**Guangyou YANG, Zhiyan MA, Wan XU, Xing HUANG, Jingjing ZHOU**

Hubei University of Technology

# The Development of Drilling Engineering Monitoring System Using Wireless Sensor Networks

***Abstract***. *In order to avoid defects of existing drilling engineering monitoring and alarming system, such as the sensors and cable which are difficult to be installed and easy to be damaged, this paper present a new embedded drilling engineering monitoring system which is based on Wireless Sensor Network(WSN) and Wireless Local Area Networks(WLAN). The system is consists of the data acquisition subsystem, duty room controller, tool-pusher room controller and engineer room controller. It acquired the data and exported control commands by WSN. The tool-pusher room controller and engineer room controller are communicated with the duty room controller by WLAN for remote monitoring. For the special field drilling environment, the system achieves the acquiring, transmission, the export of control commands and remote monitoring of drilling data.*

***Streszczenie.*** *Obecnie stosowany system monitorowania I alarmowania w technice wiercenia posiada szereg wad związanych z czujnikami i kablami, które trudno instalować i łatwo uszkodzić. Zaprezentowany w opracowaniu nowy system pozwala na uniknięcie tych wad. Oparty jest o bezprzewodową sieć czujnikową (WSN) oraz bezprzewodową sieć lokalną (WLAN). System obejmuje gromadzenie, transmisję danych i przekazywanie sygnałów sterowania oraz zdalne monitorowania danych wiercenia.* ***Rozwój systemu monitorowania techniki wiercenia z zastosowaniem bezprzewodowej sieci czujnikowej***

**Keywords:** Drilling Engineering, WSN, WLAN, Monitor System.
**Słowa kluczowe:** in the case of foreign Authors in this line the Editor inserts Polish translation of keywords.

## Introduction

It is significant to monitor the parameters of drilling engineering in order to detect the kick sign, lost circulation earlier and prevent from the drilling accidents, improve the observability and controllability during the well drilling [1]. The existing drilling monitoring systems mostly link each sensor to data terminal with cable (such as RS485 bus/CAN bus) [2-4]. The cable way will increases costs for wiring. In addition, the drilling equipment needs to be removed after well completion and to be reinstalled in the new drilling field. The work of remove/installation is both complicated and troublesome. Meanwhile, the monitoring system also may be paralyzed because of the cable fault, and can not give an alarm while a drilling accident may appear, then the accident happens. Wireless technology in industrial areas is mainly divided into the wireless local area network(WLAN), CDMA and GPRS wireless network and wireless digital radio [5-7]. Wireless Sensor Network (WSN) is a new technology [8], by virtue of the low power consumption of wireless nodes, two ordinary AA batteries can keep the node working for a few months. While using better dormancy algorithm, four AA alkaline batteries can even last the life of the node for three years [9]. The node of WSN is in small volume, higher integration, and lower cost. In addition, the WSN has large network capacity. In view of these characteristics of the network, WSN technology has been used in the field of medical care, environmental monitoring, meter reading, military, and the application is expanding [10]. In well drilling engineering, the environment is more complex and it is strict with the requirement of monitoring system, whereas, the WSN technology is not complete mature. At present, the drilling engineering monitoring systems based on WSN technology are still at the experimental stage, and there is no mature product, in view of the facts, this paper has researched implement of the wireless data acquisition and remote monitoring in well drilling engineering with Zigbee technology, wireless local area network technology and embedded system.

## The structure of system

Drilling engineering data acquisition and wireless remote monitoring system consist of wireless sensor network data acquisition subsystem, a duty room controller, a tool-pusher room controller and a remote monitoring system. The structure of system is shown in Figure 1. Data acquisition subsystem realizes the acquisition and transmission of drilling engineering parameters through WSN. The core functions of the system are monitoring, alarm and automatic grouting.

