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# Development of a Vertical Acceleration Sensor Based on Embedded Systems

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## Abstract

**This paper analyzes the acceleration detection requirements of the traveling block system and proposes an acceleration detection scheme using the traveling block as the target. An implementation plan based on the STM32 microcontroller and RS485 wired communication was developed. The hardware circuit and PCB design were carried out using components such as the STM32 microcontroller and MPU6050 gyroscope chip. Data acquisition and display were achieved through SPI and I2C communication implemented in software, while data was transmitted via wired communication using hardware UART peripherals. An experimental platform was built to test acceleration detection and wired data transmission. Compared with other design schemes, this design fully considers the impact of attitude changes on vertical acceleration detection, optimizing the sensor's detection algorithm and hardware design. It provides a technically valuable reference for engineering applications in related fields.**

## Keywords

**Embedded System; Sensor Design; Vertical Acceleration.**

## 1. Introduction

The drilling rig is one of the key components of oil extraction equipment and plays a critical role in oil extraction operations. Among the core systems of the drilling rig, the traveling block serves as a crucial element of the drilling process and, together with the crown block, forms the hoisting system [1-2]. Its primary function is to facilitate the lifting and lowering of the drilling rig, significantly influencing the efficiency and safety of oil extraction. During drilling operations, the driller must precisely control the traveling block to adjust the drilling depth of the drill bit. However, during the operation of the hoisting system, the traveling block typically undergoes four stages: acceleration, constant speed, deceleration, and stationary. Throughout these stages, due to inertial forces or external disturbances, the traveling block tends to exhibit swinging motions. This not only affects the stability and operational efficiency of the system but also poses potential safety risks. To effectively address these issues, vertical acceleration sensors, as critical components, are widely used to monitor and control the motion of the traveling block. Vertical acceleration sensors can monitor changes in the traveling block's vertical acceleration in real-time, capturing subtle fluctuations in its motion state. This provides precise motion parameters for system control. Especially during lifting and lowering phases, vertical acceleration data effectively reflect the impact of inertial effects and external disturbances, offering a basis for dynamic adjustments and vibration control. Furthermore, by combining the rapid response capabilities of embedded systems with high-precision signal processing technology, real-time monitoring and intelligent control of the traveling block's motion state can be achieved [3]. This significantly enhances the efficiency and safety of drilling operations.

In recent years, with the rapid development of embedded technology, the widespread application of high-performance microprocessors [4], low-power sensors [5], and high-

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precision algorithms has provided strong support for the development of vertical acceleration sensors[6-7]. Vertical acceleration sensors based on embedded systems integrate signal acquisition, data processing, and communication functions [8]. They not only offer advantages such as high precision, low power consumption, and real-time performance but also enable miniaturized and modular designs [9-10], meeting the demands of limited space and complex environments in drilling rigs. Moreover, with the help of wireless communication technology and Internet of Things (IoT) platforms, vertical acceleration sensors can achieve remote data transmission and monitoring, laying the foundation for the application of intelligent drilling technologies.

To address the aforementioned issues, this paper proposes the development of a vertical acceleration sensor based on an embedded system. The structure of the paper is as follows: Section 2 introduces the overall design of the control system; Section 3 details the hardware design scheme; Section 4 describes the software design approach; and finally, Section 5 summarizes the paper and offers prospects for future research directions.

## 2. System Overall Scheme Design

### 2.1. Research Object

A typical hoisting system, as shown in Figure 1, demonstrates that the winch system controls the rotation of the drum through a motor, thereby controlling the steel wire rope. The combination of the crown block system and the traveling block achieves a mechanical advantage for reducing effort. The crown block is fixed to the derrick, while the winch is secured to the track. One end of the steel wire rope is fixed, and the traveling block is mobile. The motion of the steel wire rope is directly related to the movement of the traveling block. The acceleration of the traveling block can be detected indirectly through the crown block and winch or directly through the traveling block itself.

