even at the same location. Thus the identifying proper path loss exponent exactly is not easy and the accuracy of the distance measurement based on RSS and path loss model is generally poor. In indoor positioning, the signal propagation environment is generally more complicated than outside. Hence it is more difficult to apply path loss model in the distance measurement in indoor environment.

Dead reckoning using inertial sensors such as accelerometer equipped in smartphones has emerged as an effective tool in indoor positioning [2], [3]. Moving distance and trajectory of a mobile phone from an initial location can be obtained by dead reckoning quite accurately. However, dead reckoning alone is not sufficient for positioning since accurate acquisition of an initial location should be provided for positioning using dead reckoning to function effectively. Thus the necessity of methods to acquire initial location still remains even in positioning using dead reckoning.

Recently some studies have combined RSS and dead reckoning to find an initial location of a receiver. In [1], a combination of pedestrian dead reckoning and RSS based positioning is proposed to increase the accuracy of user positioning given information on user locations. However how to acquire information on user locations is not addressed. In [4], path loss model is estimated by linear regression by assuming that distance from beacons to measuring locations are known and this estimated model is used to find other user positions. However, the assumption that all the distances from the beacons to several user locations are known for linear regression is impractical. Thus how to find initial distance from a beacon to user location or user's initial position is yet to be solved.

In this study, a method to find distance from a beacon to a user location is proposed. An iterative method using linear regression for the path loss model based on several measurements of RSS is proposed. To facilitate the regression, distances between locations measuring RSSs and the distance between the transmitting beacon and a target measuring location should be known. Distances between measuring locations can be obtained with dead reckoning. For the distance between the transmitting beacon and a target measuring location, several tentative values are assumed. For each tentative value of the distance, a linear regression expression is obtained. Among the linear regression expressions, the one closest to the known reference RSS value is selected for derivation of the distance to the target location. Test results show that the proposed method is more accurate than distance estimation based on simple path loss model.

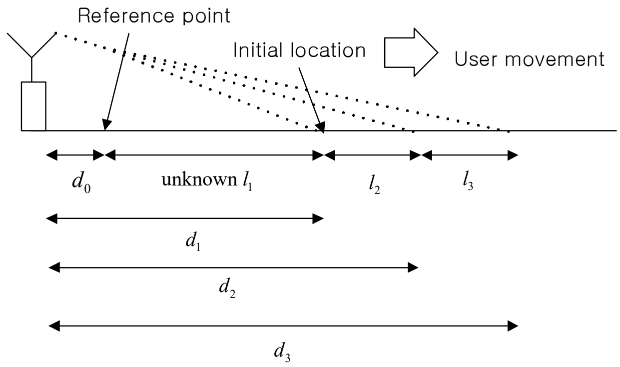


그림 1. 비콘이 전송한 신호를 측정하는 여러 위치. 측정 위치들 사이의 거리 l_2와 l_3는 가속도계로 추정하고 이에 기반한 반복선형회귀법으로 l_1을 구한다.

Fig. 1. Several locations for measuring RSSs from a beacon while distances l_2 and l_3 between measuring locations except l_1 are obtained by dead reckoning. In the proposed method, the value of l_1 is assumed tentative values which are used for linear regressions.

Ⅱ. System Model

For simplicity, an one-dimensional positioning situation is considered in this study. We consider the case that there is a transmitting beacon and a moving receiver as shown in Fig. 1. The receiver moves in one-dimensional way. Thus the distance from the beacon determines the location of the receiver. Reference point is d_0 distant from the beacon and it is assumed that the RSS at the reference point P_{r0} is known. A receiver is located initially d_1 distant with RSS P_{r1} from the beacon and moves away from the initial position. When the receiver moves from the initial position by l_2, the distance between the beacon and the receiver at the second position becomes d_2 and the RSS becomes P_{r2}. In this way, the receiver moves and in several locations RSSs are measured. Thus we have

