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Correlation Studies of a Multi-Sensor Data for Induction Motor Health Assessment

H.S OKEKE[1*], A. J OLANIPEKUN[1], O. O NUGA[1], S. O ISMAILA[2], O. J IGE[1]

[1]*Electrical and Electronics Engineering Department, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria*

[2]*Mechanical Engineering Department, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria*

Corresponding Author's Email: okekehenryabbey@gmail.com

Abstract

Induction motor failures impose substantial costs on industrial operations, yet conventional maintenance strategies struggle to balance preventive interventions with the risk of unexpected breakdowns. This study investigates the application of statistical analysis and correlation techniques to multi-sensor data for early detection of motor faults. It focuses on how vibration, temperature and current of an induction motor can be monitored under different operating conditions. In this study, a system having a vibration sensor, current sensor and temperature sensor was designed and tested on a 3-phase induction motor. The test was carried out for three days and the results were analyzed using Python. The analysis produced a correlation matrix and a performance graph which forms a basis for the health assessment of the induction motor. The results show that multi-sensor correlation patterns offer superior diagnostic capability compared to single-parameter thresholds. The performance analysis graph shows that the cycle of the motor goes on and off with the peak current around 10 A, the core temperature around 55 to 60 ℃, while the vibration level is around 15 m/s^2*. Also, the correlation matrix shows a high correlation between these measurement criteria. This ascertains the effectiveness of the designed system and reveals the efficiency achieved in multi sensor data assessment, thereby making them accessible for widespread deployment in condition-based maintenance programs.*

Keywords: *Condition Monitoring, Current, Predictive Maintenance, Temperature, Vibration.*

1.0 Introduction

Induction motors remain the workhorse of modern industry, driving everything from conveyor systems in manufacturing plants to pumps in water treatment facilities. Their reliability directly affects production schedules, operational costs, and workplace safety (Amuzuyi and Warden, 2020). When these motors fail unexpectedly, the consequences extend beyond the immediate repair costs, production stops, deadlines slip, and in critical applications, entire systems can grind to a halt (Dash *et al.*, 2010).

Traditional maintenance approaches have long relied on fixed schedules or reactive repairs after failure occurs (De Carvalho *et al*., 2018). Neither method serves industry well. Scheduled maintenance often replaces components that still have useful life remaining, while reactive maintenance accepts the risk of catastrophic failures that could have been prevented. The solution lies in understanding what the motor itself can tell us about its condition (Arhun *et al.,* 2024).

Modern sensing technology has made it possible to monitor multiple parameters simultaneously. Vibration patterns, thermal signatures, electrical characteristics, and acoustic emissions all provide windows into motor health (Ballo *et al.*,2022). Each sensor captures a different aspect of the motor's operating state, yet the real value emerges not from individual measurements but from understanding how these signals relate to one another. A bearing defect, for instance, produces a distinctive vibration signature, but it also generates heat and alters current draw in measurable ways (Caldero and Zoeke 2019).

This study examines how statistical methods can extract meaningful health indicators from multi-sensor data streams. It focuses particularly on correlation analysis and performance graphs, exploring how changes in one parameter predict or accompany changes in others, and what these relationships reveal about developing faults. The goal is straightforward; to develop practical methods that maintenance teams can use to detect problems before they cause failures (De Souza *et al.,* 2022).

Through systematic analysis of sensor correlations across different operating states and fault conditions, this work aims to advance our understanding of how multi-sensor monitoring can be deployed effectively for motor health assessment (Da Costa *et al.,* 2010). Parameters like voltage, current and temperature are monitored to give useful data to the operator, thereby producing meaningful information that would enhance predictive and preventive maintenance practices (Choudhary *et al.*, 2019).

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The body of work examining induction motor diagnostics has evolved considerably over recent decades, driven by industrial demands for reliability and the economic consequences of unexpected failures. This review examines several key contributions that have shaped current understanding of multi-sensor approaches to motor health assessment.

Olanipekun *et a*l. (2025) conducted a systematic review of twenty-five research works spanning various aspects of induction motor technology. The analysis revealed a conspicuous gap in wireless and remote monitoring implementation, with only twelve percent of reviewed studies addressing this capability. The authors argued persuasively that modern design engineers have neglected wireless technologies despite their potential to reduce downtime and simplify fault location. Their categorization of research into sensing technology, vibration analysis, and intelligent diagnostics provides a useful framework, though the emphasis on coverage rates sometimes overshadows the practical limitations that may explain sparse adoption of certain technologies.

