Sensors & Transducers, Vol. 162 , Issue 1, January 2014, pp. 102-110

Sensors & Transducers

Stability Analysis of Wireless Measurement and Control System Based on Dynamic Matrix

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Received: 4 October 2013 /Accepted: 9 January 2014 /Published: 31 January 2014

Abstract: Focus on data packet loss and time delay problems in wireless greenhouse measurement and control system, and temperature and humidity were taken as the research objects, the model of temperature and humidity information transmission was set up by decoupling technology according to the characteristics of wireless greenhouse measurement and control system. According to related theory of exponential stability in network control system, the stability conditions judgment of temperature and humidity control model was established, the linear matrix inequality that time delay and packet loss should satisfy was obtained when wireless measurement and control system was stable operation. The feasibility analysis of linear matrix inequality (LMI) was implemented Using LMI toolbox in MATLAB, and the critical values of time delay and packet loss rate were obtained when the system was stable operation. The wireless sensor network control system simulation model with time delay and packet loss was set up using TrueTime toolbox. The simulation results have shown that the system was in a stable state when time delay and packet loss rate obtained were less than the critical values in wireless greenhouse sensor network measurement and control system; With the increase of time delay and packet loss rate, and stable performance drops; When time delay and packet loss rate obtained were more than the critical values, the measurement and control system would be in a state of flux, and when it was serious, even can lead to collapse of the whole system. As a result, the critical values determination of time delay and packet loss rate provided a theoretical basis for establishing stable greenhouse wireless sensor network (WSN) measurement and control system in practical application.

Keywords: Linear matrix inequality, Packet loss rate, Decouple, Stability, WSN.

1. Introduction

Wireless sensor networks (WSN) technology is a kind of new technology that can make people obtain information of measurement and control at any time, place and environment, it can be widely used in national security, military, agricultural automation, environmental monitoring, health care and many other fields [1]. Compared with the traditional wired networks, WSN has characteristics of flexible placed, easy extension and Ad-hoc network and so on. However, compared with the traditional measurement and control cable network, wireless network system have much longer time delay and much larger packet loss, as the growth of time delay and packet loss increases, the performance stability of the measurement and control system drops [6]. When time delay exceeds a certain value or packet loss exceeds a certain value, the system stable performance will fell sharply, and the whole measurement and control systems may become paralyzed, as a result, it is a key problem that greenhouse WSN measurement and control system can be stable operation. In the paper, the proposed wireless greenhouse measurement and control system was modeled and analyzed, according to the exponential stability theory and Lyapunov stability criterion, and the critical values for system time delay and packet loss rate were analyzed, finally, the time delay threshold and the critical value of packet loss rate were obtained, and a theoretical basis was provided to establish stable greenhouse WSN measurement and control system.

2. Structure of Greenhouse Measurement and Control System

2.1. Greenhouse Measurement and Control System Structure Based on Field-Bus

Greenhouse technology widely adopted field-bus control technology in developed countries, the greenhouse measurement and control system based on field-bus has shown in Fig. 1. Each greenhouse has a collecting and a regulation site, data acquisition subsystem composed of various acquisition sites, and environmental regulation subsystem composed of the regulation sites. Each subsystem connected with control computer through field-bus, each greenhouse node has a bus controller that received commands from the control computer, and completed the corresponding task of each subsystem. Control computer can be connected with the remote management computer, and management computer connected with Internet, in this way, remote system maintenance can be carried out, but its have high cost, not suitable for the facility agriculture of large area.

2.2. Greenhouse Control System Structure Based on WSN

Now, with the rapid development of the greenhouse technology, and tend to be large-scale, but wireless network node transmission distance is limited, can't satisfy the requirement of large greenhouse, as a result, a large greenhouse can be divided into a number of measurement and control area, as shown in Fig. 2, each measurement area set up a base station with much sink nodes. Each gathering node was responsible for a measurement and control area, and formed a subnet with sensor nodes and control nodes, subnets was relatively independent, sensor nodes and control node determined their sink node by identifier [2]. Clustering nodes, the sensor nodes and control nodes formed star network, and completed the data acquisition and control of greenhouse environment. In advance, Sensor nodes were arranged in the specified location in greenhouse, and were responsible for the acquisition information such as temperature and humidity, and sent information collected to sink node through the wireless network. Gathering node transmitted collected the greenhouse environment factors information to the base station through multiple hops link way.

Base station was responsible for communicating with each part gathering node, a single greenhouse network control was implemented by managing all gathering nodes. The monitoring center was the data center of greenhouse measurement and control system, and was responsible for the control and management of the whole system.

In this way, the wireless sensor network measurement and control area were connected through the base station and sink node, and the measurement and control area were extended, large scale and partition management of greenhouse were realized.

