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# An Intelligent Fault Diagnosis Algorithm For Bearings That Integrates Attention Mechanisms With Convolutional Neural Networks

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**ABSTRACT**
Vibration monitoring equipment holds significant application value across various sectors, including industry, transportation, and construction. With the advancements in industrialization and automation, vibration monitoring technology has been extensively employed for real-time assessment and fault diagnosis of mechanical equipment. Analyzing vibration signals during equipment operation enables effective fault prediction and prevention, thereby enhancing both the safety and operational lifespan of the machinery. However, in numerous application scenarios, vibration monitoring equipment often encounters complex and variable environmental conditions, such as elevated temperatures, high humidity, and intense electromagnetic interference, which impose stringent demands on the reliability and stability of the devices.

**KEYWORDS**
Vibration Monitoring; GD32f407; Ad7606; Cloud Analysis; Safety Level

## 1 Introduction

To ensure the safe operation of vibration monitoring equipment in extreme environments, a safety level assessment is of paramount importance. The safety level serves not only as an indicator of the equipment's suitability in a specific environment but also as a crucial basis for ensuring industrial production safety. Currently, international safety level certification standards for electronic equipment, such as IEC 61508 (functional safety standard) and ISO 13849 (mechanical safety standard), are widely applied. However, research on safety levels specifically tailored for vibration monitoring equipment is still in its nascent stages. Therefore, developing a safety level assessment device suitable for vibration monitoring equipment can not only fill the gap in existing research but also provide a scientific technical basis for the design, manufacturing, and use of related equipment. This research aims to design and implement a safety level assessment device for vibration monitoring equipment. By simulating various extreme environmental conditions (such as vibration intensity, temperature, humidity, and electromagnetic interference), the device will comprehensively test the equipment's performance and stability and scientifically assess the equipment's safety level based on the test results. The development of this device provides a reliable testing tool for manufacturers of vibration monitoring equipment and offers important references for users in selecting appropriate equipment. Ultimately, this research hopes to promote the wider application of vibration monitoring equipment in critical fields by enhancing its safety, thereby ensuring the safety and efficiency of industrial production.

## 2 Overall System Architecture

The system is centered around the GD32F407 microcontroller, integrated with the AD7606 module for high-precision acquisition of vibration signals. Wireless transmission of vibration data is facilitated through the WH-LTE-7S4 module, with the data subsequently uploaded to the Tencent Cloud server for storage and analysis. Users can monitor device status and view vibration assessment results in real-time through the front-end interactive interface. The overall structure of the system is illustrated in Figure 1.

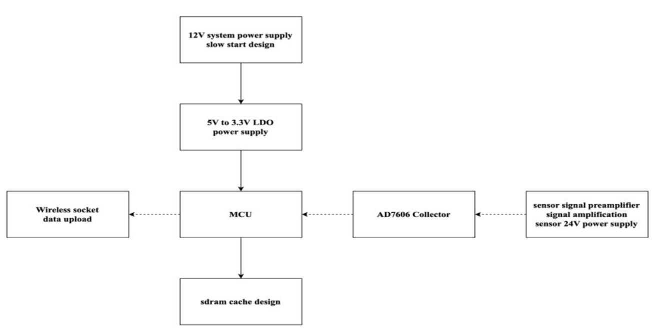


Figure 1 The overall structure of the system

## 3 System Overview

This system is an integrated data acquisition and analysis device designed for industrial environments, specifically targeting temperature, vibration, and combustible gas composition signals. Its primary objective is to enable real-time monitoring and predictive analysis of equipment operational status. The system is built around a microcontroller as the core processor, utilizing the high-precision analog-to-digital converter (ADC) AD7606 for multi-channel signal acquisition. It incorporates data analysis algorithms for signal pre-processing, feature extraction, and trend analysis. The key functionalities of this system include: Multi-physical quantity signal acquisition, implemented using the AD7606 for high-precision synchronous acquisition, supporting sensor signal inputs for temperature, vibration, and gas composition, thereby ensuring data integrity and timeliness. Data processing and analysis, which enhances signal quality through pre-processing techniques such as filtering and noise reduction, and performs anomaly detection based on national standards. Furthermore, it calculates signal change rates using numerical differentiation to analyze equipment status trends, enabling early fault warnings. Through embedded algorithms, the system can monitor the operational status of industrial equipment in real-time, analyze signal changes, and provide feedback to on-site or remote terminals, supporting operational and maintenance decisions. Data transmission is facilitated via wired or wireless 4G communication, with support for both local and cloud storage, enabling long-term data analysis and retrieval. The design goals of this system are to provide an efficient, stable, and intelligent industrial signal monitoring solution, thereby improving equipment health management, reducing unexpected failures, and enhancing the safety and reliability of industrial production. The system employs a high-performance GD32 series microcontroller as the core processor, responsible for data acquisition, pre-processing, and computation. It integrates the AD7606 as an ADC to achieve multi-channel synchronous acquisition, supporting analog signal inputs for temperature, vibration, and combustible gases. The following are some of the modules used:

