JJMIE

Volume 14, Number 1, March. 2020
ISSN 1995-6665
Pages 61 - 70

Jordan Journal of Mechanical and Industrial Engineering

Intelligent Remote Monitoring System for Minor Faults of Intelligent Unmanned Vehicle

Jia Tao*, Yuchen Jia, Yuan Gao

Information Science and Technology, Hebei Agricultural University, Baoding 071000, China

Received OCT 16 2019 *Accepted JAN 8 2020*

Abstract

Monitoring the minor faults of an intelligent unmanned vehicle is the key means to ensure the successful completion of unmanned detection. Therefore, an intelligent remote monitoring system for the minor faults of an intelligent unmanned vehicle is designed. The system takes personal computer and digital signal processor as the control center. A/D conversion circuit converts the minor fault signals collected by the system into data information stored in SD storage module, and the clock reset module records the occurrence of minor faults. In the software part of the system, the fault data are acquired according to the data acquisition process and the signal sampling interruption service process, and the data eigenvalue of remote minor faults of the intelligent unmanned vehicle is monitored based on the variable statistical analysis method, so as to realize the effective monitoring of the minor faults of the intelligent unmanned vehicle. In order to verify the monitoring performance of the system, an experimental study is carried out. The results show that the system can remotely monitor the minor faults of the intelligent unmanned vehicle. Compared with the similar systems, the system has the advantages of efficiency and provides guarantee for the smooth detection of the unmanned vehicle.

Keywords: Unmanned; Intelligent Vehicle; Minor Faults; A/D Conversion; Variable Statistical Analysis; Intelligent Monitoring.

1. Introduction

Intelligent unmanned vehicle is a new technology product. Intelligent unmanned vehicle usually refers to an unmanned, self-propelled vehicle (Li & Hu 2016; Dan et al. 2016) which is autonomously navigated by radio remote control or its own program control. Intelligent unmanned vehicles are usually used in scientific exploration, planet exploration, combat intelligence collection, and other fields. The main intelligent unmanned vehicles currently in service are MQ-1 Predator, MQ-9 Reaper, RQ-4 Global Hawk and so on. Intelligent unmanned vehicle is widely used in military and scientific research fields because of its low design cost, no casualty risk, strong survivability and good mobility. It is also the development direction of future automobile manufacturing industry (Zhou et al. 2015; Saska et al. 2017). Intelligent unmanned vehicle works in a harsh environment with abnormal temperature changes. For example, in the application fields of polar exploration and lunar exploration, the working environment temperature is below tens of degrees Celsius. The running state of the vehicle is greatly impacted by the ambient temperature, and it is prone to produce faults. The remarkable faults of the unmanned vehicle can be known through the alarm of the monitoring system, while the minor faults can not be monitored by the monitoring system. It is difficult to detect. Often because of minor faults, the intelligent unmanned vehicle runs out of control and cannot complete the detection task (Hu & Seiler 2015; Liu et al. 2015). Therefore, it is of practical value and significance to study a remote monitoring system which can monitor the minor faults of an intelligent unmanned vehicle (Chi et al. 2015). This paper designs an intelligent remote monitoring system for minor faults of intelligent unmanned vehicle from both hardware and software aspects. The system uses A/D conversion circuit and storage module to acquire fault data and save them. The system has strong reliability. The time of minor faults is accurately recorded by clock reset module, which provides precise time basis for danger detection (Li & Ge 2015; Song et al. 2015). The fault monitoring method based on variable statistical analysis is one of the hotspots in recent years. It uses the correlation between process variables to diagnose faults. This method processes the historical data of process variables, decomposes the sample space by multi-projection method, projects the sample vectors to each subspace, calculates the corresponding statistics and statistical indicators, and applies them to process monitoring. Based on the data characteristics, this method is more suitable for complex and minor faults monitoring process, so it is applied in the field of minor faults monitoring of intelligent unmanned vehicle.

* Corresponding author e-mail: tj7890609@163.com.

2. MATERIALS AND METHODS

2.1. Overall structure of remote monitoring system for minor fault of intelligent unmanned vehicle

The whole monitoring system is based on PC + DSP (Personal computer and digital signal processor) as the control center. The system is mainly composed of data acquisition A/D(Converter) conversion of slave computer, minimum system of DSP, and the communication, data processing, display output and database call of host computer (Xiao et al. 2017). Among them, the data acquisition part of minor faults is driven by a multi-chip A/D converter controlled by a DSP for synchronous sampling. The minimum system of a DSP is centered on a DSP and consists of extended program memory, data memory, power supply circuit and reset circuit. Communication display module includes keyboard, LCD display, and serial communication module with host computer. Data processing module of host computer mainly realizes data filter design, time-frequency analysis, wavelet packet analysis and waveform display. In the process of fault diagnosis analysis, the call of database is also an important part of signal analysis. The overall composition of the intelligent remote monitoring system for minor faults of an intelligent unmanned vehicle is shown in Figure 1.

Fig. 1 shows that the main working process of the minor faults monitoring system is as follows: firstly, the collected engine state parameter signal is put into the slave computer cache, then the slave computer packs the signal, and sets the data format. The serial communication module transmits the data to the host computer through the handshake protocol, and then the digital filter and the related signal time-frequency processing algorithm are used to process the various measured parameters, to make running state detection and call fault monitoring database for fault diagnosis (Goebel et al. 2015; Duan et al. 2016), and take further measures to identify, locate, isolate, alarm, and finally save the data to the host computer database. In the fault monitoring system, reasonable and reliable hardware system is very important, but the realization of monitoring tasks in the fault monitoring system, the fault diagnosis ultimately depends on the implementation of the program, the quality of the program directly affects the system performance.