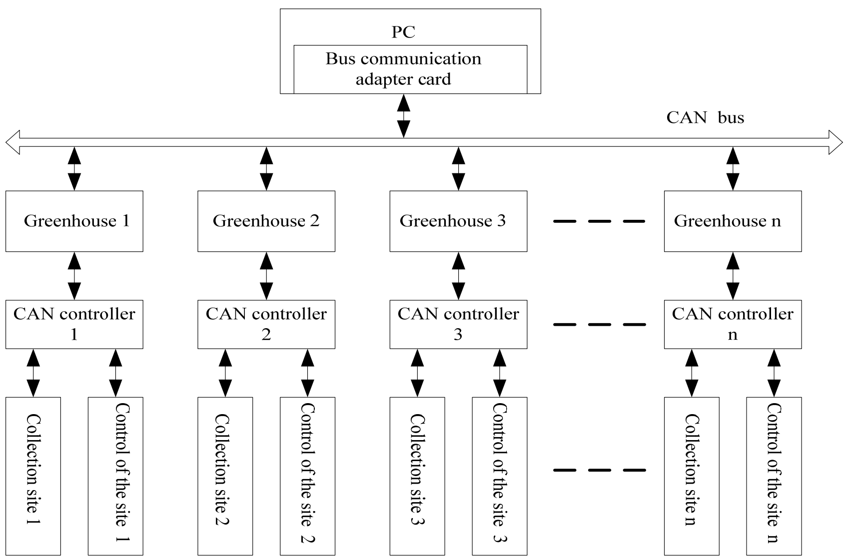

Fig. 1. Greenhouse measurement and control system based on field-bus.

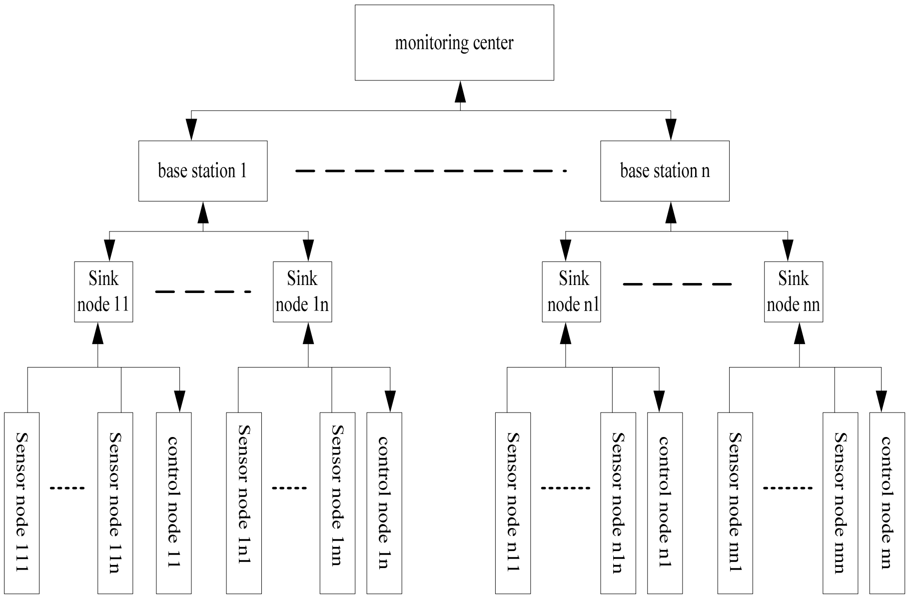

Fig. 2. Greenhouse measurement and control system based on WSN.

3. Analysis of Greenhouse WSN Measurement System with Time Delay and Data Packet Loss

Compared with the traditional wired control network, wireless sensor network (WSN) has the advantages of an area small, less economic spending and so on, but large time delay and high packet loss rate was also unable to avoid. Usually, WSN not only have time delay phenomenon, but also have some packet loss phenomenon. In the paper, greenhouse WSN measurement and control system with time delay and data packet loss were analyzed, and build the mathematical model of data transmission, combining Lyapunov stability theory and exponential stability theory, the gradually stable condition of greenhouse WSN measurement and control system with time delay and packet loss were obtained, and finally found the feasible solution by LMI toolbox of Matlab, the biggest packet loss rate was determined in order to guarantee asymptotically stable of system.

3.1. Model of Greenhouse WSN Measurement System with Time Delay and Data Packet Loss

Time delay and packet loss phenomenon in Greenhouse WSN measurement and control system occurred mainly in the wireless communication process that the sensor nodes transmitted sampling data to monitoring center and monitoring center transmitted the optimization control commands to control nodes [7]. As a result, the whole process of greenhouse WSN measurement has shown in Fig. 3.

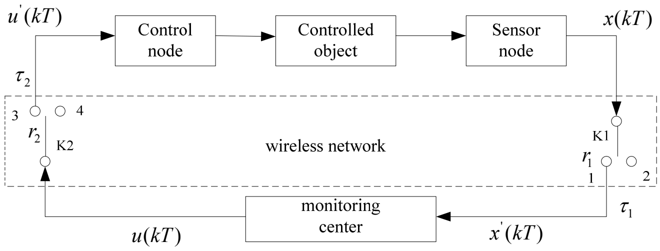

Fig. 3. Model of greenhouse WSN measurement system with time delay and data packet loss.

