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A wireless multi-parameter monitoring device for aircraft

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Abstract. For ensuring the structure integrity and safety of aircraft during flight, aircraft health monitoring requires real-time perception of aircraft structural state and service environment parameters, such as impact, damage, vibration, temperature, humidity and air pressure. At the same time, airborne monitoring environment also puts forward requirements for device including aspect of wireless communication and power consumption. In this paper, a wireless multi-parameter monitoring device is reported. This device has the function of monitoring random impact on aircraft structure through connected PZT sensor array adopting digital sequence method, and is able to reliably monitor vibration, temperature, humidity and air pressure by several digital sensors. In addition, the multi-parameter monitoring function verification experiment is performed, showing that the reported device obtains the signal from PZT and accurately locates the impact region, and some results of vibration, temperature, humidity and air pressure monitoring are given, thus proving its multi-parameter monitoring ability for aircraft structure.

Introduction

During the service of aircraft, due to its complex structure and harsh service environment, it is necessary to monitor the structural status and various environmental information in real time to ensure flight safety [1,2]. The on-line structural health monitoring of aircraft provides a favorable technical means. Through various sensors or wireless sensor networks arranged on the aircraft, various monitoring parameters of the aircraft can be collected or transmitted wirelessly, which can be used to judge the structural state and guide decision-making [3,4].

People often pay attention to the stress and strain of aircraft structure, structural temperature and whether the aircraft skin is impacted during flight. For the structural health monitoring of aircraft, Wu[5] et al. proposed a WSN node for distributed strain monitoring. By bonding 16 resistance strain sensors to the skin of carbon fiber composite wing box section, the multi-point strain monitoring function of WSN node is realized. Demo [6] et al. proposed a WSN node for aircraft structure corrosion monitoring based on Luna's intelligent sensor. The intelligent sensor measures the linear polarization resistance by sacrificing interdigital electrodes, so as to measure the instantaneous corrosion rate of materials. According to the requirements of aircraft impact monitoring, Qiu [7] proposed a system for aircraft impact monitoring, which uses 32 piezoelectric sensors distributed on the aircraft surface to monitor the impact position. Also, Qiu [8] et al. developed a stretchable large-scale guided wave sensor network that can be applied to active and passive guided wave-based health monitoring of composite structures, including damage imaging and impact imaging.

Although the conventional wireless sensor can achieve the health monitoring of the aircraft corresponding parts, the it will face a more complex environment in the flight process. A single monitoring parameter is difficult to reflect the actual health status of the aircraft, so it is particularly important to realize the multi parameter monitoring of the aircraft in service [9-12]. Nyulászi et al.

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[13] designed a fault monitoring system using multi-sensor network, which can mainly monitor parameters such as combustion chamber temperature, engine nozzle temperature, intake pressure and fuel pressure. Hall et al. [14] studied a multi parameter WSN node, which can obtain environmental parameters such as particle concentration, temperature, humidity and air pressure in the engine room in real time. Zhang et al. [15] designed an aircraft condition monitoring node based on ZigBee WSN and proved through experiments that the node has the monitoring functions of vibration, temperature, humidity and light intensity.

In this paper, a wireless multi-parameter monitoring device for aircraft is reported. The device adopts PZT array to realize random impact monitoring and positioning, and can reliably monitor vibration, temperature, humidity and air pressure through multiple connected digital sensors.

Digital Monitoring Method

In order to realize structural impact monitoring and the impact region location, the reported device adopted a digital sequence feature identification method based on a characteristic parameter. During impact monitoring, the characteristic parameter from each sensor can be calculated respectively, and then the regional characteristic parameter of the four sensors constituting the impact monitoring sub region can be calculated. The region with the largest regional characteristic parameter is the impact occurrence region. The specific method for positioning the impact region is as follows:

(1) Calculate the characteristic parameter of the digitized signal by each piezoelectric sensor, as shown in Eq 1. Where r is the serial number of the piezoelectric sensor, s is the length of the digital sequence of each sensor, j is the serial number of the sampling point, and W_j is the digital level value corresponding to the *j-th* point in the sampling point, which is 1 or 0.

$$\sum_{j=1}^{s}[(S+1-j)\times W_j] \tag{1}$$

(2) Calculate the regional characteristic parameters for each impact monitoring sub region by summing the characteristic parameters of the four piezoelectric sensors that make up the impact monitoring sub region.

(3) Calculate the serial number of impact monitoring sub region with the largest regional characteristic parameters, which is the region where the impact occurs.

For the digital sensor encapsulated into a chip, the sensing unit and conditioning unit are integrated inside, which can convert environmental parameters into electrical signals. In order to realize the data transmission between the sensor and the microcontroller, the sensor also integrates digital interfaces, including Inter-Integrated Circuit (I2C) and Serial Peripheral Interface (SPI).

