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Handheld Vibration Analyzer for Fault Prediction

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Abstract – Predictive maintenance has become a critical requirement in modern industries to minimize downtime and prevent catastrophic machine failures. Conventional vibration analyzers, while effective, are often bulky and expensive, limiting their accessibility for field engineers and small-scale industries.

This paper presents the design and development of a handheld fault-predicting vibration analyzer built around the Shrike development board and a piezoelectric vibration sensor. The system captures vibration signals from rotating machinery, processes them through the microcontroller's high-resolution ADC, and stores data. Experimental validation demonstrates that the proposed system can reliably detect early fault conditions, making it suitable for predictive maintenance

applications in industrial environments.

Keywords: Shrike development board, vibration sensor

1. Introduction

In today's world, in industries and automotive systems, unexpected mechanical failures often lead to costly downtime, safety risks, and reduced efficiency. By continuously monitoring vibration signals and digitising them through multiple ADC channels, the analyser provides precise insights into the health of machinery. The integration of an SD card for offline storage ensures that large volumes of data can be preserved and analysed over time, enabling engineers to identify patterns and predict faults before they escalate. This project is significant because it offers a compact, cost-effective, and portable solution that bridges the gap between real-time sensing and actionable maintenance decisions. It empowers organisations to move from reactive repairs to proactive. All the four ADC channels are configured to record a defined number of samples, ensuring accurate representation of system dynamics. The digitised data is stored on an SD card, enabling offline analysis and long-term monitoring of equipment health. By combining real-time acquisition with accessible storage, the analyser provides a reliable means of detecting early signs of mechanical faults, thereby reducing downtime and improving operational efficiency.

2. Literature Survey

1. The literature on gearbox fault diagnosis mainly focuses on vibration-based condition monitoring, fault detection, and predictive maintenance in railway and automotive systems. Researchers have developed several methods using accelerometer sensors, embedded systems, signal processing techniques, and intelligent monitoring algorithms to detect gearbox faults at an early stage.

2. According to the paper Gearbox Fault Diagnosis of High-Speed Railway Train by Bin Zhang, A.C.C. Tan, and Jianhui Lin, vibration analysis was used to investigate crack faults in high-speed railway gearboxes. Accelerometer sensors were mounted on the gearbox body to collect vibration and dynamic stress data during train operation. The

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researchers performed modal analysis and finite element analysis to identify resonance and stress concentration points in the gearbox structure. The study concluded that vibration monitoring effectively detected crack faults and improved gearbox reliability in railway applications.

3. Another important study, Torque Effect on Vibration Behavior of High-Speed Train Gearbox Under Internal and External Excitations by Yue Zhou et al., investigated the effect of torque and wheel–rail interaction on train gearbox vibration behavior. Multiple acceleration responses were measured from the gearbox under different torque and rotational speed conditions. Dynamic modeling and modal identification techniques were applied to analyze gearbox vibration characteristics. The study reported that torque significantly affects gear meshing vibration and gearbox modal characteristics, which is important for predictive maintenance of high-speed train gearboxes.

4. In the paper State-Degradation-Oriented Fault Diagnosis for High-Speed Train Running Gears System by Chao Cheng et al., a state-degradation-oriented fault diagnosis system was proposed for high-speed train running gears. Multiple vibration sensors were used to collect gearbox and bearing vibration signals. The collected data was processed using Wiener state degradation modeling and multi-sensor filtering methods to identify fault progression. The proposed method successfully improved fault detection accuracy and reliability of railway transmission systems.

5. Researchers have also focused on analyzing vibration and stress characteristics in railway gearboxes. In Vibration and Stress Response of High-Speed Train Gearboxes under Different Excitations, vibration data from high-speed train gearboxes was measured and analyzed under different excitation conditions. The study investigated vibration transmission characteristics and stress response behavior of the gearbox system. The authors concluded that vibration monitoring helps in understanding gearbox dynamic performance and detecting abnormal operating conditions effectively.

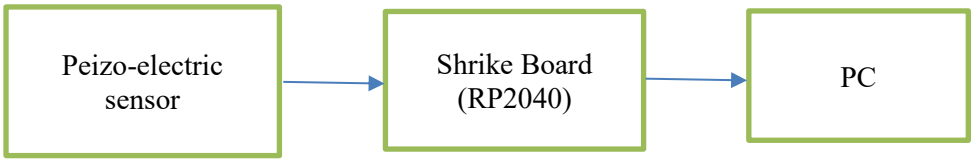
6. In automotive applications, the paper Automotive Gearbox Fault Diagnosis Using Vibration Signal Analysis proposed a vibration-based fault diagnosis system for automobile gearboxes. Accelerometer vibration sensors were mounted on the gearbox casing to collect vibration signals under healthy and faulty conditions. Fast Fourier Transform (FFT) analysis was used to identify characteristic fault frequencies caused by gear wear, broken teeth, and shaft misalignment. The study concluded that vibration signal analysis provides effective early-stage fault detection in automotive transmission systems.