In Fig. 3, K_1 and K_2 were the network switch, r_1 and r_2 were the connected probability of network switches K_1 and K_2, respectively, τ_1 represented time delay between sensor nodes and the monitoring center in the k sampling period; τ_2 represented time delay between monitoring center and control nodes in the k sampling period; it represented no packet loss when K_1=1 (closed) and K_2=2 (off), it represented the packet loss in respective transmission process; $x(kT)$ and $x^{'}(kT)$ represented the output of sensor nodes and the input of monitoring center in the k sampling period respectively; $u(kT)$ and $u'(kT)$ represented the output of monitoring center and the input of control nodes in the k sampling period respectively.

The whole greenhouse WSN measurement and control system with packets lost has four kinds of data transmission state, i.e., K_1 and K_2 were in a connected state, $x'(kT) = x(kT)$ and $u'(kT) = u(kT)$, and the probability of this state was $\hat{r}_1 = r_1 \bullet r_2$; K_1 was close and K_2 was open, $x'(kT) = x'[(k-1)T]$ and $u'(kT) = u'[(k-1)T]$, the probability of this state was $\hat{r}_2 = r_1 \bullet (1-r_2)$; K_1 was open and K_2 was close, $x'(kT) = x'[(k-1)T]$ and $u'(kT) = u(kT)$, the probability of this state was $\hat{r}_3 = (1-r_1) \bullet r_2$; K_1 and K_2 were open, the probability of this state was $\hat{r}_4 = (1-r_1) \bullet (1-r_2)$. In order to analyze conveniently, supposed that the sensor nodes were the clock driver, sampling period was T; The monitoring center and control nodes were event driven, namely, the relevant operation was immediately carried out when the information has been received; The packet loss rate of wireless sensor network was certain, and data transmission was a single direction; Closed loop delay τ of wireless sensor network (WSN) was certain, and $\tau = \tau_1 + \tau_2$, $\tau \prec T$. So, the controlled object of greenhouse WSN measurement and control system with time delay and packet loss was shown in the following.

$$\dot{x}(t) = Ax(t) + Bu'(t-\tau), \tag{1}$$

where $x(t) \in R^{n \times n}$ was state variables, $u'(t) \in R^{n \times m}$ was system control input, A and B were the corresponding dimension constant respectively, and $\tau \in [0, T)$. We put the formula (1) discrete, and as shown in the following.

$$\begin{aligned} x[(k+1)T] &= \Phi x(kT) + \\ &+ \Gamma_0(\tau) u'(kT) + \Gamma_1(\tau) u'[(k-1)T] \end{aligned}, \tag{2}$$

where $\Phi = e^{AT}, \Gamma_0(\tau) = \int_0^{T-\tau} e^{At} B dt$, $\Gamma_1(\tau) = \int_{T-\tau}^{T} e^{At} B dt$.

State feedback controller model was shown in the following.

$$u(kT) = -Kx'(kT), \tag{3}$$

where $u(kT) \in R^{n \times m}$ was controller output, K was the controller gain, and has a corresponding dimension.

When the data transmission in the greenhouse WSN measurement and control system with time delay and packet loss was in state 1 (i.e. K_1 and K_2 were in a connected).

$$x'(kT) = x(kT) \tag{4}$$

$$u'(kT) = u(kT) \tag{5}$$

Using (2), (3), (4) and (5), (6) was given in the following.

$$\begin{bmatrix} x[(k+1)T] \\ x'[(k+1)T] \\ u'(kT) \end{bmatrix} = \begin{bmatrix} \Phi & -\Gamma_0(\tau)K & \Gamma_1(\tau) \\ \Phi & -\Gamma_0(\tau)K & \Gamma_1(\tau) \\ 0 & -K & 0 \end{bmatrix} \bullet \begin{bmatrix} x(kT) \\ x'(kT) \\ u'[(k-1)T] \end{bmatrix} \tag{6}$$

When the data transmission in the greenhouse WSN measurement and control system with time delay and packet loss was in state 2 (i.e. K_1 was close, and K_2 was open).

$$u'(kT) = u'[(k-1)T] \tag{7}$$

Using (2), (3), (4) and (7), (8) was given in the following.

$$\begin{bmatrix} x[(k+1)T] \\ x'[(k+1)T] \\ u'(kT) \end{bmatrix} = \begin{bmatrix} \Phi & 0 & \Gamma_0(\tau)+\Gamma_1(\tau) \\ \Phi & 0 & \Gamma_0(\tau)+\Gamma_1(\tau) \\ 0 & 0 & I \end{bmatrix} \bullet \begin{bmatrix} x(kT) \\ x'(kT) \\ u'[(k-1)T] \end{bmatrix}, \tag{8}$$