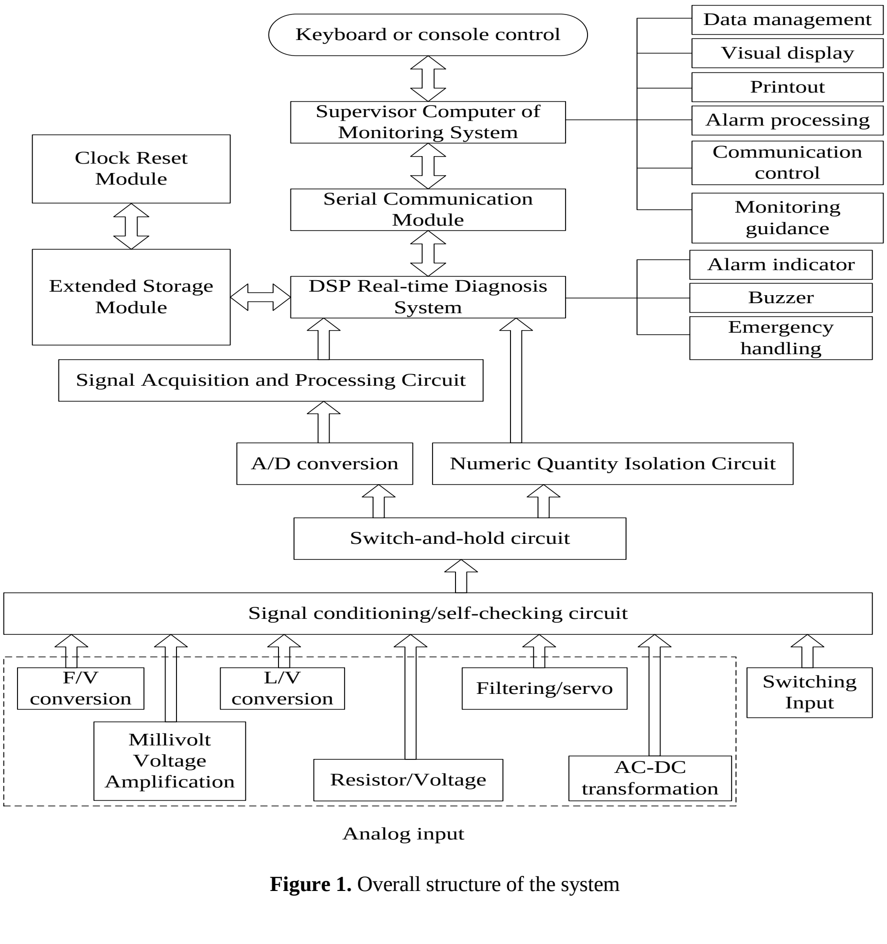


Figure 1. Overall structure of the system

2.2. Hardware design

2.2.1. A/D conversion circuit

The acquisition and analog-to-digital conversion of minor faults signal data in the system is accomplished by AD7874. It is a four-channel 12-path synchronous data acquisition device which can be developed by analog device company. The chip has built-in four-channel sampler-holder and 3 V reference power supply. It is made by LCO process with good linearity and has high accuracy and small relative delay time. The application of simultaneous sampling and time-sharing conversion technology makes that the four-channel special exchange results have phase similarity (Gu & Zhang 2016). Each A/D converter requires 8 us and four channels requires 32 us. Combined with other time expenditure, the sampling frequency of each circuit can reach 29 kHz (the period is about 34 us). Fig. 2 is the pin configuration of AD7874.

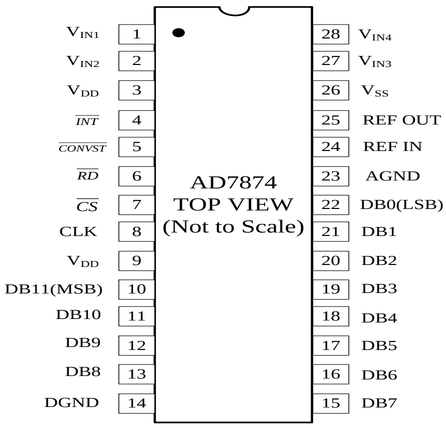
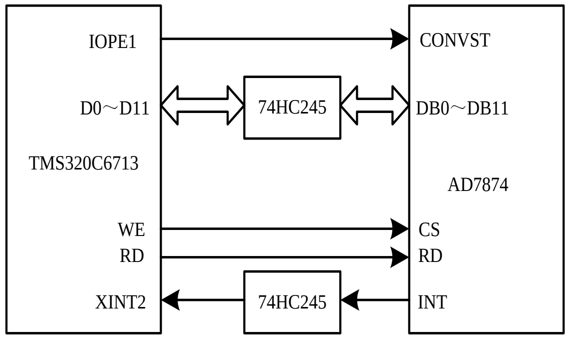


Figure. 2. Diagram of AD7874 Pin configuration

As shown in Fig. 2, the internal structure of AD7874 is composed of sampling and holding device, data register, control logic circuit, comparator, reference power supply and internal clock. The working process is as follows: AD7874 receives an operation to make CONVST signal effective from DSP TWS32006713, then AD7874 converts four channels in turn. Indicating that the data conversion of minor faults has been completed, and sends an interrupt request signal to DSP (Bi et al. 2017; Wei et al. 2017). After the interruption of the response of TMS32006713, AD7874 is read four times in succession, and the data is read from channel 1 to channel 4 in turn, so the sampling values are obtained. When reading data from A/D converter, because AD7874 has a high-speed 12-bit data bus, the output signal level is TTL level, while the data bus of TWS32006713 works at 3.3 W level standard, it is necessary to add a level converter 74HC245 between them when designing the interface circuit. It is a driver powered by two voltages, with 3.3 V on one side and 5 V on the other side, playing the role of level conversion. Other signal lines such as IMT and CONVST also need to be converted through 74HC245.Figure 3 is a schematic diagram of the interface between DSP and AD7874.



Figuer 3. Interface schematic diagram of DSP and AD7874

The interface mode between A/D converter and DSP directly affects the transmission rate of sampled data, that is, the sampling rate. It is very important for real-time system to design a reasonable interface mode according to different needs. On the one hand, it can accurately sample and reasonably arrange the hardware resources of the DSP; on the other hand, it can make the software simple and efficient, and meet the real-time processing requirements.

