Design of a high speed drawing frame monitoring system based on IoT using MQTT protocol

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Abstract. Online monitoring for sliver quality is an important part of the drawing process. This paper presents a high-speed drawing frame monitoring system based on Internet of Things (IoT) using Message Queuing Telemetry Transport (MQTT) protocol, which consists of drawing frame IoT terminal equipment, the cloud server and PC or mobile terminal equipments. Drawing frame IoT terminal equipment takes Cortex-A7 and Cortex-M4 of series of i.MX7 as its control cores. The A7 processor publishes IoT data as a communication gateway while the M4 processor collects sensor data and executes local on-line detection program. Two processors run Linux and FreeRTOS as operating system respectively, and the data exchange between them adopt rpmsg pattern. The communication gateway using MQTT publishes data of the IoT terminal to the cloud server for remoting monitoring and intelligent diagnosis, when the local on-line detection system aims at acquiring real-time status of the sliver on drawing frame. Users can check the real-time status of the drawing frame at the subscription end of IoT and on the computer or mobile phone end by subscribing message by theme. Experiments show that the system operates with reliability, and is good compatible with other devices because of the modular design. The adoption of this system can promote the digitization and the intellectualize of the drawing frame.

1. Introduction

In the modern spinning technical process, the quantity and quality of yarn are closely related to the drawing process because the merging, drafting and mixing of the sliver are all completed in the drawing process. Especially quality monitoring technique of drawing frame plays an important role in control of spinning quality [1]. With the development of science and technology, the Internet of Things (IoT) technology integrated of Internet technology, video identification technology and sensor technology is emerged [2]. The demand for remote monitoring and control of equipment in modern industry production process is also becoming more and more extensive [3]. Therefore, it is of great significance to use IoT on textile equipment to realize remote interaction between man and machine, so as to achieve the remote monitoring of operating status in drawing frame and fault diagnosis and warning.

In recent years, with the proposal of "Made in China 2025", the manufacturing industry has accelerated the transformation and upgrading of informatization and intellectualization [4]. Domestic textile equipment manufacturing enterprises have a new development in automation, digitalization and intelligence. For example, the TIS system of Tianqi in Zhengzhou uses PROFI-BUS and industrial Ethernet network architecture, and the E system of Jingwei textile machinery in Beijing uses Modbus
RTU/TCP network architecture [5]. These systems require large areas of bridge and communication cables.

The drawing frame monitoring system based on IoT described in this paper includes two subsystems: local real-time online detecting system and intelligent diagnostic and monitoring system in the cloud. The local real-time online detecting system is independent of the autoleveller control system of the drawing frame because of its sampling modular design concept. It uses wireless network and Message Queuing Telemetry Transport (MQTT) protocol to push real-time status of the drawing frame to the intelligent diagnostic and monitoring system in the cloud.

2. Materials and methods

The high speed drawing frame monitoring system based on IoT is demonstrated in figure 1. The local terminal of the drawing frame, as data publication terminal of entire monitoring system, collects the output of the current eddy sensor to detect online sliver quality and sends the result to the upper computer of the drawing frame. Meanwhile it can diagnose and warn fault according to the quality threshold set. In addition, drawing frame terminal builds network communication with the cloud server and publishes drawing frame operating parameters (such as the roller speed, sliver speed and sliver quality), technological parameters set and sliver output to the cloud server according to different topics. The main functions of the intelligent diagnostic and monitoring system are analyzing messages pushed by drawing frame terminal with cloud server, as well as pushing these messages and analysis results to subscribed mobile client or monitoring platform according to different topics. As the data receivers of IoT monitoring system, the mobile and PC terminals subscribe with the server according to different topics so that users can see the information they care about. At the same time, the fault alarm signal and alarm information will be pushed to the designated clients when fault occurs on drawing frame, so as to facilitate the informatization and digitization management of the whole production workshop.

![Figure 1. Drawing frame IoT monitoring system.](image)

2.1. Online drawing frame IoT terminal design

The drawing frame IoT terminal, including on-line detection system and IoT communication gateway, is the node that combines the drawing frame online detection and the Internet. It takes NXP’s i.MX7 Solo as its core controller including the Cortex-A7 and Cortex-M4 processors running Linux and FreeRTOS respectively. These two processors are integrated in a chip. In the IoT communication gateway, the network connection with the server and message transmission are both completed in Linux. And in the online detection system, FreeRTOS, a lightweight real-time operating system, is used for real-time signal acquisition, online monitoring of sliver fiber and communication with the upper computer of the drawing frame. Data exchange between processors is achieved through rpmsg communication mechanism. The flow diagram of the Cortex-M4 system and Cortex-A7 is shown in figure 2.
2.1.1. Online detection system design. On-line detection of drawing process includes real-time sampling and monitoring of sliver information, data processing and adopting corresponding measures in the production process.

The quality indicators that are the output of the drawing frame online detection system are shown as follow.