Implementation of Multi-Parameter Monitoring Device

The multi parameter monitoring device includes four parts: digital piezoelectric impact monitoring unit, digital sensor state environment monitoring unit, core control unit and wireless communication unit. Piezoelectric sensor is used for impact monitoring, and digital monitoring unit is designed for the analog signal of piezoelectric impact, which is processed in the digital circuit after A/D conversion. The core control unit of the monitoring system is designed to control the working state of the system and calculate, store and convey the collected sensor data. After collecting and processing sensor data, each node in the sensor network transmits the data to the communication base station through wireless communication. Fig 1 shows the architecture of the multi-parameter monitoring device.

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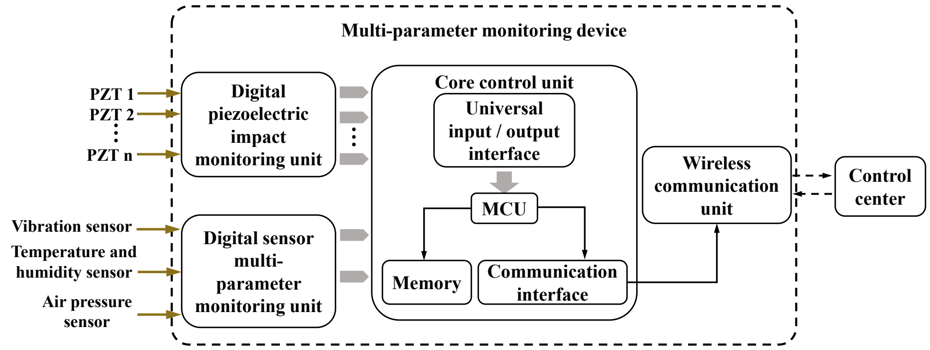

Fig 1 Overall architecture of multi-parameter monitoring device

The impact monitoring adopts piezoelectric sensor, and the direct output is analog signal. A voltage limiting circuit based on Zener diode is designed. Each Zener diode corresponds to a PZT. After digital processing based on Zener diode and TTL level standard, the piezoelectric signal is collected through the General-Purpose Input-Output (GPIO) interface of microprocessor. Based on the different time required for vibration propagation to different piezoelectric sensors, the reverse weighted sum algorithm is used to locate the impact region.

Vibration, temperature, humidity and air pressure parameters are collected by digital MEMS sensors. According to the monitoring requirements, this paper selects three sensors namely BMA250 sensor with triaxial vibration sensing function, BMP280 sensor with temperature and air pressure sensing function and SHT30 sensor with temperature and humidity sensing function.

The microprocessor sets the parameters of the digital sensor through the Inter-Integrated Circuit (I2C) communication interface, reads the sensing data stored in the sensor register, and then calibrates and calculates the data to obtain the structural vibration and temperature and humidity parameters.

In addition, after acquiring the state parameters of the aircraft structure and environment, the device first stores the data in the internal memory, and then uploads the data through the upper computer control when the user needs it. The data is transmitted between the microcontroller and the upper computer through wireless communication. And ZigBee is adopted as the wireless communication mode.

The multi-parameter monitoring device consists of two PCB layers and a wireless communication unit. One PCB layer mainly integrates the core control unit, and the other layer integrates the digital piezoelectric impact monitoring unit, digital sensor multi-parameter monitoring unit, power management circuit, sensor interface, power interface, etc. They are connected by row pins and fixed with screws.

Monitoring function verification

In order to verify the impact monitoring function of multi-parameter monitoring system, a test system as shown in Fig 2 is built, 400×400mm aluminum plate is the test piece, and its surface is pasted with 3×3 piezoelectric sensors array, with sensor spacing of 100mm, forming four impact monitoring sub regions, and all sensors are connected to the interface of the monitoring system in turn. After collecting the impact data and calculating the signal characteristic value, the system uploads the data to the computer through wireless communication.

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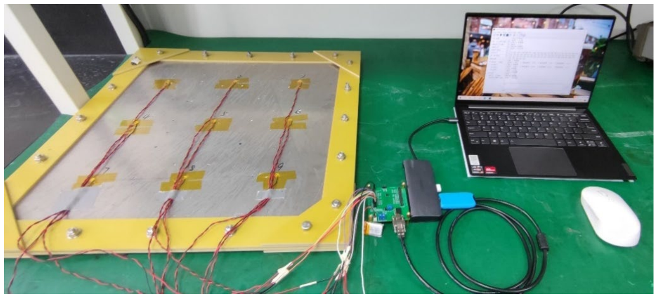
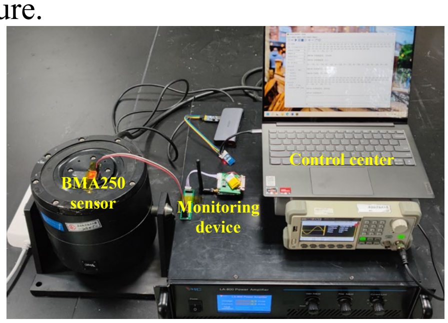


