An effective time of advent-based scheme for mitigating the influence of the non-line-of-sight propagation

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Abstract

Aiming at the problem that Time of Advent-based wireless location is easily influenced by non-line-of-sight, a set of effective wireless ranging system for mitigating the influence of non-line-of-sight has been proposed in this paper. At first, the Kalman filter model has been established to eliminate the influence of non-line-of-sight, as well as the random interference. Secondly, it carries out the off-line filter simulation with test data to verify the effectiveness of the model. Finally, a set of ranging system has been designed by taking the ATmega1280 microprocessor as the controller and the nanoPAN5375 as the radio frequency chip, and it can carry out the real test on the improved ranging platform. According to the results, the designed system can accomplish the real-time dynamic filter, which can reduce the non-line-of-sight error with a high measurement precision, and it can also be applied in the location under non-line-of-sight environment directly.

Keywords: time of advent, wireless location, non-line-of-sight, Kalman filter, nanoPAN5375

1 Introduction

The E-911 location demand released by Federal Communications Commission (FCC) in 1996 gave rise to an extensive study on the wireless location technology, which turned the location and tracking of MT to be a study field with rapid development [1]. The wireless sensor network location technology has already been applied in various fields, including the business, public security and military field, for instance, it can test the operational condition of the equipment when deploying WSN in the industrial site, it can track the logistic dynamics when deploying in warehouse, and it can even provide the optimal route for the firemen when deploying in the fire rescue scene [2, 3] etc. When compared to the GPS that enjoys the widest application at present, the wireless sensor network location system has its own advantages. At first, GPS equipment cannot work in places that GPS satellite signal cannot reach [4], such as the indoor environment, thick forest, etc. while the wireless sensor network location system is free from the restrictions of the site. Secondly, the cost of GPS is too high, and it is not applicable for the low-end and simple application site.

At present, the study on the wireless sensor network location is to make full use of the current resources in each communication standard to improve the precision of the wireless location in complicated wireless communication environment, among which NLOS transmission caused due to the shielding of physical entity is the key element that influences the location precision. Aiming at reducing the influence of NLOS transmission on the precision of the TOA-based location, substantial studies have been carried out in both home and abroad. Reference [5] proposed the location algorithm for the particle filter, reference [6] put forward a new iterative minimum residual, reference [7] came up with the residual test, and there are also some other methods, for instance, reference [8] adopts the nonlinear least square method for solving the inequality constraints, modifies the delay caused by NLOS and locates later. All these methods can reduce the unfavourable influence brought by the NLOS error to a certain degree and improves the location precision. But these methods have a huge computation quantity, and some also need to increase the storage capacity of the system, which all increases the cost and complexity of the system.

Aiming at the NLOS transmission in the individual indoor location [9], the KF algorithm that can eliminate the NLOS error has been adopted for removing the influence of NLOS. Moreover, a set of indoor wireless ranging system has been established by taking the ATmega1280 as the processor and nanoPAN 5375 as the radio frequency chip, and the distance between the moving tag and fixed base station has been measured through symmetric double-side and two-way ranging method. Meanwhile, according to the characteristics of NLOS, KF model has been established on the basis of distance, which will carry out the off-line algorithm verification for the test data through matlab simulation software, and then the algorithm will be realized specifically on the designed ranging platform. According to the experiment, for this wireless ranging system, the algorithm is easy to be realized, with strong instantaneity

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and high precision, and it can also be applied for indoor location directly.

2 System composition

The ranging system mainly relies on the anchor of the wireless ranging function and moving tag to accomplish the ranging function, while the data collector control software operates in PC to display and save the distance data measured timely and after filtering, among which, the reference node and moving tag share the same hardware system, consisting of the ATmega1280 SCM[10], radio frequency measurement module nanoPAN 5375 [11] and the interface converting chip. The radio frequency module employs the CCS [12] to finish the communication. In this paper, it mainly focuses on the study of the real-time filtering for the distance obtained by the reference node and moving tag under NLOS, aiming to achieve more accurate distance data.

2.1 TOA-BASED RANGING MODEL UNDER NLOS

TOA is a ranging method based on the arrival time [13], which will calculate the distance from the nodes according to the transmission speed and time of the signal. Suppose the reference point participating in the ranging is *A* and the moving tag is *B*, the reference point *A* is fixed, and the moving tag *B* moves towards *C* in uniform linear motion. Establish the model as shown in Figure 1, in which *D* is human or barrier, and it can form the NLOS transmission effectively.

