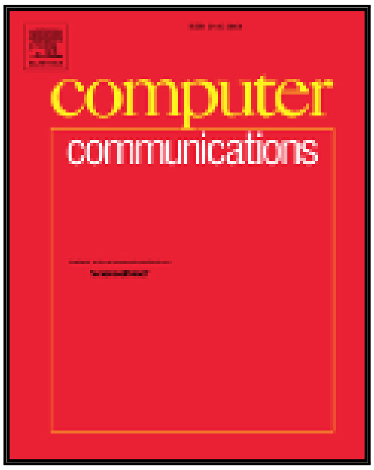
Accepted Manuscript



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PII: S0140-3664(16)30555-2
DOI: 10.1016/j.comcom.2016.11.005
Reference: COMCOM 5408

To appear in: *Computer Communications*

Received date: 12 December 2015
Revised date: 6 November 2016
Accepted date: 14 November 2016

Please cite this article as: Xuming Fang , Lei Nan , Zonghua Jiang , Lijun Chen , Robust node position estimation algorithms for wireless sensor networks based on improved adaptive Kalman filters, *Computer Communications* (2016), doi: 10.1016/j.comcom.2016.11.005

Robust node position estimation algorithms for wireless sensor networks based on improved adaptive Kalman filters

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Abstract

The Kalman filter (KF) is an optimal state estimator for position observation systems with noise; therefore, it is typically used to estimate the location of a node in a wireless sensor network (WSN) in a noisy environment. The precision of noise statistics largely determines the localization accuracy of the KF, and the statistics of noise are often unknown or time-varying in a real WSN. Therefore, the adaptive Kalman filter (AKF) is utilized for awareness of the statistical parameters of noise. However, the node position estimation (NPE) algorithm based on the state-of-the-art AKF typically lacks robustness and becomes inaccurate in the case of simultaneously perceiving the statistics of process noise and measurement noise. This study proposes a robust NPE algorithm based on an improved adaptive extended Kalman filter (RNPE-IAEKF) and another robust NPE algorithm based on an improved adaptive unscented Kalman filter (RNPE-IAUKF). The RNPE-IAEKF algorithm has low computing complexity, while the RNPE-IAUKF algorithm has high positioning accuracy. Our proposed algorithms solve the problems of poor robustness and low accuracy of the NPE algorithm based on the adaptive extended Kalman filter (NPE-AEKF) and the NPE algorithm based on the adaptive unscented Kalman filter (NPE-AUKF). In addition, the RNPE-IAEKF and the RNPE-IAUKF do not lose robustness upon simultaneous perception of the statistics of process noise and measurement noise, which is strictly proven in theory. The results of practical experiments and numerical simulations demonstrate that regardless of the placement of a static target node, the mobility of a mobile target node, and the number of anchor nodes, the RNPE-IAEKF improves upon the positioning accuracy and convergence speed of the NPE-AEKF by at least 28% and 29%, respectively and that the RNPE-IAUKF increases the localization accuracy and convergence rate of the NPE-AUKF by at least 32% and 37%.

Keywords: Robust localization algorithm; Adaptive Kalman filter; Noise statistic estimator; Wireless sensor network; RSSI

1. Introduction

The Kalman filter (KF) is an optimal state estimator in noisy environments, and it can estimate the current state of a position observation system (such as the location of a node in a network) by measuring the system output with noise [1]. Usually, a process model describing the state change of the system and a measurement model defining the relationship between the internal state and the external output of the system are needed in the KF. For practical positioning scenarios, there exist modeling errors in the process and measurement models, that is, the process noise and the measurement noise. Because the accuracy of the statistical parameter of the process and measurement noise can greatly affect the estimation precision of the KF, obtaining the exact noise parameter is of critical importance for the KF-based positioning algorithm.

A wireless sensor network (WSN) is an ad-hoc network made up of a large number of nodes equipped with sensors, microcontrollers and transceivers [2]. WSNs have been applied in various fields, for example, smart homes, health care, industrial automation, and environmental monitoring. For many WSN applications, it is necessary to know the location information of the node in the network.

In most WSNs, two nodes communicate with each other by sending and receiving wireless signals. The received signal strength indication (RSSI) between nodes is usually employed to model the inter-node distance. Because the measured RSSI is vulnerable to the interference of the external noise, the KF is often used as the node position estimator of the WSN to estimate the position of the target node (TN) without a known location based on the noisy RSSI measured by the anchor node (AN) with a known location.

Although the KF can filter the process noise in the process model and the measurement noise in the measurement model, it requires accurate statistics of the process noise and measurement noise. An inaccurate statistical parameter of the process and measurement noise can cause localization errors in the node position estimation (NPE) algorithm based on the KF (NPE-KF) to increase or even diverge [3]. An unbiased noise statistic estimator (NSE) able to estimate the noise statistic parameter in an online manner is developed [4], which allows the KF to perceive unknown or time-varying noise statistics.

The KF has already been used to estimate a WSN node's position [5,6], but it is only applicable to the linear process and measurement models. Thus, an NPE based on an extended Kalman filter (NPE-EKF) suitable for the nonlinear model is designed [7-9]. Because the NPE-EKF requires linearizing the function in the nonlinear model, it can only have an accuracy of, at most, the first-order Taylor series expansion of the nonlinear function. To overcome the limitation of requiring that the

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