2.2.2. Clock reset module

The clock reset module of the system is an important technology to record the occurrence time of minor faults of an intelligent unmanned vehicle. The clock circuit TMS320C6713 has a phase-locked loop (PLL) and an oscillator. The oscillator consists of five frequency dividers: D0, OSC, DIV1, D1, D2 and D3. PLL and oscillator can generate different clock signals to each part of the system, such as the DSP core, EMIF, McBSP and so on. The internal structures of PLL and oscillator are shown in Figure 4. Figure 4 shows that the external 3.3 V power supply is filtered and connected to PLDV to supply power to PL. The external 25 MHz crystal output terminal is connected to CLKIN foot. The CLKMODEO should be raised so that the crystal frequency can pass through the rear frequency divider and phase-locked loop. CLKIN clock signal passes through D0 frequency division (range 1-32 frequency division) and PLL frequency multiplication (range 4-25 frequency multiplication), then inputs D1, D2, D3 three frequency dividers respectively, and outputs three clock signals to provide clock for chips and peripherals. If PLLEN is 0, D0 and PLL will be bypassed. CLKIN outputs CLKOUT3 directly after OSC DIV1 frequency division, and the clock is reserved for users to use. All dividers and PLL divider frequencies can be set through the relevant registers, that is to say, the above output clock frequencies can be set by software.

Reset Circuit: For the TMS32006713, reset is an unshieldable external interrupt (interrupt vector address 0000H), which can be used at any time to put the chip in a known state. Reset is the highest priority interrupt, which is usually reset when the chip is in an unknown state after power-on (Okumus et al. 2017). Since the program memory in the reset signal operates and initializes the hardware state bits, the system should rerun the initialization program after each reset.

2.2.3. SD storage module

The system is designed based on STM32F107VCT6 microprocessor of ST company, which has the highest execution speed of 72MIPS, nearly 30 universal I/O with freely defined functions, one USB2.0 host interface communication, read-write U disk, one USB2.0 slave interface communication, one SD card read-write interface, which can be used for video image and fault data storage, and the circuit design of SD storage module is shown in Figure 5, a 10/100 m adaptive Ethernet interface, in which independent watchdog is built-in to ensure that the system never crashes. The circuit consists of CMOS camera circuit, camera buffer control logic circuit, SRAM memory and 32-bit embedded system bus interface (Miao et al. 2017; Li 2015). The system camera buffer control logic circuit is realized by programmable logic device EPM7128s.The design scheme is to connect IZl with MT9V011 by a programmable logic device, control image data to be cached in SRAM, and then notify the processor to read the data. The control logic circuit in CPLD chip reads image data and caches it into SRAM. The clock of CPLD in the system is 40 MHz, and the clock after 10 minutes is used as the clock of CMOS image sensor (Khorasani 2015). This can reduce the image output rate, and reduce the burden of STM32F107VCT6 on data processing, so that the processor has free time for other control operations.

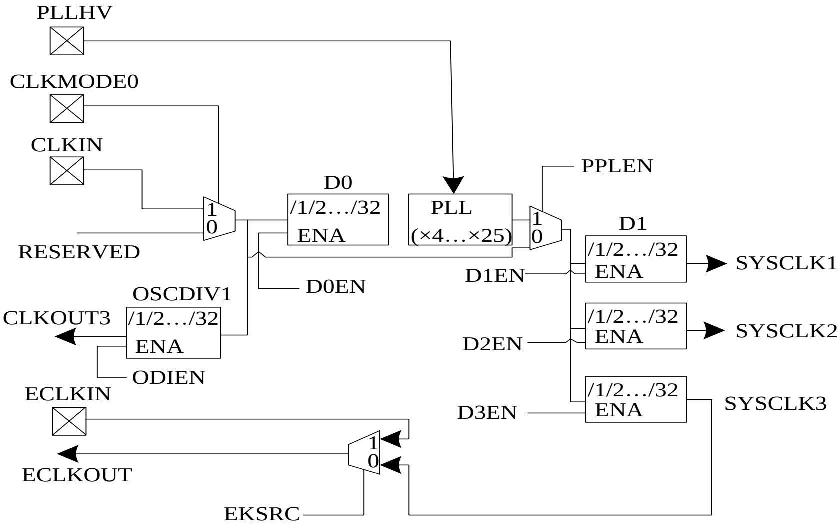


Figure 4. Diagram of clock generation circuit

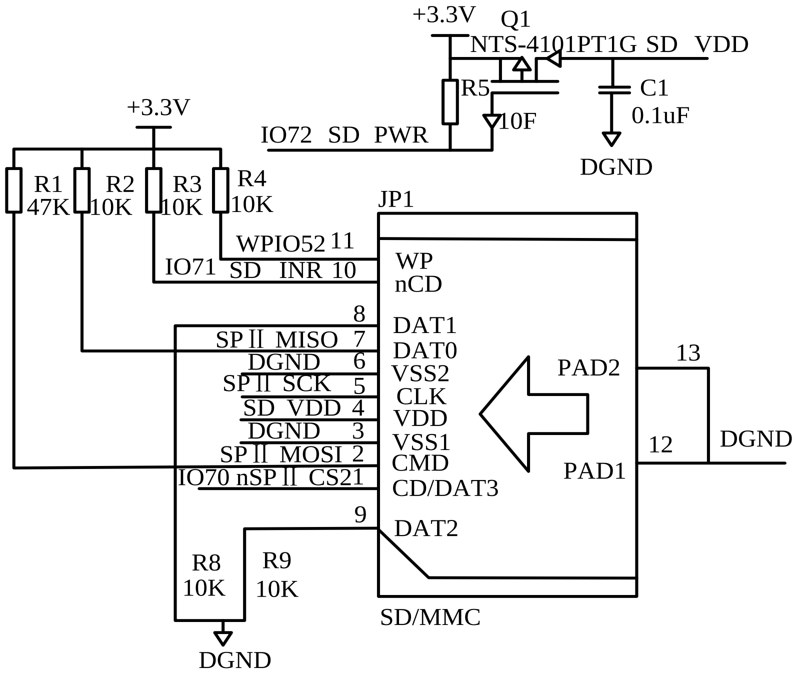


Figure 5. SD memory module circuit

2.3. Software design

2.3.1. Signal acquisition and conversion

A/D converter AD7874 is used as the main component of the acquisition module for minor faults signal acquisition. Procedure flow charts of fault data signal acquisition and interruption service flow chart of signal sampling are shown in Figs. 6 and 7. In the system, 1024-point vibration signal data of engine rotor are collected for processing and analysis, and 1024 data storage areas are set for the alarm signal. With ring queue storage, the address and length of the storage area remain unchanged (Yang et al. 2015). The first sampled data is stored in the first address of the storage area, and the latter data is stored back in turn. When the storage area is full, the last sampled data replaces the earliest data in the storage area, and saves the position of the last sampled point as a pointer for data reconstruction.

