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Online Monitoring System of Pole Tower Cloud Platform Based on Kalman Filter

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ABSTRACT

A novel Kalman filter sensor-based online monitoring system for pole and tower cloud platform is proposed. The hardware design uses STM32F103C8T6 as the controller, the gyroscope module with MPU6050 chip as the sensor and SX1278 series Lora module as the communication module to transmit the collected information to the built cloud platform through the gateway to realize the real-time monitoring of the tilt angle of the tower. The experimental comparison shows that the sensor equipped with the Kalman filter has high accuracy of output data. Its installation and fixing method are simple and low cost. It can be seen that if this product is widely promoted, the recovered loss will be enough to offset the cost, and with the accumulation of time, the recovered loss will be much more than the cost and will bring inestimable economic benefits.

1. Introduction

With the improvement of China's comprehensive national power, people's requirements for living and production level are also improved accordingly. In recent years, there are countless examples of high-voltage towers tilting and causing huge losses, which makes tower tilt monitoring an urgent requirement, and the stability of the gyroscope sensor itself has an important impact on the accuracy of the whole monitoring system [1]. High voltage transmission lines are an important part of China's economic development and construction, and transmissi-on line poles are particularly important structures on high-voltage transmission lines. High-voltage towers have a high center of gravity and a small bottom area, so they are prone to skewing. The main damage phenomena are tower skewing, movement, and consequent distance from the conductor other phenomena such as the safety distance of the ground and the change of the wire tension [2]. And the movement and deformation of the pole tower is limited by the bottom and high voltage lines [3]. Power pylons are the infrastructure of high-voltage overhead transmission lines. Tilt monitoring of power towers to ensure the safety of the line in the power line work, protection has important significance [4]. Power pylons are special, high towers are difficult to climb and the shape of the tower is not uniform, so the tilt measurement of power pylons must take appropriate methods according to the site conditions [5]. At present, the national grid is promoting the "shared tower", that is, to add mobile antennas and other communication equipment on the power tower, the communication equipment will be installed on the transmission line, so that the power line resources are reused. This will play a strong role in promoting the future tilt detection of towers linked to the network. At present, the methods used for ground detection of tilt measurement of power towers mainly include plumb method [6], latitude and longitude meter method, plane mirror method, etc. But all have certain limitations.

Now we propose a new online monitoring system based on Kalman filter for pole tower cloud platform, which is mainly composed of 4 parts: gyroscope sensor, STM32 microcontroller, network transmission, and upper computer or cloud platform. The device is small in size, high in accuracy, and has a built-in polymer lithium battery. The system can be monitored remotely in real time, overcoming the problems of traditional inspection.

2. System solution design

The acceleration is measured using accelerometers [6]. The gyroscope uses the Coriolis force principle to detect the angular velocity [7]. The magnetic field vector value is measured using a three-axis electronic compass IC. The attitude angle is solved, and the tilt angle of the pole tower is obtained by data fusion with the Kalman filter algorithm, and the remote monitoring of the pole tower is realized through a wireless communication system [8].

The tower tilt monitoring system consists of motion sensor module MPU6050 and STM8S003 and processor STM32F103C8T6 microcontroller, wireless communication module SX1278, the collected information will be transmitted to STM32F103CT86

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microcontroller, in the microcontroller internal state estimation, dynamics decoding, digital filtering, Kalman filtering of data, the microcontroller to solve the data, the use of wireless serial communication module to upload data to the host computer, the system model is shown in Figure 1.

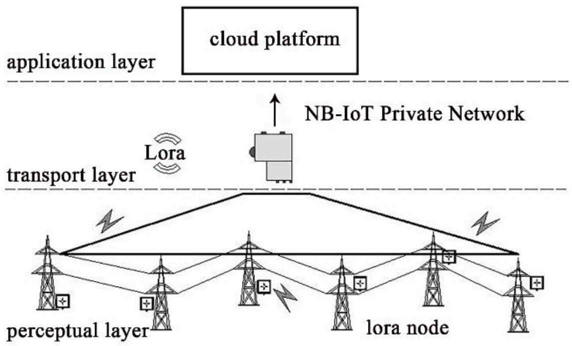

Fig. 1 Tower cloud platform monitoring system model

3. System solution design

3.1 Core processor module

The STM32F103xx enhanced family uses a high-performance ARM Cortex-M3 core operating at 72 MHz, with built-in high-speed memory (up to 128K bytes of Flash and 20K bytes of SRAM), a rich set of enhanced I/O ports and peripherals connected to two APB buses. All models include two 12-bit ADCs, three general-purpose 16-bit timers and a PWM timer, as well as standard and advanced communication interfaces: up to two 12C and SPI, three USARTs, a USB and a CAN. 3.6V, with a range of electrical modes to ensure low-power application requirements. The complete STM32F103xx Enhanced family consists of five different packages ranging from 36 to 100 pins: depending on the package, the peripherals in the device are configured differently. A basic description of all the peripherals in the family is given below. These rich peripheral configurations make the STM32F103xx enhanced microcontrollers suitable for a wide range of applications.

