A Quick-response Failure Detection Model of GNSS Airborne System

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Abstract—**The failure detection of the GNSS airborne system can reduce the navigation and positioning failure rate of the GNSS airborne system. While, it takes more longer time to complete the failure detection by traditional failure detection model. Therefore, a novel failure detection model of the GNSS airborne system has been considered and developed by differential equation of gray theory to predict the next arrival time of the heartbeat message when GNSS fails. Furthermore, the reliable message communication can be realized through the prediction result, and failure judgment of the GNSS airborne system, which is defined and utilized as the preliminary judgment basis, can be carried out. Then, the failure detection model of the GNSS airborne system is established in basis on combination logic between rumor heartbeat realization mode and monitoring heartbeat realization mode. Finally the proposed model in this present paper had been simulated and proved the shortest response time, which proves the performance of the model.**

Keywords: GNSS airborne system; quick-response; failure detection; grey theory

I. INTRDUCTION

With the wide application of the concepts PBN and RNP in civil aviation fields, and the development of CNS/ATM technology, GNSS airborne system is playing more and more important role in keeping the safe flight. The failure detection of the GNSS airborne system is focused on.

At present, the research on the failure detection model of GNSS airborne system is usually based on node detection, process detection and asynchronous distributed system detection. The failure detection model based on node detection is almost used to detect malicious attacks, logic errors and output of communication nodes to detect the failure of the whole system. The failure detection model based on process detection is mainly used to detect the working process status of the system so as to judge the failure status of the system. The failure detection model based on asynchronous distributed system mainly detects the unboundedness of message transmission and the initialization speed of process execution so as to realize the failure detection of processes such as slow execution of information, loss process and excessive information delay [1]. However, the common problem of these traditional failure detection models is the long response time. Therefore, a new failure detection model of GNSS airborne system which has shorter response time than traditional models is proposed here, which proves the effectiveness of the failure detection model through experiments.

The National Key Research and Development Program of China (2016YFB0502402).

II. DESIGN OF FAILURE DETECTION MODEL FOR GNSS AIRBORNE SYSTEM

A. *Prediction of system failure*

Grey theory differential equation, which is to predict the arrival time of heartbeat information next time when the system fails, is used to predict failure of GNSS airborne system. First, we should record the arrival time of all heartbeat messages in the past, and list heartbeat messages in the failure prediction process with numbers, and the numbered heartbeat information is taken as the original sequence of the differential equation [2]. In the prediction of the next arrival time of the failed heartbeat information, the list of the latest arrival time needs to be updated constantly. The arrival time in the past n times is taken as the original sequence $t^{(0)}$ based on the latest time. $t^{(0)}$ is given by:

$$t^{(0)} = \left(t^{(0)}(1), t^{(0)}(2), \cdots, t^{(0)}(n)\right) \quad (1)$$

The generating sequence $t^{(1)}$ of differential equation can be obtained by summing the original sequence $t^{(0)}$:

$$t^{(1)} = \left(t^{(1)}(1), t^{(1)}(2), \cdots, t^{(1)}(n)\right) \tag{2}$$

where

$$\begin{cases} t^{(1)}(1) = t^{(0)}(1) \\ t^{(1)}(k) = \sum_{n-1}^{k} t^{(0)}(n) \\ k = 2, 3, \cdots, n \end{cases} \tag{3}$$

The first order differential equation of the sequence $t^{(1)}$ is established by using the value of $t^{(0)}(k)$,

$$\frac{dt^{(1)}(k)}{dk} + at^{(1)}(k) = b \tag{4}$$

where b is the grey action; a and d are the development coefficients [4]. The response formula of the first-order differential equation is as follows:

$$\overline{t}^{(1)}(k) = \left(t^{(0)}(1) - \frac{a}{b}\right) d^{a(k-1)} + \frac{a}{b} \tag{5}$$

