Design of Bridge Monitoring System Based on Cloud Platform

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Abstract. Aiming at the safety monitoring requirements in the daily operation of bridges, a bridge monitoring system based on the cloud platform is proposed. The system is divided into two subsystems: the hardware monitoring system and the software monitoring system. The hardware monitoring system uses the single-chip microcomputer STM32 to connect multiple wireless sensors to collect the information around the target bridge and transmit it in real time to the IOT platform of Alibaba Cloud through the 4G module via the MQTT protocol. The software monitoring system retrieves the real-time data from the Alibaba Cloud platform to the web page end for real-time display via the AMPQ protocol. The software system predicts the inclination degree of the bridge through real-time information. Thus, it effectively overcomes problems such as great difficulty in real-time monitoring, high cost, and difficulty in carrying out maintenance work of the existing traditional bridge monitoring systems. Experiments show that through actual application and testing, this monitoring system can meet the design requirements and effectively solve problems such as too long a cycle and low monitoring efficiency in the existing bridge monitoring technologies. It has the characteristics of high real-time performance, low cost, small equipment volume, and strong system adaptability.

Keywords: bridge monitoring; Wireless sensors; Internet of Things platform; MQTT protocol

1 Introduction

Traditional bridge monitoring technologies often opt for wired methods, but these approaches encounter issues such as complex wiring, high costs, and significant difficulties in carrying out maintenance work during actual implementation. In recent years, wireless sensor networks [1-2] have been widely applied in the fields of structural monitoring, smart homes, environmental monitoring, and more. Wireless monitoring technology effectively overcomes the various drawbacks of traditional monitoring methods, offering distinct advantages in terms of equipment miniaturization, low operational costs, and technological intelligence, and it possesses tremendous potential for devel-

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opment [3]. Hoult NA and colleagues deployed a bridge temperature and humidity monitoring system, designed by their team, on the Humber Bridge. They distributed 11 temperature and humidity data collection nodes in the east and west chambers of the bridge's north anchorage, monitoring the real-time temperature and humidity data as well as changes at a sampling frequency below 1Hz [4]. Lynch JP deployed the bridge monitoring system, which was developed by their team, on Geumdan Bridge in South Korea, to systematically monitor the bridge's vibrational response under the load applied by trucks [9]. The design of a wireless sensor bridge monitoring system that is highly precise, real-time, and predictable has become a hot topic in the field of bridge monitoring research. This system incorporates deep learning techniques into bridge health monitoring, combining data on the temperature, humidity, and wind speed surrounding the bridge with the characteristics of inclination changes. Ultimately, it effectively determines the degree of bridge inclination and displays this information in real time on the monitoring system's web interface.

2 Overall Architecture of the Monitoring System

The system in this article consists of two parts: a hardware monitoring system and a software monitoring system. The hardware monitoring system integrates multi-mode sensors, an STM32F411CEU6 microcontroller, and a 4G transmission module; The software monitoring system includes the Alibaba Cloud platform, web deployment, database design, and functional design. The functions include user login, real-time data display, data download and query, and bridge tilt prediction. The real-time measurement data of the hardware monitoring system is transmitted to Alibaba Cloud's IOT platform through the MQTT protocol via the 4G module, and the software monitoring system transmits the data of the IOT platform to the web end through the AMQP protocol, building a complete bridge monitoring system, The overall architecture of the system is shown in Figure 1.

