Design of BeiDou-based data acquisition system for oil and gas wells in remote areas

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Abstract. The real-time operation status monitoring of natural gas wells in the wilderness area has problems such as construction suffering, high maintenance cost, and high data transmission cost. In view of the above problems, this paper studies the design of a multi-node data transmission system using BeiDou satellite short message as the data transmission means. Firstly, analysing the advantages and disadvantages of several common data transmission methods and introduced the BeiDou short message; Secondly, introduced the main working parameters of the oil and gas well; Thirdly, the data acquisition and transmission system was designed in detail and the prototype system was developed. The experimental results show that the data transmission success rate of the system can reach more than 98%. This system solution can provide a useful reference for engineering with similar requirements.

Keywords. Internet of things; BeiDou short message; Real-time transmission; Visualization processing

1. Introduction

Natural gas is a high-quality, efficient, and clean fossil energy source with the lowest carbon emission coefficient of all fossil energy sources. Natural gas has been widely used in various fields of national life and production, and currently accounts for about 24% of the world's energy consumption structure. There are many natural gas fields in China that are unattended, and there are no mobile communication networks in the wild or deserts where humans are rare. These gas fields need to collect the operational data of the gas field in real time to meet the following requirements: 1) control the collection according to consumption and gas well conditions, 2) timely treatment in the event of gas well accidents; 3) complete data accumulation, for later component failure Diagnostics and oil well life prediction provide data support. 4) Visualize the data and Through B/S, C/S release, to achieve the purpose of remote access [1].

In order to simultaneously collect various parameters of the operation of multiple gas Wells distributed in remote areas, the communication modes usually include the following schemes [2]: 1) Public 4G network 2) Self-built multiple mobile communication base stations. 3) Radio station data communication technology. 4) Microwave transmission 5) Satellite communication. Table 1 compares several schemes [3].
Table 1. Comparison of communication methods.

| Communication method          | Transmission distance | Applicable area               | Work stability                              | Post-Maintenance | Implementation difficulty                      | Cost   |
|------------------------------|-----------------------|-------------------------------|--------------------------------------------|------------------|-----------------------------------------------|--------|
| Public 4G network            | short                 | Base station establishment   | Poor stability in areas not covered by     | Easy             | It is more difficult to implement in remote areas | Low    |
|                              |                       | dense area                   | signals                                    |                  |                                               |        |
| Self-built base station      | Dozens of kilometers  | Base station coverage area   | Signals are unstable                       | Difficult        | Time consuming, construction is not easy      | higher |
| transmission                 |                       |                               |                                            |                  |                                               |        |
| Radio station communication  | Can cover dozens of   | For areas with high real-time | Good stability.                            | Easy             | Multiple slaves need to be established for "one-to-many" communication | Low    |
|                              | kilometers            | requirements                  |                                            |                  |                                               |        |
| Microwave transmission       | Up to 70 kilometers   | Difficult to route area      | Extremely susceptible to external          | Vulnerable to    | mountain will block the signal, making        | higher |
|                              |                       |                               | electromagnetic interference                | bad weather      | construction difficult                        |        |
| Beidou satellite communication | No distance limit     | No network coverage area     | Strong stability                           | Simple maintenance | Communication can be achieved by ensuring      | Low    |
|                              |                       |                               |                                            |                  | power supply                                  |        |

As can be seen from the above table, satellite communications have incomparable advantages in remote areas without mobile communication networks. Although it’s real-time performance and data length are limited, its resources can fully meet the requirements for natural gas acquisition and transmission applications. In this paper, a data acquisition system based on beidou short message communication is designed, and its details are described below [4].

2. Beidou system
The beidou satellite system, which consists of five GEO satellites (geostationary satellites) and several non-geo satellites, has achieved signal coverage in the asia-pacific region and will cover the whole world in the future. The characteristics of communication technology are as follows: 1. There are usually more than two satellites crossing over, and the redundant configuration of channels ensures the stability of communication channels; 2. It is not restricted by terrain, environment and climate, and has the characteristics of no communication blind zone. 3. Beidou satellite has two-way communication function, which can realize data communication by means of short message; 4. Good security and encryption, free from interference and damage to user data; 5. The transmission frequency is divided according to the user card, with 30 seconds and 1 minute for the user card, and the real-time performance is limited [5].

