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Data Collection Based on Mobile Agent in Wireless Sensor Networks

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***Abstract* - Environment Changes due to temperature, humidity, wind loading and so on can affect the performance of a large telescope. The real-time information of environment change must be got in order to exert control, reduce or eliminate the adverse effects of environment changes on the large telescope. A novel method of environment monitoring for a large telescope based on wireless sensor networks has therefore been proposed to realize environment data acquisition, on-line-detection and data analyzing in this paper, which provides the basis for the adjustment of the large telescope to improve its control performance and image quality.**

Index Terms* - *Wireless Sensor Networks; Environment Monitoring; Mobile Agent; ARMA Model; Ant Colony Routing.

I. Introduction

With the increasing of the telescope aperture, the whole system becomes exceptionally complex. Environment Changes such as temperature, humidity, wind loading and so on can affect the performance of the large telescope. Due to the new technology application of adaptive optics as the representative on the large telescope, the impact of environment changes on the system is more sensitive. The changes of real-time information of environment must be grasped in order to exert control, reduce or eliminate the adverse effects of environment on the system, which provides the basis for the adjustment of the large telescope to improve its control performance and image quality.

The wireless sensor network is a kind of intelligent information systems of data acquisition, transmission and processing, whose main features include low power consumption, low cost, low transfer rate, Ad-hoc network, etc. It is a special Ad-hoc network and composed of a number of co-organized wireless sensor nodes with data acquisition, wireless communication and collaboration, which can be specific or randomly distributed in the appropriate environment, organize themselves with a specific protocol to communicate, get the information of the surrounding environment and collaborate to accomplish specific tasks.

In this paper, for the effects of environment changes on the large telescope performance, based on wireless sensor networks a scheme to monitor the environment of the large telescope is designed as follows. The multi-sink topological structure of wireless sensor networks can improve the transmission efficiency of multi-hop network to meet the environment test requirements of low-latency, high frequency sampling and high data throughput, in which, with the mobile agent technology, the mobile agent of environment data collection moves to the target node to directly access its resources with fewer interactions with the sink node so as to avoid the great amount of data transmitted in the network, to largely reduce the network traffic and the dependence on the network bandwidth, to shorten the communication latency and to improve the response speed of data collection.

II. THE FRAME OF WIRELESS SENSOR NETWORKS FOR ENVIRONMENT MONITORING OF THE LARGE TELESCOPE

Environment Changes duo to temperature, humidity, wind loading and so on can affect the performance of the large telescope. People can obtain large amount of detailed and reliable information at any time, place and any environmental conditions from the wireless sensor network. Development of wireless sensor networks technology provides a new way to monitor the environment of a large telescope. To build a wireless, distributed environment monitoring system using WSN monitoring mode can solve the conflict of the data acquisition range, precision and monitoring costs and achieve the free expansion of the system and the large-scale monitoring at lower cost. At the same time, the wireless transmission of wireless sensor networks can improve the data collection methods of the monitoring process. Using the processing capacity of the sensor nodes, the front-end data processing and the data fusion synchronize the data collection and analysis to form sensor network mode of state maintenance which has preliminary self-analysis and self-diagnostic capabilities. This can not only improves the efficiency of data acquisition and processing but also effectively reduce the communication flow between the collection nodes and the system of back-end analysis and diagnosis. The frame of wireless sensor networks for environment monitoring of a large telescope is shown in fig.1.

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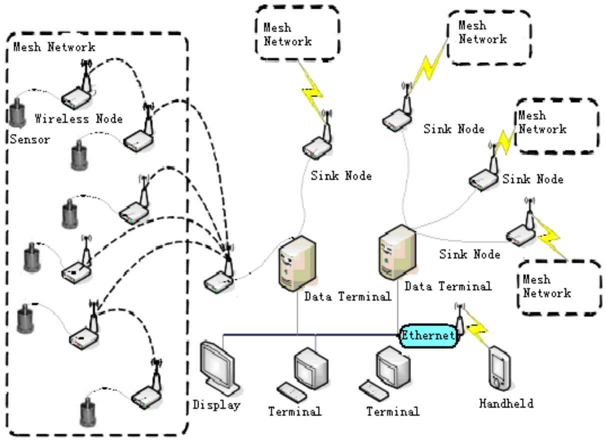

Fig. 1 The frame of wireless sensor networks for environment monitoring.