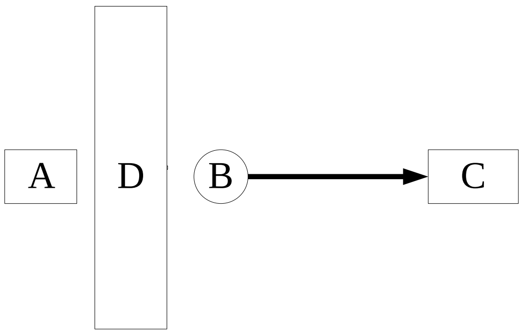

FIGURE 1 TOA-based ranging model under NLOS

Since the direct route of the signal is blocked by the barrier, it delays the signal transmission time, leading to the deviations in results and even zero value, and finally it will decrease the location precision.

2.2 RANGING PRINCIPLE

In this paper, the studied ranging algorithm is SDS-TWR ranging method [14] (also called symmetric double-side and two-way ranging method). SDS-TWR method can reduce the ranging error brought by the non-synchronization and drift, which mainly carries out a reverse TWR process on the basis of TWR ranging method. Thus, four time values can be obtained.

The principle of SDS-TWR is shown in Figure 2.

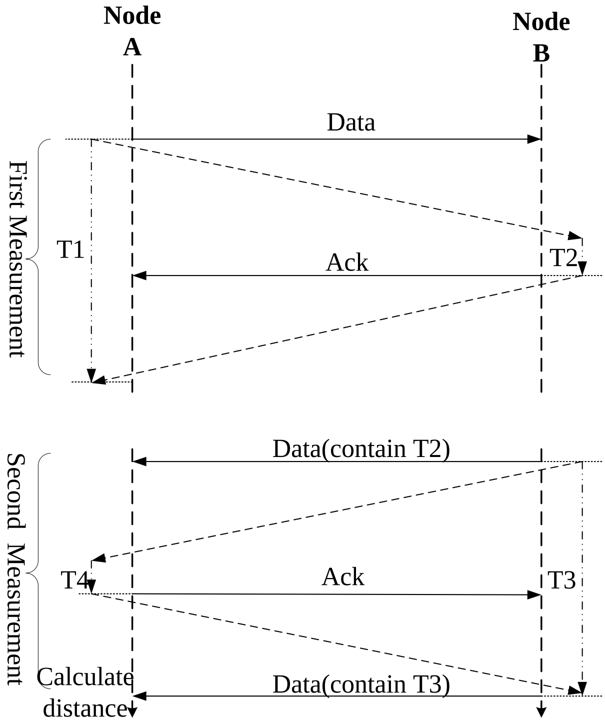

FIGURE 2 Symmetric Double Sided Two Way Ranging

In this method, it includes two symmetric measurements. Firstly, the time from sending data package by node *A* to receiving the package is T_1; the node *B* will start timing after receiving the data from node *A*, and stop timing after returning the reply, suppose the processing delay of node B is T_2; the round-trip time of the data package will be obtained by subtracting T_1 from T_2. Secondly, node B will send data package, and node A will receive and reply, suppose the time measured by node *B* and node *A* is T_3 and T_4 respectively, and then the round-trip data of the data package is $T_3 - T_4$. Suppose the transmission speed of signal in the medium is c, then the theoretical distanced between the two nodes are:

$$d = c \times \frac{(T_1 - T_2) + (T_3 - T_4)}{4}, \tag{1}$$

As shown in Figure 1, the reference point *A* achieves the distance from the moving tag *B* according to SDS-TWR, and then carries out filtering for the distance data obtained under NLOS through KF algorithm.

3 Algorithm implementation

3.1 NLOS ERROR AND KF MODEL

During the process of radio wave transmission, it will reflex or reflect if there are barriers, so that the TOA is extremely delayed. That is to say, it will produce NLOS error.