Two communication interfaces are reserved in advance, serial port 1 for wireless communication and serial port 2 for the angle acquisition module. The BOOT can provide three boot modes for the microcontroller, user memory, ISP download mode, internal RAM, and is drawn on a double-layer PCB, Figure 2 shows the PCB diagram of the physical microcontroller circuit.

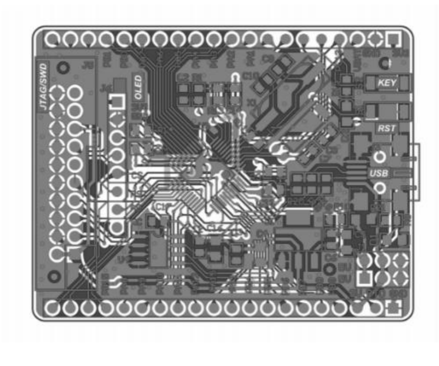

Fig. 2 The PCB circuit

3.2 Attitude sensor module

The system sensor module is selected from MPU6050, STM8S003. MPU6050 is an inertial measurement unit (IMU) composed with advanced 3-axis low gravity acceleration sensor and 3-axis gyroscope sensor; STM8S003 is an 8-bit STM microcontroller for transmitting the data collected by gyroscope [9], which applies high-sensitivity Hall sensor technology internally, ultra-compact The STM8S003 is an 8-bit STM microcontroller for transmitting the gyroscope collected data [9], which applies a high-sensitivity Hall sensor technology internally and an integrated magnetic sensor in an ultra-compact package for detecting the geomagnetic X-axis, Y-axis and Z-axis.

3.3 Wireless module

The wireless module is based on the SX1278 type LoRa module, which is a 433MHz E32-433T20DC module with small size, high sensitivity, and low power consumption. The communication distance is about 3000 m, and the module can be configured with 65536 addresses (for easy networking to support broadcast and directional transmission). The operating temperature of the module is -40 to +85 ℃. The module has a built-in watchdog, which never dies and ensures long-term working stability. NB-IoT adopts BC95 module from Shanghai Mobile Yuan and uses NB-IoT private network to report data.

4. Network transmission

4.1 Network topology

The reasonable choice of topology is directly related to the performance of the whole network. The topology of a wireless sensor network is usually selected by the communication characteristics of the sensor network and the working environment of the equipment. The network topology can be simply understood as a network connection diagram that hides the specific shape of the device terminals, abstracts them as points, and physically interconnects them by wired or wireless means [10]. The common topologies in wireless sensor networks are star, tree and mesh. This project adopts the star topology with simple networking and low latency and connects each terminal collection node to the central node directly to form a LoRa wireless network structure [11].

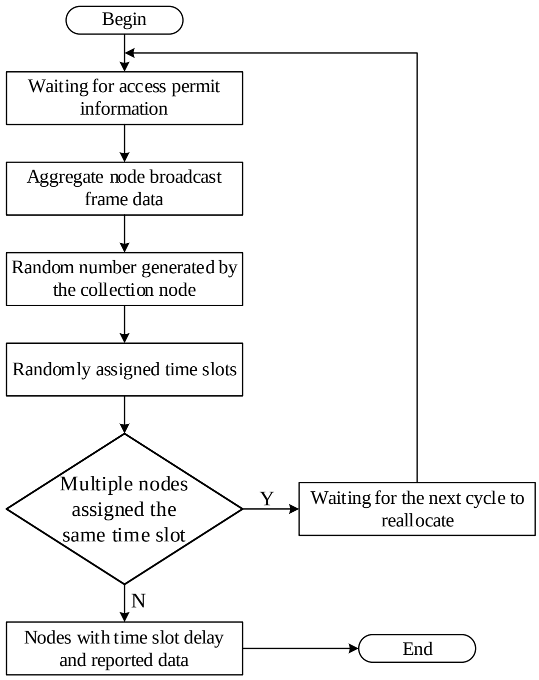

Fig. 3 Anti-collision algorithm flow chart

4.2 Node data anti-collision algorithm

For monitoring the towers in wide area, the possible collision problem of data is analyzed. Data collision can be effectively prevented by using time division multiplexing (TDMA), code division multiplexing (CDMA) or frequency division multiplexing (FDMA), etc [12]. Through the analysis, the system refers to the ALOHA algorithm logic based on collision probability and time division multiplexing. As shown in Figure 3.