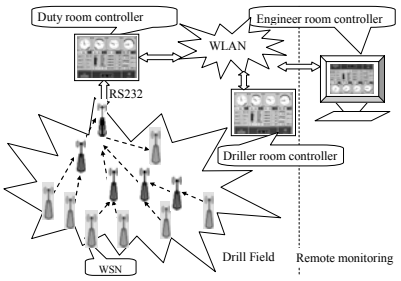



Fig.1. Structure of system

As shown in Figure 1, the duty room controller is an embedded data acquisition server, which can also be used as a system controller alone. Through getting and processing the sensor data that comes from a serial port, the grouting model, alarm model were established for the purpose of automatic grouting and giving the alarm when abnormal phenomena happens. The tool-pusher room controller communicates with the duty room controller through wireless local area network, and the function is the same as duty room controller, so that the driller can know the situation in time. The main functions of remote monitoring system is to provide with remote network monitoring, data storage, query, report output and etc, being convenient to acquire the current situation for engineers and providing technical support for scientific well drilling.

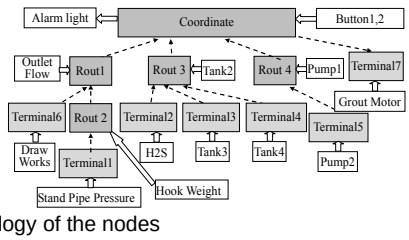



Fig.2. Topology of the nodes

## Data acquisition

The data acquisition in the well field is completed by sensors through WSN. The sensors and controlled

components (including the alarm and automatic grouting motor) are connected with a wireless module respectively and form an intelligent WSN node one by one that is shown in Figure 2.

Thereinto, the function of node is specified statically according to the actual need to make the system more stable and reliable, and to meet the high reliability requirements of well field monitoring equipments. The intelligent node connecting with duty room controller is the coordinator node in WSN, which can manage and maintain the WSN network. The coordinator node communicates with duty room controller through a serial port and communicates with other nodes in the network in Zigbee protocol. The coordinator can both read input status of the buttons through the IO module and output a warning signal from the controller. Every node in the WSN has the functions such as collecting sensor's output signal, sending, routing broadcast another node's data, resolving and carrying out the instructions from the remote monitoring system and etc.

*a) Composition and distribution of intelligent nodes*

The WSN nodes in the system consist of a 32 bit wireless micro controller JN5121 [11], a power module, ADC module, IO module, lights and buttons and etc. The diagram of hardware structure is shown in Figure 3.

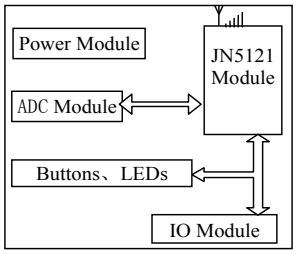
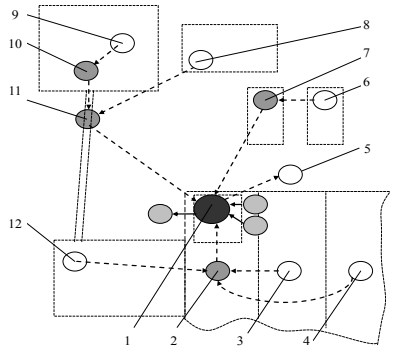



Fig.3. Hardware structure of wireless node

According to the functions of the system, those intelligent nodes are distributed in the drill site as shown in Figure 4.




1.Coordinate; 2.3.4 Mud tank liquid level node;
5.Grouting motor node; 6.7.High pressure mud pump node;
8. Draw works node; 9.Tube pressure node; 10.Hook weight node;
11. Outlet fluid flowmeter node; 12. Hydrogen sulfide detector node