$$d_i = d_1 + \sum_{j=2}^{i} l_j \ . \tag{1}$$

Distances between two measuring positions, e.g., l_2 and l_3 can be estimated with dead reckoning using accelerometer equipped in the receiver, while the initial distance d_1 from the beacon and the distance l_1 from the reference point are unknown and to be found. RSS of the receiver in dB scale can be generally represented by a path loss model as follows:

$$P_r(d) = -10\alpha \log(d/d_0) + P_{r0} \tag{2}$$

where $P_r(d)$ denotes the RSS at d meter distant from the transmitting beacon, d_0 is the distance from the beacon to the reference point, P_{r0} represents the RSS at the reference point, α is the path loss exponent which depends on environment. It is assumed that P_{r0} at the reference point is known by broadcasting. P_r is a linear function of $\log(d)$ with parameters α and P_{r0}.

Ⅲ. Proposed positioning method using iterative linear regression

Distance d from a beacon to a measuring location can be obtained directly from equation (2) as

$$d = d_0 10^{(P_{r0} - P_r(d))/(10\alpha)} \ . \tag{3}$$

where $P_r(d)$ is the RSS at d from the beacon. However, since path loss exponent α in equation (3) depends on environment and generally not known exactly, estimation of d from RSS $P_r(d)$ as in equation (3) is quite inaccurate in general.

In the proposed method, d is found by iterative linear regressions of the path loss expression in which tentative values of d are tried to facilitate the linear regressions. Thus we have several path loss expressions corresponding to the tentative values of d. Given a path loss expression, the RSS value at the reference point can be estimated and compared with the known value of P_{r0} of the reference point. Among the path loss expressions obtained by the linear regression, the one which estimates the RSS value at the reference point which is closest to the known value of P_{r0} is selected and used for obtaining the corresponding distance to other measuring locations.

Details of the proposed method are given below. First let us consider a linear regression expression :

$$y = \beta_1 x + \beta_0 \tag{4}$$

where y is RSS in dB scale, x stands for $\log(d/d_0)$ and β_1 for -10α and β_0 for RSS in the reference point. Equation (4) is a linear function and it can be estimated from RSS measurements at various locations by linear regression. It is required that a receiver moves and measures RSSs at various locations. When we have several measurements of RSSs at various locations which is represented as (x_i, y_i) where i stands for the measurement index. x_i is associated with d_i that is the distance from the beacon to the i-th measuring location such that $x_i = \log(d_i/d_0)$. l_i is the distance between i-th measuring location and $(i+1)$-th measuring location. i.e. defined as $l_i = d_{i+1} - d_i$ in the assumed one-dimensional situation. Since l_i can be estimated with dead reckoning using accelerometer, if one of d_is are assumed as a certain value, all the other d_is can be determined correspondingly.

β_0 and β_1 can be obtained by linear regression from several RSS measurements based on least square criterion as follows. First, Q is defined as

$$Q = [\beta_0 \, \beta_1]^T \tag{5}$$

where β_0 corresponds to P_{r0}. For an assumed value of one of d_i s, we have

$$X = [X_1 \, X_2 \, \cdot \cdot \, X_K]^T \tag{6}$$

where K is the number of RSS measurements and

$$X_i = [1 \log(d_i/d_0)] \tag{7}$$

and

$$Y = [y_1 \, y_2 \, \cdot \cdot \, y_K]^T. \tag{8}$$

By least square criterion, Q of a linear regression can be obtained as

$$Q = (X^T X)^{-1} X^T Y. \tag{9}$$

There exists a difference between β_0 obtained by linear regression in equation (9) and the given P_{r0} which varies depending on the assumed value of d. For example, d_1 value is assumed and d_2, d_3, etc are determined by d_1. Then the

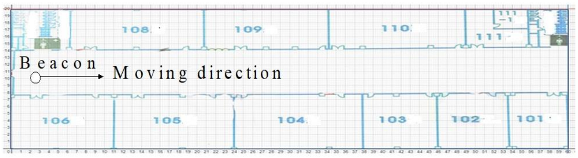


그림 2. 측정 실험을 진행한 복도의 형태.
Fig. 2. Floor plan of the corridor in which test is performed.