Mesh network is a new type of wireless sensor network which only allows a node to communicate with its adjacent nodes of short distance, in which all nodes are equal. The monitoring process of environment of a large telescope requires higher transmission stability and higher data throughput of the network. At the same time the number of sensor nodes is small, the network mobility is not strong after deployment and nodes need simple and reliable self-organization algorithm. In view of this, the wireless sensor network uses multicast clustering network mode of upper multiple base station nodes (sink nodes) combined with bottom mesh networks. Sensor nodes collect the environment signals of a large telescope. Under normal conditions the sensor nodes are usually in sleep or park. According to actual needs, the sink node will wake up the sensor nodes to query environment conditions on its own initiative. Then the sensor node will complete data collection in collaboration and send back the data to the sink node. On the top of the monitoring network the multiple base station nodes' processing capability is strong without regard to the power supply problem through the sink nodes because of the cable connection of their ends. This realizes topology control of multiple data collection points and increases data transfer rate to meet the environment test requirements of low-latency, high frequency sampling and high data throughput. The following is the specific analysis of the data collection process and its algorithm design for the above environment monitoring network.

III. MODELING AND DESIGNING OF DATA COLLECTION BASED ON MOBILE AGENT

In the wireless sensor network, data acquisition, computing and transmission consume a lot of energy of sensor nodes. The required energy consumption of data acquisition is related to the amount of the produced data, sampling frequency, sensor type and application requirement, etc. For example, 1 minute sampling data of a sound sensor is 720kb if the sampling frequency of the sound sensor is 1kHz and each analog sampling is denoted by 12 bits binary data. Thus the data collected by 100 sound sensors is approximately 72 Mb within 1 minute. If we do not deal with and direct transmit the great amount of data generated in such a short period of time it will cause network congestion of wireless sensor networks and shorten life expectancy of wireless sensor network. Similarly in this paper the sampling data in environment monitoring of a large telescope can not be directly transmitted in the wireless sensor network.

Data collection based on mobile agent[3,4] achieve flexible and efficient data collection with the mobile agent technology introduced to the data acquisition of wireless sensor networks. The mobile agent is the autonomous program, which can be moved and copied to other nodes. It can aggregate and fuse the perceived data on its path to remove the redundant, ineffective and poor reliable data, which thus reduces the amount of network data transmission, shortens the data transmission delay, reduces energy consumption and prolongs the network life cycle.

In the mesh network the sensor nodes do not directly send raw data and it is the sink node that sends the mobile agent to each sensor node to collect the reliable data. In each data collection period, the sink node in advance calculates the routing of mobile agent in order to obtain the data from each sensor node. That is to choose a route which makes the energy consumption of the data collection process least so as to maximize the network life under the premise of ensuring reliable data is collected. The mobile agent migrates among the sensor nodes through this routing, integrates the local data in accordance with the required program and sends the final result to the sink node.

A. Data acquisition function design of mobile agent based on ARMA model

The mobile agent is a kind of intelligent autonomous entity which is able to continue to run independently with some computing and storage capacity and it is flexible intelligently adapt to the environment with the change of the external conditions. The mobile agent can follow the pre-selected route to migrate among the sensor nodes in the wireless sensor network, in which it can find and deal with the right resources to complete specific tasks on behalf of the user. In the wireless sensor network, the mobile agent technology is introduced to take advantage of the lightweight mobile agent's inner real-time data acquisition, processing and fusion and the reduced data was ultimately returned to the base station by the mobile agent through the sink node, which significantly reduces the transmission energy consumption and saves the bandwidth of the whole network.

1) Establishment of ARMA model

ARMA[5,6] method is a prediction method of the short-term time series with high precision and the sequence of the predicted target formed with time changes is regarded as a random sequence. The basic idea of ARMA method is given as follows: A string of time-varying interrelated digital sequences can be approximately described with the corresponding model. Through the analysis and research of the corresponding mathematical model, we can essentially understand the inner structure and complexity of these dynamic data and achieve the best prediction of the minimum variance.

