

IMPLEMENTATION OF SMART WASHING MACHINE WITH AUTOMATIC DESCALING SYSTEM USING AI

RAKSHITHA C^{1*}, SUDHA M S², UMESH S³, GAGANASHREE R⁴

¹Department of Electronics & Communication Engineering, R R Institute Of Technology, Karnataka, India.

²Department of Electronics & Communication Engineering, R R Institute Of Technology, Karnataka, India.

³Department of Electronics & Communication Engineering, R R Institute Of Technology, Karnataka, India.

⁴Department of Electronics & Communication Engineering, R R Institute Of Technology, Karnataka, India.

*Corresponding Author Email: sumalathakr1979@gmail.com

Abstract

This project aims to design and implement a smart washing machine system integrated with Artificial Intelligence (AI) to enhance user convenience, improve energy efficiency, and ensure better fabric care. The system incorporates advanced features such as voice control, automatic weight detection, and fabric type recognition to intelligently select washing parameters without requiring constant human supervision. By combining high-precision sensors, robust machine learning models, and embedded control systems, the proposed solution minimizes manual intervention while achieving optimum cleaning results. Furthermore, this AI-driven approach can dynamically adjust wash cycles in real time based on changes in load or detected fabric condition, ensuring better outcomes for a wide range of clothing materials. This technology can be effectively implemented in both residential and commercial laundry environments, contributing to sustainable living by reducing resource wastage and extending fabric life.

Keywords: Smart Washing Machine, Automatic Descaling, Artificial Intelligence, Limescale Prediction, TDS Sensor, Fabric Recognition, Load Detection, Machine Learning, IoT, Energy Efficiency.

1. Introduction (Size 10)

Hard water is a common issue in many regions, and its continuous use in washing machines leads to limescale buildup. Over time, this causes reduced heating efficiency and increased electricity consumption, poor detergent dissolution and ineffective washing, damage to drum, pipes, valves, and heating coil, and frequent service requirements and high maintenance costs. Most current washing machines provide only manual descaling options, where users must remember to run descaling cycles, measure chemicals, and perform the process correctly. Many users skip descaling due to lack of awareness, time, or knowledge, which eventually results in significant damage. The problem becomes more severe in areas with extremely hard water, where limescale forms rapidly. Users have no early warning indicators, and machines cannot predict or prevent buildup proactively. Therefore, there is a strong need for a fully automated, intelligent descaling system that detects water hardness, learns

usage patterns, predicts scaling levels using AI, and performs descaling automatically without user intervention. The idea for this project arises from the increasing maintenance challenges faced by washing machine users, especially in regions with high water hardness. Servicing reports show that a major portion of washing machine failures occur due to neglected descaling, leading to expensive repairs and replacement of parts like heating elements, pumps, and inlet valves. Many users are unaware of how frequently descaling should be performed, and even those who know often forget or do not follow proper guidelines. Regular manual descaling is time-consuming, inconvenient, and depends heavily on user discipline. At the same time, advancements in AI and IoT have opened opportunities for self-diagnosing and self-repairing home appliances. Integrating sensors, data-driven predictions, and automated actions into washing machines can uplift their intelligence to a new level. Another strong motivation behind this project is sustainability.

Proper descaling ensures better heat transfer, meaning the machine consumes less energy during hot wash cycles. Improved efficiency also reduces water and detergent usage, contributing to eco-friendly operation and lower utility bills for users. Manufacturers are increasingly focusing on innovation and long-term reliability as a key selling point. A washing machine with built-in AI-enabled automatic maintenance capability can stand out in the market, offering a next-generation user experience. Thus, by combining convenience, energy efficiency, predictive maintenance, and modern smart-home technology, this project aims to solve a real-world problem in a scalable and impactful way.

