A New Localization and Tracking Algorithm for Wireless Sensor Networks Based on Internet of Things

Zhang Feng, Xue Hui-Feng, Zhang Yong-Heng, You Fei
1 School of automation, Northwestern Polytechnical University, Xi’an 710072, China
2 School of Information Engineering, Yulin University, 719000, Yulin, China

Received: 14 May 2013 /Accepted: 19 July 2013 /Published: 31 July 2013

Abstract: To improve the racking accuracy for wireless sensor networks and solve the problem of network overhead, reduce the energy consumption of nodes, analyzed existing localization and tracking algorithms, ensure that one of the core technology for wireless sensor network performance. In this paper, based on the existing localization and tracking mechanisms, the sensor node localization and target tracking application technology in WSN were analyzed from the views of improving precision, prolonging the network life based on the Rang-free theory, coordination theory, particle filter and other computing methods. Combining sensor activation algorithm and dynamic clustering algorithm, a parallel extended particle filter algorithm was proposed for target tracking. Considering Internet of Things target tracking, specific regions of applications such as intrusion detection, a localization and tracking prototype system based on WSN was built. For the localization problem in WSN, the localization algorithm based on mobile beacon was designed and implemented. And combined with target tracking collaborative algorithm, construct a prototype system for target tracking, which can lay the foundation for further application of localization and tracking technology in WSN.

Keywords: Target tracking, Wireless sensor network, Internet of things, Localization, Particle filter.

1. Introduction

Wireless sensor networks (WSNs) as a new information acquisition and processing technology, positioning in areas relevant to a wide range of applications in environmental monitoring, target tracking, intelligent transportation, and intrusion detection [1]. In these applications, access to monitoring information often need to know the location information of sensor nodes in WSNs, otherwise, the collected data is meaningless or invalid [2]. Gets the sensor node location information is very important, for example, only bind the location information of the monitoring data position to elaborate on what happened in what position event, in order to achieve the goal of localization and tracking [3]; Another example, access to the sensor nodes position distribution can improve the efficiency of network routing, in order to achieve the load balancing of the network [4] and the network topology auto-configuration [5], to improve the quality of the coverage of the entire network [6], can also network namespace [7]. Therefore, scientific and effective positioning algorithm design is one of the key technologies in WSNs.

Usually, WSNs positioning method is the most simple is loaded with the global positioning system (GPS) receiver for each node, to determine the location of the node. However, due to the cost,
energy of nodes and GPS has certain requirements for the deployment of environmental constraints, not actually may load the GPS receiver to all nodes. Therefore, WSNs generally only a few nodes by loading the GPS or pre-deployment in a particular position to get their coordinates, and a large number of unknown node location information must pass a certain location algorithm to obtain. In the design of WSNs algorithm for node location, need to consider many factors, including the proportion of anchor node, network scale, network fault tolerance, ranging and error, ranging and error, positioning accuracy [7]. Therefore, WSNs location problem is a very challenging task.

Target tracking as a scientific and technological development in one direction, the first can be traced back to the eve of World War II; the world's first tracking radar station SCR-28 [8]. After that, with the continuous development of sensor technology, such as radar, infrared, sonar, laser and satellite-based target tracking system emerging and maturing, the theories and methods of target tracking has been greatly developed. With the development of wireless sensor network technology in the wireless sensor network environment maneuvering target tracking has become an important research target tracking direction. Target tracking in wireless sensor networks as a multidisciplinary subject, it involves including control, signal processing, network architecture, distributed computing and optimization algorithm [9] to achieve target tracking, wireless sensor networks has become a popular research direction [10].

In this paper, from the target tracking theory, in-depth analysis based on the principle of particle filter, based on dynamic clustering, this paper proposes a parallel extended particle filter algorithm. Through the expansion filter to generate the proposal distribution, a reduction in the required number of particles to improve the particle filtering accuracy at the same time, reduce the calculation of target tracking algorithm complexity, thus reducing the energy consumption. In the particle filter stage, the cluster head will particle set into subsets, and assign it to run in parallel cluster member nodes in each cluster, and information fusion in the cluster head, get the target state estimation. Between each member node cluster does not exist the exchange of information, only the information exchange between the sensor nodes and cluster head, reducing the energy consumption of network communication. Meanwhile, since the particle filter is assigned to each sensor node in parallel to improve the efficiency of particle filtering, avoid single node excessive energy consumption, the equalization network energy consumption.

2. WSN Target Tracking System

Based on Internet of things target tracking, the specific area of intrusion detection applications, often with the monitoring area, the poor monitoring the environment and the lack of the necessary communications infrastructure characteristics, and wireless sensor networks with large-scale random deployment, and so on ad hoc networks, wireless sensor networks used in these occasions can give full play to the advantages of wireless sensor networks, location tracking has broad application prospects.