5. Gyroscopic attitude angle solving

The relationship between the Euler angle carrier coordinate system and the ground coordinate system reflects the attitude of the carrier relative to the ground with three Euler angles [10], which are the heading angle, roll angle, and pitch angle, as shown in Fig. 4. The roll angle Φ is the angle between the Z-axis of the carrier coordinate system and the plumb plane passing through the X-axis of the carrier, and the roll angle θ is positive when the carrier rolls to the right and negative vice versa. The pitch angle Φ is the angle between the axis of the carrier coordinate system and the horizontal plane. When the positive half-axis of X-axis is below the horizontal plane passing through the origin, the pitch angle is negative, otherwise it is positive. The heading angle φ is the angle between the projection of the X-axis of the carrier coordinate system on the horizontal plane X_g and the X-axis of the ground coordinate system, and it is assumed that the angle is positive when the projection of the carrier is turned counterclockwise by the axis X_b, that is, the carrier yaws to the left as positive, otherwise it is negative. The relationship between the geographic coordinate system $X_gY_gZ_g$ and the carrier coordinate system $X_bY_bZ_b$, after the carrier motion, is:

$$\begin{bmatrix} X_g \\ Y_g \\ Z_g \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} X_b \\ Y_b \\ Z_b \end{bmatrix} \tag{1}$$

The matrix in the middle is called the coordinate rotation matrix of the Z-axis. With the rotation matrix around the Z-axis, the coordinate rotation matrices around the X-axis and Y-axis can be derived as follows.

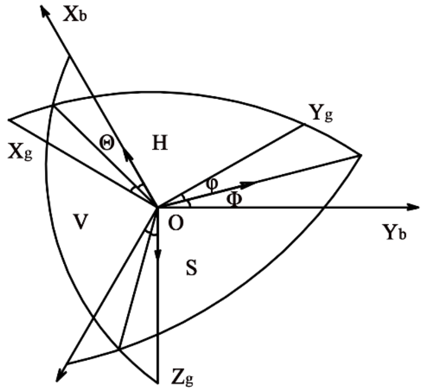

Fig. 4 Eulerian angle carrier coordinate system

The rotation matrix of the coordinates rotated around the X-axis is:

$$C_0^1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \tag{2}$$

The coordinate rotation matrix for the rotation around the Y-axis is:

$$C_1^2 = \begin{bmatrix} \cos\varphi & 0 & -\sin\varphi \\ 0 & 1 & 0 \\ \sin\varphi & 0 & \cos\varphi \end{bmatrix} \tag{3}$$

The coordinate rotation matrix for the rotation around the Z-axis is:

$$C_2^3 = \begin{bmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

The following is a synthetic superposition of the three rotation matrices. The total correspondence of the coordinate transformations is obtained.

$$C_g^b = \begin{bmatrix} \cos\varphi\cdot\cos\phi + \sin\varphi\cdot\sin\phi\cdot\sin\theta & \sin\varphi\cdot\cos\phi\cdot\sin\theta - \cos\varphi\cdot\sin\phi & -\sin\varphi\cdot\cos\theta \\ \sin\phi\cdot\cos\theta & \cos\phi\cdot\cos\theta & \sin\theta \\ \sin\varphi\cdot\cos\phi - \cos\varphi\cdot\sin\phi\cdot\sin\theta & -\sin\varphi\cdot\sin\phi - \cos\varphi\cdot\cos\phi\cdot\sin\theta & \cos\varphi\cdot\cos\theta \end{bmatrix} \tag{5}$$

It is the coordinate rotation matrix from coordinate system g to coordinate system b. This matrix, in its entirety, describes the transformation of the point P of the g system to the point P' of the b system, and the correspondence between the points of the two different coordinate systems. The result of this matrix is called the "direction cosine matrix", or "rotation matrix". With this matrix, the object can be completely rotated to the new attitude.