Eq. (5) can be reduced by the least square method, we get:

$$[a, b] = \left(B^T B\right)^{-1} B^T(k) \tag{6}$$

where B and T are the correlation sequences of the generated sequence and the original sequence, and the calculation is:

$$B = \begin{bmatrix} -0.5\left(t^{(1)}(1) + t^{(1)}(2)\right) & 1 \\ -0.5\left(t^{(1)}(2) + t^{(1)}(3)\right) & 1 \\ & \cdots \\ -0.5\left(t^{(1)}(n-1) + t^{(1)}(n)\right) & 1 \end{bmatrix} \tag{7}$$

$$T_{(n)} = \left[t^{(0)}(2), t^{(0)}(3), \cdots, t^{(0)}(n), \cdots\right]^T \tag{8}$$

then t can be obtained:

$$\begin{cases} \overline{t}^{(n)} = \left(\overline{t}^{(0)}(1), \overline{t}^{(0)}(2), \overline{t}^{(0)}(3), \cdots, \overline{t}^{(0)}(n), \cdots\right) \\ \overline{t}^{(0)} = t^{(0)}(1) \end{cases} \tag{9}$$

After $\overline{t}^{(0)}$ IAGO reduction and data restoring:

$$\overline{t}^{(0)}(k) = \left(\overline{t}^{(0)}(1) - \frac{a}{b}\right)(1-)d^{a} \times d^{a(k-1)} \tag{10}$$

The estimated arrival time of the heartbeat message $\overline{t}^{(0)}(k)$ can be obtained by Eq. (10). Considering there is still a certain deviation in the estimated arrival time. The prediction modifier α is necessary. α can be used to adapt and adjust different prediction needs. When the system fails next predicted arrival time can be obtained by:

$$t = \overline{t}^{(0)}(k) + \alpha \tag{11}$$

B. *Failure determination*

Reliable message communication is realized through the predicted arrival time and then the failure judgment of GNSS airborne system is carried out by using reliable message communication [5]. First, we could use the prediction result of the next arrival time of heartbeat message to judge the failure message packet. The failure message packet includes control message packet and heartbeat message packet, among which the control message packet is mainly responsible for cluster resource management and node management. Heartbeat message packet is mainly responsible for notifying the status of surviving nodes in the cluster. In the failure detection of GNSS airborne system, only heartbeat message packet can realize reliable message communication, so the category of failure message packet must be determined [6]. Using the predicted result of the next arrival time of the failed HEARTBEAT message and combining HEARTBEAT to send the failed message packet to the same communication channel, in order to realize the category determination of the failed message packet [7]. The process of HEARTBEAT for determination is shown in Figure 1.

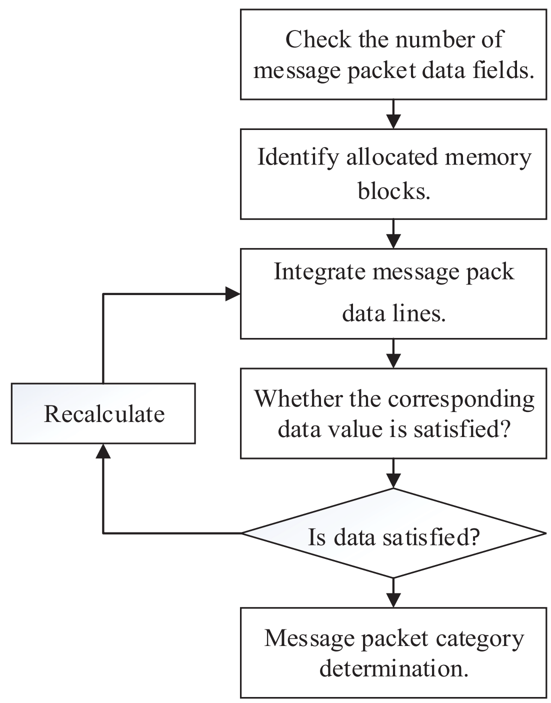

Figure 1 The HEARTBEAT decision flow

After finishing the category determination of failed message packets, heartbeat message packets are used to achieve reliable message communication [8], in which the retransmission process of heartbeat message packets needs to be completed jointly by the receiver and the sender. The specific implementation process is shown in Figure 2.