### 3.1 Data acquisition module

Data acquisition module integrates the HG6800A vibration sensor with the AD7606 high-precision analog-to-digital converter to facilitate the efficient capture of vibration signals from mechanical equipment. The HG6800A is a highly sensitive vibration sensor capable of detecting subtle vibrational characteristics during machinery operation and outputs an analog voltage signal. The AD7606 is responsible for performing high-resolution analog-to-digital conversion of the signals produced by the HG6800A, supporting synchronous sampling across 8 channels with 16-bit precision, and achieving a maximum sampling rate of 200 kSPS, making it suitable for multi-axis vibration monitoring applications. The HG6800A and AD7606 are connected via shielded cables to effectively minimize electromagnetic interference, ensuring the integrity of the acquired signals.

### 3.2 Data processing module

The data processing module is responsible for the efficient processing and analysis of collected vibration signals, serving as a crucial component in assessing vibration safety levels. The raw data acquired is filtered, feature-extracted, and subjected to frequency domain analysis using the GD32F407 microcontroller. Initially, IIR or FIR digital filtering algorithms are employed to eliminate high-frequency noise and low-frequency interference, ensuring the integrity of the signal. Subsequently, Fast Fourier Transform (FFT) is utilized to convert the time-domain signals into frequency-domain representations, extracting spectral characteristics of the vibration data, including fundamental frequency and amplitude.

### 3.3 Wireless transmission module

The wireless transmission module facilitates the remote transmission of vibration data through the WH-LTE-7S4 4G communication module, serving as a critical link between the device endpoint and the cloud. After collection and processing, the vibration data is organized by the GD32F407 microcontroller and transmitted to the WH-LTE-7S4 module via the UART interface. This module supports TCP/UDP protocols, enabling rapid upload of vibration data to the Tencent Cloud server, thereby ensuring low latency and high reliability in data transmission. To accommodate complex industrial environments, the module is equipped with reconnection and data buffering capabilities, effectively addressing signal interruptions and network fluctuations.

## 4 System Software Documentation

The software algorithms within this system are primarily designed for the acquisition, processing, and analysis of temperature, vibration, and combustible gas signals. These algorithms facilitate anomaly detection and generate alerts based on observed trend variations. The comprehensive algorithmic framework encompasses several key modules: data pre-processing, signal feature extraction, rate-of-change computation, anomaly detection, and trend prediction. The ultimate objective is to furnish an efficient and precise industrial monitoring solution.

### 4.1 Data preprocessing

In a data acquisition system based on the AD7606, a Kalman filter algorithm is employed for preprocessing the acquired data to effectively eliminate low-frequency noise and enhance signal quality. As an optimal estimation technique, the Kalman filter utilizes a recursive algorithm to provide real-time state estimation of the system, making it particularly suitable for processing dynamic systems with noise. In this design, the state and observation equations of the Kalman filter are formulated as follows:

$$x_k = Ax_{k-1} + w_k$$
$$z_k = Hx_k + v_k$$

Here, xk represents the state vector of the system at time kk, A denotes the state transition matrix, wk signifies the process noise, zk is the observation vector, H is the observation matrix, and vk represents the observation noise. Through the prediction and update steps of the Kalman filter, the system can iteratively refine the state estimation, thereby effectively mitigating the impact of low-frequency noise. Experimental results demonstrate a significant enhancement in the signal-to-noise ratio of the data following Kalman filter preprocessing, providing a robust foundation for subsequent signal analysis and processing.