Under NLOS, the ranging equation can be represented by:

$$R(t_i) = N(t_i) + T(t_i) + S(t_i)\,, \tag{2}$$

where the $R(t_i)$ refers the distance measurement from moving tag B to base foundation A at t_i moment (obtained by multiplying the transmission speed with the transmission time), $N(t_i)$ stands for the real NLOS error, since the error caused by NLOS is positive deviance, then $N(t_i) > 0$; $T(t_i)$ stands for the real distance from the tag to the foundation base value, $S(t_i)$ stands for the standard ranging error, and it is a random process with zero average value.

The KF model can be designed according to equation (2), in which $z(t)$ stands for the TOA measured value sequence, namely $R(t_i)$.

The related parameter settings of KF Equation (3) and (4) are shown as follows:

$$x(t+1) = Ax(t) + p(t)\,, \tag{3}$$

$$z(t) = Gx(t) + h(t)\,, \tag{4}$$

$$A = \begin{bmatrix} 1 & \Delta \\ 0 & 1 \end{bmatrix}\,,\quad G = \begin{bmatrix} 1 & 0 \end{bmatrix}\,,\quad x_t = \begin{bmatrix} R(k) & \dot{R}(k) \end{bmatrix}^T\,,$$

$$p(t) = \begin{bmatrix} 0 & u_n \end{bmatrix},\ h(t) = n_m\,.$$

In which, $R(k)$ is the TOA waiting to be estimated, $\dot{R}(k)$ is the first derivative of $R(k)$, Δ is the sampling gap of KF, u_n is the process noise component, and n_m is the measurement error.

3.2 CHARACTERISTIC ANALYSIS

At first, since the NLOS error distribution in TOA measurement is related to the barrier distribution on the radio wave propagation route, NLOS error has a random characteristic. The randomness gives rise to the dramatic changes in NLOS error, so that the deviation in TOA measurement value is extremely huge. These measurement value greatly influenced by NLOS will severely impact the correct estimation for TOA. As a result, if the influence including relatively huge error measurement can be eliminated, it can remove the NLOS error to a great extent.

3.3 MEASURED VALUE DROPPING METHOD AND OVERALL SHIFTING METHOD

The measured value dropping method refers to dropping the measured value with great deviations through KF. It will judge if the deviation in the current measured value is within the acceptable error range through comparing the deviation with the threshold value. The overall shifting method makes advantage of the NLOS error and makes the overall measured value has a feature of positive deviation, and offsets the overall estimation downwardly to eliminate the NLOS error. It has advantages in eliminating the NLOS error of measured value with small deviation, but it cannot eliminate the influence of measured value with a huge deviation on the follow-up estimation value effectively.

3.4 REALIZATION OF ALGORITHM SOFTWARE

The system software mainly includes the main program, initial sub-program and functional sub-program, among which, the initial sub-program mainly includes the initialization of clock module, drive initialization of radio frequency chip and initialization of application level, while the functional sub-program mainly includes the ranging sub-program, KF sub-program and display sub-program. The ranging sub-program is mainly applied in receiving and sending signal, as well as achieving the distance data. The KF sub-program is mainly responsible for carrying out the mathematic processing for the distance data obtained, thus to improve the ranging precision. The displaying sub-program is mainly responsible for sending the unprocessed distance data and filtered distance data to the serial port, and then displays it on the upper computer software.

The whole filtering algorithm is realized in reference point A, and it is pre-processed with the measured-value dropping method and overall shifting method, and then the KF algorithm is employed to carry out the dynamic filtering.

4 Design of system hardware

The system employs the nanoPAN 5375 radio frequency module of the German nanotron Company, responsible for generating the chirp spread spectrum signal. The master control module employs the ATmega1280 SCM, responsible for controlling the work of nanoPAN 5375 module.

The wireless communication module employs the nanoPAN5375 module with 20dBm radio frequency power, and the longest communication distance can reach 800 meters. The module integrates the nanoLOC TRX receiver, radio frequency switch, power amplifier and other matching and conditioning unit, which is applicable for long-distance measurement and communication. The unique CSS technology of nanotron has been employed to measure the distance between the two points accurately. Within sight distance, the ranging precision is within 0.6 and 1.5 meters. The module provides three un-overlapped 2.4 GHz ISM channels that can be adjusted freely, and it supports several independent physical networks, and improves the co-existence with the current 2.4 GHz wireless technology [15]. Meanwhile it can provide reliable data communication with optimal transmission range. Therefore, the module can be widely applied in the LBS, as well as the high-precision ranging, real-time location and wireless sensor network.