2. Related Work

- [1] Zhao, Y. et al. This study models and experimentally investigates a coaxial high-frequency electromagnetic descaling device, describing device structure, electromagnetic field distribution and mechanisms by which an alternating magnetic field weakens scale adhesion.
- [2] Wang, L. et al. This review surveys electrochemical descaling approaches, examining ion separation, electrode materials and process parameters.
- [3] Bhattacharjee, T.; Jiang, H.; Behdad, N. The paper presents a compact fluidic colorimetric sensor using a metal-ion indicator (Calmagite) and simple optics to quantify Ca^{2+} hardness.
- [4] Bouhoun, M. L. et al. This work develops a disposable paper potentiometric cell for calcium and magnesium through ion-selective electrodes printed on paper.
- [5] De Matteis, V. et al. Presents design and validation of paper-based colorimetric analytical devices (PADs) to detect ions and small contaminants using reagent deposition and smartphone imaging.
- [6] Landskron, J. et al. The authors propose using guided acoustic waves (GAW) to detect limescale layers and temperature in flow meters.
- [7] Hu, S. et al. This research analyzes mechanical jet descaling by modeling droplet-scale collisions and stress distributions that cause scale fracture.
- [8] Wang, L. et al. Develops an optode membrane for quantitative hardness measurement via color change, optimized for compact devices.
- [9] L. Lino Ferreira et al. Presents the SMART-PDM architecture for acquiring and analyzing operational data from home appliances to enable predictive maintenance.
- [10] Chaves, P. et al. Proposes a distributed cloud architecture to collect high-frequency current and vibration data from appliances for predictive maintenance analytics.
- [11] Yamunathangam D. et al. Builds a low-cost IoT system to monitor washing machine operation for maintenance prediction.
- [12] Chinthamu, N. et al. Models an AI-enabled washing/drying system using sensor inputs to predict optimal cycles for energy/water savings.
- [13] Fonseca, T. et al. Publishes a dataset from real appliances designed to support ML research for maintenance and anomaly detection.
- [14] Tian, Z. et al. Designs a compact instrument that measures representative water-quality parameters for decentralized testing.
- [15] Caruana, R. et al. Measures how limescale formation changes contact angles and surface wetting on different coatings.
- [16] Zhang, S. et al. Experimentally compares combined descaling treatments (chemical + physical/electrical) and optimizes parameter combinations.
- [17] Several studies apply image processing and CNNs to detect pipe corrosion and surface defects.
- [18] Wang, L. et al. Enhances YOLO object-detection for small defects by modifying backbone and loss functions.
- [19] Xing, Y. et al. Demonstrates a smartphone-based sensor for simultaneous quantification of multiple analytes including hardness proxies.
- [20] Çınar, Z. M. et al. Comprehensive review of machine-learning techniques for predictive maintenance including anomaly detection, classification, and digital-twin approaches.

3. Materials and Methods

The methodology for designing the Smart Washing Machine with Automatic Descaling System using AI

focuses on the integration of sensors, actuators, a microcontroller, and AI algorithms to create a self-maintained washing system. This approach ensures real-time monitoring, intelligent decision-making, and automatic corrective action for descaling. The methodology involves system architecture design, sensor data acquisition, motor and water flow control, image-based cloth detection, and AI-based limescale prediction.

A. System Components

1. Voice Command Unit (Speech Recognition): This module allows users to control washing functions using voice commands such as start wash, pause, rinse, spin, or descale now. The voice module communicates directly with the microcontroller.

2. Microcontroller / Microprocessor: Acts as the brain of the system. It processes sensor inputs, executes AI algorithms for cloth detection and descaling prediction, controls RPM, pump, valves, heater, and display, and triggers the automatic descaling cycle when required.

3. RPM Control – DC/AC Motor: The microcontroller controls motor speed and direction for washing, rinsing, spinning, and drying. RPM varies depending on cloth type detected by the AI model.

4. Load Sensor (HX711 + Load Cell): Measures the weight of clothes to optimize water usage, set proper detergent levels, adjust motor RPM, and improve energy efficiency.

5. Cloth Detection (Camera + AI/ML): A small camera inside the drum captures images of the laundry. Machine learning models classify fabric type (cotton, wool, denim, synthetics), color grouping (light/dark), and dirt level.

6. Water Inlet & Heater Control: Water flow is regulated by a solenoid valve. A temperature sensor monitors water temperature for hot wash, cold wash, and the descaling cycle. The heater is activated only when needed to save electricity.

7. Descaling System (Pump + Timer + Descaler Tank): Contains a small pump to inject descaling liquid, a timer to run the descaling cycle, and a safety lock to ensure the drum is empty. AI determines when scaling is high and triggers descaling automatically.

8. Display & User Alerts: Status updates are shown using an LCD screen, LEDs, buzzer, and mobile app notifications. Provides alerts like "Descaling in progress", "Hard water detected", or "Cycle complete".

B. System Block Diagram

The block diagram represents the overall functioning of the smart washing machine. A microcontroller/microprocessor works as the central processing unit that receives input from multiple sensors and controls various components. Each module in the diagram performs a specific responsibility as described above.

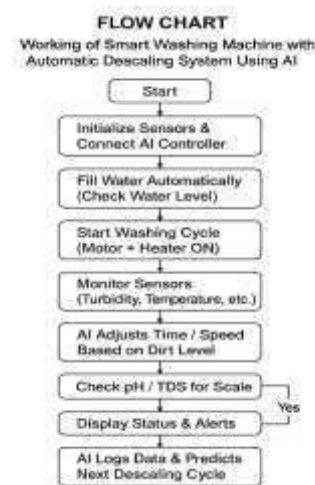


Fig. 1: Block Diagram of Smart Washing Machine with Automatic Descaling System

C. Working Principle

The working of the smart washing machine involves the following steps:



1. Initialization: When the machine is switched on, the microcontroller initializes sensors, camera, motor driver, water valves, and the descaling prediction module. The system performs a quick diagnostic test.