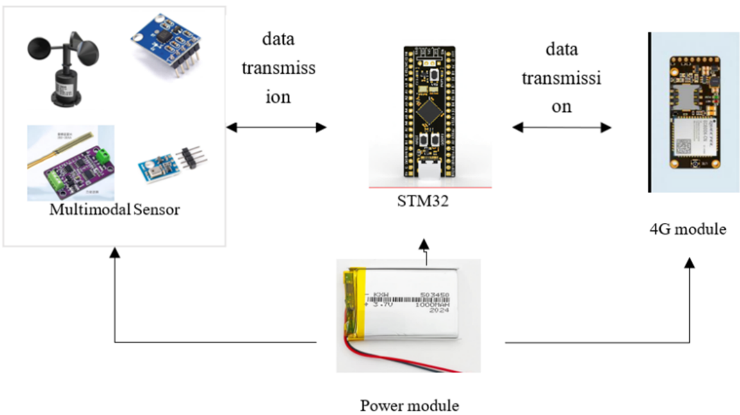


Fig. 1. Overall system architecture

3 Hardware Monitoring System Design

The hardware monitoring system consists of an ADXL tilt sensor, AHT10 temperature/humidity sensor, strain sensor, wind speed sensor, STM32 microcontroller, 4G communication module, and power module. The power module supplies power, and the multi-sensor module starts working. Real-time information from the bridge is collected and transmitted to the STM32 microcontroller, which converts digital signals into digital data. The data is stored in external SRAM through DMA and then sent to the 4G communication module through the UART serial acquisition circuit. It is then sent to Alibaba Cloud's IoT platform via the 4G public network. Figure 2 shows the framework diagram of the hardware monitoring system.

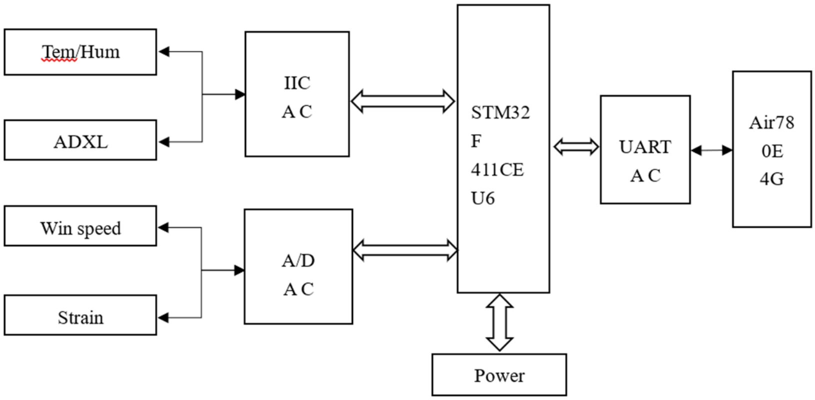


Fig. 2. Block diagram of hardware monitoring system

3.1 Multimode Sensor Module

The ADXL tilt sensor is capable of measuring acceleration within a minimum ± 3 g full-scale range. It can measure static gravity acceleration in tilt detection applications, as well as dynamic acceleration caused by motion, impact, or vibration [5-6]. SCL is connected to the B10 serial port of the STM32 microcontroller, SDA is connected to the B3 serial port of the microcontroller, and SDO is connected to the power module.

The strain sensor is a BF350 foil strain gauge, The output voltage of the single arm bridge of the strain gauge is UL$=\frac{UEk\varepsilon}{4}$ [7]. The OUT of the sensor is connected to the A6 serial port of the microcontroller STM32, and the VCC is connected to the power module.

The temperature and humidity sensor adopts the AHT10 temperature and humidity sensor, with a power supply range of 1.8-3.6V. VDD is connected to the power module, and SDA and SCL are connected to the A8 and A9 serial ports of the microcontroller to complete data transmission.

Wind speed sensors, with a range of 0–60 m/s (default 0–30 m/s), and a resolution of 0.1m/s, can be used for both four-wire and three-wire connection methods. The green wire is connected to the positive terminal of the system, the brown wire is connected to the acquisition terminal, and the black wire is connected to the negative terminal of the system.

3.2 Data Processing Module

The hardware selection for data processing uses the STM32F411CEU6 microcontroller, which reserves Flash pads to meet the needs of big data storage and micro Python. It provides USB Disk&&FATFS routines, supports Micro Python programming, provides available Micro Python firmware, and supports Arduino programming. It has 3 pins USART for connecting with 4G communication modules and 2 pins full duplex IIC for connecting with temperature and humidity sensors and tilt sensors.

3.3 4G Communication Module

The 4G communication module uses the Air780E communication module from Shanghai Hezhou Company, which has three power consumption modes: normal mode, low-power mode, and PSM+mode [8-9]. Connect to the A2 and A3 serial ports of the STM32 microcontroller through UART to complete the data transmission function. This module supports the MQTT protocol and is connected to Alibaba Cloud's IoT platform through the MQTT protocol.

3.4 Power Module

In practical applications, due to the prominent power consumption of the 4G communication module during operation, for the system to achieve a longer battery life, the module is composed of a HU9196 charging module (including type-c interface) and an 18650 lithium battery (3.7V, 2.6Ah). The charging module can effectively charge the lithium battery while cooperating with the lithium battery to supply power to the hardware monitoring system. Figure 3 shows the system's physical diagram.