Target tracking system based on wireless sensor network usually consists of sensor nodes, the base station and remote monitoring center. Sensor nodes by aircraft or other random dispenser in the monitoring area, the emergence of positioning sensor nodes detect the target, once the target appears, the sensor nodes measuring a moving target the message sent by the application of the proposed target tracking algorithm, the target tracking and forecasting, and real-time status information sent to the gateway target. The target state is estimated by the WSN gateway, the information is sent through the GPRS network to the monitoring center, and real-time display of the trajectory of the target position in the monitoring center to achieve real-time tracking of the target. WSN-based target tracking network architecture is shown in Fig. 1.

The overall system is divided into three layers: the perception layer, network layer and application layer. Sensing layer, using the 802.15.4 protocol, sensor nodes target perception and detection. This layer is mainly responsible for the perception of the detected target information and self-organizing clusters strategy for the measurement of target information for efficient data co-processing and data fusion, to calculate the target position status information to predict the target trajectory tracking of the merged transmission of information to the gateway device. The network layer implements the transmission, routing and control of information, and to convert between the different protocol stacks and access, and to guarantee the security of data transmission process in the data network and the transmission reliability. Application layer information interaction through remote communication network and field station, real-time monitoring of target track and display, and can be real-time network state information to the target query.

3. Tracking Filter Algorithm

3.1. Bayesian Filtering

The principle of Bayesian filtering is the a priori probability density and the state observer state variables of the system function to construct the posterior probability density, i.e. with the predicted state of the system model a priori probability density using a combination of the recent systematic observation value correction, thereby obtaining the posterior probability density.
Variable system problems in reasoning and analysis of target localization, tracking, dynamic properties, often use the state space model to describe the time-varying system. The state-space model can describe the unknown amount of dynamic or tense and observed signal with an unknown amount of the relationship, it is suitable to solve the multi-variable data and non-linear, non-Gaussian process. The state space model typically includes a description of the state variables change over time system model and observation model state variables associated with measurement noise. The state variable contains information that describes the system state variables for target tracking, target position, speed and motion characteristics. The measurement vector typically means that the noise associated with the state vector of observations. Based on Bayesian framework, based on the discrete state-space model, recursive obtain the probability density distribution. Control input is ignored; the discrete state space model of the system is described as follows:

State-space model: 
\[ x_m = f_m(x_{m-1}, q_{m-1}) \]  

Observation model: 
\[ z_m = h_m(x_m, v_m) \]

where \( f_m(x_{m-1}, q_{m-1}) \) and \( h_m(x_m, v_m) \) are bounded by nonlinear functions, \( x_m \in \mathbb{R}^n \) as the state vector of the system at time \( m \), \( z_m \in \mathbb{R}^n \) is the observation vector \( x_m \) of the system state, \( q_{m-1}, v_m \) respectively, for the process noise and observation noise. The process noise and measurement noise probability density distributions of ships are known. Definition:

\[ z_m = \{ z_1, z_2, \ldots, z_m \}, x_m = \{ x_1, x_2, \ldots, x_m \}, \]

were all observed values of \( k \) points in time, the set of values of the state variables. Assumes that the system state of a priori probability distribution is known, that is \( p(x_0 | z_0) = p(x_0) \), \( p(x_m | z_m) \)

filtering distribution can be obtained through the prediction and update of a two-step.

Assuming the probability of time \( k-1 \) adhesion \( p(x_m | z_m) \) is known, where

\[ p(x_m | Z_{m-1}) = \int p(x_m | x_{m-1}, Z_{k-1}) p(x_m | Z_{k-1}) dx_{m-1} \]

\[ = \int p(x_m | x_{m-1}) p(x_m | Z_{k-1}) dx_{m-1} \]

where \( p(x_m | x_{m-1}) \) \( v \) is a first-order Markov process, prior probability density distribution for the state variables not get the latest observations by the system of equations obtained.

3.2. Trilateral Localization Algorithm

In WSNs positioning algorithm, the triangular positioning algorithm based positioning algorithm, and on its basis also spawned a lot of improved algorithm. The principle of trilateral positioning algorithm is shown in Fig. 2.

In Fig. 2, the location of the three anchor nodes is known, their coordinates are \( (x_i, y_i) \), \( i = 1, 2, 3 \). Fig. 2 white dots represent unknown nodes, its location \( (x_u, y_u) \), \( d_1, d_2, d_3 \) denote the unknown nodes to measure the distance of three anchor nodes, then the following relationship:
\[(x_i - x_j)^2 + (y_i - y_j)^2 = d_i^2 \quad (i = 1, 2, 3) \tag{4}\]

\[
\begin{pmatrix}
    x_u \\
    y_u
\end{pmatrix} = \begin{bmatrix}
    2(x_1 - x_3) & 2(y_1 - y_3) \\
    2(x_2 - x_3) & 2(y_2 - y_3)
\end{bmatrix}^{-1}
\begin{bmatrix}
    x_1^2 - x_2^2 + y_1^2 - y_2^2 + d_1^2 - d_2^2 \\
    x_2^2 - x_3^2 + y_2^2 - y_3^2 + d_2^2 - d_2^2
\end{bmatrix}
\tag{5}\]

It is not difficult to see, three side positioning algorithm is extended to high dimension space is quite convenient.