(1) Definition of ARMA model

The model with the following structure is known as the autoregressive moving average model, which is denoted as ARMA(p,q):

$$\begin{cases} x_t = \phi_0 + \phi_1 x_{t-1} + \cdots + \phi_p x_{t-p} + \varepsilon_t - \varphi_1 \varepsilon_{t-1} - \cdots - \varphi_q x_{t-q} \\ \phi_p \neq 0, \varphi_q \neq 0 \\ E(\varepsilon_t) = 0, Var(\varepsilon_t) = \sigma_t^2, E(\varepsilon_t \varepsilon_s) = 0, s \neq t \\ E(x_s \varepsilon_t) = 0, \forall s < t \end{cases} \quad (1)$$

Where, p and q denote the order of the model, $\beta=(\Phi_0,\Phi_1,\ldots,\Phi_p,\varphi_1,\varphi_2,\ldots,\varphi_q)\in R^{p+q+1}$ the model parameters and R a real number set. The model is called the centralized ARMA(p,q) if $\Phi_0=0$, the moving average model MA(q) if p=0 and the autoregressive model AR(p) if q=0.

(2) Order determination of ARMA model

For a known time series X_t (t=1,2, ..., N), first we need to conduct a smooth processing to determine whether it is a stable time series, and then the correlation analysis to calculate the sample autocorrelation function r_k and partial autocorrelation function φ_{kk} of the time series and distinguish the model through the cutting tail and delaying tail of the above two functions.

(3) Prediction of the stationary time series

In the case of known observations X_t, X_{t-1}, X_{t-2}, … of the stationary time series X_t at time t and previous time, now the t+l moment observation X_{t+l}(l>0) is predicted with the time series X_t at moment t. This prediction is known as the prediction of step length l with t as the origin and the predicted value is denoted by $\hat{X}_t(l)$, in which the smooth linear minimum mean square error is mainly used.

(4) Adaptive test of the model

The adaptive test of the model is essentially to test whether the residual sequence $\{a_t\}$ in the model is white noise sequence, that is, the model is reasonable if it is the white noise sequence according to the test, otherwise the model should be further improved.

In summary, ARMA(1,1) model can be used to describe the data collection process in the wireless sensor network according to the simulation for the prediction model. The data result of 5-step prediction can reflect the actual situation of environment changes of a large telescope and the predictive value can replace the real monitoring data in the range of 95% confidence level.

2) Process design of the reliable data collection in the wireless sensor network based on mobile agent

Data collection is completed by the mobile agent run in each sensor node. The main process[7,8,9] is given as follows: The sink node initiates the data collection of the mobile agent and the sensor node begins to collect the monitoring value of the environment after receiving the mobile agent of data collection. The data collected is first stored in the local tuple space 1. When the data is to reach a certain length, call the ARMA(1,1) prediction model in the mobile agent of data collection to calculate and the calculated data will be placed into the tuple space 2. The data processing process is given as follows:

(1) When the calculated data of the prediction model is reliable data, only the model parameters are send back to the sink node and delete the historical data stored in the tuple space 1 and 2. When the sink node receives the returned parameters, it will call the calculation model in the agent to calculate the predicted value and replace the actual monitoring value.

(2) When the predicted data is not reliable data, the data at this moment will be placed in tuple space 3. When the data inside the data space is to reach a certain length, call the ARMA(1,1) again to predict. If the predicted data is reliable data, return to (1). If prediction data still is not the reliable data, the actual monitoring value will be directly sent to the sink node.

From the above process for the two kinds of data, it can be seen that it can be always guaranteed that the sink node receives the data with high reliability whether the prediction data is reliable or unreliable.

B. Migration route design of mobile agent based on novel ant algorithm

Research shows that ants[9] in nature can find the shortest path between the food source and their nest through the mutual cooperation in the feeding process. The reason is that in the move course ants could release pheromone in their path and the probability for the follow-up ants to choose this path is proportional to the intensity of pheromone in the path at that time. For a path, the more the ants select it, the greater is its intensity of pheromone left by ants in it. The intense pheromone will attract more ants and thus a positive feedback is formed. Through this positive feedback, the ant will find the shortest path in the end, on which the ant colony algorithm is based. In this paper, we use the novel ant colony algorithm to calculate the migration path of the mobile agent.

In the wireless sensor network, due to the limited communication capability of sensor nodes, sensor nodes can only communicate with the nodes within the scope of the wireless signal coverage and these nodes within the coverage area of the wireless signal are called the adjacent nodes. In this paper, only the information of the adjacent nodes in the mobile agent's migration route will be stored in the node's routing table, which can be used as the node's next hop routing object. Each node stores a table to record the information such as its residual energy, pheromone intensity, respectively consumed energy to migrate to each adjacent node, adjacent nodes' residual energy and so on[10,11].