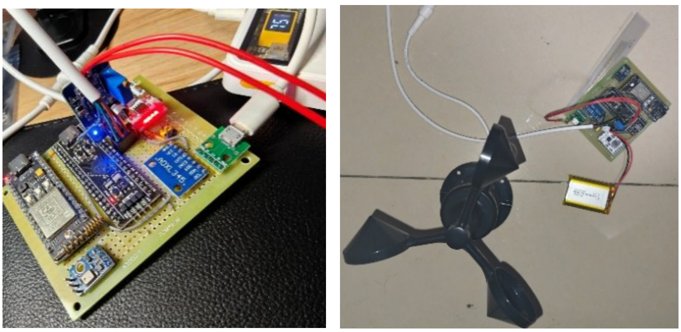


Fig. 3. The System physical diagram

4 Bridge Tilt Prediction Methods

Convolutional neural networks are currently one of the most widely used artificial neural networks, with excellent nonlinear mapping ability, self-learning ability, and fault tolerance. It is the core part of the feedforward neural network [10-11]. Mainly used in pattern recognition, function approximation, data compression, prediction estimation, and classification. This article uses single-layer linear regression to predict bridge deflection. The basic formula of the regression model is:

$$y\hat{}=\beta 0+\beta 1x1+\beta 2x2+\cdots+\beta nxn$$

Among them, y ^ is the predicted value (in this case, the inclination angle of the bridge). β 0 is the intercept. β 1, β 2,..., β n are regression coefficients corresponding to features x1, x2,..., xn, respectively. X1, x2,..., xn are input features (in this system, wind speed and temperature). In the running code of this system, the prediction model is trained using the model. fit (X_train, y_train), where X_train is the feature matrix of the training data (including wind speed and temperature), and y_train is the corresponding target variable (the inclination angle of the bridge). The training process will find the optimal β 0, β 1, β 2 (in this case, there are only two features, so there are only two regression coefficients β 1 and β 2, corresponding to wind speed and temperature). When the web end of the software monitoring system sends new wind speed and temperature data through POST requests, these data will be used to create a new Data Frame, which will then be predicted using the model. redist (input_data). Index.html, retrieve interface data through Python API link, and then render it to the display interface. The data processing is shown in Figure 4.

```
</div>
<!-- <li class="PopUp"><span></span></li> -->
<img class="Angle_BridgeImage" src="../src/images/WuHanBridge-Photoroom.png" />
<div class="RealAngle">
    RealAngle:<span class="Angle_Number">5</span>° <br />
    Pre Angel:<span class="Predict_Angle_Number">5</span>°
```

Fig. 4. Data processing diagram

5 Design of Software Monitoring System

The software monitoring system adopts a typical modern web application development technology architecture, covering both front-end and back-end technology stacks.

HTML is used to define the specific content of the system, CSS is used for the layout and style design of web pages, JavaScript is used for the dynamic interaction function of web pages, Axios is used for data interaction with the backend, and Webpack is used for packaging and optimizing frontend resources. Node.js provides a high-performance runtime environment for the entire system, Express is used to build web services, Mongoose and MongoDB are used for data storage and management, and Alibaba Cloud

IoT platform and AMQP are used to achieve message communication between IoT devices and backend systems. The Alibaba Cloud IoT platform and AMQP are used to achieve message communication between IoT devices and backend systems.

5.1 User Login Management

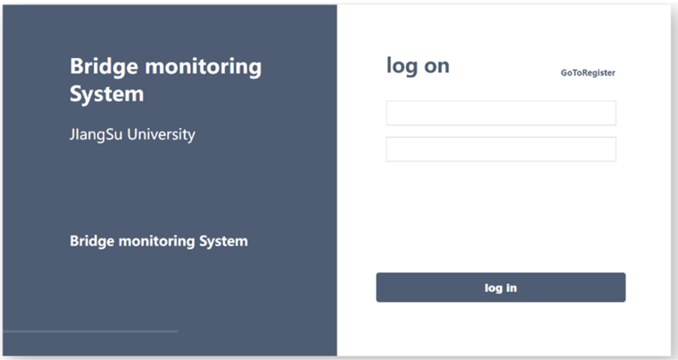
On the login page, the functions of user login management and new user registration can be completed. The user login management function of this system is implemented using the Flask Login framework. The essence of the Flask Login framework is to set up and run this function based on sessions because sessions usually have a long time limit during system operation. Therefore, Flask Login will accurately record the session data information of logged-in users within the expiration time set by the system.

