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A Portable and Cost-Effective Multi-Sensor Fusion System for Fault Diagnosis of Electric Motors and Generators

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Stick to produce imbalance

Fig no.1- grinding machine with mobile

Fig no.2- grinding machine with mobile

The proposed system combines information from vibration, acoustic, and temperature measurements.

The combined feature set is represented as:

$F = [F_v + F_a + F_t]$

where:

F_v = vibration features

F_a = acoustic features

F_t = temperature features

Fault diagnosis was carried out using simple decision rules.

Fault Type	Observed Characteristics
Healthy	Low vibration and stable temperature
Imbalance	Increased vibration amplitude
Misalignment	Harmonic frequency components
Bearing Fault	High-frequency noise and temperature rise

1. EXPERIMENT AND DATA ACQUISITION

Before conducting the experiment, the bench grinder was visually inspected to ensure proper mechanical condition and safe operation. The smartphone was securely mounted on the motor housing using a rope support arrangement to maintain sufficient mechanical coupling between the machine body and the smartphone sensors.

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The smartphone was configured with the phyphox application operating in FASTEST acquisition mode for recording accelerometer and acoustic data. The experimental trial was conducted in three stages and data was captured in all the three stages. As experiments were carried for shorter time so no much variations were observed in temperature data and also it was not possible to create such situation on bench level,

a. Normal-Speed Trial

Initially, the bench grinder was operated under normal balanced condition without introducing any disturbance. Vibration, acoustic, and temperature data were recorded to establish baseline operating characteristics of the machine. The recorded data for vibration and acoustic are shown in fig No.3 &4

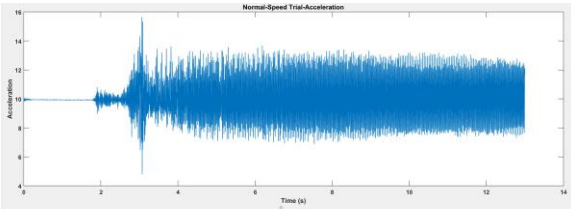

Fig no.3-Vibration data at normal sp

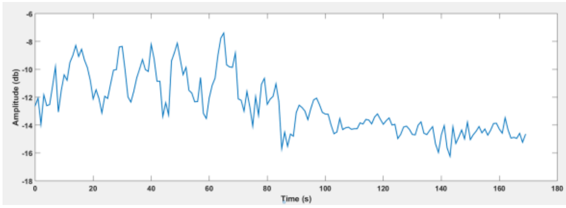

Fig no.4-acoustic data at normal speed

b. High-Speed Trial

In the second stage, the motor was operated at increased rotational speed. Data acquisition was repeated under this condition and shown in fig no.5 &6.

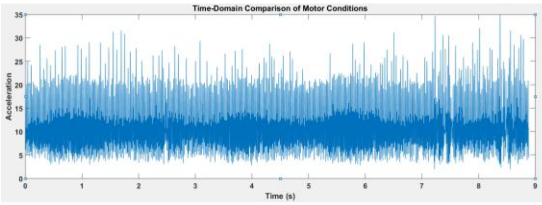

Fig no.5-Vibration data at high speed

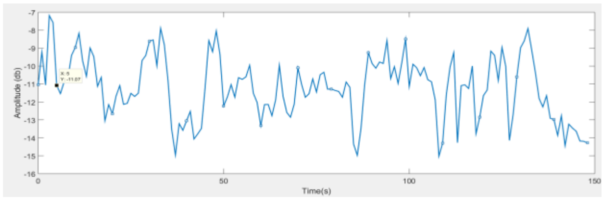

Fig no.6-acoustic data at high speed

c. Disturbed / Imbalance Trial

In the final stage, a small metal piece was intentionally attached to the rotating grinding wheel to create imbalance in the rotating system and Data acquisition was repeated under this condition and shown in fig no.7&8