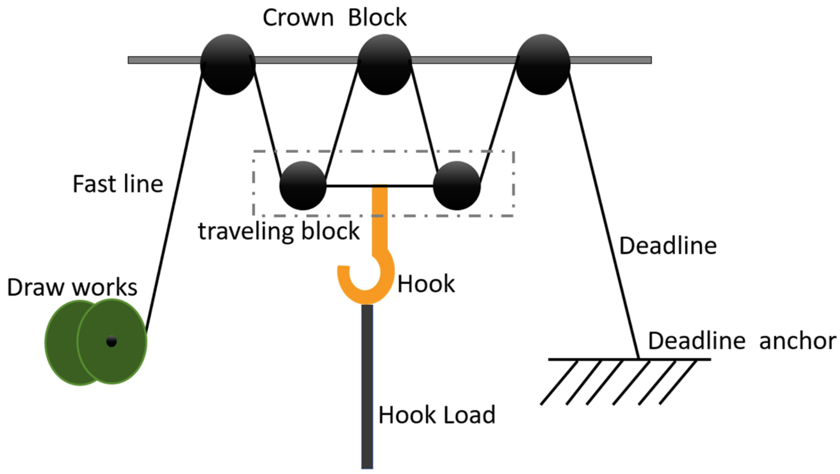


**Figure 1.** General lifting system

### 2.2. Detection Scheme

In current drilling operations, the drilling process is complex, tedious, and time-consuming, placing significant pressure on workers. Despite the company's substantial investment of resources into optimizing the motion curve of the drilling rig's hoisting system, the expected results have not been achieved, and worker safety remains a major concern. To address these issues, the acceleration detection system is designed with the traveling block as the measurement target. By installing an acceleration sensor on the traveling block, it directly

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measures its acceleration while ensuring safety. This design focuses primarily on the secondary development of the acceleration chip and control chip, along with the design of a circuit board and the programming of detection software to enable acceleration measurement. The measured signals are ultimately transmitted to the host computer via the RS485 module for storage and analysis. The overall design block diagram is shown in Figure 2.

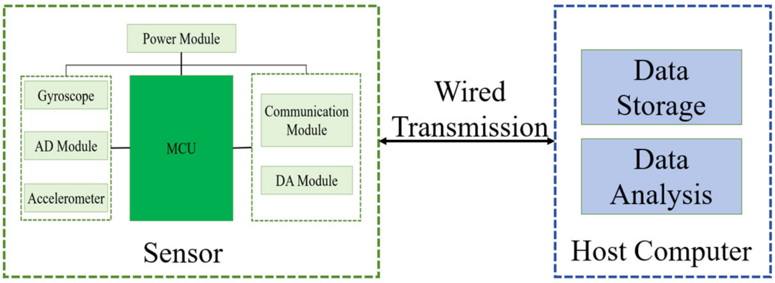


**Figure 2.** Overall Design Block Diagram.

## 3. Hardware Design Scheme

Based on the project requirements, this design primarily includes the following modules: power supply module circuit, RS485 interface circuit, AD/DA conversion circuit, peripheral circuits for the accelerometer and gyroscope chip, program download circuit, and MCU peripheral interface circuit, among others.

### 3.1. Power Module Circuit

Based on the selected core chips, a reasonable circuit design was implemented. Since the power supply voltage is 24V and the operating voltage requirements of each chip vary, voltage conversion and power protection circuits were designed for the power supply. It was determined that 5V, 3.3V, and 1.8V power supplies were needed, so circuits were designed for 24V to 5V, 5V to 3.3V, and 3.3V to 1.8V conversions, respectively. Considering the working environment and potential conditions such as thunderstorms, a power protection circuit was also designed. The circuit diagram is shown in Figure 3.