Fig.4. Distribution of the node in well field

The arrow in dotted line in Figure 4 shows the flow direction of wireless sensor network's data, it forms the network node tree structure according to the layout of well site, on one hand, the distance of data transmission between the nodes becomes shorten, on the other hand it also reduces the burden of the coordinator's communication and increases the stability of the system. In this WSN, No.3, 4, 6, 8, 9 and 12 nodes only complete the acquisition of sensor data respectively and the transmission to its father node, including nodes which are the liquid level of mud tank, the pulses number of high pressure mud pump 1, the pulses of rotation draw works and hydrogen sulfide detector. No.2, 7, 10 and 11 node not only collect native sensor data, but also work as a router that gather the sensor data from the child node and have a process and aggregation respectively, then transmit to its father node (the liquid level of mud tank, the pulses number of high pressure mud pump 2, the hook load and outlet flow meter). The way of data aggregation is realized as follows: extract the data bits that place in units, hundreds, thousands of the dada upload from the child nodes respectively, and place them in an array specified with continuous position, and then transmit the elements in the array to the node's father node in the wireless network. No.5 node (the grouting motor node) monitors the instruction of NO.1 coordinator node in real-time and controls the start/stop of grouting through its output port. Coordinator has the child nodes of No.2, 5, 7 and 11. In addition, the coordinator node still has three IO ports, two of which are used as a button input port, and the rest one is used as an output port of alarm.

*b) The design of data acquisition software*

The WSN communicates in Zigbee protocol. Analyzing different routing mechanisms comprehensively [12-14], the topology of the tree structure network is adopted according to environment of well field and the distribution of acquisition variables that require to be monitored and have a wide distribution. In order to improve the stability of the network, node type is statically specified according to its function for the purpose of forming a fixed and more stable network structure. Program codes for nodes are divided into two kinds: one is the coordinator node code and the other is terminal node code, and the block diagram is shown as in Figure 5.

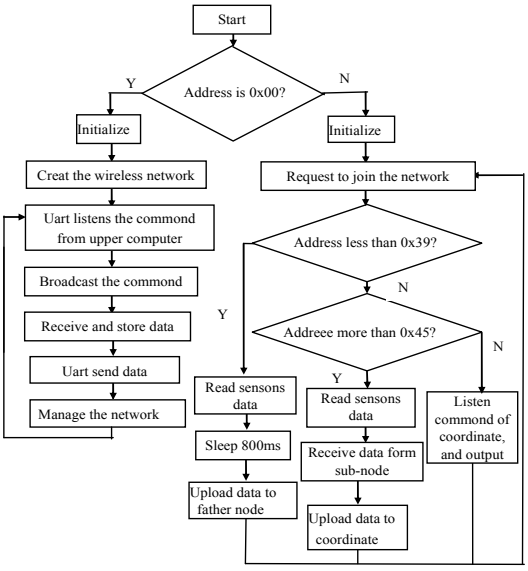



Fig.5. Program structure of wireless node

In order to improve the universality of nodes, a macro is defined for the address for each node, so that only need to modify this macro value and make it be the corresponding node address when download the code (the nodes' address in the network is unique). The program of nodes can distinguish between coordinator node and each terminal nodes through the value of node's address, then realize their functions respectively. Thereinto, the address of the coordinate node is 0x00, the sensor & terminal node's address is less than 0x39 while routing node's address is more than 0x45, and the rest address is used for the nodes that connect to control parts. The main functions of coordinator node are to create and maintain wireless network automatically, collection data and communicate with upper computer through serial port, broadcast the control command from the upper computer & upload sensor

data and perform the monitoring & output control of the IO port. Coordinator node can automatically organize the network after power up (the time that node joins the net is less than 30 ms), receive the nodes' request signal to access network and let the node join the network, besides, the coordinate node can also get rid of node that loses signal from wireless networks and increase new nodes dynamically.

The program function of wireless nodes is mainly implemented in the event queue, which is queried by the operating system in cycle, then it execute the events in the queues in proper order. The main components make up the event queue are as follows:

```
PRIVATE void vProcessEventQueues(void)
1   {……
2   //management entities
3   vProcessIncomingMlme(psMlmeInd);
4   vProcessIncomingData(psMcpsInd); //data entities
5   //hardware events
6   vProcessIncomingHwEvent(psAHI_Ind);
7       ……}
```

In the program above, management entities, data entity and hardware events correspond with the management entities MLME, data entity MLDE and hardware events AHI in the MAC layer in Zigbee protocol respectively. What the MLME entity processes are the scanning channels, building networks and dynamically deleting or adding a node. What the data entity can do are processing wireless input data and making corresponding processing. Hardware event can handle the serial events, timing counter events, IO interrupt and etc.