Choudhary *et al*. (2019) offered a comprehensive synthesis of condition monitoring techniques, organizing fault types into bearing defects, stator failures, rotor problems, and eccentricity issues. Their review stands out for its practical orientation, noting that acoustic emission and motor current signature analysis, while effective, require expensive sensors that limit widespread industrial adoption. The discussion of artificial intelligence techniques including neural networks and fuzzy logic reflects the field's trajectory toward automated diagnosis, though the authors acknowledged that human interpretation remains a significant bottleneck. Their statistical analysis showing bearing and stator faults constitute seventy-five percent of all failures underscores where monitoring efforts deliver the greatest return.

The work by Barusu and Deivasigamani (2020) traced the evolution of induction motor control from its 1888 origins through modern vector control systems. Their historical perspective illuminates how control strategies have progressed from simple voltage manipulation to sophisticated space vector modulation techniques. The distinction they drew between scalar and vector control systems clarifies why certain applications still rely on simpler U/f control despite the superior dynamic performance of vector methods. Their discussion of sliding mode control and direct torque control suggests these approaches may gain prominence in servo applications where precise control justifies added complexity.

Larabee *et a*l. (2005) examined starting methods from an industrial practicality standpoint, evaluating full voltage, autotransformer, soft starter, and adjustable frequency drive options. The paper's strength lies in its frank assessment of trade-offs: full voltage starting offers simplicity and low cost but stresses both electrical systems and mechanical loads; reduced voltage methods ease power system impact while potentially requiring larger motors to achieve necessary starting torque. Their analysis of power factor correction during starting, including detailed calculations in the appendix, provides engineers with concrete guidance rarely found in purely theoretical treatments. The warning about voltage spikes when reconnecting motors with capacitors addresses a practical hazard often learned through expensive experience.

Usman and Anhar (2024) developed a voltage mismatch technique for detecting stator winding deterioration without requiring carefully calibrated sensors. Their experimental validation using a universal laboratory machine demonstrated that the method remains robust under conditions of supply unbalance, construction imperfections, and varying mechanical loads. The theoretical framework built on symmetrical components elegantly separates inherent system asymmetries from actual deterioration, allowing early fault detection before catastrophic failure. Their proposed implementation procedure for mining applications shows awareness that academic methods must survive translation into harsh industrial environments. The distinction between using the method during scheduled maintenance versus continuous monitoring reflects understanding of practical constraints.

Tsypkin (2016) brought decades of field experience to bear on electromagnetic vibration sources in motors operating with modern power electronics. His clarification of slip frequency versus pole pass frequency definitions addresses confusion that persists in the diagnostic community. The case studies demonstrated vibration signatures from voltage imbalance, rotor bar problems, and drive faults provide practitioners with reference patterns rarely documented in academic literature. Particularly valuable is the discussion of torque pulsation as a vibration source distinct from radial electromagnetic forces, a mechanism that explains failures at twice line frequency when air gap eccentricity is minimal. The emphasis on resonance conditions reminds analysts that vibration severity depends not just on forcing function magnitude but also on structural response characteristics.

Collectively, these works reveal a field grappling with the gap between what laboratory studies show possible and what industrial environments permit. The push toward intelligent systems and multi-sensor fusion reflects recognition that no single measurement captures motor health completely. Yet practical barriers, sensor cost, installation difficulty, environmental factors, and the need for domain expertise slow adoption of sophisticated techniques. Future research might profitably focus less on demonstrating yet

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another diagnostic method and more on simplifying deployment of proven approaches, particularly in cost-sensitive applications where elaborate monitoring remains economically unjustifiable despite technical merit.

The progression from simple vibration monitoring to integrated analysis of electrical, thermal, and mechanical parameters represents genuine advancement. Whether this complexity proves sustainable in routine industrial practice, or whether simpler robust methods ultimately prevail, remains an open question that time and market forces will settle.