When the data transmission in the greenhouse WSN measurement and control system with time delay and packet loss was in state 3 (i.e. K_1 is open, and K_2 was close).

$$x'(kT) = x'[(k-1)T] \tag{9}$$

Using (2), (3), (5) and (9), (10) was given in the following.

$$\begin{bmatrix} x[(k+1)T] \\ x'[(k+1)T] \\ u'(kT) \end{bmatrix} = \begin{bmatrix} \Phi & -\Gamma_0(\tau)K & \Gamma_1(\tau) \\ 0 & I & 0 \\ 0 & -K & 0 \end{bmatrix} \bullet \begin{bmatrix} x(kT) \\ x'(kT) \\ u'[(k-1)T] \end{bmatrix}, \tag{10}$$

When the data transmission in the greenhouse WSN measurement and control system with time delay and packet loss was in state 4 (i.e. K_1 and K_2 are open).

$$u'(kT) = u'[(k-1)T], \tag{11}$$

Using (2), (3), (9) and (11), (12) was given in the following.

$$\begin{bmatrix} x[(k+1)T] \\ x'[(k+1)T] \\ u'(kT) \end{bmatrix} = \begin{bmatrix} \Phi & 0 & \Gamma_0(\tau)+\Gamma_1(\tau) \\ 0 & I & 0 \\ 0 & 0 & I \end{bmatrix} \bullet \begin{bmatrix} x(kT) \\ x'(kT) \\ u'[(k-1)T] \end{bmatrix} \tag{12}$$

Therefore, the probability of four kinds of states connected with the connectivity rate of network switch K_1 and K_2, the system stable performance changed with the changes of r_1 and r_2.

3.2. Analysis of Exponential Stability Conditions in Greenhouse WSN Measurement and Control System

Supposed that $z(kT)=\{x^T(kT),x^{'T}(kT),u^{'T}[(k-1)T]\}^T$, and the 4 kinds of data transfer states in the greenhouse WSN measurement and control system of can be given in the following.

$$z[(k+1)T]=\Psi_i \bullet z(kT), i=1,...,4, \tag{13}$$

where

$$\psi_1=\begin{bmatrix}\Phi & -\Gamma_0(\tau)K & \Gamma_1(\tau)\\ \Phi & -\Gamma_0(\tau)K & \Gamma_1(\tau)\\ 0 & -K & 0\end{bmatrix} \quad \psi_2=\begin{bmatrix}\Phi & 0 & \Gamma_1(\tau)+\Gamma_0(\tau)\\ \Phi & 0 & \Gamma_1(\tau)+\Gamma_0(\tau)\\ 0 & 0 & I\end{bmatrix}$$

$$\psi_3=\begin{bmatrix}\Phi & \Gamma_0(\tau) & \Gamma_1(\tau)\\ 0 & I & 0\\ 0 & -K & 0\end{bmatrix} \quad \psi_4=\begin{bmatrix}\Phi & 0 & \Gamma_1(\tau)+\Gamma_0(\tau)\\ 0 & I & 0\\ 0 & 0 & I\end{bmatrix}$$

In order to facilitate the writing, the $x(kT)$ expressed with $x(k)$, $\Gamma_0(\tau)$ expressed with Γ_0, $\Gamma_1(\tau)$ expressed with Γ_1. According to references [8], when $V(x(k+1))-a_i^{-2}V(x(k))\prec 0$, system exponential was stability, and ensured that the system was asymptotically stable.

$L\in R^{n\times n}$, $M\in R^{n\times n}$ and $N\in R^{r\times r}$ were chosen the symmetric positive definite matrices, and Lyapunov function was

$$V(x(k))=x^T(k)Lx(k)+x^{'T}(k)Mx^{'}(k)+u^{'T}(k-1)Nu^{'}(k-1).$$

So, when (14) was met, the index of the system was stability.

$$\begin{aligned}&V(x(k+1))-a_i^{-2}V(x(k))=x^T(k+1)Lx(k+1)+\\&+x^{'T}(k+1)Mx^{'}(k+1)+u^{'T}(k)Nu^{'}(k)-\\&-a_i^{-2}x^T(k)Lx(k)-a_i^{-2}x^{'T}(k)Mx^{'}(k)-\\&-a_i^{-2}u^{'T}(k-1)Nu^{'}(k-1)\prec 0\end{aligned} \tag{14}$$

When the data transfer in greenhouse WSN measurement and control system was in state 1, namely, i =1, substituting (2) and (6) into (14), (15) was given in the following.

$$\begin{aligned}&\begin{bmatrix}\Phi^T L\Phi-a_1^{-2}L & -\Phi L\Gamma_0 K & \Phi^T L\Gamma_1\\ -K^T\Gamma_0^T L\Phi & K^T(\Gamma_0^T L\Gamma_0+N)K-a_1^{-2}M & -K^T\Gamma_0^T M\Gamma_1\\ \Gamma_1^T L\Phi & -\Gamma_1^T L\Gamma_0 K & \Gamma_1^T L\Gamma_1-a_1^{-2}N\end{bmatrix}\\&+\begin{bmatrix}\Phi^T\\ -K^T\Gamma_0^T\\ \Gamma_1^T\end{bmatrix}\bullet M\left[\Phi-\Gamma_0 K\Gamma_1\right]\prec 0\end{aligned} \tag{15}$$