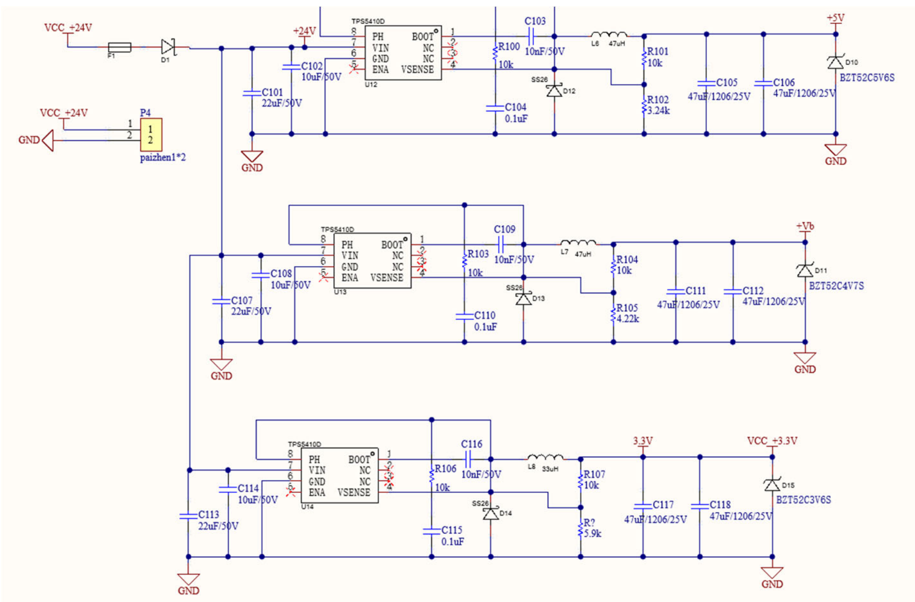


**Figure 3.** Power Module Circuit Design

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## 3.2. MCU Peripheral Circuit

The main control unit circuit design primarily involves designing the peripheral circuits of the STM32F103RCT6, such as the clock circuit, reset circuit, and SWD download circuit. The MCU peripheral circuit design is shown in Figure 4.

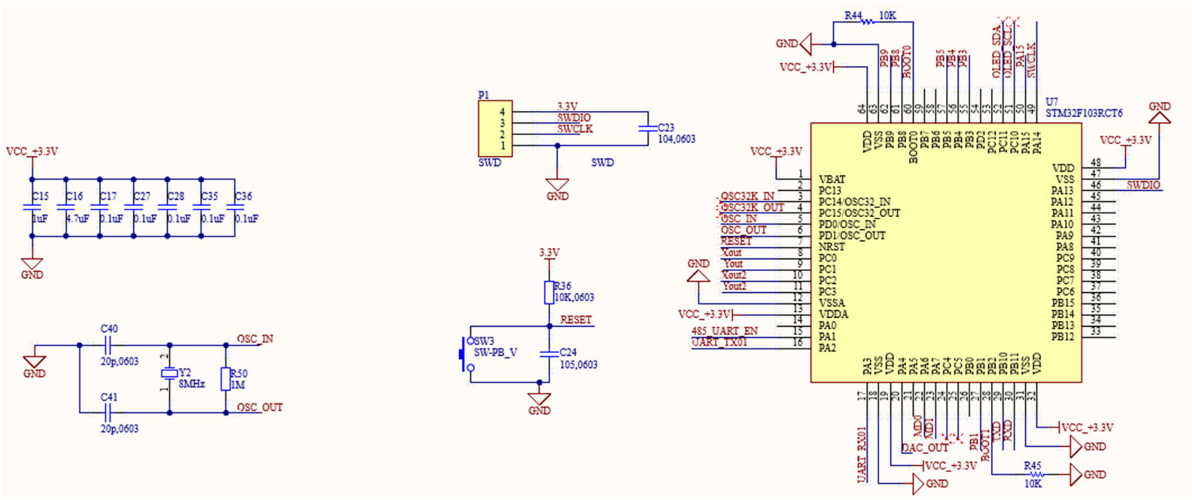


**Figure 4.** MCU peripheral circuit design

## 3.3. Communication Circuit

The RS485 communication adopts the MAX3485 chip, which is a high-performance, low-power RS485 transceiver chip. It offers strong anti-interference capability, high-speed transmission (supporting up to 10 Mbps), long-distance communication (up to 120 meters), and support for multi-point networking (up to 32 nodes). The chip includes built-in termination resistors, thermal protection, and short-circuit protection features, enhancing system reliability. Its compact package facilitates integration, making it suitable for applications in industrial control, communication, and automation. The RS485 communication circuit design is shown in Figure 5.