5 Experiment and analysis

In this paper, the test data has been employed to testify the feasibility of the whole plan through simulation and real system test.

5.1 ALGORITHM OFF-LINE SIMULATION

The system firstly carries out the ranging for moving tag B according to Figure 1 without adding any algorithm. Suppose in the experimental environment, the coordinate of the reference point *A* is (0, 0), the cabinet is fixed in (1, 0) for making the NLOS transmission between *A* and *B*, in which the moving tag *B* (2, 0) moves to C (13, 0) along the x axis with 1 m/s speed, and the distance data obtained will be stored. It will take advantage of matlab simulation software to write the KF program to process the distance data obtained with offline filtering, thus to verify the effectiveness of the algorithm. The simulation result is shown in Figure 5, in which the sampling time is 20 ms, the threshold is 2.5, the horizontal coordinate stands for the quantity of the distance data obtained, about 575, while the vertical coordinate stands for the moving distance of the tag, and the unit is meter.

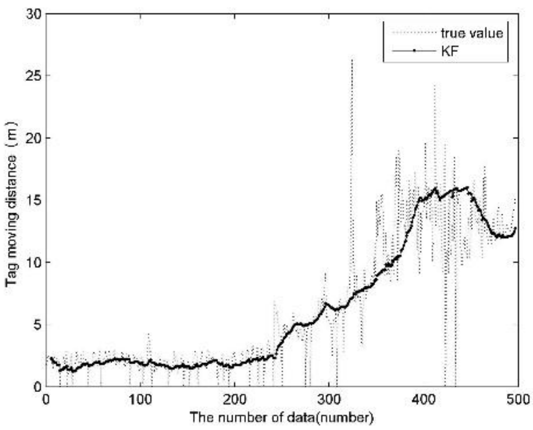

FIGURE 3 True value and filtering of the offline data

In Figure 3, it can be seen obviously that under NLOS, the real test value shakes severely, and there is also xero value. After it is processed with KF algorithm, it can decrease the fluctuation effectively, and eliminate the zero value well, thus it can demonstrate the effectiveness of the algorithm completely.

5.2 INFLUENCE OF THRESHOLD ON THE MEASURED VALUE DROPPING METHOD

The selection of threshold value in the measured value dropping method will have a great influence on the measurement results. It will not be able to eliminate the TOA measurement value with great errors if it is set too high, or it will eliminate too much measurement value, and the estimation value will not change with the measurement value, thus the KF will not converge. In Figure 4, it is the offline filtering simulation when the threshold value is 0.3, while in Figures 5 and 6, it is the offline filtering simulation when the threshold is 3 and 6 respectively. It can be seen from Figure 4 that the threshold value is too small, and the estimation value does not change according to the measurement value, resulting that the KF does not converge. In Figure 5, it is the normal condition about the threshold value selection. In Figure 6, since the threshold value is too great, some great TOA measurement value cannot be eliminated, thus it cannot eliminate the influence of NLOS on TOA estimation, and the KF cannot play a good role.