2.0 Materials and Methods

In this research work, a simple design was done which involves the use of an accelerometer and a gyroscope both forming the vibration sensor, the microcontroller, the DS1820, a versatile type of temperature sensor, and the current sensor. The design has a 5V supply to the microcontroller and this voltage is obtained from the Switch Mode Power Supply (SMPS) which has its input as 220V. The sensors were programmed with a determined value shown in Table 1. Figure 1 shows the assembled components on the PCB ready for printing. After the design of the system, it was tested with a 3-phase, 415V, 3000rpm 50Hz induction motor. The test was done for three days, readings logged in every hour, and different data were collected for the three basic input parameters considered. That is the vibration, current and temperature. Thereafter, the data was analyzed using Python, and the correlation matrix was generated, as well as the performance graph. All plotted with Matplotlib for clearer visibility over the test period. The test condition was maintained all through. Figure 2 shows the induction motor used. The system was sectionalized into three phases. The first phase includes the hardware design and integration, then the data acquisition phase and finally the experimental analysis phase using Python. In the selection of component stage for hardware design, the vibration sensor was chosen because of its dual-axis sensitivity while the current and temperature sensors were chosen because of their accuracy.

Table 1: The input conditions for the motor used

Motor Test Condition	**Current Rating (A)**	**Vibration Rating (m/s^2)**	**Temperature Rating (°C)**
Good	0-10	0-14	0-60
Mid	10-15	15-19	61-79
Bad	>15	>20	>80

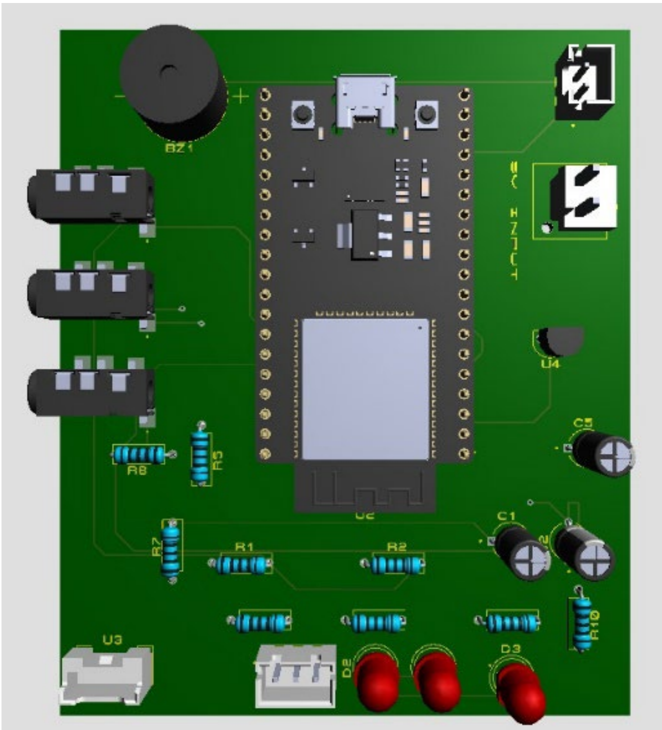

Figure 1: The assembled components ready for printing

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Figure 2: Induction Motor Used.

3.0 Results and Discussion

Figure 3 and Figure 4 show the results from the vibration analysis, temperature rise test, the no-load and on-load test all to determine the vibration, temperature and magnetizing current respectively. The results are represented with the correlation matrix and the motor performance graphs as indicated. The complete developed system is equally shown in Figure 5, while Figure 6 shows the circuit diagram of the design.

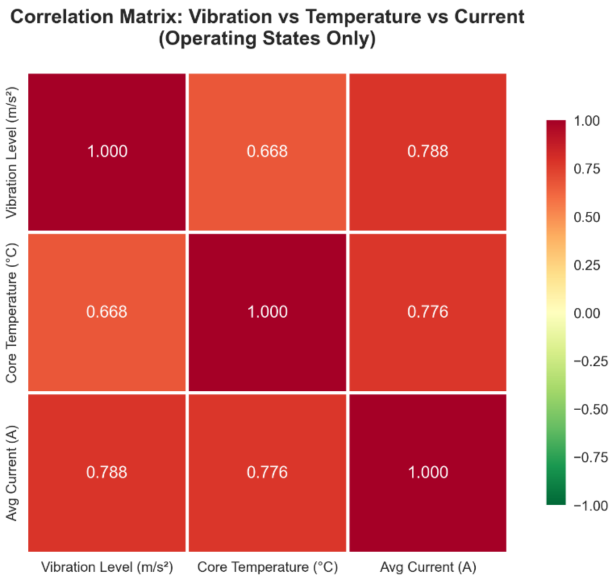

Figure 3: Correlation Heatmap for Current, Vibration and Temperature.