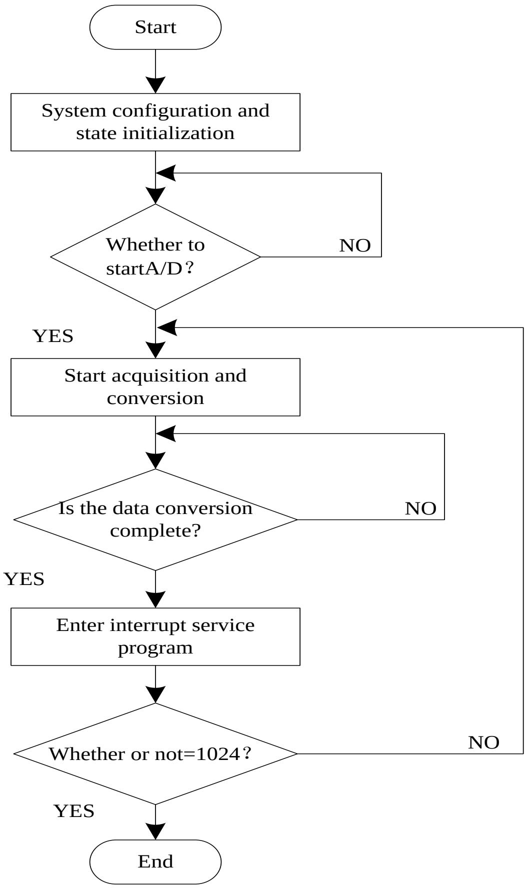


Figure 6. Flow chart of program for acquisition and conversion of minor faults signals

In Fig. 7, the timer 1 triggers the direct memory controller EDMA to control sampling. According to the requirement of the system, the core resources of the DSP are precious and need to complete a lot of calculation and communication control. Sampling time takes up a large part in running data sampling and other programs. Sampling module uses timer to trigger CPU to sample at a certain frequency, and EDMA to design sampling module can avoid CPU resources interfering with sampling module, so that CPU can use all resources to perform algorithm and other program operations. The process of data sampling using EDMA is described below.

Since the sampling is carried out at a certain frequency, a timer must be used to trigger an EDMA event, so that EDMA can move the data from the A/D digital output to RAM. Before sampling, the timer 1 should be set to determine the sampling period, and then the EDMA and timer 1 should be correlated so that the timer 1 can trigger the EDMA event, and then the EDMA channel can be enabled.

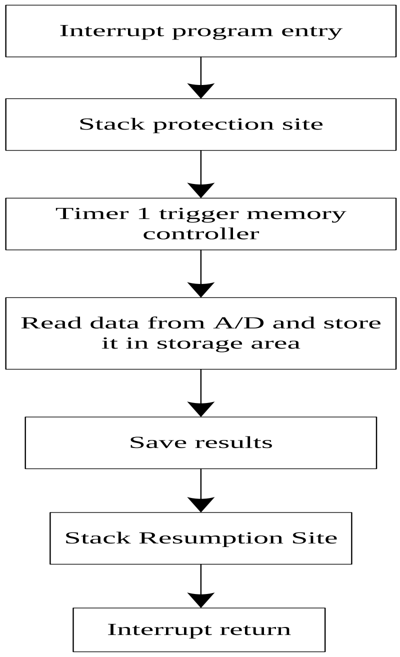


Figure 7. Flow chart of sampling interrupt service program for minor fault signal

2.3.2. Minor fault monitoring method based on variable statistical analysis

According to the collected monitoring data of the intelligent unmanned vehicle, the minor faults of the intelligent vehicle are monitored based on the statistical analysis of variables. Variables are transformed vectors of the original fault data matrix, and they are not correlated with each other. Their statistical characteristics reflect some points in the process. For example, the variance of variables is the eigenvalue of the covariance matrix of normalized data. Statistical characteristics of monitoring variables can reflect the change of working conditions.

Considering the original fault data matrix $X \in R^{n\times m}$, n represents the number of independent measurements and m represents the number of sensors. After standardizing the original process data (zero mean and unit standard deviation), the covariance of the sample of minor faults is calculated by the following formula:

$$S = \operatorname{cov}(X) = \frac{1}{n-1} X^T X \tag{1}$$

By singular value decomposition of S, the load matrix P (matrix composed of eigenvalue vectors of S) can be obtained. Then the data matrix of minor faults inoriginal process can be transformed as follows:

$$T = XP \tag{2}$$

In the formula, $P \in R^{m\times m}$ is the load matrix; $X \in R^{n\times m}$ is the score matrix (each column of T represents the corresponding TC).

Because TCSA is an algorithm based on sliding time window, it is necessary to calculate TC in each window and calculate its statistical characteristics. Let the length of the sliding time window be $w, X(k)$ is the process measurement value representing the length of a window:

$$X(k)=\begin{bmatrix} x_1A_1 & x_2A_1 & \vdots & x_mA_1 \\ x_1A_2 & x_2A_2 & \vdots & x_mA_2 \\ \vdots & \vdots & \vdots & \vdots \\ x_1(k) & x_2(k) & \cdots & x_m(k) \end{bmatrix} \quad (3)$$

In the formula, $A_1 = k-w+1$; $A_2 = k-w+2$.