6. Traceless Kalman filtering algorithm

The model equations of the gyroscope in this paper are constructed based on the implementation process of Kalman filtering, using the last optimal result to predict the current value, i.e., a priori estimation, and then using the observed value to correct the current value to obtain the optimal result. For a discrete control system the state space expression is.

$$\begin{cases} x(k) = Ax(k-1) + Bu(k) \\ z(k) = Hx(k) + v(k) \end{cases} \tag{6}$$

From the a priori estimating equation.

$$x(k \mid k-1) = Ax(k \mid k-1) + Bu(k) + w(k) \tag{7}$$

where $x(k \mid k-1)$ is the current forecast of the best estimate at the previous moment. $x(k-1 \mid k-1)$ is the optimal result of the moment. A is the state transfer matrix and B is the input matrix. $u(k)$ is the state input quantity. $w(k)$ is process noise.

The model equation to predict the current angle value is obtained.

$$angle_i = angle_{i-1} - Q_{bias} \cdot dt + Gyro_{new} \cdot dt \quad (8)$$

$angle_i$ is the current angle value. Q is the noise induced bias. $Gyro$ is the angular value measured by the accelerometer.

The error covariance equation is.

$$P(k \mid k-1) = AP(k-1 \mid k-1)A^T + Q \quad (9)$$

$P(k)$ is the predicted covariance matrix. Calculating the Kalman filter gain, the Kalman gain coefficient equation is.

$$K(k) = P(k \mid k-1)H^T \left[HP(k \mid k-1)H^T + R \right]^{-1} \quad (10)$$

The optimal estimate obtained is.

$$x(k \mid k) = x(k \mid k-1) + K(k)\left[Z(k) - Hx(k \mid k-1) \right] \quad (11)$$

Update the error covariance matrix.

$$P(k \mid k) = \left[I - K_g(k)H \right] P(k \mid k-1) \quad (12)$$

Prepare the next iteration of the calculation.

7. Uplink/Cloud platform development

This design is the upper computer design of the pole tower cloud platform monitoring system, which contains the following aspects: Configuration King human-machine interface, data processing module, interface conversion circuit, voice communication module five parts.

(1) Configuration King HMI: The objects such as form, command button, text box and selection box are organically combined according to the user's needs. Through communication with the underlying microcontroller, Configuration King accesses the relevant device registers to obtain the operation of each device, and displays them through animation connections, etc.

(2) Data processing module: Real-time data in the system is collected and converted by the microcontroller and shared by the microcontroller and Configuration King through the common microcontroller communication protocol. When Configuration King wants to read the data from the microcontroller, it will send a read command packet based on this protocol to the microcontroller, and then the microcontroller will respond and send the data to Configuration King, and then process the data.

(3) Data storage module: Configuration King can store the data collected by the microcontroller, so that it is convenient to organize and query the data in the future.

(4) Interface conversion circuit: Through the interface conversion circuit, Configuration King can communicate and exchange data with the node machine.

(5) Voice communication module: The voice signal is collected and played using the 1000 module. It is a low bit rate, high quality voice compression algorithm based on technology, with the advantages of good voice sound quality and low coding rate, etc. There are mutually independent voice coding units and decoding units inside the chip, which can complete the coding and decoding tasks of voice at the same time. And all the encoding and decoding operations can be done inside the chip, no additional memory is needed. These features make it ideal for digital voice communication, voice storage and other applications that require digital processing of voice.

After the system design is completed, the control room can monitor and control the operation process of the system through the Configuration King interface. It is also possible to select different towers for communication on a one-to-one basis, and each tower can also take the initiative to request communication with the control room to achieve two-way communication.

