INTERNATIONAL JOURNAL OF TECHNOLOGY AND ACADEMIC RESEARCH

ISSN: 2224-6878 | Pakistan Volume 6, No. 10.

IF: 14.91 | 2026 http://waerasia.org/index.php/ijtar

SENSOR-BASED MONITORING AND DIAGNOSTICS OF THE TECHNICAL CONDITION OF COTTON PROCESSING TECHNOLOGICAL LINES

Asliddin G‘anisher o‘g‘li Maxmadaminov
maxmadaminov.asliddin@mail.ru
Doi: https://doi.org/10.5281/zenodo.23217204

Abstract: This paper presents a comprehensive investigation into the monitoring and diagnostics of the technical condition of technological equipment deployed in cotton processing enterprises using mechatronic systems. During operation, machinery is subjected to mechanical stress, high vibration, thermal buildup, fluctuating electrical drive loads, and mechanical wear, all of which degrade overall processing efficiency [1]. To supervise and mitigate these phenomena, a mechatronic monitoring architecture is proposed, integrating high-precision sensor nodes, a microprocessor-based controller (PLC/MCU), executive mechanisms (actuators), and algorithmic diagnostic routines. The proposed framework enhances operational stability and reduces maintenance expenditures.

Keywords: mechatronics, cotton processing, technical condition, monitoring, diagnostics, sensor, actuator, microprocessor control, automation.

1. Introduction

In cotton processing facilities, the continuity, throughput, and operational safety of technological lines depend directly on the structural and mechanical integrity of deployed machinery. Heavy-duty units—such as ginning stands, linters, mechanical conveyors, pneumatic separators, and exhaust fans—undergo prolonged, continuous operational cycles. Over time, these dynamic regimes cause progressive component wear, excessive vibration, bearing overheating, and phase/load imbalances in electrical drives [2].

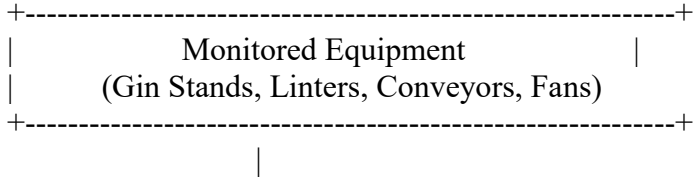
Relying solely on manual oversight or periodic visual inspections fails to detect micro-level deviations in real time, often allowing incipient defects to evolve into catastrophic failures. Consequently, engineering automated, mechatronic monitoring and diagnostic systems—unifying sensor instrumentation, programmable logic controllers, and responsive actuators into a cohesive cyber-physical architecture—represents a pressing practical and scientific imperative.

2. Research Objective

The primary objective of this study is to develop an integrated mechatronic monitoring and diagnostic architecture capable of continuously measuring the operational parameters of cotton processing equipment via specialized sensor arrays, executing digital signal processing at the controller level, and actively modifying operational regimes via mechatronic actuators to maintain system stability.

3. Structure and Operation of the Mechatronic Monitoring System

The architecture tracks primary physical variables governing machine health in real time. Transduced analog and digital signals are routed directly to a central processing unit, such as an Industrial PC (IPC), Programmable Logic Controller (PLC), or Microcontroller Unit (MCU).



ISSN: 2224-6878 | Pakistan Volume 6, No. 10.