5.2 Real Time Display of Data

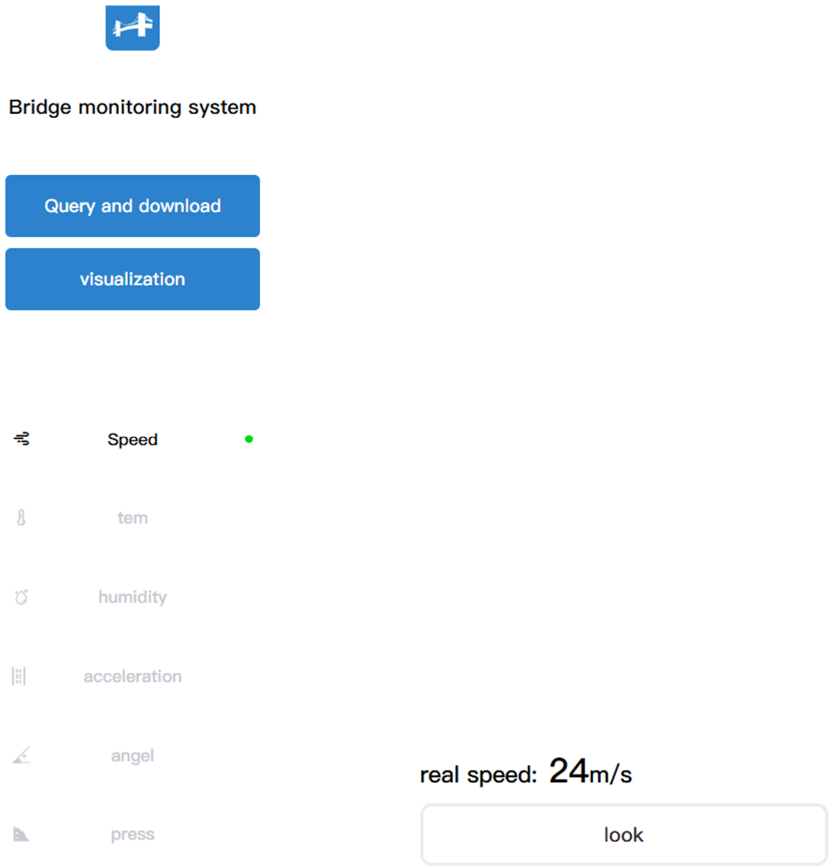
The real-time data display page is set to display in the form of a line chart and an overall large screen display. In practice, due to the intermittency of data collection and transmission, there may be a certain time deviation in data display (which can be reduced by setting the interval between hardware monitoring system collection and upload). The chart display is a line chart created using Echarts [12], and the data used to create the chart is obtained through requests from Axios to the server and Node.js.

5.3 Data Query and Download

The data query here is also obtained through Axios requesting from the server and Node.js. The time selection control uses Bootstrap's time component "daterangepicker", and is also designed with queries for default and custom time periods. The line chart under this module is also created using Echarts, and the data table is created using the Bootstrap table plugin in Bootstrap. The file was downloaded using Excel data download mode Figure 5 shows the Login interface(a) and the main system interface(b).



(a)