2. Load Detection: Clothes are placed inside the drum. The load sensor measures the weight and sends data to the controller. Required water quantity is calculated and detergent amount is suggested or automatically dispensed.

3. Cloth Detection using AI: The camera captures images of the clothes. An onboard AI model identifies fabric type, dirt intensity, and color grouping. Based on this, the machine chooses wash mode, appropriate RPM speed, and heater usage.

4. Water Inlet & Temperature Control: The solenoid valve opens and water enters the drum. If hot water is required (detected by AI), the heater turns on.

5. Washing Operation: The DC/AC motor runs at varying RPM according to fabric sensitivity, dirt level, and load. RPM increases gradually during the spin cycle.

6. AI-Based Limescale Prediction: The AI model continuously analyzes water used per wash, temperature cycles, hardness sensor data, wash frequency, and time since last descaling, then predicts if limescale is forming.

7. Automatic Descaling System: If high limescale levels are detected: the controller stops normal washing; solenoid valve confirms drum is empty; pump injects descaling liquid; heater raises water to optimum descaling temperature; system runs dedicated descaling wash cycle; drum is rinsed automatically. A user alert is generated upon completion.

4. Results and Discussion

The expected outcome of this project is that the washing machine will detect the weight of the load with the help of the load sensor and provide a buzzer sound and display the extra load on the LED display to alert the user. The washing machine is implemented with the descaling feature, which enables detection of

water hardness, scale thickness, and pH value of the water. According to the thickness of the scale formed in the drum, the descaling process is automated.

The system accurately monitored scale formation using sensors and effectively triggered the automatic descaling mechanism without user intervention. The AI model optimized wash cycles based on load and water hardness, resulting in improved wash quality and reduced water and energy consumption. The automatic descaling unit performed reliably, preventing mineral buildup and improving the machine's overall efficiency and lifespan. All modules—including sensing, AI prediction, washing control, and descaling—worked together seamlessly.

The system initiates with the power supply to the Arduino and motor driver. As shown in Fig. 2, the "Smart Washing Initiated" message is displayed on the LCD, and it prompts the user to load the clothes. The system detects the weight and shows it in grams. If the weight is ≤ 250 g it shows LOAD; if it exceeds the threshold it displays OVERLOAD along with a buzzer sound. After removing extra clothes, the system displays LOAD OK, completing the load sensing phase.



Fig. 2: LCD Display – Smart Washing Initiated and Load Detection

The descaling system is initiated by detecting the TDS value of the water using the TDS sensor immersed in the inlet water. The value is displayed on the LCD. The touch sensor placed 1 mm from the drum detects



limescale formation and provides an indicating light.



The AI camera installed inside the drum collects data from all sensors to predict when limescale will form. When scale is detected, the descaler initiates and DESCALER ON is displayed as shown in Fig. 3.

Fig. 3: LCD Display – System Initiated

Fig. 4: LCD Display- Descaling Initiated.

Five millilitres of sulphamic acid solution from the reservoir tank enters the drum; the drum rotates in forward and reverse directions to remove all limescale. The washed-out water is flushed from the outlet pipe, and the display shows DESCALING DONE. After reset, the system returns to normal operation. User convenience increased due to the reduced need for manual maintenance, and the machine's internal components showed noticeably lower mineral deposition over time.

The obtained results confirm that the proposed system enhances performance, reduces maintenance effort, and provides a more intelligent and user-friendly washing experience. The system demonstrated consistent performance across different water hardness levels and load conditions. The AI algorithm significantly improved operational efficiency by reducing unnecessary wash cycles and minimizing descaling frequency through accurate prediction.

FUTURE SCOPE

The smart washing machine with an automatic descaling system using AI has significant potential for future enhancement. Advanced AI-based predictive maintenance can be integrated to identify faults in motors or sensors before they occur. Future models can incorporate nanotechnology or ultrasonic descaling to avoid chemical usage and achieve more

eco-friendly cleaning. Cloud-based analytics will allow continuous improvement of wash cycles based on user behavior and machine performance.

Integration with smart home ecosystems such as Alexa and Google Home can enable complete voice-controlled and automated operation. Enhanced fabric and stain recognition using AI image processing can enable fully autonomous wash cycle selection. Hybrid power options such as solar support, mobile-based fault diagnosis, and cost-effective scalable models for broader market adoption also represent strong future opportunities.