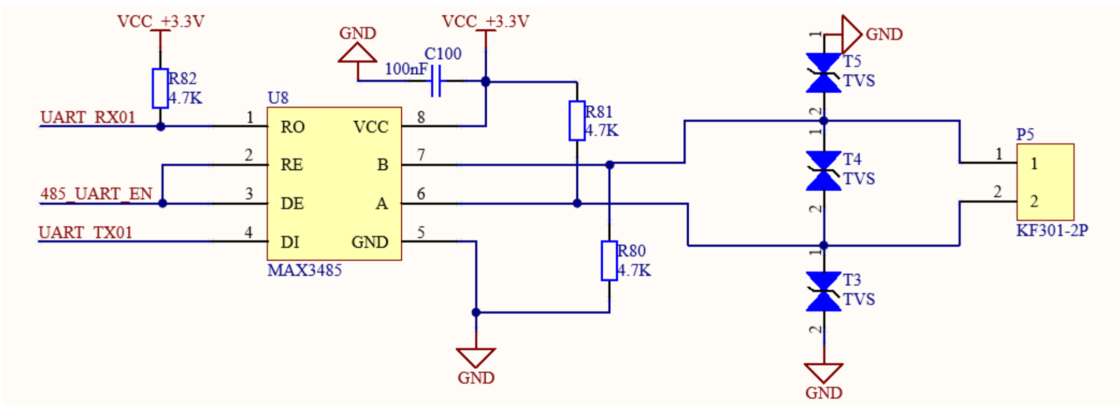


**Figure 5.** RS485 communication circuit design

## 3.4. Accelerometer and Gyroscope Peripheral Circuit

The accelerometer and gyroscope peripheral circuit design is shown in Figure 5.

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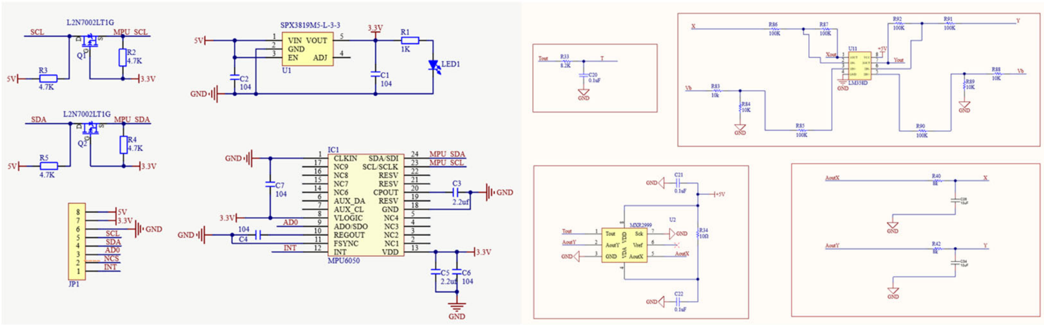
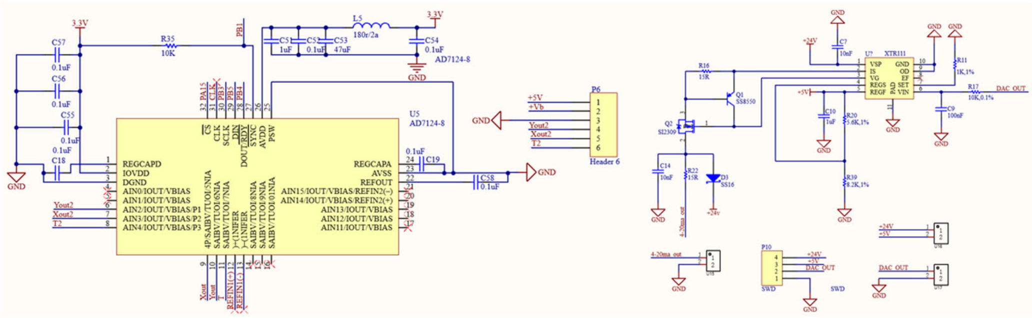


(a) Gyroscope (b) Accelerometer

**Figure 6.** Accelerometer and gyroscope peripheral circuit design

## 3.5. AD/DA Conversion Circuit

The AD7124 chip is selected to convert the analog signal data into digital signals for input into the STM32 controller, while the XTR111 chip is chosen to convert the digital signals from the STM32 into current signals for output. The AD/DA conversion circuit is shown in Figure 7, where (a) represents the AD module and (b) represents the DA module.



