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A novel adaptive Kalman filter based NLOS error mitigation algorithm

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Abstract: In this paper, we presented an algorithm for NLOS error mitigation based on adaptive Kalman filter with colored measurement noise. To eliminate NLOS error which induced by TOF-based distance measurements, a colored noise model is firstly established according to measurement noise and the filter parameters are adjusted dynamically based on the severity of NLOS environment. Then combined with adaptive Kalman filtering algorithm, the NLOS error mitigation process is adjusted in real time in order to obtain optimal estimation. The simulation experiments show that the algorithm has small error and high precision and is suitable for real-time dynamic location systems.

Keywords: colored noise, Kalman filters, adaptive algorithm, ranges, measurement noise.

1. INTRODUCTION

In recent years, wireless localization techniques have attracted more and more attention as its wide application of emergency response, intelligent transportation systems, target tracking, and so on. Short range wireless localization techniques have been proposed, which addressed the issue that GPS is unable in uncovered space such as indoors areas. Compared with other short range localization techniques which are widely used, such as received signal strength indicator (RSSI) based localization, angle of arrival (AOA) based localization and time difference of arrival (TDOA) based localization, time-of-flight (TOF) based localization has higher accuracy. However, the accuracy of TOF based localization is still affected by various factors and NLOS propagation is the main factor which causes the NLOS error. Thus, how to eliminate the influence of NLOS error in localization becomes an urgent task. In this paper, we focus on the NLOS error mitigation problem in the time of flight based localization.

As a famous adaptive linear filtering algorithm, Kalman filter improve the TOF ranging accuracy by smoothing TOF ranging result to mitigating NLOS propagation effects. The traditional Kalman filter is not ideal due to the limitations of the model. Modified Kalman filters with consideration of NLOS error mitigations has been investigated by many researchers. A typical method is Adaptive Kalman Filtering (AKF), which achieve adaptive filtering with estimating covariance matrix of the system noise or the measurement noise. The federal Kalman filtering algorithm is employed to eliminate NLOS error through combining overall translation with discarding useless measurements. However, the thresholds of federal Kalman filter are set by experience. Therefore the accuracy is greatly reduced. Channel Classification and Kalman Filter (CC-KF) has been presented, in which signal propagation path is divided into three types and the parameters of the Kalman filter are adjusted according to these types. But misidentification will cause greater error.

Non-Kalman filtering algorithms have been also raised to further increase the TOF localization accuracy. The maximum posteriori probability algorithm use probability calculation to identify NLOS paths and LOS path, but the process require the probability density function of NLOS error, which is difficult to achieve in a real environment. In addition, Convex relaxation is proposed to mitigate the effect of NLOS errors on the localization performance. The method jointly estimates the source location and another parameter that is related to the NLOS errors.

The traditional Kalman filter is originally designed to smooth White Gaussian noise, mean of which is 0m. Because mean of TOF ranging error caused by multipath and NLOS propagation could be several meters and even larger, the realistic indoor TOF ranging error may be typical colored noise, but not White Gaussian noise. Due to this mismatch, the traditional Kalman Filter is not sufficient enough to limit the huge ranging error. In this paper, we first analyzes the distribution of TOF ranging error. And then we would demonstrate that ranging error can not be

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modeled with Gaussian white noise. Finally we proposed a new algorithm Kalman filter with adaptive colored noise. In our algorithm, the filter parameters are adjusted according to the observed distance and the observed distance is smoothed by Kalman filter according to the adjusted parameters to minimize the error. To validate the above proposed methodology, its performance is compared with traditional Kalman Filter, adaptive Kalman Filter and others. Result shows that Kalman filter with adaptive colored noise has an excellent capability of reducing the effect of NLOS on the accuracy of TOF ranging and its performance is much superior to the others.

The rest of this paper is organized as follows: In Section II, we provides fundamental backgrounds including TOF ranging theory, model of TOF ranging error and demonstration that TOF ranging error is typical colored noise. In Section III, we introduce the mathematical derivation of algorithm of Kalman filter with adaptive colored noise. Simulations are conducted to verify the performance of the proposed methods in Section IV, and conclusions are drawn in Section V.