According to the complement nature of Schur, (15) was reduced, and (16) was given in the following.

$$\begin{bmatrix}-a_1^{-2}L & 0 & 0 & \Phi^T & \Phi^T\\ 0 & K^T NK-a_1^{-2}M & 0 & -K^T\Gamma_0^T & -K^T\Gamma_0^T\\ 0 & 0 & -a_1^{-2}N & \Gamma_1^T & \Gamma_1^T\\ \Phi & -\Gamma_0 K & \Gamma_1 & -M^{-1} & 0\\ \Phi & -\Gamma_0 K & \Gamma_1 & 0 & -L^{-1}\end{bmatrix}\prec 0 \tag{16}$$

In the same way, when the data transmission in greenhouse WSN measurement and control system was in state 2, namely, i = 2, substituting (2) and (8) into (14), and after it was reduced, (17) was given in the following.

$$\begin{bmatrix}-a_2^{-2}L & 0 & 0 & \Phi^T & \Phi^T\\ 0 & -a_2^{-2}M & 0 & 0 & 0\\ 0 & 0 & (1-a_2^{-2})N & (\Gamma_0+\Gamma_1)^T & (\Gamma_0+\Gamma_1)^T\\ \Phi & 0 & \Gamma_0+\Gamma_1 & -M^{-1} & 0\\ \Phi & 0 & \Gamma_0+\Gamma_1 & 0 & -L^{-1}\end{bmatrix}\prec 0 \tag{17}$$

When the data transmission in greenhouse WSN measurement and control system was in state 3, namely, i = 3, substituting (2) and (10) into (14), and after it was reduced, (18) was given in the following.

$$\begin{bmatrix}-a_3^{-2}L & 0 & 0 & \Phi^T & 0\\ 0 & M-a_3^{-2}M & 0 & -K^T\Gamma_0^T & K^T\\ 0 & 0 & -a_3^{-2}N & \Gamma_1^T & 0\\ \Phi & -\Gamma_0 K & \Gamma_1 & -L^{-1} & 0\\ 0 & K & 0 & 0 & -N^{-1}\end{bmatrix}\prec 0 \tag{18}$$

When the data transmission in greenhouse WSN measurement and control system was in state 4, namely, i = 4, substituting (2) and (12) into (14), and after it was reduced, (19) was given in the following.

$$\begin{bmatrix}a_4^{-2}L & 0 & 0 & \Phi^T\\ 0 & M-a_4^{-2}M & 0 & 0\\ 0 & 0 & N-a_4^{-2}N & (\Gamma_0+\Gamma_1)^T\\ \Phi & 0 & \Gamma_0+\Gamma_1 & -L^{-1}\end{bmatrix}\prec 0 \tag{19}$$

Therefore, according to the four data transmission state in Greenhouse WSN measurement and control system and the exponential stability theory, the matrix inequality that can guarantee the index stability of four state was obtained, in the case of the state feedback system with time delay $\tau\prec T$ and data transfer connectivity rate r_1, r_2, (it has shown in Figure 3), if there was a scalar a_i, $a_i\succ 0, i=1,...,4$

and symmetric positive definite matrices $L \in R^{n\times n}$, $M \in R^{n\times n}$, and $N \in R^{r\times r}$, and met (16), (17), (18), (19) and (20), the system guaranteed the exponential stability.

$$a_1^{r_1 r_2} a_2^{r_1(1-r_2)} a_3^{(1-r_1)r_2} a_4^{(1-r_1)(1-r_2)} \succ a \succ 1 \tag{20}$$

3.3. Biggest Network Transmission Packet Loss Rate Analysis of System

Temperature and humidity were two important parameters in greenhouse environment, and they were a pair of strong mutual coupling factor, that is, when the temperature was adjusted, humidity easily changed, when the humidity was controlled, and will affect the temperature too [3-5]. Therefore, when the information transfer mathematic model was built, the coupling process must be carried out. Supposed that the temperature was $x_1(t)$ in greenhouse, the humidity was $x_2(t)$ in the greenhouse, the temperature control input in the greenhouse was $u_1(t)$, the humidity control input in greenhouse was $u_2(t)$, according to the literature [2], temperature control structure block diagram and humidity control structure block diagram have shown in Fig. 4 and Fig. 5. In Fig. 4 and Fig. 5, ρ was air density, C_p was the constant pressure heat capacity, V was the effective volume of greenhouse, β was the lumped parameters considering the thermodynamics constants and air mobile and so on factors in greenhouse.