3. Proposed System

The proposed system is a low-cost vibration-based fault prediction and condition monitoring system built around a Shrike board, a piezoelectric accelerometer. The piezoelectric sensor is mounted directly on the machine to capture vibrations and convert them into electrical signals. These sinewave signals are fed to the Shrike board, where they undergo A-to-D conversion and real-time processing. The system continuously compares the processed vibration levels against predefined threshold values to detect abnormal conditions and potential faults. All collected vibration data and detected fault information are automatically logged onto the PC for further analysis and record-keeping.

This approach enables early fault detection, shortens unplanned machine downtime, and offers an affordable solution for predictive maintenance in industrial environments.

1) BLOCK DIAGRAM



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4. Methodology

4.1. Mathematical Calculations:-

- 100 kHz per channel
- That means:
- 100,000 samples / second / channel
- samples with respective time
- 0.05 sec
- 100,000 × 0.05 = 5,000 samples
- 0.10 sec
- 100,000 × 0.10 = 10,000 samples
- 0.20 sec
- 100,000 × 0.20 = 20,000 samples
- Total samples (4 ADC channels)
- You are using 4 channels (ADC0–ADC3)
- Formula:
- Total samples = Samples per channel × Number of channels
- 0.05 sec
- 5,000 × 4 = 20,000 total samples
- 0.10 sec
- 10,000 × 4 = 40,000 total samples
- 0.20 sec
- 20,000 × 4 = 80,000 total samples

- **SOFTWARE PART:-**

- **GPIO Configuration**

GPIO 20	**Function Start acquisition button**
GPIO 21–24	**Data acquisition channel selection**
GPIO 17	**Acquisition time = 0.05 s**
GPIO 18	**Acquisition time = 0.10 s**
GPIO 19	**Acquisition time = 0.20 s**

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All inputs use internal pull-down resistors to ensure stable logic levels

ADC Inputs

Port pins	Alternate function
GPIO 26	ADC0
GPIO 27	ADC 1
GPIO 28	ADC 2
GPIO 29	ADC 3

- **ADC Configuration**
  1. ADC Channel:- ADC0 ADC1 ADC2 ADC3
  2. ADC operates in round-robin mode
  3. FIFO enabled with DMA request
  4. ADC resolution: 12-bit
  5. FIFO threshold: 1 sample

  Data stored as 16-bit unsigned values

- **Memory Allocation**

  Total samples are calculated as:

  Samples Rate Time Count Total Samples = Sample Rate×Acquisition Time×Channel Count Dynamic memory allocation (malloc) is used to store the acquired samples. Error handling ensures safe operation if memory allocation fails.

- **Data Acquisition Flow**
  1. User selects ADC channels and acquisition time
  2. User presses the START button
  3. DMA and ADC are started simultaneously
  4. ADC samples are captured into RAM
  5. DMA signals completion
  6. ADC is stopped
  7. System waits for PC command The LED indicates active acquisition status.

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- **Algorithm: RP2040 ADC Data Acquisition System**

➤Step 1 Start the system → Initialize USB standard I/O → Delay for USB enumeration

➤Step 2 Initialize GPIO pins → Configure channel select pins → Configure time select pins → Configure START button → Configure LED pin

➤Step 3 Initialize ADC → Enable ADC GPIO pins (ADC0–ADC3) → Configure ADC FIFO → Enable DMA request

➤Step 4 Read ADC channel selection pins → Generate ADC channel mask Step 5 Read acquisition time selection pins → Determine acquisition time

➤Step 6 Check configuration validity → At least one ADC channel selected → Valid acquisition time selected → START button pressed

➤Step 7 Generate channel list → Count number of selected ADC channels

➤Step 8 Calculate ADC clock divider → clkdiv = 48 MHz / (Sample Rate × Channel Count)

➤Step 9 Configure ADC clock divider → Enable round-robin ADC mode

➤Step 10 Calculate total samples → Total Samples = Sample Rate × Acquisition Time × Channel Count

➤Step 11 Allocate memory for ADC buffer → If allocation fails → Halt system

➤Step 12 Configure DMA → Source = ADC FIFO → Destination = ADC buffer → Transfer size = 16-bit → Transfer count = Total samples

➤Step 13 Turn ON status LED → Start DMA → Start ADC conversion

➤Step 14 Wait until DMA transfer completes

➤Step 15 Stop ADC conversion → Turn OFF status LED

➤Step 16 Send acquisition complete message to PC → Enter command wait mode

➤Step 17 Receive USB command → If command = READ → Send ADC data in CSV format

➤Step 18 Remain in idle state waiting for further commands

- **Algorithm: PC-Side Python Data Logging**

➢ Step 1 Start Python program → Import serial and time libraries
➢ Step 2 Open USB serial port → Wait for communication stabilization
➢ Step 3 Send READ command to RP2040
➢ Step 4 Wait for BEGIN_CSV marker from RP2040
➢ Step 5 Read incoming data line by line → Store CSV data
➢ Step 6 Detect END_CSV marker → Stop data reception
➢ Generate timestamp-based filename
➢ Create CSV file → Write stored data → Close file
➢ Close serial port → End program CSV File Screenshot Commands To run Program files:for
➢ rp2040 SDK :-