A fault data matrix can be created:

$$X_{sum} = [X_{normal}; X_k] \quad (4)$$

In the formula, $X_{normal} \in R^{w\times m}$ is the measurement data matrix under normal working conditions. Then the normalized covariance matrix of X_{sum} is calculated, and the SVD decomposition is carried out to obtain the matrix T. The statistics (mean, variance, skewness, kurtosis) of the matrix are calculated, and the fault statistics matrix is constructed.

$$S(k)=[mean(k), \mathrm{var}(k), skewness(k), kurtosis(k)] \quad (5)$$

The detection index can be calculated by the following formula:

$$DI(k)=\left\| S(k)-S^{(mean)}\left(diag\left(S^{(std)}\right)\right)^{-1}\right\|_p \quad (6)$$

It should be pointed out that, because the matrix T satisfies formula (7), when the statistics are only used differently and norm 2 is taken, the detection index degenerates as shown in formula (8):

$$\frac{1}{2w-1}T^T T=\begin{bmatrix} \lambda_1 & & \\ & \ddots & \\ & & \lambda_m \end{bmatrix} \quad (7)$$

$$DI(k)=\left\| \left(\mathrm{var}(k)-\mathrm{var}^{(mean)}(k)\right)\cdot\left(diag\left(\mathrm{var}^{(std)}(k)\right)\right)^{-1}\right\|_2 = \sum_{j=1}^{m}\left(\frac{\lambda_j(k)-\lambda_j^{(mean)}}{\lambda_j^{(std)}}\right)^2 \quad (8)$$

The above operation is transformed into the monitoring of eigenvalues of covariance matrix. The monitoring eigenvalues are the fault data eigenvalues of unmanned vehicles. Based on these eigenvalues, the minor faults of intelligent unmanned vehicle can be monitored.The EDMA parameter code is set as follows:

```
EDMA Configcfgedma= {
EDMA_ OPT_RMK (/ * EDMA_OPT)*/
EDMA_ OPT_ PRI_ LOW, /* EDMA Event Priority*/
EDMA OPT ESIZEes 32BIT, /* Unit length is 32 bits, read data of two channels at a time*/
EDMA OPTes 2DS NO, /* One-dimensional transmission of source data*/
EDMA_OPT_SUM_NONE, /* Source address is fixed mode, because A/D address remains unchanged*/
EDMA_OPT_2DD_NO, /* One-dimensional transmission of target data*/
EDMA_OPT_DUM_INC, /* Target address is self-increasing mode*/
EDMA_OPT_ TCINT_YES, /* Transmission completes sending interruption*/
EDMAPT_TCC_OF (TCCINTNUM), /* Transmission completion code*/
EDMA_OPT_LINK_YES, /* Connection enables*/
EDMA_OPT_FS_NO/* Synchronization of use unit */
)
EDMA_SRC_ OF (OxA0300000), /* Setting source address*/
EDMA_CNT_OF (sample count), /* Sampling points*/
EDMA_DST_OF (SAMPLE_DATA_ADDR), / * Target data address*/
EDMA_IDX_OF (Ox00000004), / * Set index, 4 bytes increase by itself*/
EDMA_RLD_OF (sample count, 16 0x0) / * Count is reset to sampling point*/
} ;
```

After starting the timer, the timer will trigger EDMA according to the sampling period. EDMA triggers an interrupt notification CPU after all sampling points are moved. Finally, the EDMA channel and timer are closed to complete the sampling process. In the engine monitoring system, the selection of various parameter filtering methods should be based on the characteristics of the monitored signal of the engine and its changing rules.

3. RESULTS

In this paper, BJUT-IV, an intelligent unmanned vehicle, is used as an experimental object to study the effectiveness of the intelligent monitoring system for minor faults in this paper. In the experiment, 10 minor faults occurred in the driving process of BJUT-IV, named AB-1, AB-2, AB-3-AB-10, and the complex environment of 80 m×80 m is selected as the driving section of the intelligent unmanned vehicle.

3.1. Fault data acquisition and analysis

In this paper, the system collects the minor faults characteristic data of the intelligent unmanned vehicle as shown in Fig. 8.

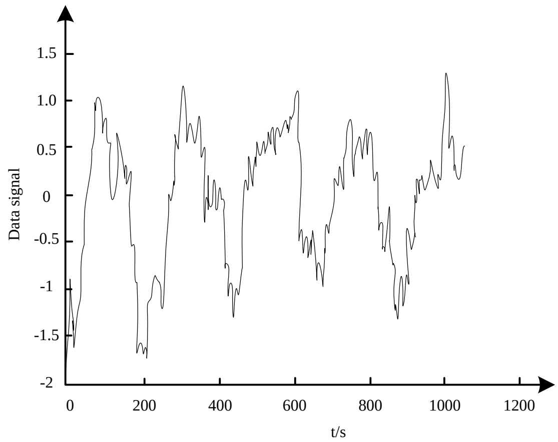


Figure 8. Data acquisition results of minor faults

Fig. 8 shows that the system can accurately collect the minor faults data of the intelligent unmanned vehicle, and then carry out fault analysis, which proves that the system is effective.

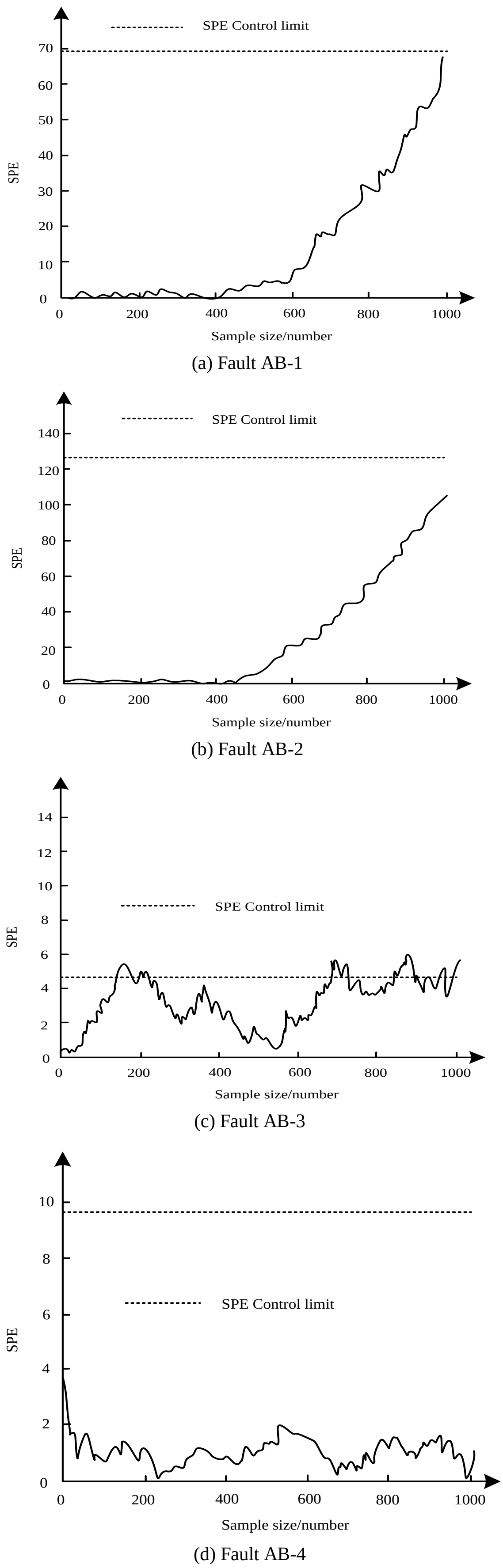
3.2 Comparison of system monitoring results