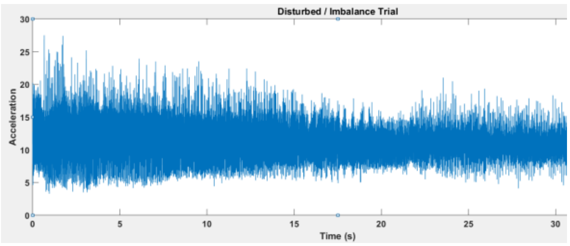

Fig no.7-Vibration data at Imbalance

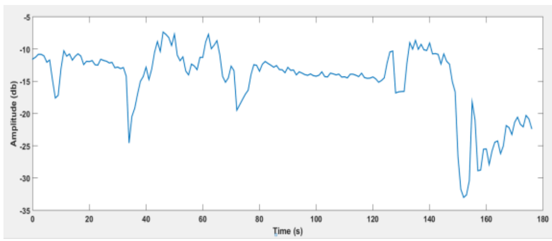

Fig no.8-acoustic data at Imbalance

The built-in accelerometer was used for vibration measurement, while the microphone was used for acoustic monitoring.

An LM35 temperature sensor interfaced with an Arduino microcontroller was attached near the motor body for temperature monitoring during operation.

2. DATA PROCESSING PROCEDURE

After completion of the trials, the recorded data was exported in CSV/XLS format and processed in MATLAB. Time-domain analysis, FFT analysis [2], [5] were performed to compare the behaviour under different operating conditions. Fast Fourier Transform (FFT) was applied to convert the vibration signal into the frequency domain.

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Dominant frequency components observed:

- Fundamental component near 50 Hz
- Harmonic component near 100 Hz

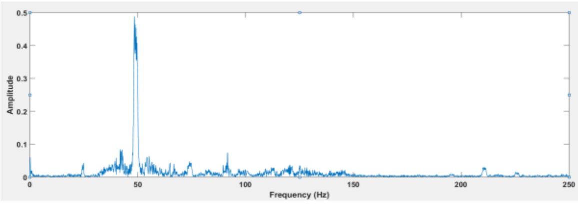

Fig no.9-FFT spectrum at normal speed

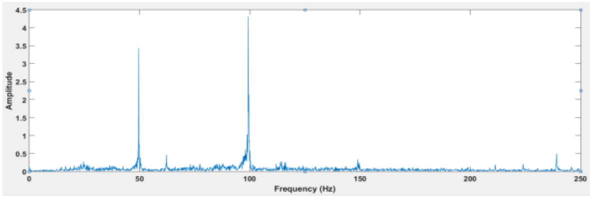

Fig no.10-FFT spectrum at high sp

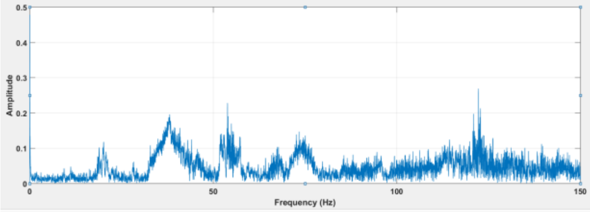

Fig no.11-FFT spectrum at Imbalance

Figure 9-11 show the FFT spectrum of the vibration signal. Dominant peaks were observed near 50 Hz as shown in fig no. 9 when Normal-Speed Trial was conducted. But when motor was operated at high speed then Dominant peaks were observed near 50 Hz and 100 Hz. as shown in fig no. 10. The 50 Hz component may correspond to the motor rotational frequency or supply-related vibration component. The observed 100 Hz peak is likely the second harmonic of the fundamental 50 Hz component and 100 Hz, indicating the presence of harmonic vibration components. But in fig No 11, different dominant frequency rather the 50 Hz and 100 Hz were observed Since an imbalance fault was intentionally introduced by attaching metal to the rotating blade, nonlinear vibration effects were generated in the motor system. Such nonlinearities commonly produce harmonic components at integer multiples of the different fundamental frequency. This observation demonstrates that smartphone-based vibration sensing can successfully capture harmonic components related to motor fault conditions [2], [3].