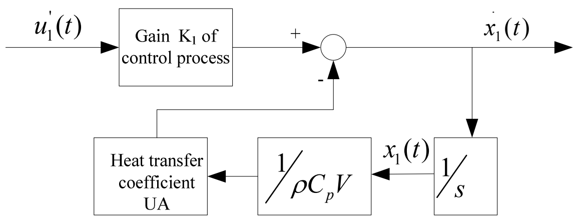

Fig. 4. Temperature control structure block diagram.

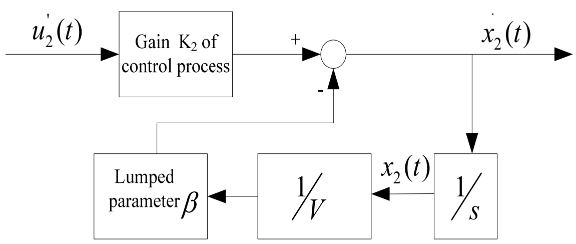

Fig. 5. Humidity control structure block diagram.

So, the temperature and humidity control equation with time delay and packet loss can be obtained, as shown in the following.

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -\dfrac{UA}{\rho C_p V} & 0 \\ 0 & -\dfrac{\beta}{V} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} K_1 & 0 \\ 0 & K_2 \end{bmatrix} \begin{bmatrix} u_1'(t-\tau) \\ u_2'(t-\tau) \end{bmatrix} \tag{21}$$

In general, $UA = 1.3\times 10^3 J/mK\sec$, $\rho = 1.2Kg/m^3$, $C_p = 1006J/(Kg*K)$, $\beta \in [0,2]$. Set $\beta = 1$, each monitoring the effective volume of gathering node was 400 m^3, the sampling period T of sensor nodes was 100 s, network induced total delay was 1s, the gain of control process was 2×10^{-3}, to simplify the analysis, the wireless connectivity rate between sensor nodes and the monitoring center was equal to that of monitoring center and the control node, supposed that $r = r_1 = r_2 = 0.9$, (22) is given in the following.

$$\dot{x}(t) = \begin{bmatrix} -2.69\times 10^{-3} & 0 \\ 0 & -2.5\times 10^{-3} \end{bmatrix} x(t) + \begin{bmatrix} 2\times 10^{-3} & 0 \\ 0 & 2\times 10^{-3} \end{bmatrix} u'(t-\tau) \tag{22}$$

We put (22) discrete, and (23) was given in the following.

$$x[(k+1)T] = \Phi x(kT) + \Gamma_0(\tau) u'(kT) + \Gamma_1(\tau) u'[(k-1)T], \tag{23}$$

where $\Phi = e^{AT}$, $\Gamma_0(\tau) = \int_0^{T-\tau} e^{AT} B dt$, $\Gamma_1(\tau) = \int_{T-\tau}^{T} e^{AT} B dt$, and substituting data into it, as follows.

$$\Phi = \begin{bmatrix} 0.7641 & 0 \\ 0 & 0.7788 \end{bmatrix}, \Gamma_0(\tau) = \begin{bmatrix} 0.1738 & 0 \\ 0 & 0.1754 \end{bmatrix},$$

$$\Gamma_1(\tau) = \begin{bmatrix} 0.0015 & 0 \\ 0 & 0.0016 \end{bmatrix}$$

Supposed that $a_1 = 1.2357$, $a_2 = 0.8207$, $a_3 = 0.4393$, $a_4 = 0.5951$, and substituting $r = r_1 = r_2 = 0.9$, Φ, $\Gamma_0(\tau)$ and $\Gamma_1(\tau)$ into (16), (17), (18), (19) and (20), the feasible solutions can be found Using LMI toolbox in Matlab, as follows.

$$L = \begin{bmatrix} 0.2244 & 0 \\ 0 & 0.3208 \end{bmatrix} M = \begin{bmatrix} 0.0223 & 0 \\ 0 & 0.0216 \end{bmatrix}$$
$$N = \begin{bmatrix} 0.0658 & 0 \\ 0 & 0.0587 \end{bmatrix} K = \begin{bmatrix} 0.0877 & 0 \\ 0 & 0.0626 \end{bmatrix}$$

Due to L, M, N and K existed, so the greenhouse WSN measurement and control system was exponential stability. According to (16) and (20), for WSN control systems with time delay and packet loss, when the system was stable index, the upper bound of maximum allowable data r' meet (24).

$$\begin{cases} r'^2 \cdot \lg\dfrac{a_1 a_4}{a_2 a_3} + r' \cdot \lg\dfrac{a_2 a_3}{a_1} + \lg a_1 \succ 0 \\ 0 \le r' \prec 1 \end{cases}, \qquad (24)$$

So the biggest packet loss rate of wireless network loop circuit was 0.1591, due to each sink node was in the parallel, so as long as wireless packet loss rate between the sensor node and the monitoring center and that of between the monitoring center and the control nodes were not more than 15.91 % in the greenhouse, and the greenhouse WSN measurement and control system was exponential stability.