The ASCII data format is used during the communication of wireless network. According to Zigbee protocol, 0x00 is used as the coordinator's address, and the destination address 0xFF stands for broadcasting. BCC(block check character) is used for data validation, The format of data frame is shown as in Figure 6.

Data frame of upper machine:

| 0x40 | 0x6a 0x65 0x6e 0x30 | 0x35 0x31 | 0x0d |
|---|---|---|---|
| Head | Data payload | Check sum | End |

Broadcast data frame format of the coordinate:

| 0x30 0x30 | 0x66 0x66 | 0x6a 0x65 0x6e 0x30 | 0x35 0x31 | 0x0d |
|---|---|---|---|---|
| SrcAddr | DstAddr | Data payload | Check sum | End |

The frame format of coordinate's data that come from the terminal:

| 0x30 0x31 | 0x30 0x30 | 0x31 0x30……0x30 0x30 | 0x30 0x33 | 0x0d |
|---|---|---|---|---|
| SrcAddr | DstAddr | Data payload | Check sum | End |

Fig.6. Data frame format of Wireless Communication

Coordinator node gets a data frame which contains the frame head, data payload, check sum and the frame end from the site controller per second through serial port. Data payload includes the instruction of data collection and the output state control, among which, "0x6a 0x65 0x6e" shows that it needs all the sensor data from the coordinate, "0x30" means the switch status of the controller is closed. The data payload from the valid data of the upper computer, source node's address, destination node's address, checksum and the frame end are encapsulated to a data frame, and then it is broadcasted with the coordinator. The child nodes of coordinator gather their own and their child's sensor data, and encapsulate the sensor data with four ASCII characters into data payload, then sent to the node after adding source node's address, destination node's address, check sum and frame end.

**The field controller**

The field controllers are made up of the two embedded controllers as follows: duty room and tool-pusher room controller, and these two controllers play a role of on-site monitoring, which can't set the parameters of controller.

*a) The duty room controller*

The embedded controller of duty room adopts the ARM-Linux platform, and writes application interface in Qt/E. The hardware and software structure of duty room controller is shown in Figure 7.

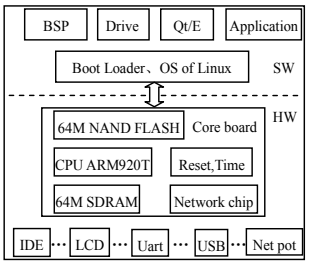



Fig.7. Hardware structure of duty room

The hardware platform consists of the core board which contains the ARM920T CPU, 64M SDRAM, 64M NAND FLASH, network chip and etc, and the external extensional serial port, network port, LCD & the touch screen interface and etc. The software of the controller uses the VIVI as its boot loader and embedded Linux as its operating system, then forms the software platform with the hardware driver and Qt/E environment. The software functions of duty room are mostly realized in the timer and contain the serial communication, data acquisition, data processing, modeling of monitoring function, real-time display and etc. The duty room can be used as the system controller individually, so it establishes the No.0 serial port communication sub-thread and the network communication sub-thread. The structure of program function is shown in Figure 8. The controller gets the parameters of well drilling engineering through the serial communication with the data acquisition subsystem and processes the data after obtaining data of each sensor.

*b) The design of embedded database*

As the duty room controller program needs to use the database for data storage, however, the duty room controller is an embedded platform, so it needs to choose an appropriate embedded database. At present, the commonly used database is: SQLite, Birkeley DB, Firebird in embedded server edition[15]. According to the actual demand of hardware platform resources, choose the SQLite which is compact, large capacity, high access speed and portable as the embedded database of duty room controller.