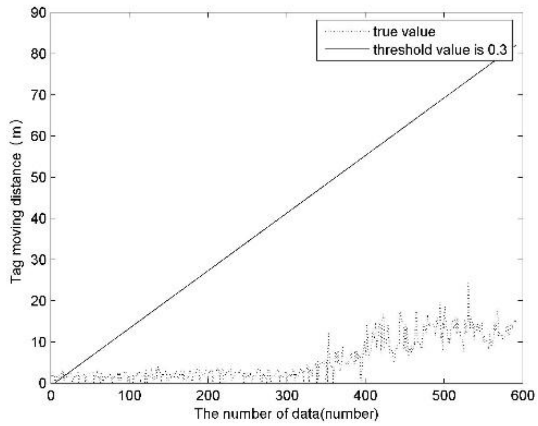

FIGURE 4 Threshold value is 0.3

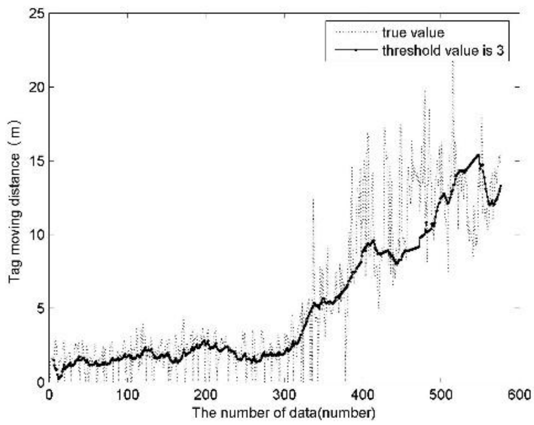

FIGURE 5 Threshold value is 3

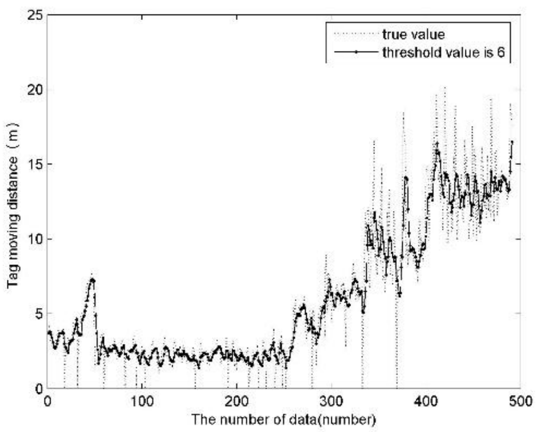

FIGURE 6 Threshold value is 6

In the offline model, the threshold value will be appropriate between 1.5 and 4. However, the threshold value obtained through offline filtering cannot be put into practice. In order to select the threshold value appropriate for the experimental environment, it should pass substantial on-site real tests to determine appropriate threshold value. The sampling time of the system is 20 ms, and the threshold between 0.3 and 1.8 is relatively appropriate for the experimental environment, as shown in Figure 7, the threshold value is 0.9, and from which it can be seen that KF plays an excellent role.

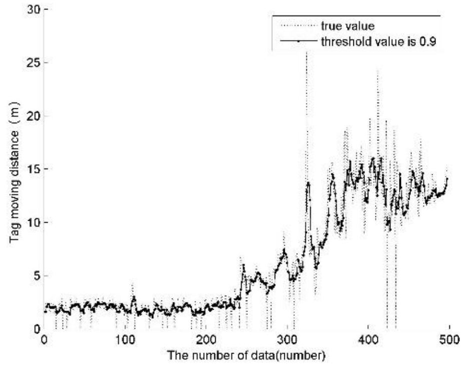

FIGURE 7 Threshold value is 0.9

5.3 REAL SYSTEM TEST

In this paper, the designed ranging system is employed to carry out the real-time filtering test, according to the test environment and procedure in 4.1, and it is applied to prove the algorithm is feasible in the real system test. The sampling time selected is 20 ms, the threshold value is 0.3, after comparing the distance before and after the filtering, the result is shown in Figure 8, in which the quantity of the distance data is 575.

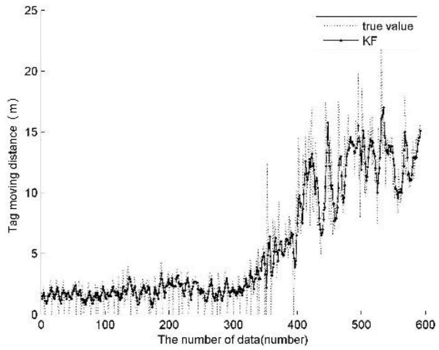

FIGURE 8 The system measured and filtering data

It can be seen from Figure 8 that since the dramatic shaking in the measured value caused by NLOS generates a huge error, and the filtering method is adopted to carry out the real-time processing. When there is a measured value with huge error, the measured value including great NLOS error will be dropped during the iteration process. Meanwhile, it can also eliminate the zero value caused by the inaccessible signal, which reduces the influence of NLOS error.

6 Conclusion

In this paper, the TOA-based scheme for eliminating the influence of NLOS proposed establishes the KF model and carries out the pre-processing for the data according to the statistical characteristics of NLOS error, and it reduces the measurement errors effectively. Through offline and real system test, the results have shown that the algorithm receives obvious effect in reducing the NLOS error, improves the ranging precision and provides good data support for further ranging-based location application.

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