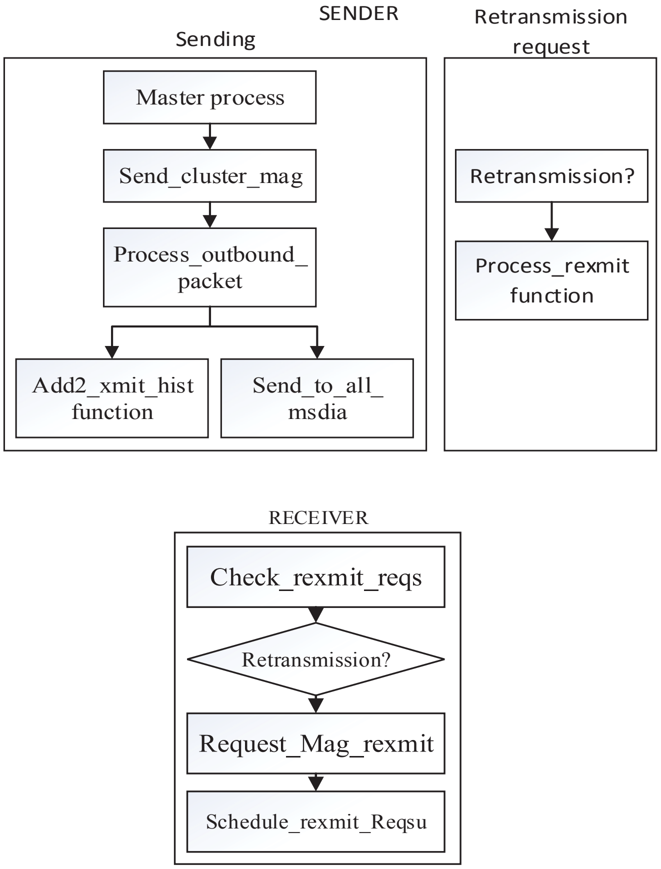

Figure 2 The implementation process

During the heartbeat message packet retransmission, the message sender need to call *Send_cluster_msg* function in the main process in order to implement the sending of the message, the receiver need to call *Schedule_rexmit_Reques* function to check if message packet miss, so as to request the sender retransmit[9].During the heartbeat message packet retransmission, the role of each function as shown in Table 1.

TABLE 1 THE ROLES OF EACH FUNCTION

Message packets objects	**Function name**	**Function effect**
Sender	Send_cluster_msg	send messages
	Process_outbound_packet function	Implementation of multicast protocol
	Add2_xmit_hist function	Send messages to the history message queue
	Send_to_all_msdia function	Send messages to multiple network interfaces
	Process_rexmit function	Retransmit the messages
Recevier	Check_rexmit_reqs function	Check for missing messages
	Request_Msg_rexmit function	Message sender for retransmission packet loss after request
	Schedule_rexmit_Reques function	The sending of retransmission request

After realizing reliable message communication, the message can be used in the failure determination of GNSS airborne system. First, the Main function is called to obtain the transmission media information and all node information contained in the configuration file, and all the obtained information is written into the corresponding global variable. Then, in the corresponding global variables, FIFO(......) process, main control process and the write and read process of the heartbeat transmission medium are judged to determine the failure of GNSS airborne system [10]. The main control process is started to create the failure clock. Using FIFO process to package the local state node information into a packet based on the clock signal according to the cycle difference and send it to the writing IPC of heartbeat transmission medium. Using each write process of corresponding heartbeat transmission medium to read the information in IPC. When the new information is read, the write process transmits the information to the heartbeat transport media cluster using the message sending channel in the write IPC.

The heartbeat transmission medium reading process is used to package the node information of transmission medium into a packet simultaneously, which is converted into a format and written into the heartbeat transmission medium read IPC. The Main function could connect the write and read process of each heartbeat transmission medium. When the data is written to the IPC, the Main function can extract the corresponding data in the write IPC, and then transfer it to the read IPC after verifying and processing. Similarly, the Main function can also transfer the data in IPC to the write IPC. The Main function can update the state of data nodes in the write and read process of heartbeat transmission medium. The main control process can be used to call the state of data nodes in the write and read process of heartbeat transmission medium, and check the retransmission and time difference of transmission medium through failure clock. The main control process also needs to record the acquisition time of node state information and calculate the response time of the node through now, so as to carry out failure judgment. The formula for failure determination is as follows:

$$\begin{cases} \overline{T} = T_c - T_d \\ \overline{T} \le T_1 \end{cases} \tag{12}$$

where $\overline{T}$ means the death time of the node; T_d means the interval between node deaths. T_c represents the current time; T_1 is the response time of the node; When $\overline{T}$ is less than or equal to T_1, it can be judged that the node has failed.