4. Extended Particle Filter Algorithm

The particle filter is recursive Bayesian filtering method based on Monte Carlo simulation (Monte-Carlo), the key idea is to use random sample weighted with the value of the related rights and to represent the posterior probability. When the sample size is very large, this probability estimates will be equivalent to the posterior probability density. Assumptions can be independent from the state of the posterior probability distribution \( p(x_m | z_m) \) random sample of \( N \) independent samples \( \{X^{(i)}_m, i = 1, 2, ..., N\} \) state probability density distribution can be approximated as:

\[
p(x_m | Z_m) = \frac{1}{N} \sum_{i=1}^{N} \delta_{x_m^{(i)}} (dX_m) \tag{6}\]

where \( \delta_{x_m^{(i)}} (dX_m) \) as a Dirac pulse function, the corresponding function is expected to

\[
\bar{T}_N(g_m) = \int g_m(X_m) \bar{p}(X_m | Z_m) dX_k = \frac{1}{N} \sum_{i=1}^{N} g_m(X^{(i)}_k)
\tag{7}\]

It can be guaranteed on convergence by the law of large numbers, and convergence is not dependent state dimension, can easily be applied to the case of the high-dimensional.

Because of sampling a probability to estimate distribution is often very difficult or even impossible, the importance sampling method avoids direct sampling difficulty, from the distribution of another more easily in samples randomly sample. If the probability density \( p(X_m | Z_m) \) directly from the sample is difficult to obtain particles directly from sampling, here introduce a probabilistic easier sampling and sampling from the distribution of \( q(X_m | Z_m) \), that is called the importance distribution. In this case, the above formula becomes:

\[
I(g_m) = \int g_m(X_m) \frac{p(X_m | Z_m)}{q(X_m | Z_m)} q(X_m | Z_m) dX_m
= \int g_m(X_m) w(X_m) q(X_m | Z_m) dX_m
= E_{q(Z_m)}[g_m(X_k) w(X_k)]
\tag{8}\]

One of the important weights:

\[
w(X_m) = w(X^{(i)}_m) = \frac{p(X_m | Z_m)}{q(X_m | Z_m)}
= \frac{p(X_m | Z_m) p(X_m)}{p(Z_m) q(X_m | Z_m)}
= \frac{1}{p(Z_m)} \frac{p(X_m | Z_m) p(X_m)}{q(X_m | Z_m)}
\tag{9}\]

5. Simulation Testing and Analysis

The most important parameters to measure the performance of target tracking accuracy of target tracking, target tracking algorithm based on wireless sensor networks should protect high tracking accuracy under the premise as much as possible to save energy consumption of sensor nodes and to meet short track reaction time. In this paper, considering the target tracking accuracy and network energy consumption of two performance metrics, the experiment will be presented in this chapter improved particle filter algorithm with the traditional distributed particle filter were compared, the main difference between the two lies in the selection of the target node to select two aspects, two aspects of the target
tracking accuracy and network energy consumption simulation comparison.

In the experiment of Fig. 3, the 126 Rules unknown node deployed in the area of 200 × 100 m² of, respectively, in the anchor nodes 6, 9, 12, 15 case, all the unknown nodes to locate the positioning error respectively: 2.93 m, 4.01 m, 3.06 m, 3.12 m.

Fig. 4 compares the tracking error target tracking in the case of different particles. The figure shows, with the increase in the number of particles, the higher the accuracy of target tracking, but the increase in the number of particles increases the amount of computation of the sensor node, the network power consumption increases.

![Fig. 3. Randomly deployed sensor nodes and network connectivity graphs.](image1)

![Fig. 4. Different particle number.](image2)

6. Conclusions

In this paper, the theory and application of technology based on wireless sensor network target tracking conducted in-depth research, around of target tracking in wireless sensor networks in recent years carried out research work, three algorithms, and these algorithms built for wireless sensor networks targeting tracking prototype system achieved a certain theory and applied research in the relevant fields, and forming characteristics. The main contribution of the features include: research target tracking in sensor nodes collaboration strategy to solve the problem of target detection and tracking process node collaboration. A parallel expansion of the particle filter algorithm. Algorithm using the extended filter to generate the importance density function of the particle filter, making the important density function sample of closer inspection the probability density of the sample, to improve the efficiency of particle filter weakened particle degradation. Considering Internet of Things target tracking, specific regions of applications such as intrusion detection, localization and tracking prototype system based on WSN was built. For the localization problem in WSN, the localization algorithm based on mobile beacon was designed and implemented. And combined with target tracking collaborative algorithm, construct a prototype system for target tracking, which can lay the foundation for further application of localization and tracking technology in WSN.

Acknowledgements

This work is partially supported by the Defense basic research projects in 2013 #A0420131501, Funding Project for Department of Education of Shaanxi Province in 2013 #2013JK1167, Research and Cooperation Project for Department of Yulin city in 2012 #2011SKJ09. Thanks for the help.

References


2013 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved. (http://www.sensorsportal.com)