4. Simulation Analysis

In view of the above analysis of greenhouse wireless sensor network measurement and control system with time delay and packet loss, it was simulated using TrueTime toolbox, and analyzed that the size of time delay and high and low packet loss impacted on the stability of the whole greenhouse wireless sensor network.

4.1. Simulation Platform and Architecture

Matlab simulation platform was mainly implemented by TrueTime toolbox, TrueTime toolbox was simulation software based on Matlab/Simulink, the function of the corresponding module can be realized by Matlab language or C++ language, the simulation model has shown in Fig. 6. Wireless Network of the whole greenhouse measurement and control system was simulated by TrueTime Wireless Network module, using TrueTime Kernel 1 module to simulate the sensor nodes and control nodes in Wireless networks, using TrueTime Kernel 2 module to simulate the monitoring center of the whole Wireless measurement and control system. The SND port of TrueTime Wireless Network received sampling information packet of sensor nodes, according to the internal settings of TrueTime Wireless Network, the time delay and packet loss of Wireless Network were simulated, and the processed packets were sent to the monitoring center through the rev2 port, the packets received in the monitoring center were corresponding processed, then sent packets to the TrueTime Wireless Network SND port by snd2 port. Wireless Network transmission quality was simulated, and sent to the control nodes through the rev1 port. In Fig. 6, DC Servo module was wireless network data transfer function, and described control of the control variables in the measurement and control system. Two output display module displayed the system data u and control output signal y, respectively.

4.2. Simulation System and Results

DC servo module was set to $\dfrac{0.002}{s+0.00269}$, it was the transfer function of controlled object, and the system equation was given in the following.

$$\begin{cases} \dot{x}(t) = -0.00269x(t) + 0.002u(t) \\ y(t) = x(t) \end{cases}$$

In order to ensure the rapid and stability of the wireless network control system, PD control algorithm was adopted in monitoring center, the control discrete model was as follows.

$$u(k) = P(k) + D(k) = k(r(k) - y(k)) + a_d D(k-1) + b_d(y(k-1) - y(k)),$$

where $a_d = \dfrac{T_d}{N.h + T_d}$, $b_d = \dfrac{NKT_d}{N.h + T_d}$, N was the differential gain, h was the sampling period, K was the proportional gain, T_d was differential constant.

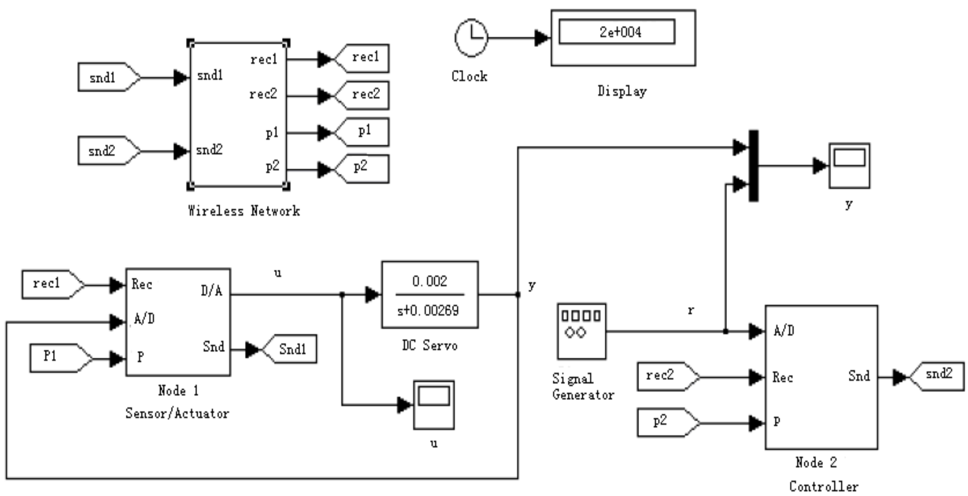

Fig. 6. Greenhouse WSN measurement and control system simulation model.

IEEE802.15.4 communication protocol was adopted in wireless network module, the data transmission rate was set to 25000 bits/s, minimum data frame was set to 24 bits, the sampling period was set to 100s, differential gain N was set to 100000, the proportional gain was set to 10, differential constant T_d was set to 0.0035, and time delay that sensors send data to the monitoring center was set to 2.5 s, time delay of monitoring center processing data and make optimization scheme was set to 0.5 s, time delay that the monitoring center will eventually sent control commands to the control node was set to 2 s, the random packet loss of the entire wireless network was 1 %, the input signal in the monitoring center was sine wave, simulation was started in the absence of interference, under the condition of 20000 s, the simulation control output and sampling graphics were shown in Fig. 7 and Fig. 8.

Simulation results shown that the wireless network packet loss rate was 1 %, and it was unchanged, time delay that sensors sent data to monitoring center was changed and time delay that monitoring center sent control commands to control nodes was changed too, and this will affect control output and control input signal, as the extension of time delay, the system shock enhanced obviously, even can lead to instability. Stability of the system related to sampling period, the smaller the sampling period was, the greater the stability of the system was. At the same time, the data transfer rate was changed, minimum data frame and control algorithm parameters will affect the stability of the system.