C. *Establish the failure detection model*

After the failure determination of the GNSS airborne system, the failure detection is established by using the failure determination results and combining the rumor heartbeat realization mode with the monitoring heartbeat realization mode. During the GNSS airborne system failure detection, the test node needs to send the detection message to the tested node regularly. When the test node receives a reply message from the tested node within the timeout period, it is proved that the tested node is not invalid. Therefore, when the failure detection is carried out by means of rumor and monitoring heartbeat, at least two messages need to be transmitted between the two nodes. The implementation principle of the rumor mode is shown in Figure 3, and the implementation principle of monitoring heartbeat is shown in Figure 4.

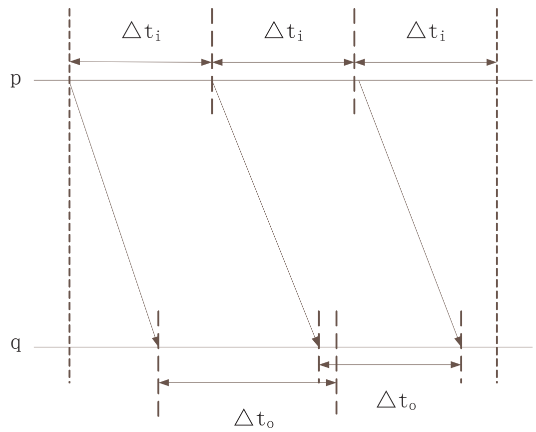

Figure 3 Implementation principle of rumor mode

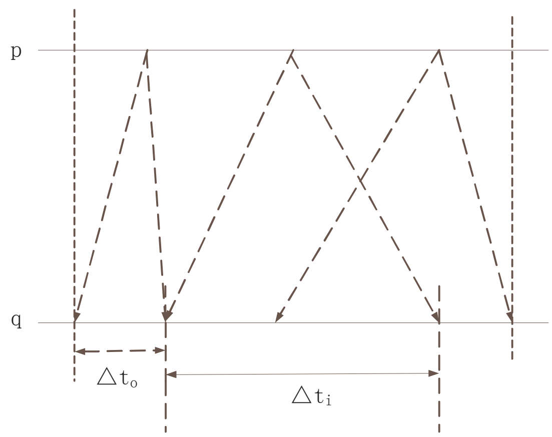

Figure 4 implementation principle of monitoring heartbeat implementation mode

For nodes in the failure logic loop, it is necessary to satisfy the delivery of messages between nodes, and the types of messages are divided into: node normal state; node failure state; node state from failure to normal; node state from normal to failure. The failure detection model of GNSS airborne system is constructed by combining failure logic rings in a certain order until several failure logic rings form a closed state. The concrete model diagram is shown in Figure 5.

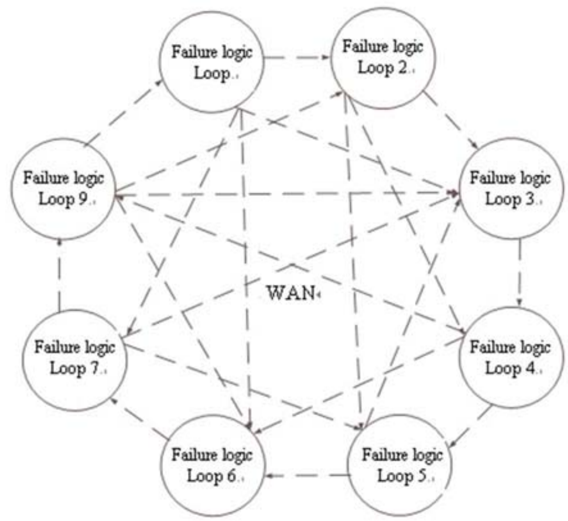

Figure. 5 Schematic diagram of specific model

In conclusion, the failure detection model of GNSS airborne system is constructed.