The migration probability p_{ij} for the mobile agent in node i to migrate to node j is calculated according to the following formula:

$$p_{ij}=P_1+P_2 \quad (2)$$

Where, P_1 is calculated in accordance with the migration probability formula of ant colony algorithm as follows.

$$P_{ij}^k = \begin{cases} \dfrac{[\tau_{ij}(t)]^\alpha [\eta_{ij}(t)]^\beta}{\sum[\tau_{iu}(t)]^\alpha [\eta_{iu}(t)]^\beta}, j,u \in J_k(i) \\ 0, \quad otherwise \end{cases} \quad (3)$$

Where, $\tau_{ij}(t)$ denotes the pheromone intensity between node i and node j at moment t, η_{ij} expectations, usually set to the reciprocal of the distance between node i and node j, $J_k(i)$ the adjacent nodes set that ant k at node i has not yet visited, α and β parameters that determine the relative importance between the pheromone intensity and the distance.

Pheromone updating: Ants will leave pheromone in the path that they passes by and the residual pheromone path is called pheromone trail to distinguish with the path which no ants have traversed or whose pheromone has been evaporated. Pheromone updating of each node is given as follows:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{k=1}^{k} \Delta\tau_{ij}^k \quad (4)$$

Where, $\tau_{ij}(t)$ and $\tau_{ij}(t+1)$ denote the pheromone value of node i and node j at moment t and t+1, ρ the pheromone evaporation parameter, $0<\rho<1$.

$$\Delta\tau_{ij}^k = \begin{cases} \dfrac{Q}{L_k}, & if\ node\ i\ and\ j\ are\ in\ the\ solution\ path\ L \\ & bing\ constructed\ by\ the\ ant \\ 0, & otherwise \end{cases} \quad (5)$$

Where, L_k denotes the total length of path L which ant k has completed, Q the total intensity of the pheromone that ants release.

P_2 is calculated according to the following formula:

$$P_2 = \max_{j \in FT_l} \frac{E_j}{C_j \eta} \quad (6)$$

Where, E_j denotes the remaining energy of node j, C_j the spent energy of the mobile agent's migration from node i to node j, η the ratio coefficient that adjusts the importance of E_i and C_j.

In this algorithm, after the mobile agent reaches node i, calculate the next hop routing according to the migration probability formula (2). The formula's considering the node residual energy and migration consumption in addition to considering the pheromone intensity between nodes will not cause a node's long reuse and early energy depletion.

IV. REALIZATION OF DATA COLLECTION BASED ON MOBILE AGENT

The data collection based on the mobile agent conducts the establishment, maintenance of routing and data collection, transmission by simulating ants of MA using ant colony optimization algorithm to find the path with the high efficiency. The data collection based on the mobile agent is achieved as the following:

(1) System initialization: The network nodes are randomly generated. Set the type of the monitoring data to be collected this time. The system constant parameters are set as follows: Q=100, α=0.1, β=0.1, ρ=0.2 and the initial number of the mobile agents to find the path is 50.

(2) Initialization of the node's routing table: Calculate the distance of the adjacent nodes, the node's power and the initial pheromone intensity of the node.

(3) Set the number of cycle.

(4) The mobile agent to route begins to move among the network nodes. Calculate the migration probability according to the formula (2) to select the next node to reach and add the current node to the taboo list. If the current node is the target node, the next mobile agent starts traversing.

(5) Calculate each mobile agent's path length and store the optimal solution in the global variable.

(6) For each mobile agent, update the pheromone according to the formula (3) and (4).

(7) Repeat (3) until establish the routing from the sink node to the target node.

(8) The mobile agent of data collection distributed by the sink node collects data along the route established to the source node and returns to the sink node after it traverses all the nodes of the target area.

(9) Start the next cycle.

V. CONCLUSION

In this paper, the multi-sink topological structure of WSN can improve the transmission efficiency of multi-hop network to meet the environment test requirements of low-latency, high frequency sampling and high data throughput, in which with the mobile agent technology, the mobile agent of data collection moves to the target node to directly access its resource having fewer interactions with the sink node so as to avoid the great amount of data transmission in the network, largely reduce the network traffic and the dependence on the network bandwidth, shorten the communication latency and improve the response rate of the data collection. During routing choice, the sink node first distributes mobile agents to explore the routing and then to collect the data. The above method of environment monitoring for a large telescope based on the mobile agent in the wireless sensor network can realize environment data acquisition, on-line-detection and data analysing in this paper, which provides the basis for the adjustment of the large telescope to improve its control performance and image quality.

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