IF: 14.91 | 2026 http://waerasia.org/index.php/ijtar

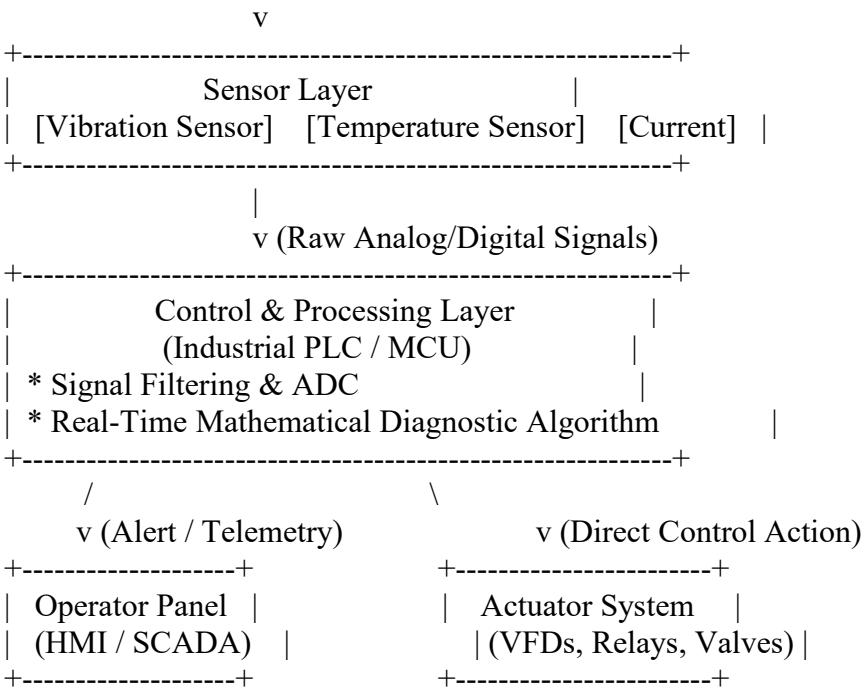


Figure 1. Structural flowchart of the mechatronic monitoring and diagnostic system for cotton processing machinery.

The firmware algorithm compares incoming telemetry against predefined nominal baselines. When measured values breach specified tolerance bands, the system either dispatches alert flags to the supervisory interface (HMI/SCADA) or triggers closed-loop corrective actuator responses.

Table 1. Functional elements of the mechatronic monitoring system

Element	Functional Purpose	System Role
Vibration Sensor	Measures mechanical oscillation and spectral acceleration	Predictive diagnostics
Temperature Sensor	Monitors thermal dissipation in bearing units and motor windings	Thermal condition monitoring
Current Sensor	Measures drive power consumption and phase load dynamics	Electrical load surveillance
Microprocessor / PLC	Executes data acquisition, digital filtering, and logic routines	Central processing unit
Diagnostic Algorithm	Computes multi-parameter degradation indexes and evaluates faults	Analytical diagnostic engine
Actuator	Implements corrective mechanical, electrical, or pneumatic actions	Active operational control

ISSN: 2224-6878 | Pakistan Volume 6, No. 10.

IF: 14.91 | 2026 http://waerasia.org/index.php/ijtar

4. Technical Condition Diagnostics and Assessment

Accurate health estimation requires concurrent evaluation of mechanical vibration, thermal expansion, and electrical current profiles. Deviations from nominal operating ranges are processed synthetically. To quantify health state in a single metric, the integrated diagnostic index (D) is computed as:

$$D = w_1 \cdot \left(\frac{V}{V_{\text{nom}}}\right) + w_2 \cdot \left(\frac{\Delta T}{T_{\max} - T_{\text{nom}}}\right) + w_3 \cdot \left(\frac{\Delta I}{I_{\text{nom}}}\right)$$

Where:

- D — calculated integrated diagnostic state index;
- V — recorded root-mean-square (RMS) vibration severity, relative to nominal baseline V_{nom};
- ΔT — measured thermal deviation relative to operating limits;
- ΔI — electrical current deviation relative to rated drive capacity;
- w_1, w_2, w_3 — empirical weighting coefficients assigned to vibration, temperature, and current parameters, respectively ($\sum w_i = 1$).

Table 2. Evaluation criteria for mechatronic diagnostic states

Technical Condition	Parameter Status	System Response
Normal	Parameters remain within nominal boundaries	Unaltered baseline operation
Warning	Initial parameter drift detected; trend indicates onset of wear	Non-critical warning sent to HMI
Hazardous	Values approach critical design limits	Automatic load de-rating via actuators
Emergency	Values exceed critical fail-safe limits	Controlled emergency shutdown sequence

5. Sensor Operational Duty Cycle and State Distribution

To evaluate the long-term reliability and duty cycle of the sensing instrumentation, continuous operation is mapped against total annual calendar hours (365×24=8,760 h). Planned maintenance, technological line reconfiguration, and cleaning cycles reduce effective monitoring time. Assuming a nominal 95% availability target, net annual monitoring uptime equals 8,760×0.95=8,322 h.