In order to highlight the advantages of this system in monitoring minor faults of intelligent unmanned vehicles, CUSUM-PCA monitoring system and DISSIM monitoring system are selected for comparative testing. Because the three systems all use statistical analysis methods to monitor minor faults of intelligent unmanned vehicles, the comparative effect is obvious. The usage time of the three systems for remote monitoring of the minor faults of the intelligent unmanned vehicle is shown in Table 1. The results of the three systems for monitoring the minor faults of the intelligent unmanned vehicle are analyzed from the perspective of statistical analysis variable SPE, as shown in Fig. 9, Fig. 10 and Fig. 11 (with limited space, only the first four minor faults are compared).When the monitoring curve is above the SPE control limit, the system can accurately monitor the minor faults of the unmanned vehicle, and the monitoring rate is higher. When the monitoring curve is below the SPE control limit, the system can not accurately monitor the minor faults of the unmanned vehicle, and the monitoring rate is lower.

Table 1. Time-consuming for monitoring and controlling minor faults in three systems/s

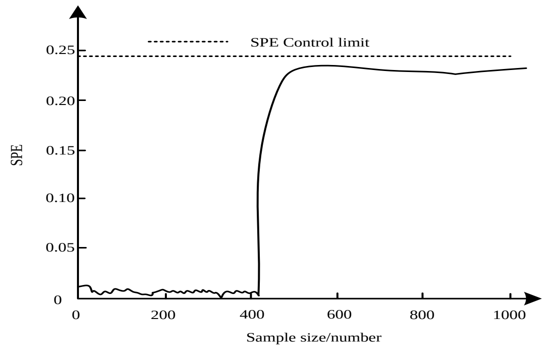
Fault name	Paper system	CUSUM-PCA Monitoring System	DISSIM Monitoring System
AB-1	0.20	1.90	2.20
AB-2	0.10	1.70	2.10
AB-3	0.11	1.60	2.50
AB-4	0.21	1.50	1.90
AB-5	0.19	2.10	2.23
AB-6	0.18	1.85	2.19
AB-7	0.11	1.64	2.74
AB-8	0.15	1.73	2.11
AB-9	0.20	2.50	2.13
AB-10	0.13	2.46	1.98

Table 1 shows that the system consumes about 0.10-0.21 seconds to monitor minor faults, 1.4-2.29 seconds less than that of CUSUM-PCA monitoring system and 1.8-2.53 seconds less than that of DISSIM monitoring system.

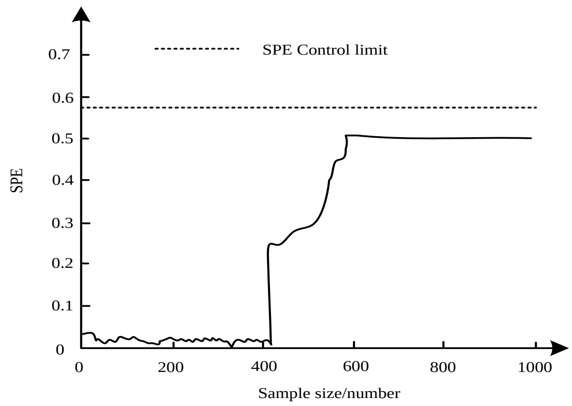


(a) Fault AB-1
(b) Fault AB-2
(c) Fault AB-3
(d) Fault AB-4

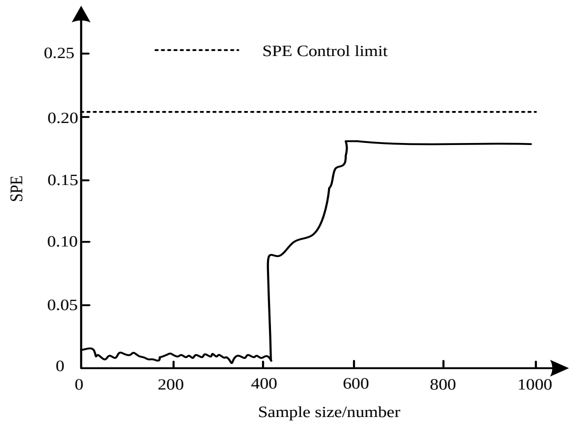
Figure 9. Fine fault recognition results of CUSUM-PCA monitoring system