### 4.2 Data Alert Module

In data acquisition and monitoring systems, threshold alarms and rate-of-change alarms are two commonly employed real-time monitoring mechanisms designed to detect data anomalies and promptly issue alerts. Following data preprocessing steps, such as Kalman filtering, this system incorporates both threshold and rate-of-change alarm modules to ensure a rapid response to anomalous conditions. A detailed description of this module is provided below:

Threshold alarms function by establishing upper and lower data thresholds to determine if the acquired data falls outside the acceptable range. The implementation details are as follows:

Threshold Configuration: Define upper (Uth) and lower (Lth) threshold limits for the data, based on the specific application context and signal characteristics.

Alarm Trigger: Initiate a threshold alarm when the acquired data, denoted as xk, satisfies the following condition:

$$x_k > U_{th} \ \ or \ \ x_k < L_{th}$$

Alarm Output: The system logs alarm timestamps, values, and types (upper or lower limit), notifying the user via audible and visual alerts, SMS, or software interface.

The rate-of-change alarm functions by monitoring the velocity of data fluctuations to ascertain the presence of anomalous oscillations. The specific implementation is as follows:

Rate of Change Calculation: At time step kk, compute the rate of change xk of the current data xk-1 with respect to the previous time step data rk.

$$r_k = \frac{x_k - x_{k-1}}{\Delta t}$$

Here, Δt denotes the sampling time interval.

Rate-of-change threshold configuration: Define the rate-of-change threshold, Rth, based on system requirements.

Alarm condition: Trigger a rate-of-change alarm when the rate of change, rk, satisfies the following condition:

$$|r_k| > R_{th}$$

Alarm output: The system logs the alarm time, rate-of-change value, and alarm type (positive or negative change) and notifies the user.

The threshold and rate-of-change alarm modules enable real-time data monitoring for timely anomaly detection. Threshold and rate parameters are flexibly adjustable to accommodate diverse application scenarios. Integration with Kalman filtering for preprocessing effectively mitigates noise interference, thereby enhancing the accuracy of the alarm system.

## 5 Experimental Description

This experiment aims to validate the performance of the designed signal acquisition and analysis system in an industrial field environment, focusing on its ability to acquire, process, and analyze temperature, vibration, and combustible gas signals. The experiment is divided into five main stages: system setup, data acquisition, signal processing, anomaly detection, and results analysis.

Initially, the experimental platform is constructed, comprising signal acquisition hardware, a GD32 microcontroller for data processing, and storage and communication modules, with an AD7606 utilized as the analog-to-digital converter. The sensor suite includes thermocouples/PT100 (temperature), IEPE accelerometers (vibration), and electrochemical gas sensors (combustible gases). Calibration of the sensors is performed to ensure data accuracy. As shown in Figure 2.

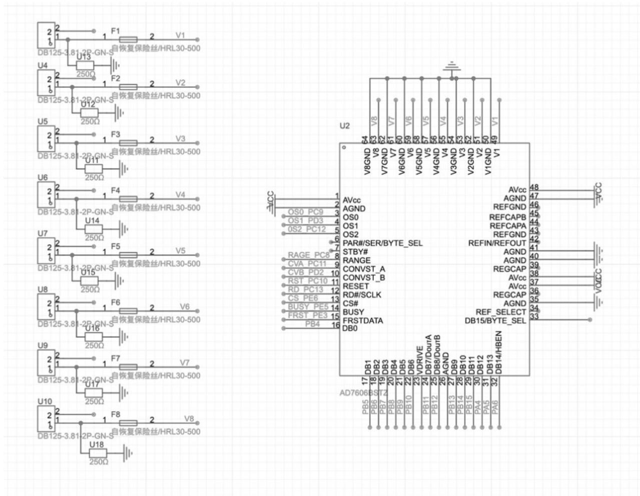

*Figure 1. The circuit diagram for the data acquisition module*

During the data acquisition phase, sensors were installed within a temperature-controlled chamber, a vibration table, and a flammable gas testing chamber. Signal data under various operating conditions were obtained by controlling environmental temperature, simulating mechanical vibrations, and adjusting gas concentrations. The system recorded data at a sampling rate of 50 kHz (vibration) and 1 Hz (temperature, gas), transmitting the data in real-time to a host computer for analysis.