*c) The tool-pusher room controller*

The tool-pusher room controller mainly facilitates the driller to understand the drilling process with real-time data, the software and hardware architecture is almost the same with the duty room controller, besides, which basic data such as the volume of the mud tank, outlet flow and inlet flow are from duty room controller through the wireless local area network. When the tool-pusher room controller is used as a separate controller, it implements automatic/manual grouting in pulling out of hole through enabling the function in the software. In fact, independent controller that is designed for meeting the demand in the abnormity situation can be one of the duty room and tool-pusher room controller.

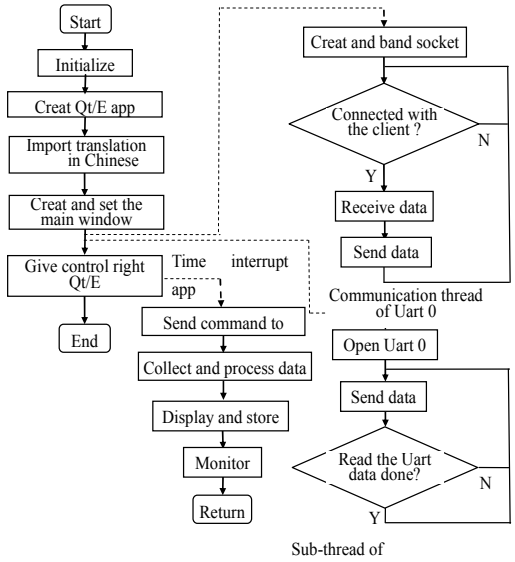



Fig.8. Flowchart of the program structure for duty room

**Remote monitoring system**

This system is C/S mode, in which the duty room controller makes the embedded controller server with data acquisition function and the remote monitoring system is the client. The hardware platform of remote monitoring system is based on industrial PC, and connects with duty room controller through the WLAN. The system software was developed in Visual Basic, which provides the main functions such as remote monitoring, analysis of drilling, related data processing, the curve shown in the historical or real-time way, simulated meter's indication, query of historical data and the output of report. It is not easy to set parameters for the embedded controller, so the parameter is set in remote industrial PC. The main function of parameter setting module is to set the key parameters of system, such as the correction of hook height etc. The time and interrupt service program is the data processing center of system, in which the network communication, data processing & storage, and output control are completed in the interrupt service program, besides, the cycle of data exchange with the site controller is 1s. As the communication data including drilling parameters and the state of controlled components each time is few and high frequency, thus UDP data transmission protocol was adopted, in which the data only needs to bind and doesn't need to connect before transmission. The communication packet consists of the drilling parameters, control instruction and other information. All the data in drilling engineering is saved with the Access database so as to query later.

**Conclusions**

According to the drilling site, this system implements the parameters collection, transmission and remote monitoring with the hybrid network structure based on Zigbee WSN, WLAN and embedded technology. To meet the demand of the drilling engineering with complex condition and high moving frequently, this paper provides available solutions for guaranteeing the safety of drilling. In addition, there is a lot of work such as the resistibility and anti-interference in the severe environment need to be solved in wireless network data exchange in future.

***Acknowledgments***

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***Authors**: prof. PhD. Guangyou Yang, School of Mechanical Engineering, Hubei University of Technology, Wuhan, 430068, China, E-mail: pekka@126.com; PhD. Zhiyan Ma, School of Mechanical Engineering, Hubei University of Technology, Wuhan, 430068, China, E-mail: mazhiyan2010@sohu.com; PhD. Wan Xu, School of Mechanical Engineering, Hubei University of Technology, Wuhan 430068, China, E-mail: cool handou@yahoo.com.cn; Xing Huang, School of Mechanical Engineering, Hubei University of Technology, Wuhan 430068, China, E-mail: huangxing2008135@yahoo.cn; Jingjing Zhou, School of Mechanical Engineering, Hubei University of Technology, Wuhan 430068, China, E-mail: zhoujing419354897@qq.com.*