When the wireless network packet loss was 35 %, the rest parameters remained the same, without interference, the control input and output signals simulation was shown in Fig. 9 and in Fig. 10.

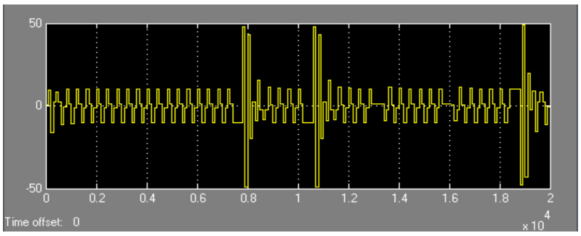

Fig. 7. The control input when the Packet loss rate was 1 %.

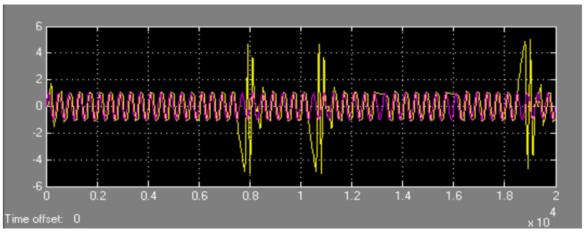

Fig. 8. The control output when the Packet loss rate was 1 % (dotted line is the reference input signal).

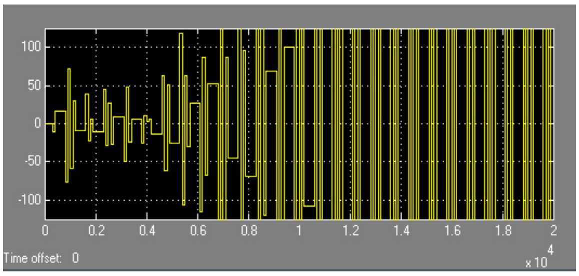

Fig. 9. The control input when the Packet loss rate was 35 %.

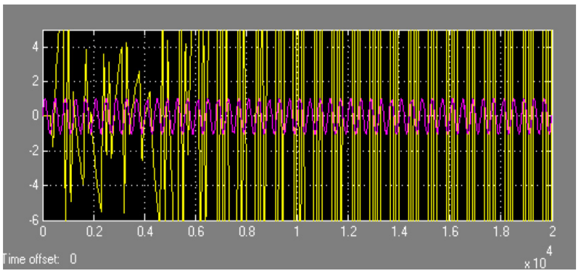

Fig. 10. The control output when the Packet loss rate was 35 % (dotted line is the reference input signal).

The simulation waveform had a proportional control, and the results were shown in Fig. 11 and Fig. 12.

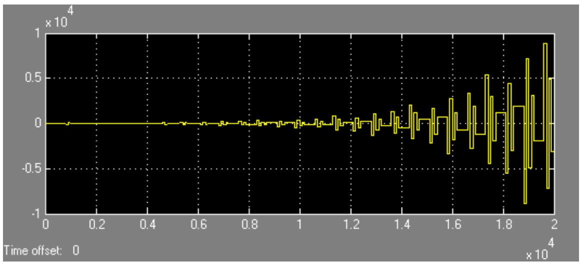

Fig. 11. The control input when the Packet loss rate was 35 %.

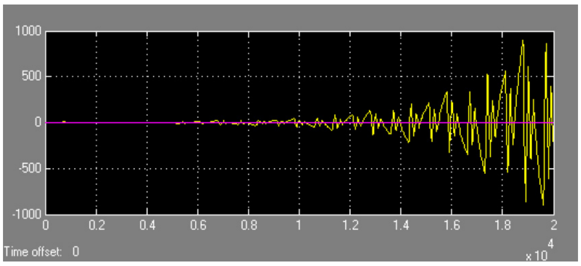

Fig. 12. The control output when the packet loss rate was 35 % (dotted line is the reference input signal).

It can be seen from the simulation graph, with the increase of packet loss, the system oscillation frequency will be increased, and the amplitude will be also increased. When packet loss was more than the critical value, with the passage of time, the system overshoot volume will be bigger and bigger, eventually, the whole system was a state of out of control.

5. Conclusions

In this paper, we discussed the stability problem of wireless greenhouse measurement and control system. First, the strong coupling factors of temperature and humidity were decouple, a corresponding control mathematical model of WSN measurement and control system was established. Secondly, the exponential stability conditions of the temperature and humidity discrete control system was analyzed using the control system stability index determination methods, Finally, using the LMI toolbox in Matlab, the feasibility solution was obtained to meet the exponential stability in the greenhouse WSN measurement and control system, and determines packet loss threshold when the system was not out of control.

Acknowledgment

This work was supported by the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD) and Project BK2011398 of the Jiangsu Province Natural Science Foundation.

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