Beidou short message communication is a special technological breakthrough of beidou. Short message refers to that the satellite positioning terminal and beidou satellite or beidou ground service station can directly carry out two-way information transmission through satellite signals, while GPS can only transmit in one direction (the terminal receives position signals from the satellite). Short message
communication is a major feature of beidou communication. Each user machine has a unique ID number and adopts a 1-household, 1-secret encryption method. All communication needs to be forwarded through the ground central station. Similar to the positioning function, the transmission delay of short message communication is about 0.5 seconds. For example, in the case that the ordinary mobile communication signal cannot be covered (for example, the communication base station is damaged after the earthquake disaster), the beidou terminal can carry out emergency communication through short message [6].

3. Main operating data of gas well

The main operating data of gas well include flow rate, pressure difference, pressure, temperature, etc. Flow rate refers to the volume or mass of liquid flowing through a section of a pipe per unit time. The intelligent differential pressure flowmeter can be used to measure the operation data of gas well. According to the conservation of energy, pressure difference (static pressure difference) \( p = p_1 - p_2 \) will occur before and after the throttling device. Since it is a throttling device, there is \( p_1 > p_2 \). There is a certain functional relationship between the pressure difference \( p_1 - p_2 \) and the flow rate through the fluid, and the flow rate can be obtained according to the pressure difference. The relationship between mass flow and pressure difference as in equation (1) [7].

$$ q_m = \alpha \rho F_0 \sqrt{2 \rho \Delta p} = \alpha \rho F_0 \sqrt{2 \rho (p_1 - p_2)} $$

In the formula, the significance and unit of each parameter are specified as follows: \( q_m \) is mass flow, and the unit is kg/s. \( \alpha \) is flow coefficient, which can be determined by experiment. Usually according to the throttle form, pipeline conditions, Reynolds number, fluid properties and other query table; \( \varepsilon \) is the correction factor for fluid expansion, usually between 0.9 and 1.0. \( \varepsilon = 1 \) for incompressible fluid; \( \varepsilon < 1 \) for compressible fluid; \( F_0 \) is the orifice area \( m^2 \) of the throttle piece. When the orifice diameter of throttle piece \( d (m) \) is known, \( F_0 = 4d^2 \); \( \rho \) is fluid density, \( \text{kg/m}^3 \); \( p = p_1 - p_2 \), is the pressure difference before and after the throttle (Pa). The flow rate of the fluid to be measured can be displayed in real time through the input flow coefficient and the correction coefficient of fluid expansion.

In the figure 1, according to the flow direction of the fluid, the throttle device should be installed. There will be a difference in the hydrostatic pressure at the pipe wall of the throttle device 1-1 and 2-2. The height of the pressure difference can be obtained by the displacement sensor. The fluid density can be obtained by installing standard volume and pressure sensors at A.

![Figure 1. Principle of flow meter.](image)

4. Design of data acquisition system

As in figure 2, it could collect the data acquisition device is located in the well site, automatically collecting, processing, storage, data, and the processed data coding, and then each instrument are
connected a corresponding beidou transmitter, through beidou short message sending data to the terminal, terminal to upload data to the cloud, can be in the mobile phone or PC to check the data. The data acquisition function is mainly realized by multi-parameter differential pressure transmitter. Differential pressure transmitter is a new type of flow transmitter. It with high precision compound monocrystalline silicon resonant sensor for measuring element, the precision of the algorithm to eliminate the influence of temperature and static pressure on the measured value, through the automatic real-time measurement process fluid flows through the traffic signal timing of differential pressure, pressure, combined with the process fluid temperature signal, for temperature compensation, automatic calculation of fluid flow process, and local display, store and output measurement parameters and measurement results. The beidou transmitter is powered by a solar panel, which can solve problems such as power supply difficulties and battery replacement in wilderness areas.

Figure 2. Principle of flow meter.
5. Overall design scheme

As shown in the figure 3, the system adopts a four-layer structure: first, the solid layer, and the parameters that need to be measured during the operation of each well, such as flow. Network layer can achieve the function of data transmission: beidou transceiver support "multiple to send, one receive" mode, namely every Wells are equipped with a Beidou transmitter, each big dipper transmitter in the process of data communication has its own identification information, terminal only equipped with a beidou receiver can receive all the well information from transmitter. The transmitter of each oil well receives the data collected by the flowmeter and automatically sends it to the beidou receiver at the main station.

Application layer mainly realize the data receiving, parsing and display function: PC can receive the beidou receiver message, will receive the information in accordance with the corresponding data format is parsed, convenient store the parsed data in the database query, parsed data ualization processing, make each parameter of the gas gathering pipeline more convenient and intuitive access by people.