1. Sliver weight deviation (A%). It is the deviation of the actual weight of sliver fragment relative to the nominal weight.

2. Sliver Random quality variation (CV%). It is the random fluctuation of the sliver quality, mainly to monitor the short and medium sliver so as to avoid clouds on the fabric.

3. A% charts. They include A% (1m) chart, A% (5m) chart, A% (minute) chart and A% (hour) chart. As the name suggests, all the charts describe the deviation of the sliver weight, but the sliver lengths or production time of the corresponding sliver are different.

4. Wave spectrogram. The periodic quality variation in the yarn can cause harmful patterns on the fabric. These patterns are not caused by raw materials, but by failures in the production process. So these failures must be monitored as early as possible. The wave spectrogram can be used to analyse these periodic defects.

![Diagram](image_url)

Figure 2. Flow diagram of the Cortex-M4 system and Cortex-A7.

![Diagram](image_url)

Figure 3. The hardware block diagram of the drawing frame terminal.

The Cortex-M4 provides compatibility with Cortex-M3 and adds significant new capabilities with Digital Signal Processor (DSP) and Single Instruction Multiple Data (SIMD) extensions. It also includes a single-precision floating-point unit (FPU), which includes an extension register file of thirty-two 32-bit floating-point data registers. In the online detection system, Cortex-M4 is used to collect the sliver thickness signal from the eddy current sensor for on-line identification of the fiber movement and quality detection. The speed of the high speed drawing frame can reach 800 min/s to 1200 min/s, so the Cortex-M4 runs FreeRTOS to ensure the real-time performance of signal collection. The results are displayed on the local upper computer through Modbus 485 communication and are
used as feedback of the autoleveller control system to control the sliver quality well. A Power Supply module (5Vdc) of MORNSUN is provided to power the i.MX7 core board and REF3030AID module is used to convert 5Vdc into the reference voltage of Cortex-M4, as shown in figure 3. In order to match the input voltage of the AD convert module on the core board, the output signal of the eddy current sensor ranging between 0V and 10V is reduced to the range of 0-3.3V. In addition, some non-volatile variables such as technological parameters set in the system need to be stored through ferroelectric memory when power failure occurs. The picture of real product is shown in figure 4.

![Figure 4. The picture of real product.](image)

There are three system tasks to handle the Modbus communication, handle the rpmsg communication and detect the sliver signal respectively in the FreeRTOS. During dealing with the Modbus communication task, the processor will update the values of these non-volatile variables stored in the ferroelectric memory while finding that the Modbus master station changes them, in order to prevent them losing along with power failure. The rpmsp communication task is to send data to Cortex-A7. The operation cycle of the sliver signal detection task is 500us. During the task, the processor collects the AD values of the sliver signal and calculates the corresponding sliver quality indicators including A% value, CV% value and spectrum diagrams. The flow of the task is shown in figure 5. If an indicator is more than the set threshold, the drawing frame terminal will sound alarm and stop the drawing machine, meanwhile send the alarm information to the upper computer. If the upper computer sends a calibration command, the sensor calibration or sliver calibration program will execute. And the sliver quality indicators will be calculated afresh according to new calibrated parameters after calibrating.

2.1.2. IoT communication gateway design. The IoT gateway, which is used to connect the LAN and the WAN, plays a decisive role in the IoT system. It serves as the intermediate connector between the sensor network and the communication network [6]. In this paper, IoT communication gateway is used for reliably communication with the cloud server and data transmission that include the result of online detection system and drawing frame operating parameters. It packages the drawing frame data into MQTT control messages and publishes the control messages to MQTT server through MQTT client.

MQTT is a lightweight broker-based publish/subscribe messaging transport protocol, which is suitable for low bandwidth and unreliable network environment. The packet length is so short that the network load can be reduced greatly. It is an important communication protocol in the Internet of things [7]. An MQTT Control Packet consists of fixed header, variable header and payload. Each MQTT Control Packet contains a fixed header, whose length is 2byte. The format of the fixed header is shown in table 1 [8].
Sampling analog signal
Calculate the A% value for each length
The A% value for each length exceeds the threshold?
Y
N
System calibration
Sampling length of sliver reaches 100 m?
Y
N
Calculate the CV% value for each length
The CV% value for each length exceeds the threshold?
Y
N
Output alarm signal and alarm information
Alarm cleared
Calculate the spectrum diagrams

Figure 5. The flow diagram of the sliver signal detection task.

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-----|---|---|---|---|---|---|---|---|
| Byte1 | Message Type | DUP flag | QoS level | RETAIN |
| Byte2 | Remaining Length |

QoS level represents quality level of service for message. The corresponding message publishing and confirmation flow is shown in figure 6.

Figure 6. MQTT message publishing and confirmation flow.