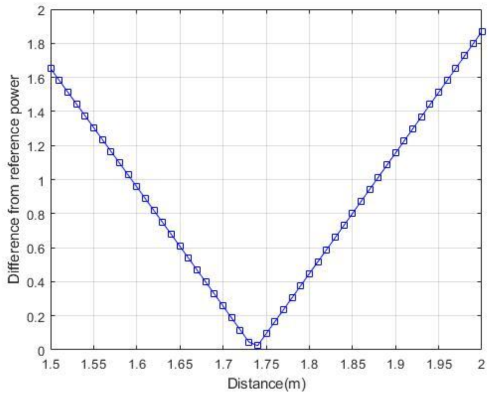


그림 3. 비콘으로부터의 거리가 2m일 때에 거리 추정값에 따른 β_0와 P_{r0} 사이의 차이.
Fig. 3. Difference of β_0 and P_{r0} with respect to the assumed values of distance from the beacon when the real distance is 2 m.

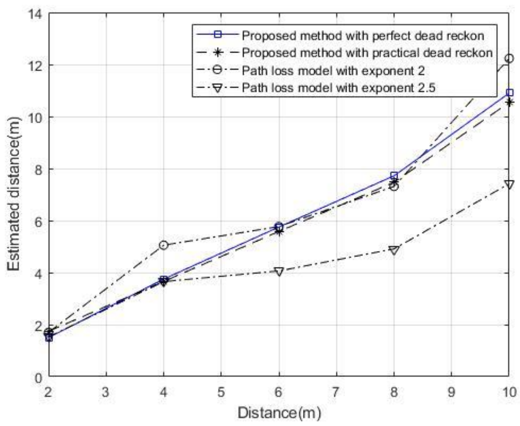


그림 4. 제안 방식과 단순 경로손실 모델을 각각 이용한 비콘으로부터의 거리에 따른 거리 추정값.
Fig. 4. Distance estimations using the proposed iterative regression or path loss model with respect to the distance from the beacon.

estimated value of d_1, $\hat{d_1}$, is obtained as the one corresponding to the minimum of $|\beta_0 - P_{r0}|$. Thus $\hat{d_1}$ is obtained as

$$\hat{d_1} = \max_{d_1} |\beta_0(d_1) - P_{r0}| \tag{10}$$

where $\hat{d_1}$ can be obtained by linear exhaustive search on d_1 .

Ⅳ. Test Results

Indoor positioning test using the proposed iterative linear regression method is performed in a corridor of a building in Korea Aerospace University. The floor plan of the test area is given in Fig. 2. Bluetooth beacon, i-beacon, and an i-phone 6 smartphone are used in the test. A receiver moves away from the transmitting beacon through the corridor and stops at some locations to measure RSS. Received beacon signals are averaged at each location to remove fading effect.

Fig. 3 shows the absolute difference between β_0 obtained with the regression using the estimation of the distance between measuring locations using dead reckoning and P_{r0} with respect to the assumed values of the target distance d from the beacon when real distance d is 2 m. For the regression, RSS measurements at locations 2, 4, 6 m distant from the beacon are used. Among the assumed values of the distance d, the one with the minimum difference $|\beta_0 - P_{r0}|$ is selected as the estimated value of distance. We can see that at 1.75m the absolute difference between β_0 and the reference RSS P_{r0} is the smallest and thus 1.75 m is selected for the estimated value of d whose real value of 2m.