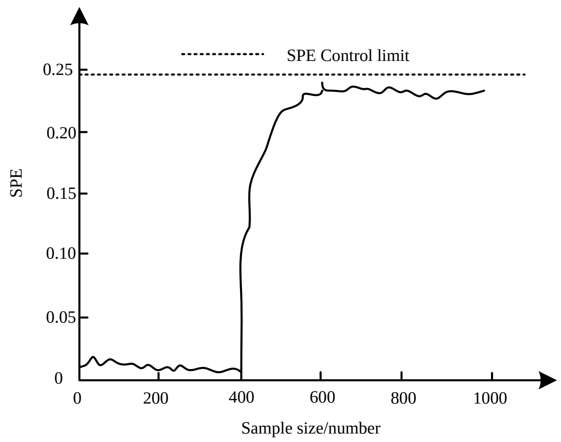
(a) Fault AB-1



(b) Fault AB-2

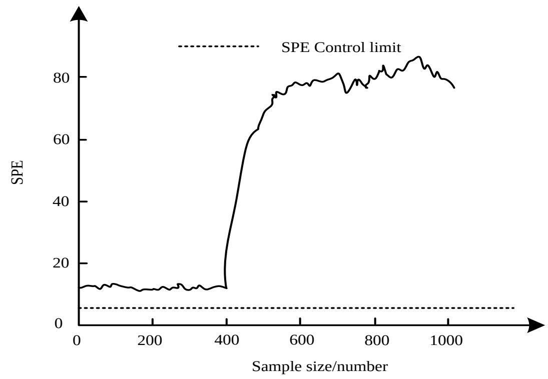


(c) Fault AB-3

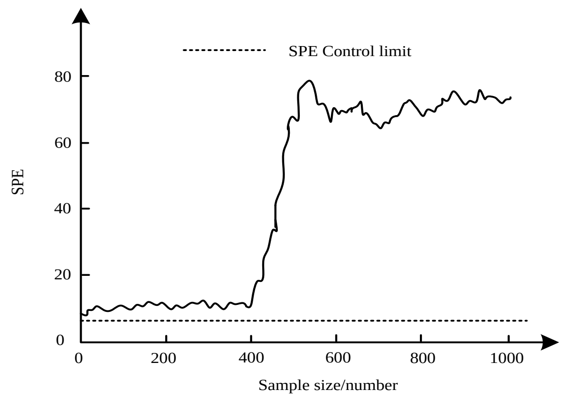


(d) Fault AB-4

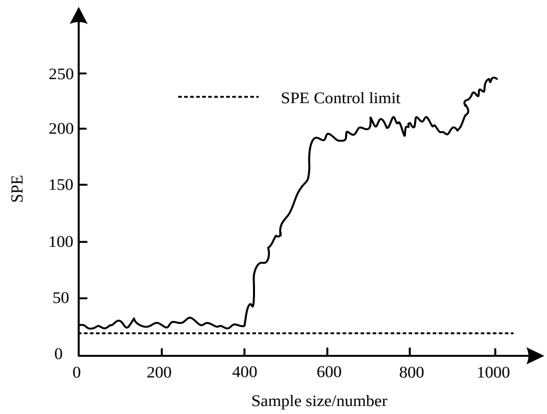
Figure 10. Fine fault recognition results of DISSIM monitoring system



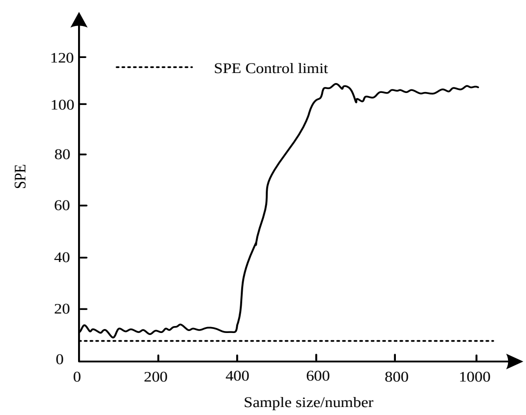
(a) Fault AB-1



(b) Fault AB-2



(c) Fault AB-3



(d) Fault AB-4

Figure 11. Fine fault identification results of the method in this paper

The above results show that the system can correctly monitor the minor faults of the intelligent unmanned vehicle, and achieve the purpose of remote monitoring the minor faults of the intelligent unmanned vehicle, while the CUSUM-PCA system and DISSIM system can not accurately monitor the minor faults of the intelligent unmanned vehicle.

4. DISCUSSION

The performance of this system is verified by unmanned driving test. Table 1 shows that the system consumes about 0.10-0.21 s to monitor minor faults, saves 1.4-2.29 s compared with CUSUM-PCA monitoring system and 1.8-2.53 s compared with DISSIM monitoring system. It can be seen that this system has a shorter time to monitor the minor faults of the intelligent unmanned vehicle, and improves the efficiency of the minor faults monitoring. Under the remote monitoring of this system, the minor faults of the intelligent unmanned vehicle are all within the scope of monitoring, which provides a reliable basis for the remote control and normal driving of the intelligent unmanned vehicle.

The results of Fig. 9 show that four kinds of minor faults curves of CUSUM-PCA monitoring system are under the SPE control limit, which shows that the system can not accurately monitor the minor faults of the intelligent unmanned vehicle, and the monitoring rate is low. The process of monitoring fault AB-1, AB-2 and AB-4 in CUSUM-PCA system is similar, and there is no junction between monitoring curve and SPE control limit, which indicates that the data collected by the system is not effective enough to correctly monitor minor faults of intelligent unmanned vehicles. When monitoring fault AB-3 in CUSUM-PCA system, there is a junction between monitoring curve and SPE control limit, which indicates that the data collected by the system is effective at this time, which increases the probability of system monitoring minor faults. But in general, the monitoring system cannot correctly monitor the minor faults of the intelligent unmanned vehicle. Similarly, from Figure 10, we can see that the DISSIM monitoring system cannot monitor four kinds of minor faults of the intelligent vehicle.