5.1. The hardware design

The hardware system is mainly composed of processor module, sensor module, keyboard module, LCD module, RS485 communication module, and power supply module. The hardware structure is shown in the figure 4.

The processor module is the core of the system, which is mainly responsible for the completion of equipment control, data calculation and other work. The high-performance microcontroller STM32F103RBT6 of ST company based on cortex-m3 kernel is adopted as the core chip. The designed processor module has the functions of automatic reset on power and manual key reset. All tasks scheduling, data processing, function coordination and communication control are completed under the support of this module.

The sensor module is mainly responsible for collecting the corresponding data within the monitoring area. According to the variation range and accuracy requirements of the collected data, multi-parameter differential pressure transmitter is adopted to realize the measurement of various parameters, with the output of 4-20 ma simulated current. The differential pressure transmitter USES precise algorithm to
eliminate the influence of temperature and static pressure on the measured value, making the collected data more accurate [8].

The key module improves the flexibility of the equipment, which can change the address of the instrument and the basic parameters such as the serial port baud rate. RS485 communication module mainly provides 485 communication function. Instrument can communicate through RS485 wiring and beidou transmitter to transmit instrument information.

The power supply module is provided by photovoltaic panels. The power supply of beidou transmitter and flow meter is 24V dc. Therefore, the photovoltaic panel battery with the product power of 24V and 300w is adopted to ensure the power supply of field instruments and beidou transmitter.

5.2. The software design

5.2.1. Introduction to system model. The core content of this system content of this system is the transmission of data. First of all, the source of data is the data collected by the flowmeter during the operation of gas Wells. The data transmission consists of two parts: on the one hand, the beidou transmitter receives the data from the instrument connected by the serial port; on the other hand, the beidou transmitter sends the received data to the beidou receiver through the beidou short message communication. The E-R model relationship of the system is shown in the figure 5 [9].

The data of gas well mainly includes pressure, flow, temperature and other data needed to be collected by flowmeter. Different parameters correspond to different data types. There are only three attributes of natural gas flowmeter, namely: the identification number (unique) of the table, the geographical position of the table and the corresponding time of data collection; The gas Wells that need to collect data are scattered in various places. There is only one natural gas flowmeter in each gas well, and each flowmeter is connected with a beidou transmitter, which is a one-to-one relationship. Each beidou transmitter has its unique beidou card number, but its communication address is the local address of beidou receiver. The relationship between beidou transmitter and beidou receiver is "many-to-one", that is, only one beidou receiver can receive data of all dispersed gas Wells.

![Figure 4. Schematic of hardware structure.](image-url)
5.2.2. Communication data structure. Communication information composition: address code-function code – data segment – CRC checksum code, a message is sent and received continuously, the character interval cannot be greater than one character, otherwise it is considered that a new message begins or the old message ends. The information body consists of hexadecimal Numbers.

Data definition: IEE standard floating point data format has a length of 4 bytes, which adopts IEEE standard method, where the mantissum high order is always 1, and the distribution of bits is as follows: 1 bit symbol bit, 8 bit exponential bit, 24 bit mantisse, the symbol bit is the highest bit, the mantisse is the lowest 23 bit, sorted by byte as summarises in table 2.

| Address 0 | 1 | 2 | 3 |
|-----------|---|---|---|
| Content   | SEEEE | EMMMM | MMMM | MMMM |

Where S: sign bit, 0= integer, 1= negative number. E: exponent (in two bytes), offset code 127. M: the mantissum of 23 bits, the highest bit is 1, and the significant bit is 24. For example: 100=0x42, 0xc8, 0x00, 0x00; 0=-0x00, 0x00, 0x00, 0x00; -100=0xc2, 0xc8, 0x00, 0x00.

The returned data contains 51 bytes in total: address code, function code, number of bytes, accounting for the first three bytes, 12 data to be accepted, each data accounting for 4 bytes, CRC check code two bytes. The specific structure is shown in the following table. Since the baud rate of the flowmeter is 1200-9600 and that of the beidou integrated machine is 9600-115200, the communication baud rate is 9600. Description of baud rate of flowmeter: 9600n81 means baud rate is 9600, 1 bit start bit, 8 bit data bit, 1 bit stop bit, no check; 9600n81 means the baud rate is 9600, 1 bit start bit, 8 bit data bit, 1 bit stop bit, no check [10].
Table 3. Data commands.