(a) AD Module (b) DA Module

**Figure 7.** AD/DA conversion circuit

## 3.6. PCB Design Considerations

The structural layout and the organization of traces on the PCB have a significant impact on whether the designed circuit board can function properly. Therefore, when designing the PCB for the vertical acceleration sensor, as shown in Figure 8, the following points should be considered:

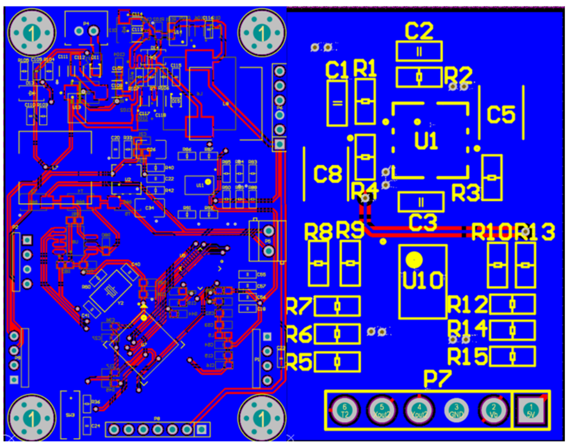



**Figure 8.** PCB diagram

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(1) To minimize coupling with other signals, the traces from the main control chip to the sensor coil should be as close as possible;

(2) Capacitors should be placed close to the components to filter out noise;

(3) Avoid routing too many traces around the sensor to prevent the magnetic field generated by current from affecting the geomagnetic sensor;

(4) After verifying the PCB layout rules are correct, apply large-area copper fills to improve anti-interference capability;

(5) The crystal oscillator should be placed close to the MCU, components should be arranged evenly, and traces should avoid 90-degree angles.

The physical circuit board is shown in Figure 9.

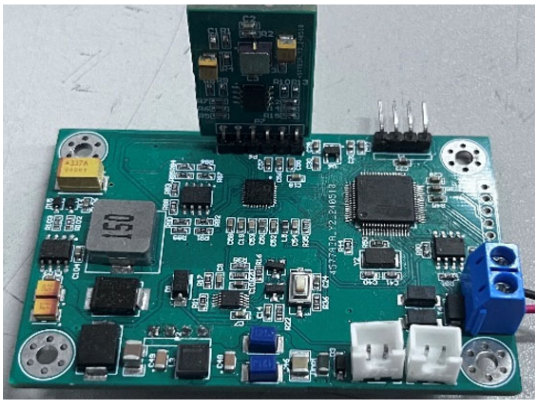

**Figure 9.** Vertical acceleration physical diagram

## 4. Software Design Scheme

### 4.1. Embedded System Program

Using KEIL software, a modular design approach was adopted to improve the readability and portability of the program in this study. Modular programming is a popular software design method, where the system's functionality is broken down into individual, manageable sub-tasks, and these smaller modules are then assembled to achieve the desired functionality. The software for the vertical acceleration sensor primarily implements three functions: data acquisition and processing, and data communication and transmission. It includes three main program modules: system initialization module, data acquisition and preprocessing module, and data transmission module. Figure 10 shows the functional block diagram of the vertical acceleration sensor software.

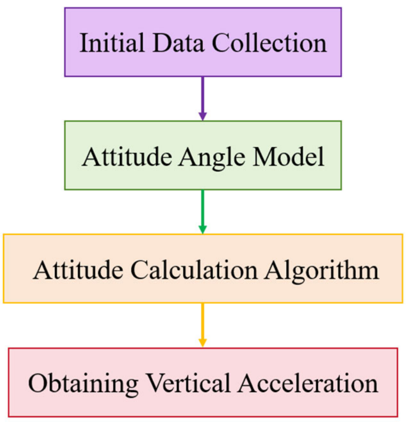


**Figure 10.** Functional implementation block diagram

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## 4.2. Embedded Program Design