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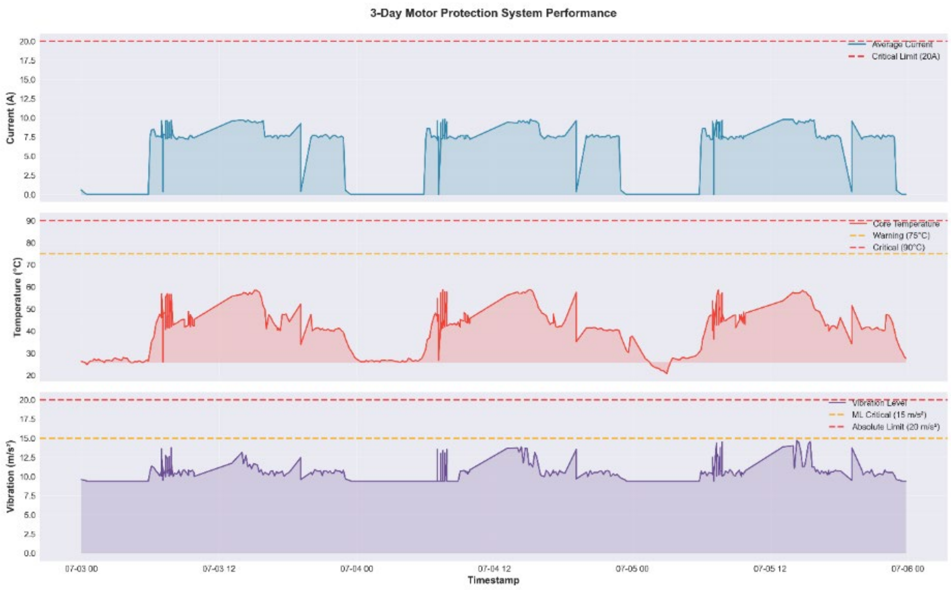