| Send                      | Response                        |
|---------------------------|---------------------------------|
| 01 (address)              | 01 (address)                    |
| 03 (Function code)        | 03 (Function code)              |
| 00 (Register address height)| 04 (number of bytes)           |
| 01 (Register address low) | 80 (data1)                      |
| 00 (High register number) | 04 (data2)                      |
| 02 (Low register count)   | 80 (data3)                      |
|                           | 80 (data4)                      |
| CRCL                      | CRCL                            |
| CRCH                      | CRCH                            |

5.2.3. The software design. The upper computer program mainly consists of three tabs: initializing the interface of setting basic parameters of serial port, real-time online parameter display interface, real-time online parameter graph, and dashboard display interface. The host computer starts two parallel threads -- the main thread and the child thread. The main thread receives the information from the lower machine and parses and stores the information. The child thread is responsible for real-time drawing. The upper computer workflow is shown in the figure 6.

Analysis of the specific process is as follows: first of all need to all the basic parameters of the serial port, such as: baud rate, parity, etc., set judgment available serial port, serial port is open, continuous query whether there is new data, the new data from the judgment and parsing, stored in a database on one hand, on the other hand, will the parsed data real-time change curve drawing; The process stored in the database continues to send data to the server side, repeating the two processes [11].

5.2.4. The software design. The functions of the upper computer to display data are described as follows: 1) data reading and analysis: the main data source of the upper computer software is the operation parameters of the natural gas acquisition pipeline, so as to ensure the accurate transmission of information, and finally display the analyzed data in the chart. 2) real-time change curve of collected data and dashboard display. The dashboard shows the current real-time data of the well, and the graph can calculate the average of five minutes, half an hour and one hour data to show how each data changes.

The program development of the upper computer is oriented to the client, which facilitates the observation and query of local data. The web program development of the server is oriented to the network end, that is, various parameters of the natural gas acquisition process can be viewed at any time and anywhere. The design process of the server-side program and the upper computer is roughly the same. There is no need to go into details here. It mainly realizes four functions: 1) data reception and analysis; 2) data storage and query; 3) real-time display of data; 4) user rights management. The first three functions are almost the same as the upper computer, and we don't explain too much here. The authority management of users is different from that of other users. Logging in your own account can only view the information within the scope of your authority, which greatly strengthens the security of gas well data and facilitates the management of enterprises. The software system presents in figure 7.
6. Software testing
The program of the upper computer and the program of the server side have been described above. The instrument flowmeter and the software system of the upper computer communicate through the RS485 to USB port to receive the information from the lower computer. The beidou transmitter is placed outside the laboratory window to connect the RS485 communication line of the instrument, and the beidou receiver is directly connected to the computer through the RS485 to USB interface for synchronous data collection and real-time data transmission to the server. After the field test, the real-time data received by local and server side is compared with the real data. The results are as follows:

Data loss rate: After comparing the time period (24 hours) from 10:20 on May 26 to 10:20 on May 27, 1440 messages should be received and 1417 messages are actually received due to the data being sent every one minute. The packet loss rate is 1.59%. After careful examination of the data, it was found that most of the data loss was concentrated in the time period from 12:00 to 13:00. The analysis was based on the fact that the signal in the experimental area was at the weakest stage during this period, which might lead to the failure of communication. Figure 8 shows a partial display of the data in the database.
Through comparative tests, it can be concluded that:

- The system can realize remote monitoring with low cost. Especially in remote areas without signal, the advantages of beidou satellite communication are irreplaceable.
- The stability of the system is more than 98%, and the data is lost. The preliminary suspicion is that the signal strength of the beidou satellite system will change in different periods, which needs to be further verified.

The test results show that the gas well data transmission system in remote areas designed in this paper can pass all functional tests. Although there is loss of data, the system achieves the expected design goal in terms of functions and meets the requirements of enterprise automation office.
7. Outlook and summary

This paper studies the data transmission of gas Wells in remote areas without network and designs a data transmission system for gas Wells in remote areas. According to the characteristics of the enterprise and the Internet environment, this paper demonstrates the requirements of enterprise data transmission and management, and then designs the system, analyzes and constructs the software architecture and network architecture of the system. Finally, the function test and performance test of the system are carried out. The test results show that the system completes all functions and meets the requirements of enterprise management in real time. The current single-point transmission test is correct, and the follow-up research needs to carry out "many-to-one transmission" test. Theoretically, there is no limit to the amount of data a receiver can receive, but the actual data capacity needs to be further tested to improve the system.

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Figure 8. Demonstration of experimental results.
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