Big data acquisition and processing platform for embedded prognostics of the ultrasonic motor

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Abstract. To ensure reliability and safety, embedded prognostics are essential for ultrasonic motor, which is a key component of spacecraft. Although many big-data algorithms have been proposed for prognostics and health management (PHM), no suitable embedded prognostic platform is found for the ultrasonic motor. In this paper, a big data acquisition and processing platform is proposed. The platform is composed of a high-speed signal acquisition board, an edge computing module and a display screen. As the key part, the high-speed signal acquisition board is discussed in detail. Moreover, this platform has been tested with an ultrasonic motor. The results show that the acquired waveform is quite clear, which indicates this platform can successfully be used for prognostics of ultrasonic motors.

1. Introduction

Spacecraft performs complex tasks and suffers harsh space environment, so high reliability and safety are essential for it [1]. Prognostics and health management (PHM) technology utilizes working state monitoring data, combining with environmental factors, to assess the current health status, provide early warning of impending failures, and estimate the remaining service life to prevent catastrophic consequences [2, 3].

Big data technology has been widely used in the PHM field. In terms of architecture, researchers proposed suitable frameworks according to the engineering requirements. Alonso-Gonzalez [4] proposed a big data architecture for prognostics of electronic devices. Petrillo [5] proposed a big data architecture for model-based vehicular prognostics. Based on the internet of things cloud platform, Wu[6] designs a prognostic and health management system architecture. In terms of data processing and modeling, researchers proposed various methods according to the product characteristics. Duan [7] proposed a novel bearing health prognostic method based on time-frequency analysis and long short-term memory (LSTM) neural network. Orozco [8] proposed a diagnostic model for wind turbine gearbox components using a multi-feature supervisory control and data acquisition data set spanning multiple years. However, there is little research about data acquisition, although it is the foundation of big data analysis. Chen [9] established a corrosion big data standard acquisition platform for the
refining process. Based on LabVIEW, Liu [10] realized the real-time state monitoring and fault diagnosis of a motor. Based on the cloud, Jia [11] designed a motor state monitoring system. The working frequency of the ultrasonic motor is between 40kHz and 50kHz. To ensure the clear time-domain waveform, the sampling frequency should be 10 times of the working frequency, that is, 500KHz. One ultrasonic motor includes 6 working parameters and 2 environmental parameters, the amount of data generated by continuous sampling for just 1 hour is about 150GB. No suitable big data acquisition and processing platform is reported for this circumstance.

In this paper, a big data acquisition and processing platform for embedded prognostics of the ultrasonic motor is designed. The platform contains a high-speed signal acquisition board, an edge computing module (Jetson TX2), and a display screen. With this platform, the required data can be acquired and processed successfully.

2. System architecture
The system is composed of a high-speed signal acquisition board, an edge computing module (Jetson TX2), and a display screen. Among them, the high-speed signal acquisition board is a self-developed board card, the Jetson TX2 and the display screen are shelf products. High-frequency data acquisition card and Jetson TX2 together to achieve real-time sampling and processing of the ultrasonic motor signal. The acquisition card includes the analog to digital converter (ADC), microcontroller unite (MCU), static random access memory (SRAM), interface control circuit, reference voltage circuit, clock circuit. The logical block diagram is shown in Figure 1.

![Figure 1. The logical block diagram](image)

The motor signal includes analog signal and digital signal. Analog signals contain ultrasonic motor driving voltage, driving current, feedback voltage, ambient temperature, and so on. The analog signals can be sampled synchronously in multiple channels through the ADC module, and the sampling frequency can be adjusted according to the actual demand. To ensure the accuracy and stability of ADC sampling, a reference voltage circuit is designed to provide a reference for ADC. Under normal circumstances, the data collected by the ADC chip will be sent to the cache of MCU. However, due to the large amount of data generated by the 8-channel sampling at the same time, the built-in storage space of MCU is not enough. If the cached data are not sent out in time, the sampled data may be overwritten, and the data would be lost. To solve this problem, an SRAM memory is used to expand the MCU cache. The data collected by ADC will be stored in the SRAM, and the MCU will uniformly read and send the sampled data in SRAM for a period of one second.

The digital signals contain drive frequency and speed, which are collected directly by MCU. Digital signals take up less storage space, so the MCU internal storage is enough. Since the MCU only supports the USB full-speed mode and the interface speed is only 12Mbps, the technical requirements of real-time transmission of a large amount of data cannot be met. This paper designed a USB switching circuit, which can reach the data transmission rate of 480Mbps.
3. Functional circuit design
This part describes the analog-to-digital converter circuit, the microcontroller unit circuit, the data storage circuit, and the interface control circuit.

3.1. Analog to digital converter circuit
The driving voltage, driving current, feedback voltage, ambient temperature, and other signals of the ultrasonic motor are continuous analog signals, and the signal acquisition needs to be sampled by the analog-to-digital converter. The number of data sampling channels should be no less than 8, the sampling rate should be no less than 500kHz, and the resolution should be no less than 16bit. Also, the chip should have a low-pass filter and over-voltage protection function. The ADC chip AD7606B designed by Analog Devices is selected, which can meet all the above requirements. The schematic design of ADC is shown in Figure 2.