Figure 4: Performance Graph for Current, Vibration and Temperature

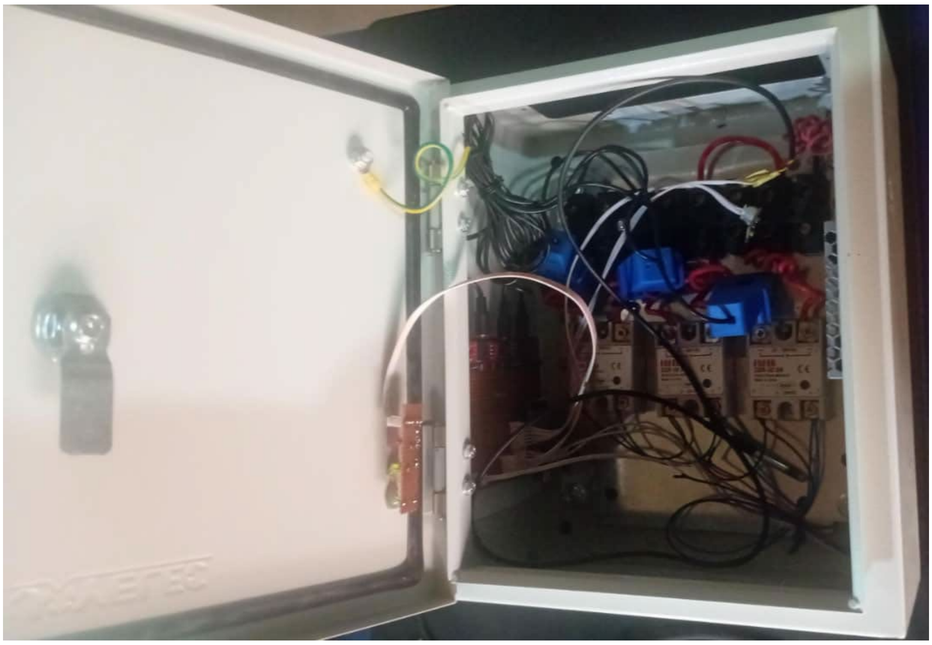

Figure 5: The pictorial display of the developed system

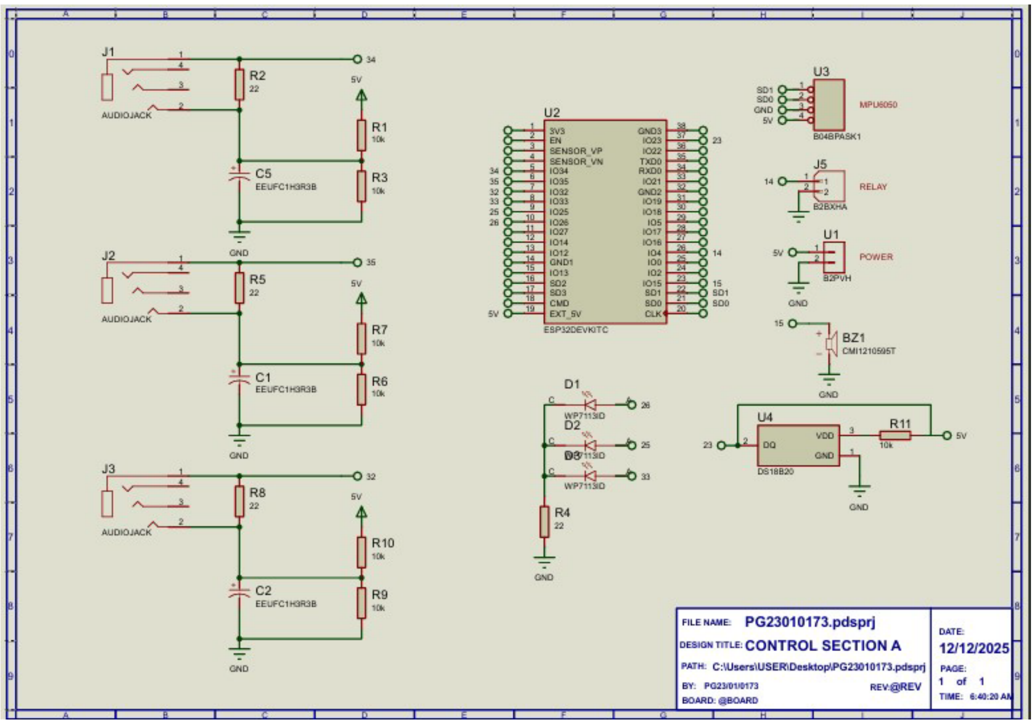

Figure 6: The circuit diagram of the system.

From Figure 3 which shows the correlation matrix, we can see that a strong correlation exists between vibration and current (0.788). Also, for Temperature-Current relationships, a strong correlation exists between them (0.776) and lastly, for vibration-temperature relationship, it also has a strong relationship of 0.668. This strong correlation depicts that the motor protection system captures meaningful data that helps prevent failure. From the vibration current relationship, it indicates that there is a proportional relationship between the two. For the temperature and current relationship, it shows us that a high current drawn leads to a higher motor temperature. The relationship between vibration and temperature as seen here shows that although there is a relationship between the two, it is less direct. Overall, the data tells us that the motor systems are tightly coupled.

From the performance graph in Figure 4, we have different graphs for temperature, current and vibration. The graph for each of these criteria does not exceed 60 °C, 10 A and $15m/s^2$ respectively. This shows us the health status of the induction motor when compared with the data in Table 1. The induction motor never exceeded safe current levels during the three days of test viz-a–viz the temperature but the vibration level had occasional spikes which can be attributed to an increase in load conditions. Overall assessment from these performance graphs points towards the monitoring of this vibration level, although in terms of current and temperature, the motor worked within safe region.

4.0 Conclusion

It is evident from this analysis that the multi sensor data for health assessment in an induction motor provides more detailed and useful information when compared with the single sensor system of monitoring. This is seen from the test carried out which provided different information about the vibration, current and temperature used as input parameters. From the test done, it has proven that the induction motor used is still in good working condition, although it must be monitored as continual operation ensues. Aside from this, it also certifies the system was designed with effective workability of the sensors.

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