2. RANGING MODEL AND NLOS ERROR MODEL BASED ON TOF

In this section, we first and foremost introduce the general process of TOF based distance measurement, and later on, present the NLOS error model. Finally, we will demonstrate that ranging error is typical colored noise.

2.1 Ranging Model Based on TOF

To perform a TOF measurement between two nodes, the local node sends a packet to the remote node and the remote node automatically sends an acknowledgement (ACK) in response to this packet, as show in Fig.1.

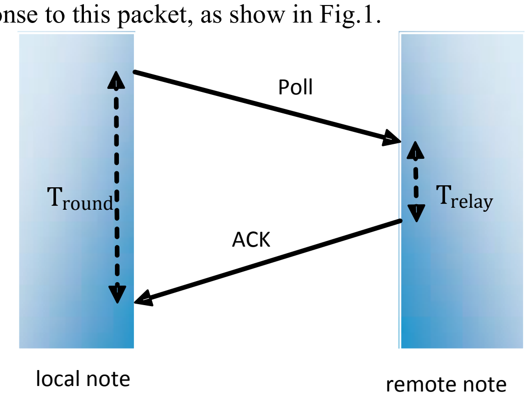

Fig.1 Two-way TOF ranging

The local node is able to measure the time from sending the poll to receiving the ACK. T_{round} represents the total time. In addition, the remote node records how long it took to respond to the poll, T_{relay}. Subtracting this from the total time then get the round trip time. It can be assumed that each direction take an equal amount of time and thus the time of flight, T_P, is equal to half the round trip time, as indicated in equation 1 below.

$$d = T_p \times C = \frac{T_{round} - T_{relay}}{2} \times C \tag{1}$$

Because the signal travel at the speed of light, it is clear that if NLOS propagation and multi-path occur, eventually they will lead to huge ranging error.

2.2 NLOS Error Model

Consider a two-dimensional space , where the wireless sensor network (WSN) include a unknown mobile station (MS) and M base stations (BS). TOF measurements performed between MS and all BS. As show in Fig2, NLOS path may exist between MS an BS because of reflection and blockage.

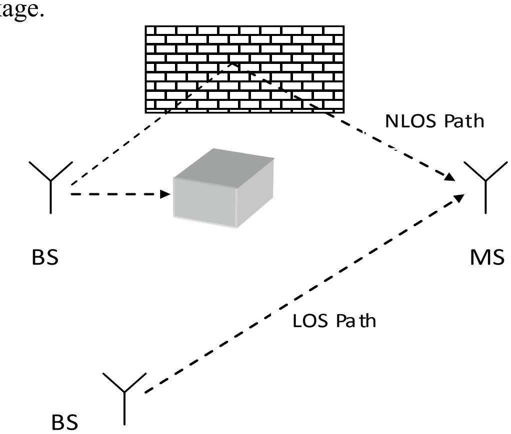

Fig. 2 LOS and NLOS path

The location of MS is denoted by *X*, and the location of the ***i***th BS is denoted by X_i (*i=1,2...M*). Therefore, the rang measurements are denoted by

$$r_i = d_i + \beta_i = d_i + n_i + e_i \tag{2}$$

where $d_i = \|X - X_i\|_2$ is the distance between MS and ith BS with $\|\cdot\|_2$ representing the Euclidean norm, β_i is ranging error, n_i is standard error and e_i is NLOS error. The β_i is a zero-mean white Gaussian variable with known variance. When the path of signal propagation between MS and BS is LOS path, e_i is zero, and when the path is NLOS path, we assume that e_i is a positive random variable. Therefore, we have

$$\begin{aligned} e_i > 0, &\quad NLOS \ \ path \\ e_i = 0, &\quad LOS \ \ path \end{aligned} \tag{3}$$

Because the NLOS error generally is larger than the standard error, mitigating the NLOS errors means mitigating the ranging error.

2.3 Distribution of Ranging error

In this section, we will analyze the ranging data of the actual experiment and it's distribution. And then we would demonstrate that ranging error is colored noise. In the