- mkdir build
- cd build

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- cmake
- make -j4
- cp <project name>.uf2 /media/$USER/RPI-RP2/
- minicom -b 115200 -D /dev/ttyACM0 for check terminal data for python script
- python3 <project name>.py

1. Results and Discussion

1. The ADC values represent the digitized signals captured from the reference of stable pot.
2. The readings show consistent and smooth variation across samples, indicating stable data acquisition by the Shrike board .

sample	adc0	adc1	adc2	adc3
0	637	689	724	1072
1	684	715	748	1048
2	722	741	770	1031
3	753	763	789	1014
4	779	780	806	1001
5	801	798	821	989
6	820	814	834	979
7	836	828	846	971
8	851	839	857	964
9	862	849	864	958
10	873	858	874	953
11	882	866	881	948
12	888	873	888	945
13	897	880	892	941
14	901	884	898	939
15	907	890	903	937
16	911	893	906	934
17	914	898	909	933
18	918	901	913	932
19	921	905	915	930
20	923	907	918	930

```
START ADC
Channels selected      : 4
Acquisition time       : 0.20 sec
Total samples (DMA)    : 80000

===== ACQUISITION SUMMARY =====
Total samples stored   : 80000
Samples per channel    : 20000
==============================

First 10 samples:
Sample  0: ADC0= 920 ADC1=1248 ADC2=1610 ADC3=2127
Sample  1: ADC0= 946 ADC1=1204 ADC2=1529 ADC3=1977
Sample  2: ADC0= 964 ADC1=1166 ADC2=1452 ADC3=1848
Sample  3: ADC0= 977 ADC1=1133 ADC2=1382 ADC3=1733
Sample  4: ADC0= 987 ADC1=1106 ADC2=1324 ADC3=1634
Sample  5: ADC0= 993 ADC1=1081 ADC2=1274 ADC3=1546
Sample  6: ADC0= 997 ADC1=1062 ADC2=1229 ADC3=1480
Sample  7: ADC0= 998 ADC1=1044 ADC2=1191 ADC3=1413
Sample  8: ADC0= 998 ADC1=1028 ADC2=1158 ADC3=1355
Sample  9: ADC0= 998 ADC1=1015 ADC2=1129 ADC3=1302
```

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➢ Conclusion:-

In this project, a handheld vibration monitoring system was successfully developed for vibration data acquisition. The user interface allows selection of channels and data acquisition time, followed by starting the data acquisition process. The RP2040 (Dual-core ARM Cortex-M0+) was utilized as the central processing unit for high-speed data acquisition and analog-to-digital conversion.

Overall, the project demonstrates a simple, effective, and low-cost solution for vibration analysis that can be applied in industries to monitor machine health, reduce breakdowns, and improve maintenance efficiency.

➢ Future Scope:-

The developed handheld vibration analyzer provides a strong foundation for predictive maintenance using vibration analysis. However, several enhancements can be implemented to make the system more advanced, intelligent, and industry-ready:

1. Wireless Connectivity and IoT Integration
   - Add Wi-Fi or Bluetooth module to enable real-time data transmission to a cloud platform or mobile application for remote monitoring.
2. Advanced Machine Learning Algorithms
   - Implement AI/ML models (such as SVM, Random Forest, or Deep Neural Networks) for automatic fault classification and more accurate fault prediction.
3. Multi-Sensor Fusion
   - Integrate additional sensors like temperature, acoustic emission, and current sensors to provide comprehensive machine health monitoring through sensor fusion techniques.
4. Real-Time FFT and Advanced Signal Processing
   - Enhance onboard processing capabilities to perform real-time Fast Fourier Transform (FFT), envelope analysis, and kurtosis calculation for better fault diagnosis.
5. Data Logging and Cloud Analytics
   - Implement long-term vibration trend analysis on the cloud to predict Remaining Useful Life (RUL) of machinery components.
6. Mobile Application Development
   - Develop a dedicated Android/iOS application for live data visualization, historical trend analysis, and instant fault alerts.
7. Miniaturization and Improved Battery Life
   - Further reduce the size and weight of the device and optimize power consumption for extended field usage.
8. Industrial Integration
   - Enable compatibility with Industry 4.0 standards for seamless integration into large-scale industrial automation and SCADA systems.
9. Edge Computing Capabilities
   - Upgrade the processing unit to support edge AI for faster on-device decision-making with minimal latency.

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