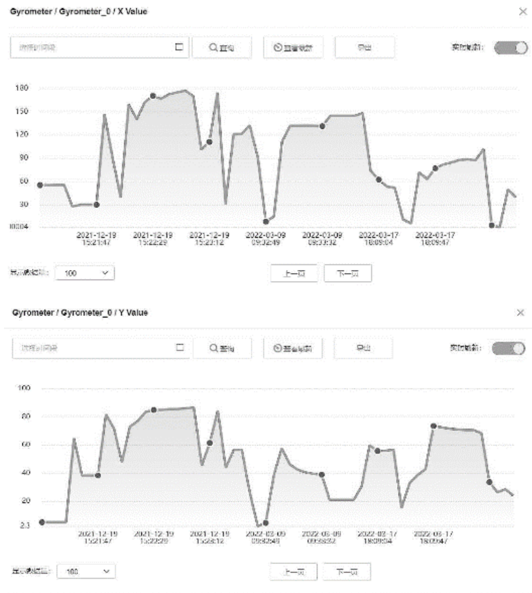

Fig. 5 Upper computer interface

8. Experiments and analysis

8.1 Data acquisition comparison experiment

First of all, the acquisition accuracy comparison test, the JY61 module containing Kalman filter iterative algorithm and the original data output gyroscope sensor at the same time to collect 20 sets of gyroscope sensor X-axis tower tilt data, the collection data range -90 ° ~ +90 ° through the serial communication to upload the acquisition results to the upper computer debugging assistant, and the data and the real value for comparison, the results are shown in Figure 6, Y axis and X-axis algorithms are consistent. The results show that the measured value after filtering by Kalman filter iterative algorithm basically matches with the true value (X), and the measurement accuracy is 0.35° with an average error rate of 0.8%. And the measurement accuracy is 0.5° with an average error rate of 1.7% after the original output of gyroscope.

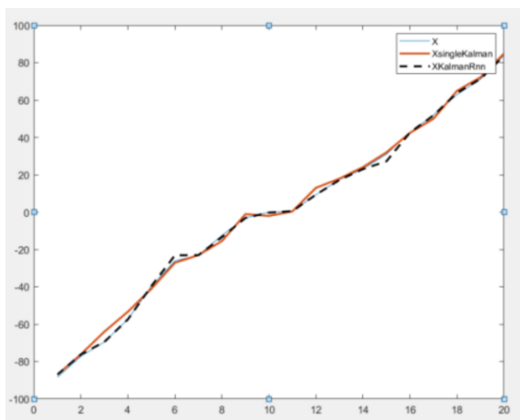

Fig. 6 Comparison of measurement accuracy

8.2 Data acquisition comparison experiment

For the impact of the working environment of transmission towers, in winter time, due to the wire covering ice, so that the force at both ends of the transmission tower is different, which is easy to cause the tower tilt, so the test scene is chosen in snowy days, which can shorten the experimental cycle. The test time is one week, and the experimental tilt threshold is set at 5°. When the transmission tower tilt exceeds this value, the monitoring system will consider that the transmission tower is working in a poor environment and has collapsed or is at risk of collapse. The data was collected 14 times by JY61 sensor module equipped with recurrent neural network combined with Kalman filter iterative algorithm, and the cumulative tilt over 5° was considered as collapse.

First, the node acquisition boards are installed horizontally on transmission towers, one is deployed on each tower 200m apart, and a total of five acquisition boards are deployed within 3km from the acquisition board with a gateway transmission version for reporting the collected data to the cloud platform. The node acquisition board collects attitude data once every 24h. In total, 7 sets of data are collected in a week (Table 1). Since the tilt angle of the tower is relatively small, the prediction and judgment are mainly made by the subtle changes of the angle. When it exceeds 5°, the status flag position is 1, i.e., tilt alarm.

Table.1 tower attitude data acquisition

Serial number	X-axis angle/°	Y-axis angle/°	Temperature/°	Working Status	Status bits
1	90.90	-0.50	-18	1	1
2	90.39	-1.58	-24	1	0
3	85.77	5.26	-16	1	1
4	89.88	3.05	-26	1	0
5	91.88	-3.51	-15	1	0
6	96.37	-5.79	-23	1	1
7	94.52	4.78	-18	1	0

9. Conclusions

The transmission tower attitude online monitoring system is designed and implemented through MEMS sensor module, Lora communication module and NB-IoT narrowband IoT communication technology, with MPU6050, STM32F103, SX1278, BC20 and other chip modules as the hardware design basis, and the measurement accuracy of gyroscope is improved through Kalman filter algorithm, and the data collected by gyroscope is transmitted to the cloud platform through The data collected by the gyroscope will be transmitted to the cloud platform through wireless communication for real-time observation, and the data will be stored in the database for secondary development. The cloud platform interface of application layer can monitor the data of transmission tower such as inclination and temperature in real time, and realize the functions of alarm, data display and firmware upgrade. And connected to a large database, using a standardized form of data interaction, to ensure that the open data system structure and other systems data structure can be integrated and shared. The system is easy and fast to deploy and can be used in a wide range of transmission tower attitude monitoring, with good application prospects.

A well resolved (spatially and temporally) and highly accurate direct numerical simulation (DNS) tool has been developed to understand the fundamental difference in the hydrodynamics of flow over two-dimensional and three-dimensional ripples in a channel geometry and its implications on sediment transport. As a first step, in this paper we focus on the steady flow over the ripples.

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