In the signal processing phase, algorithms such as digital filtering (low-pass filtering, Kalman filtering) and rate of change calculations (numerical differentiation) were employed to denoise, extract features, and analyze trends in the raw data. Subsequently, anomaly detection was performed on the acquired data based on national standard thresholds to determine the presence of temperature anomalies, excessive vibration, or flammable gas leaks.

Finally, the experimental results were compared to analyze the system's detection accuracy under different operating conditions and to validate the predictive capabilities of trend forecasting algorithms (ARIMA/LSTM) for early warning of anomalous signals. The results of this experiment will be used to optimize system parameters, improve monitoring accuracy, and enhance real-time performance, thereby providing reliable data support for industrial equipment health management. The data is shown in Figure 3.

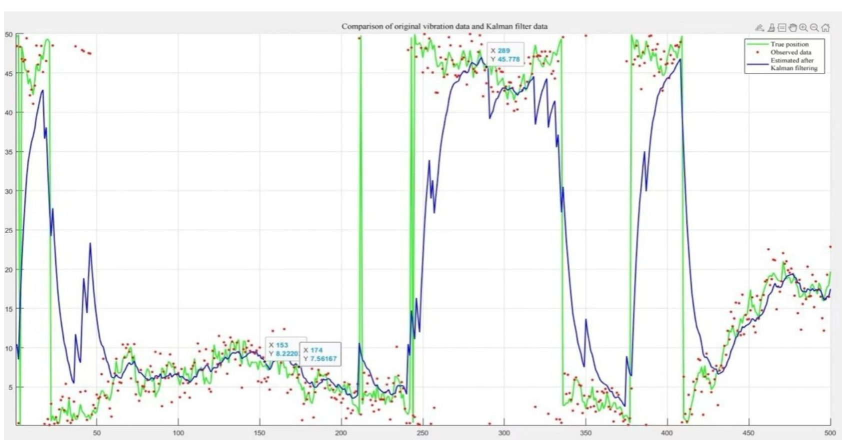


Figure 3 Comparison of original vibration data and Kalman filter data

During the acquisition of vibration signals, the data obtained are often corrupted by high-frequency noise due to the operational characteristics of circuits and sensors, leading to signal drift or fluctuation. This noise originates not only from the precision errors of the sensors themselves but also from external factors such as electromagnetic interference and power supply fluctuations. To address this issue, a Kalman Filter algorithm is employed to smooth the acquired signals.

The Kalman Filter is a recursive estimation algorithm that effectively extracts the true trend of a signal from noisy observational data by comprehensively considering the system's process model and the noise characteristics of the observations. Through prediction and update of the signal, the Kalman Filter dynamically adjusts the system's estimated values and adaptively optimizes the filtering process based on the noise level, significantly reducing the impact of high-frequency noise and improving signal stability and accuracy. In this project, the Kalman Filter has been successfully applied to the processing of vibration signals, effectively removing signal drift caused by circuit noise and external interference, thus providing a more reliable signal foundation for subsequent fault diagnosis and analysis.

## 6 Conclusion

This research effort has resulted in the design and implementation of a multi-signal acquisition and analysis system based on a single-chip microcomputer and the AD7606, tailored for the real-time monitoring and anomaly detection of industrial field signals, including temperature, vibration, and combustible gases. The system integrates high-precision sensors, analog-to-digital conversion, electrical signal processing, and intelligent analysis algorithms. Through methods such as numerical differentiation, anomaly detection, and trend prediction, the system conducts in-depth signal analysis to provide reliable equipment condition assessments and early warning capabilities. Experimental results demonstrate that the system can stably acquire and process multiple signals under complex operating conditions, exhibiting high accuracy in anomaly detection and trend prediction. By optimizing signal processing algorithms and machine learning models, the system achieves precise evaluations of industrial equipment operating states, contributing to enhanced equipment operational safety, reduced failure rates, and optimized maintenance management. Future work will focus on further algorithm optimization, improving model adaptability, and integrating wireless transmission and cloud computing to enable remote monitoring and intelligent decision analysis, thereby enhancing the system's industrial application value.

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## About the Author

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