Condition	Fundamental Frequency	Harmonic Frequency	FFT Characteristics	Possible Cause
Normal Speed	**~50 Hz**	**Weak/Minimal**	**Low spectral amplitude and stable frequency content**	**Normal balanced operation**
High Speed	**~50 Hz**	**~100 Hz (2nd harmonic)**	**Increased FFT amplitude and stronger harmonics**	**Increased rotational speed and centrifugal force**
Disturbed / Imbalance	**~50 Hz**	**~100 Hz and irregular harmonic components**	**Irregular spectral peaks and nonlinear vibration behavior**	**Intentional imbalance caused by attached metal on rotating blade**

The smartphone microphone recorded variations in acoustic amplitude during motor operation. The acquired audio data mainly represented amplitude variations rather than raw high-speed acoustic waveform samples. Therefore, the analysis was focused on trend-based acoustic monitoring. The acoustic signal exhibited noticeable fluctuations during faulty operation, indicating increased acoustic activity caused by imbalance in the rotating blade. During the imbalance condition, increased vibration and acoustic activity were simultaneously observed, indicating that the introduced fault affected both mechanical vibration and sound generation of the motor [3], [8].

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During the experimental trials, the LM35 temperature sensor did not show a significant increase in motor surface temperature. This behavior was mainly due to the short duration of the experiments. Since the tests were conducted for a limited time interval, sufficient heat was not generated and transferred from the internal motor components to the outer motor surface where the LM35 sensor was mounted.

In rotating electrical machines, temperature rise at the external surface generally occurs gradually because heat generated inside the motor requires time to propagate through the motor body by thermal conduction [1], [4]. Therefore, short-duration experimental trials may not produce noticeable surface temperature variation even when vibration and acoustic changes are present.

Although the observed temperature variation was relatively small during the present experiments, temperature monitoring still remains an important parameter for motor condition monitoring. Under prolonged operation or severe fault conditions, abnormal motor behavior such as:

- bearing friction,
- overload,
- imbalance,
- and misalignment

can generate excessive heat, resulting in measurable temperature rise [1], [3].

Thus, the inclusion of the LM35 temperature sensor in the proposed multi-sensor system improves the overall capability of the monitoring setup and provides additional diagnostic information for long-term condition monitoring applications [5], [6].

3. **Advantages of Proposed System**

- Portable monitoring system
- Easy deployment
- Simple hardware setup
- Improved reliability through multi-sensor analysis

4. CONCLUSION

A portable multi-sensor system for fault diagnosis of electric motors using smartphone-based sensing has been successfully developed and experimentally evaluated. The proposed system utilized the built-in accelerometer and microphone of a smartphone for vibration and acoustic monitoring, along with an LM35 temperature sensor interfaced with a microcontroller for thermal observation[5], [6].

Experimental trials were conducted on a bench grinding machine under three different operating conditions: normal-speed operation, high-speed operation, and disturbed/imbalance condition. The disturbed condition was intentionally created by attaching a small metal piece to the rotating grinding wheel to generate imbalance-related vibration.

The vibration analysis demonstrated clear differences between the operating conditions. Time-domain signals showed increased vibration amplitude and irregular fluctuations during the disturbed condition. FFT analysis revealed dominant frequency components near 50 Hz and 100 Hz. The observed 100 Hz component was interpreted as the second harmonic generated due to imbalance-induced nonlinear vibration behaviour [1], [2]..

Acoustic monitoring also showed noticeable fluctuations during disturbed operation, indicating increased acoustic activity associated with the imbalance condition. Comparative analysis of normal, high-speed, and disturbed conditions confirmed that smartphone-based sensing can successfully capture changes in vibration and acoustic behavior in rotating machinery [3], [8]..

During the present short-duration experiments, the LM35 temperature sensor did not exhibit significant temperature variation because sufficient heat generation and thermal propagation to the motor surface did not occur within the limited experimental duration. However, temperature monitoring remains an important parameter for long-term condition monitoring because prolonged abnormal operating conditions may produce measurable thermal rise [4].

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The overall experimental results demonstrate that smartphone-based sensing combined with auxiliary temperature monitoring provides a simple, low-cost, and portable approach for preliminary fault diagnosis of electric motors. The proposed system shows potential for educational, laboratory, and low-cost industrial monitoring applications [6], [7], [9].

5. REFERENCES

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