In the software design, the system initialization module includes the initialization of microprocessor peripherals, such as IO ports, UART, SPI, and I2C, as well as the initialization of sensors like the MXR2999 and MPU6050. The data acquisition and preprocessing module focuses on the collection of data from the accelerometer and gyroscope, along with data filtering and attitude calculation. Figure 11 shows portions of the software code, where (a) is part of the main program code and (b) is part of the algorithm code.

```
int main(void)
{
    int16_t j=0;
    HAL_Init();
    SystemClock_Config();
    delay_init(72);

    MX_DAC_Init();
    MX_USART2_UART_Init();
  _485_Config();
    AD7124_Init();
    delay_ms(20);

    AD7124_8_Reset();/
    AD7124_8_INIT1();
    Delay(4000);
    delay_ms(100);

    HAL_DAC_Start(&hdac,DAC_CHANNEL_1);
    delay_ms(100);

    i2c_GPIO_Config();
    MPU6050_Init();
    if (MPU6050ReadID() != 1)
    {
         while (1);
    }
  HAL_UART_Receive_IT(&huart2,Rx_dat,4);
  while (1)
  {

    MPU6050ReadAcc(Accel);
    MPU6050ReadGyro(Gyro);
    Angle_Calcu();

  4ma  -0.5g
   12ma    0g
   20ma  0.5g
     if(Acc<-0.5) Acc=-0.5;
     if(Acc>0.5)  Acc=0.5;

     Data_value=5000+5000*Acc/0.5;
     set_dac(Data_value);
     GetVin[j]=voltage;
     GetAcc[j]=Acc;

    printf(" %.4f  %.4f \
    %5d  %5d  %5d \
     %5d  %5d  %5d\r\n",\
    Angle_X_Final,Angle_Y_Final,Accel[0], Accel[1],Accel[2],\
    Gyro[0],Gyro[1],Gyro[2]);

        }


  }

/**
  * @brief System Clock Configuration
  * @retval None
```

(a) Partial Main Program Code

```
void Angle_Calcu(void)
{
    float accx,accy,accz;

    MPU6050ReadAcc(accel);
    MPU6050ReadGyro(gyro);
    Accel_x = accel[0];
    Accel_y = accel[1];
    Accel_z = accel[2];
    Gyro_x  = gyro[0];
    Gyro_y  = gyro[1];
    Gyro_z  = gyro[2];

    if(Accel_x<32764) accx=Accel_x/16384;
    else              accx=1-(Accel_x-49152)/16384;
    if(Accel_y<32764) accy=Accel_y/16384;
    else              accy=1-(Accel_y-49152)/16384;
    if(Accel_z<32764) accz=Accel_z/16384;
    else              accz=(Accel_z-49152)/16384;

    Angle_x_temp=(atan(accy/accz))*180/3.14;
    Angle_y_temp=(atan(accx/accz))*180/3.14;

    if(Accel_x<32764) Angle_y_temp = +Angle_y_temp;
    if(Accel_x>32764) Angle_y_temp = -Angle_y_temp;
    if(Accel_y<32764) Angle_x_temp = +Angle_x_temp;
    if(Accel_y>32764) Angle_x_temp = -Angle_x_temp;

    if(Gyro_x<32768) Gyro_x=-(Gyro_x/16.4);
    if(Gyro_x>32768) Gyro_x=+(65535-Gyro_x)/16.4;
    if(Gyro_y<32768) Gyro_y=-(Gyro_y/16.4);
    if(Gyro_y>32768) Gyro_y=+(65535-Gyro_y)/16.4;
    if(Gyro_z<32768) Gyro_z=-(Gyro_z/16.4);
    if(Gyro_z>32768) Gyro_z=+(65535-Gyro_z)/16.4;

    Kalman_Filter_X(Angle_x_temp,Gyro_x);
    Kalman_Filter_Y(Angle_y_temp,Gyro_y);
}
```

(b) Partial Algorithm Program Code

**Figure 11.** partial code

## 5. Conclusion

Compared with traditional detection solutions, the vertical acceleration sensor based on an embedded system has the following significant advantages: it can capture dynamic changes during the lifting process in real time, directly reflecting the instantaneous state of the load; by integrating attitude calculation algorithms, the detection accuracy and stability of the system can be further improved; and in the circuit hardware design of the acceleration sensor, protective circuits are incorporated based on the functional characteristics of each module, enhancing operational stability. Through the application of the vertical acceleration sensor, this paper aims to optimize the motion curve of the drilling rig's hoisting system, minimize the adverse effects caused by motion attitudes, and improve both system operating efficiency and operational safety. However, more systematic and long-term field testing is needed in the future to further optimize the sensor and improve detection accuracy.

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