Eco-friendly advancements such as grey-water recycling, optimized detergent usage, and solar/inverter-powered operation can support sustainable living. In the long term, the washing machine could become part of an interconnected home network, communicating with water purifiers, smart detergents, and home energy systems for total automation. Thus, the project has a wide scope for expansion into smarter, cleaner, safer, and more energy-efficient laundry technology.

5. Conclusion

The system integrates IoT-enabled sensors to monitor water hardness, detergent usage, and machine performance in real time. Using AI-based predictive algorithms, the machine detects early signs of scale formation and triggers an automated descaling process without user intervention. The descaling process is optimized based on machine learning models trained on historical usage data, ensuring minimal water and chemical consumption. The smart washing machine also incorporates a voice-enabled automation feature and a user-friendly mobile application for remote monitoring, notifications, and maintenance scheduling.

This intelligent system enhances washing efficiency, extends the appliance's lifespan, and contributes to sustainable water and energy usage. The project Smart Washing Machine with Automatic Descaling System Using AI successfully demonstrates how artificial intelligence can enhance the efficiency, safety, and convenience of modern household appliances. By integrating sensors, AI-based monitoring, and an automated descaling mechanism, the system continuously detects scale formation, predicts maintenance needs, and performs descaling without user intervention. Overall, the project proves

that the combination of AI and automation can transform traditional appliances into intelligent systems, offering improved reliability, reduced maintenance costs, and a better user experience

References

- [1] G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of [1] Y. Zhao, L. Zhang, X. Zhao, J. Liu, and M. Gao, "Research on Descaling Characteristics and Simulation Calculation of a Coaxial High-Frequency Electronic Descaling Device," *Water*, 2021.
- [2] [2] L. Wang et al., "Research Progress on Novel Electrochemical Descaling Technology," *Water*, 2024.
- [3] [3] T. Bhattacharjee, H. Jiang, and N. Behdad, "A Fluidic Colorimetric Sensor Design for Water Hardness Detection," *IEEE Sensors Journal*, 2015.
- [4] [4] M. L. Bouhoun et al., "A Paper-Based Potentiometric Platform for Determination of Water Hardness (Ca^{2+} and Mg^{2+})," *Sensors (MDPI)*, 2021.
- [5] [5] V. De Matteis et al., "Colorimetric Paper-Based Devices for Water Contaminant Detection," *Scientific Reports*, 2020.
- [6] [6] J. Landskron et al., "Acoustic Limescale Layer and Temperature Measurement in GAW-Based Flow Meters," *Sensors (MDPI)*, 2022.
- [7] [7] S. Hu et al., "Transient Calculation Studies of Liquid-Solid Collision in Jet Descaling," *Energies*, 2022.
- [8] [8] L. Wang et al., "Colorimetric Water Hardness Sensor Optode Containing Neutral Ionophore and Chromoionophore," *Sensors*, 2025.
- [9] [9] L. Lino Ferreira et al., "Predictive Maintenance of Home Appliances: Focus on Washing Machines," *IEEE Conference Proceedings*, 2021.
- [10] [10] P. Chaves et al., "An IoT Cloud and Big Data Architecture for Predictive Maintenance of Home Appliances," *arXiv*, 2022.
- [11] [11] D. Yamunathangam, G. Govindasamy, and M. Suguna, "Smart Care — Predictive Maintenance System in Washing Machine using IoT," 2018.
- [12] [12] N. Chinthamu et al., "AI-Driven Smart Washing Machine with Automatic Drying: Modeling and Optimizing Energy and Water Consumption," *SSRN*, 2025.
- [13] [13] T. Fonseca et al., "A Dataset for Identifying Maintenance Needs of Home Appliances," *Data in Brief (Elsevier)*, 2023.
- [14] [14] Z. Tian et al., "Small-Scale Detection Instrument for Drinking Water Quality," *Sensors (MDPI)*, 2023.
- [15] [15] R. Caruana et al., "Experimental Analysis of the Effect of Limescale on Surface Wettability and Performance," *Fluids*, 2024.
- [16] [16] S. Zhang et al., "Experimental Study on the Combined Effect of Descaling Treatments," *Water*, 2024.
- [17] [17] Various authors, "Image Processing-Based Detection of Pipe Corrosion and Defects," *IEEE/Scientific Reports*, 2019–2024.
- [18] [18] L. Wang, C. Song, G. Wan, and S. Cui, "A Surface Defect Detection Method for Steel Pipes Based on an Improved YOLO Framework," *Mathematical Biosciences and Engineering*, 2024.
- [19] [19] Y. Xing et al., "Cellphone-Based Colorimetric Multi-Channel Sensor for Environmental Water Monitoring," *Sensors*, 2022.
- [20] [20] Z. M. Çınar et al., "Predictive Maintenance in Industry 4.0: Survey and Key Methods," *Sustainability (MDPI)*, 2020.