Table 3. Annual operational distribution models for sensing nodes

Operational Metric	Availability Ratio (%)	Annual Time (Hours)	Annual Time (Days)	Description
Theoretical Continuous	100%	8,760.0	365.00	Theoretical upper bound

ISSN: 2224-6878 | Pakistan Volume 6, No. 10.

IF: 14.91 | 2026 http://waerasia.org/index.php/ijtar

Operational Metric	Availability Ratio (%)	Annual Time (Hours)	Annual Time (Days)	Description
High-Readiness Regime	99%	8,672.4	361.35	Minimal, negligible stoppages
Stable Monitoring Regime	97%	8,497.2	354.05	Minor technological breaks
Baseline Operational Regime	95%	8,322.0	346.75	Standard scheduled downtime included
Maintenance & Service Share	5%	438.0	18.25	Non-monitoring offline window

Sensor technical availability (K_a) is expressed as:

$$K_a = \frac{T_{\text{active}}}{T_{\text{theoretical}}} \times 100\%$$

Where:

- T_{active} — verified duration of active data acquisition (8,322 h);
- $T_{\text{theoretical}}$ — total duration of the observation window (8,760 h).

$$K_a = \frac{8{,}322}{8{,}760} \times 100\% = 95\%$$

This coefficient reflects the operational availability of the monitoring hardware, though it remains independent of the mechanical degradation state of the machine itself.

Telemetry logs from vibration sensors can be segmented statistically into normal, warning, and hazardous state bins over the observation window:

Table 4. Model distribution of machine states based on annual vibration telemetry

Diagnostic State	Proportion (%)	Equivalent Duration (8,760 h base)	Physical State Description
Normal	90%	7,884.0 h	Vibration within ISO/nominal tolerance bands
Warning	8%	700.8 h	Increasing harmonic trends; inspection required
Hazardous	2%	175.2 h	Critical thresholds breached; immediate shutdown
Total	**100%**	**8,760.0 h**	Complete annual operational cycle

ISSN: 2224-6878 | Pakistan Volume 6, No. 10.

IF: 14.91 | 2026 http://waerasia.org/index.php/ijtar

6. Prospects for Robotic Integration

Coupling this mechatronic sensing system with automated robotic maintenance arms offers substantial efficiency gains for cotton ginneries. Once the algorithm pinpoints localized mechanical wear (such as bearing raceway degradation or drive eccentricity), industrial robotic manipulators can execute autonomous lubricating, thermographic cross-validation, or fastener re-torquing routines without manual intervention. This shifts the installation from a passive supervisory tool to a closed-loop, autonomous maintenance complex.

Conclusion

Deploying mechatronic monitoring and automated diagnostics across cotton processing lines provides a robust framework for improving equipment reliability. Real-time acquisition of vibration severity, thermal signatures, and electrical loads enables early-stage fault isolation well before catastrophic mechanical breakdown. Integrating automated actuators creates a closed-loop protection system that actively adjusts operating regimes or initiates failsafe stops, mitigating secondary damage and reducing unplanned industrial downtime.

References

1. Obidov, A. A., Khamidov, S., & Abdurasulov, A. (2022). Investigation into impurity separation via fiber loosening on the cylinder sections of fiber separators. *Journal of Mechanical Engineering Science and Technology*, (1), 340–348.
2. Obidov, A. A., Abdurasulov, A., Khamidov, S., & Atamirzaev, Z. (2021). Improving the fiber separation device from fibrous waste. *Journal of Hunan University (Natural Sciences)*, 48(12), 2126–2136.
3. Mobley, R. K. (2002). *An Introduction to Predictive Maintenance* (2nd ed.). Butterworth-Heinemann.