Figure 2. Schematic design of ADC
3.2. Data storage circuit

Static random-access memory (SRAM) is a kind of random access memory, mainly used for high-speed cache. ADC data is cached by an SRAM-IS61WV102416ALL chip produced by the Core Semiconductor. This chip contains 16MB memory, and has 20 address lines and 16 data lines. The schematic design of ADC is shown in Figure 3.

![Figure 3. Schematic design of data storage circuit](image)

3.3. Interface control circuit

To realize the high-speed operation of the MCU, a USB transmission chip USB3300 designed by Microconductor is utilized in this paper. It supports any USB2.0 Transceiver Macrocell Interface (ULPI) protocol chip connection, so as to realize high-speed USB communication. The ULPI interface has relatively few signals, including eight data lines, one clock line and three control lines. After the MCU sends the data to the USB3300 chip through the ULPI interface, the data is output by the USB signal interface (DM&DP) through the internal bus. The schematic diagram is shown in Figure 4.
3.4. Microcontroller unit circuit
The MCU plays the function of center control. The parallel data output by the ADC chip cannot be directly transmitted to Jetson TX2. It needs to be processed by the MCU chip first and then connected to Jetson TX2 through the peripheral serial interface (RS232/USB) of the MCU. The MCU used in this paper is STM32F427IGT6 chip from STMicroelectronics, which is an M4 core 32-bit high-performance MCU with the main frequency up to 180MHz; it contains 140 I/O, 1024KB FLASH, 256KB RAM, and rich peripheral interfaces such as I2C bus, SPI serial peripheral interface, UART universal asynchronous transceiver, CAN bus, and so on. It has a built-in 90MHz memory controller and a 32-bit parallel interface, supporting compact flash, SRAM, PSRAM, NOR, NAND, and SDRAM memory expansion. Also, it is integrated with an integrated USB2.0 high-speed controller., and the circuit diagram is connected in the same way as the other parts, which will not be described here.

4. Printed circuit board design
The printed-circuit board (PCB) contains four layers. The first layer and the fourth layer are the signal layer, the second layer is the ground layer, and the third layer is the power layer. The second layer provides a reference plane and backflow path for the first layer and the third layer, while the third layer (power layer) is used as the reference plane and backflow path for the fourth layer (signal layer). By using this design mode, a good signal and power quality can be guaranteed.

Parallel data bus speed of ADC chip, SRAM chip and USB interface chip are relatively high. In order to reduce the time delay of signal transmission and ensure the signal quality, during PCB wiring, the relevant signal lines are designed for equal length with serpentine shape. Also, the single-end impedance is controlled to be 50 Ω, so as to avoid the signal reflection caused by the discontinuous characteristic impedance. The distance between two adjacent signals is greater than 3 times the width of signal lines, which can reduce the crosstalk by more than 90%. The PCB of high-speed signal part is shown in Figure 5.
The USB signal is a differential signal with a transmission rate up to 480Mbps. According to the USB protocol, in PCB design, the USB signal needs to control the differential characteristic impedance to be 90Ω, and the lines are needed to be parallel and of equal length. The PCB of the USB-signal part is shown in Figure 6.

The eight input channels of ADC chip are all analog signals, which have the weak anti-interference ability and are easy to be affected by interference sources. In this paper, the analog input signal is placed in an area independently, far away from other signals and power supply. Moreover, to prevent the analog ground from interfering by the noise of the digital ground, the magnetic beads are used to isolate the digital and analog ground.

5. Results and discussion
The big data acquisition and processing platform is shown in Figure 7, in which the acquisition card is directly connected to the controller of the ultrasonic motor. Sampling is controlled by the software in Jetson TX2. The data is automatically saved to a default folder as a comma-separated values (CSV) file. In this project, each CSV field contains 20-second data. To avoid excessive storage usage by continuous sampling, so the data processing software on Jetson TX2 will delete the CSV file after read.
Figure 7. PCB of USB signal

The data format is shown in Figure 8, which contains driving current, driving voltage, feedback voltage, driving frequency, rotating speed, motor temperature, ambient temperature, and ambient vibration. Taking driving voltage as an example, the sampling data is shown in Figure 9. The voltage waveform is clearly visible, which proves that this platform can meet the requirements of PHM for ultrasonic motors.

Figure 8. Sampling results
Figure 9. Sampling result of driving voltage: (a) all data showing the working process; (b) local data showing the detailed waveform

6. Conclusion
A big data acquisition and processing platform is proposed for embedded prognostics of the ultrasonic motor. This platform is composed of a high-speed signal acquisition board, an edge computing module, and a display screen. Detailed circuit diagrams and PCB design are given. The real measurement shows that this platform can meet the requirement of ultrasonic motor prognostics.

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