The results of Fig. 11 show that the monitoring curves of the system in this paper are above the SPE control limit, which shows that the system can accurately monitor the minor faults of the intelligent unmanned vehicle, and provide an effective basis for solving the faults of the intelligent vehicle and reducing the probability of the unmanned accident. This system has strong ability to monitor minor faults, which is mainly embodied in the following aspects: (1) This system takes PC+DSP as the control center, and is driven by DSP to synchronously sample multiple A/D converters to complete the fault data acquisition of intelligent unmanned vehicle; PC+DSP combination has excellent performance and wide application scope, which provides an excellent component for minor faults monitoring system, and DSP control A/D converter to complete data acquisition, improving the accuracy of minor faults data to a certain extent, and improving the accuracy probability of monitoring minor faults. (2) The fault monitoring method adopted in this system has a strong ability in monitoring minor faults. The data collected by the hardware of the system are analyzed by variable statistics. Variables are transformed vectors from the original minor faults data matrix, and they are not related to each other. Variable statistical analysis method first calculates the covariance of minor fault samples, and decomposes the singular value of variance results to get the load matrix, then calculates the process measurements in the length of sliding time window, creates the data matrix and constructs the statistical matrix, which is transformed into the monitoring of the eigenvalues of the covariance matrix, and the monitoring eigenvalues are the fault data eigenvalues of the unmanned vehicle. It can control the minor faults of the intelligent unmanned vehicle and improve the ability of the system to monitor the faults.

5. CONCLUSIONS

Intelligent unmanned vehicle started late, but it has broad application prospects. It is mainly used to detect complex environment and unknown areas. However, the navigation control system of unmanned vehicle is often threatened by complex environment, resulting in uncontrollable faults, while minor faults are not easy to detect, easy to lose direction, seriously affecting the detection effect of unmanned vehicle. Therefore, this paper designs a remote monitoring system for minor faults of intelligent unmanned vehicle. Monitoring minor faults of intelligent unmanned vehicle mainly uses variable statistical analysis method to monitor minor faults from the data point of view, with higher accuracy and better effect. In order to verify the effectiveness of the system in monitoring the minor faults of the intelligent unmanned vehicle, the experimental study shows that the system has strong ability and high efficiency in monitoring the minor faults of the intelligent unmanned vehicle. It provides a new means for monitoring the minor faults of the intelligent unmanned vehicle, and shows a high application value.

ACKNOWLEDGEMENT

This research was supported by Project of Scientific Research Youth Fund for Higher Education Institutions in Hebei Province in 2019. Item number: QN2019211.

REFERENCES

[1] Bi, H., Zheng, W. & Ren, Z. 2017. Using an unmanned aerial vehicle for topography mapping of the fault zone based on structure from motion photogrammetry. International Journal of Remote Sensing 38 (8-10): 2495-2510.

[2] Chi, Y., Zhang, Y. & Liu, Z. 2015. A survey on technologies for automatic forest fire monitoring, detection, and fighting using unmanned aerial vehicles and remote sensing techniques. Canadian Journal of Forest Research 45 (7): 150312143318009.

[3] Dan, L., Duan, J. & Hui, S. 2016. A Strong Tracking Square Root Central Difference FastSLAM for Intelligent unmanned Vehicle With Adaptive Partial Systematic Resampling. IEEE Transactions on Intelligent Transportation Systems 17 (11): 3110-3120.

[4] Duan, J.M., Shi, H. & Liu, D. 2016. Research of Navigation Control System for Intelligent unmanned Vehicles. Computer Simulation 33 (2): 198-203.

[5] Goebel, M.E., Perryman, W.L. & Hinke, J.T. 2015. A small unmanned aerial system for estimating abundance and size of Antarctic predators. Polar Biology 38 (5): 619-630.

[6] Gu, A., Zhang, X.X. 2016. Fault diagnosis system for power battery based on RBF neural network. Chinese Journal of Power Sources 40 (10): 1943-1945.

[7] Hu, B., Seiler, P. 2015. Pivotal decomposition for reliability analysis of fault tolerant control systems on unmanned aerial vehicles. Reliability Engineering & System Safety 140 (4): 130-141.
[8] Khorasani, K.2015. A hybrid fault detection and isolation strategy for a team of cooperating unmanned vehicles. International Journal of Control 88 (1): 90-103.
[9] Li, L., Hu, D. 2016. Introduction to the Special Issue on Intelligent unmanned Vehicles in China. IEEE Transactions on Intelligent Transportation Systems 17 (7): 2020-2021.
[10] Li, Y.H. 2015. Temperature remote monitoring system design and GSM-based STM32. Automation & Instrumentation (1): 56-59.
[11] Li, Y.X., Ge, X.L. 2015. Characteristic Performance Analysis of Traction Motor on EMU with Broken Bars Using FEM. Journal of Power Supply 13 (1): 41-47.
[12] Liu, X.M., Zhu, J.L. & Zhang, L. 2015. The model of WDM optical network for Unified Avionics Network. Journal of China Academy of Electronics and Information Technology 10 (2): 138-143.
[13] Miao, Y., Yu, H. & Zhou, J. 2017. Modeling of landslide topography based on micro-unmanned aerial vehicle photography and structure-from-motion. Environmental Earth Sciences 76 (15): 520.
[14] Okumus, E., San, F.G.B. & Okur, O.2017. Development of boron-based hydrogen and fuel cell system for small unmanned aerial vehicle. International Journal of Hydrogen Energy 42 (4): 2691-2697.
[15] Saska, M., Baca, T. & Thomas, J. 2017. System for deployment of groups of unmanned micro aerial vehicles in GPS-denied environments using onboard visual relative localization. Autonomous Robots 41 (4): 1-26.
[16] Song, Y., Weng, X. W. & Guo, X. 2015. Small UAV Attitude Estimation Based on the Algorithm of Quaternion Extended Kalman Filter. Journal of Jilin University (Science Edition) 53 (3): 511-518.
[17] Wei, W., Tischler, M.B. & Cohen, K. 2017. System Identification and Controller Optimization of a Quadrotor Unmanned Aerial Vehicle in Hover. Journal of the American Helicopter Society 62 (4): 1-9.
[18] Xiao, W., Chen, Y.G. & Yang, Y.P. 2017. The impact of intelligent vehicle on the two-route system with a work zone. International Journal of Modern Physics C 28 (8): 1750106.
[19] Yang, P., Tang, K. & Lozano, J.A. 2015. Path Planning for Single Unmanned Aerial Vehicle by Separately Evolving Waypoints. IEEE Transactions on Robotics 31 (5): 1130-1146.
[20] Zhou, H., Kong, H. & Wei, L. 2015. Efficient Road Detection and Tracking for Unmanned Aerial Vehicle. IEEE Transactions on Intelligent Transportation Systems 16 (1): 297-309.