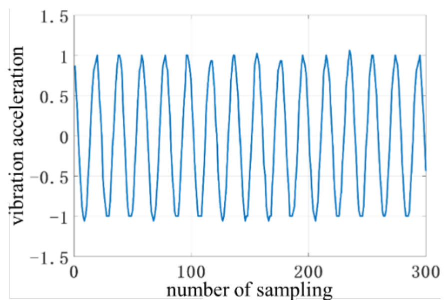
Fig 2 Impact monitoring test system

Fifty impacts were carried out in different regions of the aluminum plate specimen, of which 47 were precisely located, with a positioning accuracy of 94%. Therefore, through the impact digital sequence, the characteristic parameter of piezoelectric sensors and the regional characteristic parameter test results, it is proved that the multi-parameter monitoring system can effectively realize impact monitoring.

In addition, verification experiments have been conducted for in-service environmental monitoring. Fig 3(a) illustrates the experimental setup for the vibration monitoring validation of the multi-parameter monitoring device. Fig 3(b) shows the vibration acceleration data collected by the digital vibration sensor under 50 Hz sinusoidal vibration, and it can be seen that the test data has good periodicity, which can reflect the actual vibration state and vibration intensity of the structure.



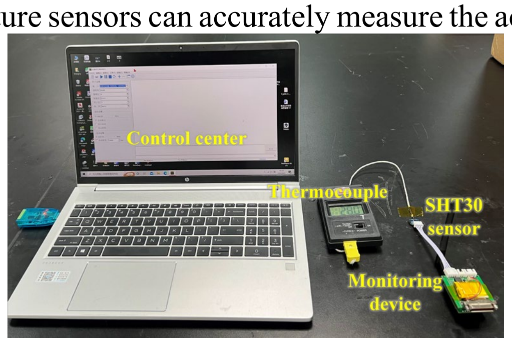
(a) Monitoring test settings



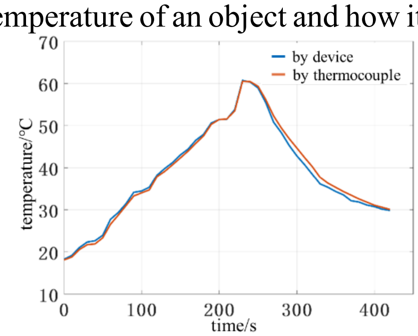
(b) Test result

Fig 3 Vibration monitoring test

Fig 4(a) shows the physical diagram of the temperature monitoring test, using thermocouples as a reference during the test. The output temperature data was recorded during the heating of them with a heat gun and their cooling, and the test results are shown in Fig 4(b). It is clear that digital temperature sensors can accurately measure the actual temperature of an object and how it changes.



(a) Monitoring test settings



(b) Test result

Fig 4 Temperature monitoring test

Since the ambient humidity and air pressure are difficult to control, the experiments were conducted to verify the multiparameter monitoring function of the device by using digital sensors

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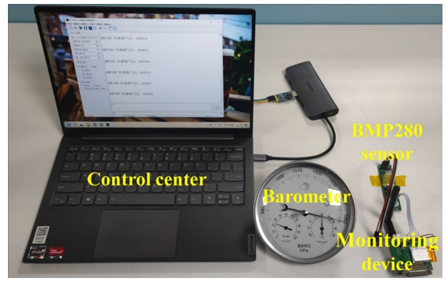
to measure the humidity and air pressure values at a certain moment and comparing them with traditional sensors. Fig 5 shows the physical diagram of humidity monitoring test and air pressure monitoring test.

(a) Humidity monitoring test



(b) Air pressure monitoring test

Fig 5 Multi-parameter monitoring test

The humidity of the environment is about 23.5% RH obtained from the hygrometer in the experiment, and the humidity data collected from the SHT30 sensor in the control center is 23.15% RH, which shows that the multi-parameter monitoring device can accurately monitor the humidity parameters.

Also in the experiment, the pressure of the environment is about 105120Pa obtained through the barometer, and the air pressure data collected by the control center from the BMP280 sensor is 104917Pa, which shows that the multiparameter monitoring device can accurately monitor the air pressure parameters.

Conclusion

A wireless multiparameter monitoring device is reported in this paper. The device is capable of converting analog signals from PZT sensor arrays to digital signals, and adopts a impact monitoring and positioning method based on the inverse weighted sum and a digital sensor environment monitoring method based on the I2C bus, which can realize the monitoring of multiple parameters such as impact, vibration, temperature and humidity of the vehicle structure. In addition, the functional verification experiments of the multiparameter monitoring equipment were carried out. For the impact monitoring verification, the equipment showed good monitoring positioning accuracy under multiple impacts. Moreover, the verification experiments for vibration, temperature, humidity and air pressure monitoring were carried out to verify the capability of the device for multi-sensor monitoring by comparing with conventional sensors.

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