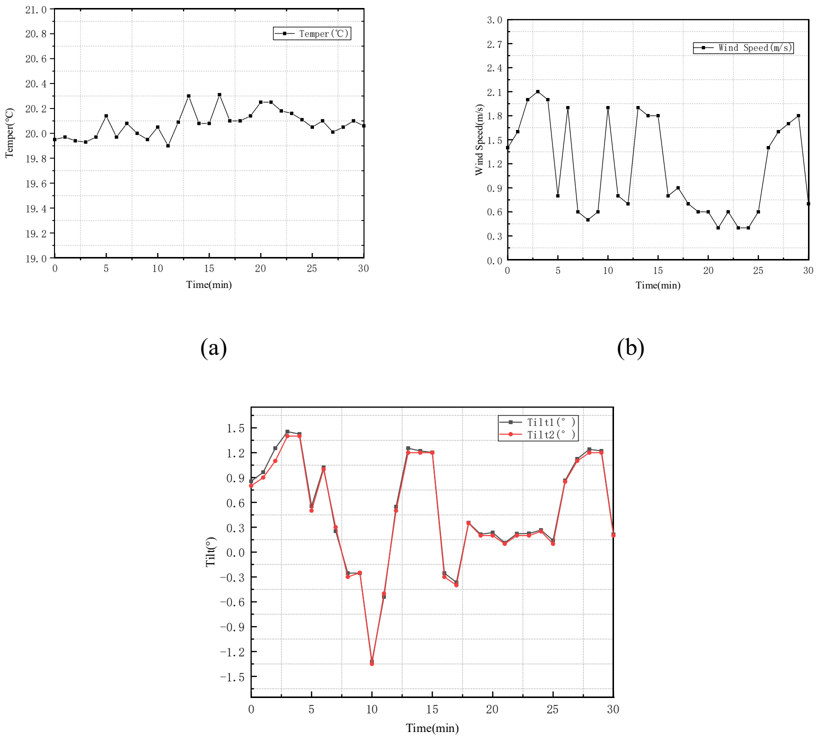


(b)

Fig. 5. Software system diagram

6 Test Results and Analysis

The bridge monitoring system is closely related to practical engineering applications and facilitates the deployment of hardware monitoring systems. The designed hardware monitoring system was used for functional verification on a simulated bridge. During on-site testing, the hardware monitoring system was installed on the bridge deck and the collection time was 30 minutes. The measured data are shown in Figure 6, which includes real-time temperature data, wind speed data, as well as actual inclination (Tilt1) and predicted inclination (Tilt2).



(c)

Fig. 6. Real time data graph

7 Conclusions

This article studies and designs a bridge monitoring system based on a cloud platform. The system consists of multiple sensors, an STM32F411 microcontroller, 4G module, Alibaba Cloud's IoT platform, and the entire software monitoring system. The hardware monitoring system can measure the surrounding information of the bridge in real time and upload the information processing through MQTT protocol to Alibaba Cloud's IoT platform. The software monitoring system retrieves real-time information from Alibaba Cloud's IoT platform through AMQP protocol and displays various functional modules on the web end. After experimental testing, the entire bridge monitoring system has stable and reliable performance, meeting the design requirements.

References

1. AKYILDIZ I F, SUW, SANKARASUBRAMANIAM Y, etal. A survey on sensor networks [J]. IEEE Communications Magazine, 2002, 40(8): 102-114.
2. YICK J, MUKHERJEE B, GHOSAL D. Wireless sensor network survey [J]. Computer Networks, 2008, 52(12): 2292-2330.
3. KIM S, PAKZAD S, CULLERD, et al. Wireless sensor networks for structural health monitoring [D]. Berkeley: UC Berkeley, 2005.
4. HOULT NA, FIDLERPRA, WASSELL I J, et al. Wireless structural health monitoring at the Humber Bridge UK [J]. Bridge Engineering, 2008, 161(4): 189 - 195.
5. Li Jian, Yao Jin jie, Han Yan. Design of an Omnidirectional Vibration Detection Sensor [J]. Journal of Testing Technology, 2014, 28 (1): 64-68
6. Sun Jie. Design and Research of Detection Circuit for Capacitive Acceleration Sensor [D]. Shanghai: Fudan University, 2013
7. Xu Qiang, Sun Lu, Li Jianqing, et al. Design of a ZigBee based multi-channel multi-point wireless bridge strain monitoring system [J]. Sensors and Microsystems, 2020, 39 (6): 79-82
8. Li Haiyuan. Design and Implementation of Indoor Environment Monitoring System Based on Cortex A9 Processor [D]. Xi'an University of Petroleum, 2020. DOI:10.27400/d.cnki.gxasc.2020.000031
9. Zhang Han Development of a Water Meter Reading Remote Transmission System Based on Open CPU Architecture [D] Linyi University, 2024. DOI: 10.442522/d.cnki.glydx.2024.000129
10. Wang Yong, Zhou Huiyi, Feng Hao, et al. Network traffic classification method based on deep convolutional neural network [J]. Journal of Communications, 2018, 39 (1): 14-23
11. Wen Yuanmei, Yu Tingsong, Ling Yongquan. Method for determining the number of convolutional kernels based on edge detection [J]. Computer Application Research 2018, 35 (11): 3454-3457
12. Zhang Xiaokun Design and Application Research of Solar Energy Utilization Monitoring System Based on Cloud Platform [D] Beijing Jianzhu University, 2021. DOI:10.26943/d.cnki.gbjzc.2021.000048