III. SIMULATION EXPERIMENT

A. Experimental parameters

In order to detect the failure detection model of GNSS airborne system proposed in this paper, the simulation experiment was based on Matlab Web platform. The experimental parameters are shown in Table 2:

TABLE 2 EXPERIMENTAL PARAMETERS

Project	**Data**	**Environment**
Platform	MATLAB® Web	Software environment: the unit of service
Resource	Analog wide area network	
Processing system	Windows server 2012R2	
Device parameters	Intel(R) Xon(R) CPU, 1T, 64G	
Environment	Same configuration computer as testee and detector	Hardware environment: failure detection client
Topological structure	A hybrid topology with ring topology and tree topology	
Technology	Failure detection model based on node detection, process detection and asynchronous distributed system	The combination of hardware and software environment
Access to data	Actual parameter	
Process	Failure detection of GNSS airborne system	
Criterion	Response time	
OS	Microsoft Windows 10	

B. Experimental process

Based on MATLAB® Web platform, the testee and the detector are connected through the simulated wan. The two computers with the same configuration were used to detect the failure of the GNSS airborne system. Use the failure detection client to set the periodicity of the message sent by the detected machine. The failure detection server is used to analyze and count the heartbeat messages received by the detected machine. Within the time limit, when the testee does not receive the heartbeat message sent by the detector, the testee will send a query message to the detector and wait for the feedback message from the testee. In this simulation experiment, the message sending cycle of heartbeat information is set as one second when the mechanical system fails and the test indexes including value P_A, window size and average detection time are controlled under the same condition. In order to ensure the effectiveness, the failure detection model based on node detection, the failure detection model based on process detection and the failure detection model based on asynchronous distributed system were compared with the failure detection model proposed in this paper to observe the results of the simulation experiment.

C. Experimental results

Failure detection model based on node detection, failure detection model based on process detection, failure detection model based on asynchronous distributed system and failure detection model proposed in this paper are used to compare the response time of failure detection for GNSS airborne system, as shown in Figure 6.

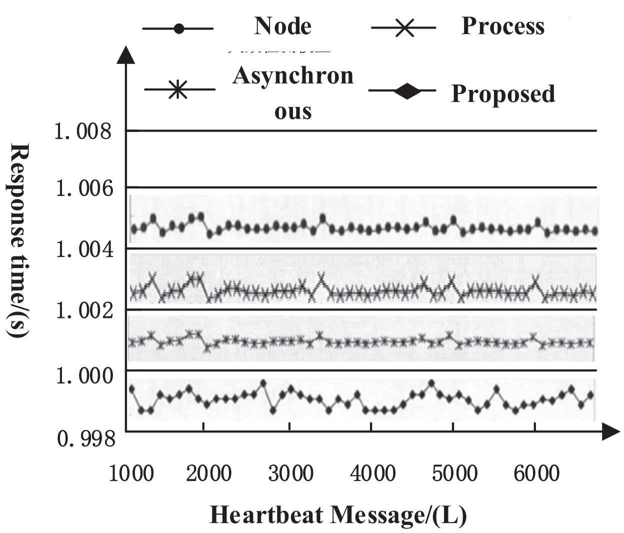

Figure 6 Comparison of response time

According to Fgure 6, the response time of failure detection model based on node detection for GNSS airborne system is about 1.00495s on average. The response time of failure detection using the failure detection model based on process detection is about 1.00254s on average and the time of using model based on asynchronous distributed system is about 1.0011s on average. The response time of using the model proposed in this paper is about 0.9992s on average. By comparison, the mean response time of the failure detection model proposed in this paper is the shortest, which proves the performance of the model.

IV. CONCLUSION

A novel failure detection model for GNSS airborne system is proposed to solve the problems of long response time in the detection process of the traditional failure detection model. Experiment results show that the proposed model is more suitable for the failure detection of GNSS airborne system, and the response time is lower than the traditional failure detection model, with superior performance and extensibility.

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