In this paper, the processor of Internet communication gateway is Cortex-A7. The Cortex-A7 MPCore platform is a high-performance, low-power processor compliant with the ARMv7-A architecture. The Cortex-A7 MPCore platform has dual symmetric ARM® Cortex®-A7 cores with a L1 cache subsystem, integrated L2 cache subsystem, and integrated Generic Interrupt Controller (GIC). Therefore it runs Linux. Linux is open and cuttable, which make it suitable for some small-memory embedded platforms, especially Internet of things terminal [9]. There are two threads to handle two
tasks: communicate with Cortex-M4 to obtain on-line detection data and other data information of the drawing frame, as well as publish these data to the server timely. For these data whose length is indefinite, a structure is defined for data transmission of rpmsg for ease of encapsulating MQTT Packet. The synchronization and data consistency of two threads in the system are guaranteed by mutex and condition variable. In the thread responsible for rpmsg communication, Cortex-A7 receives data from Cortex-M4 passively, stores them in the shared structure and releases the mutex and condition variable. This causes the thread responsible for message publish to block when waiting for the condition variable. After condition variable obtained, the shared structure will be locked in order to prevent these data being written during the MQTT Packet encapsulation. These data with their corresponding topics and QoS service levels are encapsulated into PUBLISH Packet and published to the server. During thread blocked, PINGREQ Packet is sent to the server to maintain the heartbeat connection of MQTT with the heartbeat cycle set in the Keep Alive Timer. Different from the heartbeat mechanism in the TCP/IP protocol, the heartbeat mechanism of MQTT is a handshake mechanism that the application layer in the network system detects the client network connection. It defines the maximum time interval that the server receives message from the client. In order to minimize the network load of the system, the heartbeat cycle designed in this paper is 300s. After sending PINGREQ Packet to the serve, the gateway will close MQTT connection and TCP/IP connection and reconnect if it doesn’t receive PINGRESP Packet from the server in one heartbeat cycle. If the connection fails, the alarm light will be lit to inform staff to detect the network connection. The execution process of the thread is shown in figure 7.

2.2. Server design
In this paper, the server-side mainly is responsible for the functions of message forwarding, data preservation, state monitoring and topic statistics. The entire server is divided into three tiers. The first tier is the MQTT proxy server, which is responsible for the bottom network communication and the forwarding of different types of messages. The second tier is the business processing layer, which consists of three parts: access authority control module, authentication module and status monitoring module. The third tier is used as the storage layer, saving the statistics data of the drawing frame which are used for the analysis and intelligent diagnosis in the later stage. The entire system framework is shown in figure 8.

![Figure 7. MQTT message publishing thread execution process.](image-url)
Figure 8. The server-side framework of drawing frame monitoring system with IoT.

The system uses the Ali-cloud server that installs the Ubuntu 12.04 release, so the open source Mosquitto is selected as MQTT broker. Mosquitto is implemented in C language, is easier to debug, and has various functions defined in the complete MQTT protocol. Access authority control module in the business tier is used to match different users (workshop workers, workshop supervisors, supervisors, etc.) and their corresponding access rights to enhance system security. Authentication module is mainly used to manage registration, login and logout of users thereby prevents anonymous access. Status monitoring module is used to monitor CPU occupancy rate, memory occupancy rate and other system information as long as the server is running [10]. The storage tier is used to save the information of users and the statistical information of the drawing frame. The system uses MongoDB database for data management because it is mainly to preserve a large number of unrelated statistical information.

3. Experimental results
In the experiment, the monitoring system has been deployed in a drawing frame. The effect of on-line detection is shown in figure 9. The A% value is -0.1, which illustrates that the error between the actual sliver quality and the ideal quality is very small. The CV% value is 3.5%, which illustrates that The sliver quality fluctuation is relatively small. The result is similar with the result that USTER calculates. USTER is the maker of the online detection standard for drawing frame. Mosquitto is installed on the raspberry pi and is used as a subscription terminal to subscribe for some information of the drawing frame whose topic is DrawingFrame. After testing, raspberry pi can receive the test information pushed by the drawing frame terminal. The result is shown in figure 10. The log information in the test process through using the mosquito --v command on the service side is shown in figure 11. These results illustrate that the performance of entire system is good.

(a) (b) (c)

Figure 9. Online Monitoring effect.
4. Conclusions
The drawing frame monitoring system designed in this paper is a networked intelligent system with sensing, computing and control [11]. It combines the existing on-line detection system and the latest IoT technology to realize the information monitoring and management of drawing frame. It retains the original features, and conforms to traditional operating habits. At the same time, it also promotes the transformation and upgrading of enterprises. Its main advantages include:

1) Comparing with the commonly used network protocols such as nRF24L01, GPRS [12], a lightweight IoT transmission protocol is selected in the paper, which is more suitable for the poor stability and low bandwidth of the factory network.

2) Based on the widely used wireless network transmission, it avoids the problem of rewiring in the production workshop and increasing the cost and difficulty of management.

3) The system is designed with modular ideas. The new system does not influence the function of the original system. Modbus protocol used to communicate with the upper computer is compatible well with existing products. The product can be added to an existing drawing frame in the form of module, which reduces the cost for enterprise to upgrade.

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