Fig. 4 shows the test results of the proposed regression method and the estimation by typical path loss model for the distance from the beacon. For each distance estimation, 3 RSS measurements are used. When real d is 2, 4, 6 m, RSS at distances 2, 4, 6 m from the beacon are used. When real d is 8m, RSSs at 2, 6, 8m and when d is 10m, RSSs at 4, 8, 10m from the beacon are used. This means that measurements close to the beacon are used for linear regression. For estimation of moving distance by practical dead reckoning, Weinberg method is adopted [6]. By dead reckoning using Weinberg method, for moving distance of 2 m, 1.92 m is estimated on average as the moving distance. For the proposed regression method, estimation of moving distance between measuring locations by the practical dead reckoning or moving distance estimation assuming ideal perfect dead reckoning is compared. The estimation results of the proposed method with different dead reckoning results are quite accurate regardless of the assumed dead reckoning, that is, practical dead reckoning or ideal dead reckoning. For comparison with the proposed method, distance estimation based on the path loss model by equation (2) is used with different path loss exponents. Estimation based on the path loss model shows that the estimation error depends on the assumed value of the path loss exponent α and the distance from the beacon. For α of 2, estimations of distance 6 and 8 m are quite accurate and for α of 2.5, estimations of distance 2 and 4 m are accurate.

As the distance from the beacon changes, the value of path loss exponent also changes. Thus same α cannot be used in the entire range of the distance. In the method using simple path loss model, different path loss exponents cannot be applied in different user locations. However, the proposed iterative linear regression method can estimate the distance from the beacon more precisely in spite of the varying path loss exponent. This is possible because in the proposed method, by applying several linear regressions most appropriate linear regression model is obtained. This linear regression model actually has the associated path loss exponent and path loss exponent proper for the receiver's current location can be obtained by the proposed method. The proposed method has the property of adapting path loss exponent to the situation, which results improved accuracy of the distance estimation.

Ⅴ. Conclusions

We have proposed an iterative linear regression method to find the distance from a transmitting beacon to a receiver based on RSS and mobility information of the receiver obtained with dead reckoning using accelerometer. The proposed method has improved the accuracy of the distance estimation considerably compared with the distance estimation based on a general path loss model. The proposed method could be extended to two or three-dimensional cases by exploiting moving direction as well as moving speed.

Acknowledgments

This work was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(NRF2018R1D1A1B07048319).

References

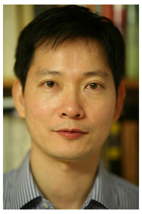
[1] S. He, and S.-H. G. Chan, “INTRI:Contour-based trilateration for indoor fingerprint-based localization,” *IEEE Transactions on Mobile Computing*, Vol. 16, No. 6, pp. 1676-1690, 2017.

[2] R. Ban, K. Kaji, K. Hiroi, and N. Kawaguchi, “Indoor positioning method integrating pedestrian dead reckoning with magnetic field and wifi fingerprints,” in *Proceeding of 8th International Conference on Mobile Computing and Ubiquitous Networking*, Hokkaido: Japan, pp. 169-174, 2015.

[3] P. Davidson, and R. Piche, “A survey of selected indoor positioning methods for smartphones,” *IEEE Communications Surveys and Tutorials*, Vol. 19, No. 2, pp. 1347-1370, 2017.

[4] N. Yu, X. Zhan, S. Zhao, Y. Wu, and R. Feng, “A precise dead reckoning algorithm based on bluetooth and multiple sensors,” *IEEE Internet of Things Journal*, 2018, Vol. 5, No. 1, pp. 336-351, 2018

[6] H. Weinberg, :Using the ADXL202 in Pedometer and Personal Navigation Applictions,: Application Notes AN-602, 2, pp. 1-6, 2002.



이 동 준 (Dong-Jun Lee)
1996년 2월 : 한국과학기술원 전기전자공학과 (공학석사)
2000년 2월 : 한국과학기술원 전기전자공학과 (공학박사)
2000년 3월 ~ 2005년 2월 : 삼성전자 네트워크 사업부
2005년 3월 ~ 현재 : 한국항공대학교 항공전자정보공학부 교수
※관심분야 : 위치추정, 이동통신, 저지연통신

김 다 영 (Da-Yong Kim)
1996년 3월 ~ 현재 : 한국항공대학교 항공전자정보공학부
※관심분야 : 위치추정, 이동통신

이 은 혜 (Eun-Hye Lee)
2020년 2월 : 한국항공대학교 항공전자정보공학부 (공학사)
2019년 9월 ~ 현재 : 퀄컴코리아
※관심분야 : 위치추정, 이동통신