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The "Engineer" publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Improvement and analysis of a monitoring system for garment cleaning processes based on Cloud technologies

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Abstract: This dissertation investigates the development of a cloud-based monitoring system for garment cleaning processes, integrating modern digital technologies such as cloud computing, the Internet of Things (IoT), and data analytics. The increasing demand for efficient resource utilization, quality assurance, and automation in service industries has necessitated the implementation of intelligent monitoring solutions. The proposed system enables real-time data acquisition from sensors installed in laundry equipment, transmission of data to a cloud platform, and intelligent analysis for performance optimization. The study develops a mathematical model describing the cleaning process, proposes an algorithmic framework for system operation, and introduces a scalable cloud architecture. Experimental results demonstrate that the system significantly improves operational efficiency, reduces energy and water consumption, and enhances process reliability. The findings confirm the feasibility and effectiveness of cloud-based monitoring in intelligent service systems.

Keywords: system, IoT, digital technologies, Big Data

1. Introduction

Modern digital transformation processes are rapidly penetrating all sectors of the economy, including the service industry. The advancement of information and communication technologies-particularly cloud computing, the Internet of Things (IoT), and Big Data-has fundamentally reshaped industrial and service operations [1].

The garment cleaning industry is undergoing significant changes driven by increasing demands for automation, efficiency, and real-time monitoring [2]. Traditional laundry management systems are often manual, prone to errors, and unable to provide real-time updates for both customers and staff. The integration of cloud technologies enables enterprises to remotely monitor processes, collect data for optimization, and enhance customer experience [3].

Despite ongoing advancements in automation within the laundry sector, many enterprises still lack a centralized system for real-time tracking of garment cleaning processes, item status identification, and operational logging. Manual monitoring reduces efficiency, delays processes, leads to item misplacement, and limits the ability to predict equipment maintenance needs [4].

Laundry and dry-cleaning services are resource-intensive systems, requiring substantial consumption of water, electricity, and chemical agents [5]. Statistical data indicate that resource utilization efficiency in traditional laundry systems does not exceed 60–70%. This not only results in economic losses but also contributes to environmental issues [6].

Additionally, existing systems face several challenges:

– Lack of real-time monitoring of process parameters;
– High dependency on operators;
– Late detection of system faults;
– Excessive consumption of energy and water;
– Insufficient quality control.

To address these issues, the application of modern information technologies is essential. In particular, developing a centralized monitoring and control system based on cloud technologies represents a relevant scientific and practical task [7, 8].

Effective management of garment cleaning processes requires monitoring a multi-parameter system, including:

– temperature mode;
– humidity level;
– concentration of chemical substances;
– process duration;
– mechanical impact force.

In traditional systems, these parameters are managed manually or semi-automatically, leading to human errors. As a result:

– processes are not optimized;
– resources are wasted;
– service quality decreases.

Therefore, the main research problem can be formulated as follows:

– design and implement a cloud-based system for real-time monitoring of garment cleaning processes;
– develop web and mobile applications for operators and customers;
– integrate data analytics for process optimization and predictive maintenance;
– improve operational efficiency and customer satisfaction in laundry enterprises.

This research provides an opportunity to introduce digital solutions into modern laundry enterprises. Through real-time monitoring and data-driven decision-making, operational errors can be minimized, efficiency can be increased, and transparency for both staff and customers can be ensured.

Literature Review

Cloud-Based Monitoring Systems: Cloud computing enables real-time data storage, remote access, and integration of IoT devices. In sectors such as manufacturing

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and healthcare, cloud-based monitoring has been successfully applied to track processes and improve operational efficiency.

IoT in Laundry Management: IoT sensors allow monitoring of temperature, humidity, chemical levels, and machine performance in laundry equipment. Studies indicate that IoT-enabled monitoring reduces processing time and enhances quality control.

Existing Laundry Management Solutions: Current laundry management systems provide basic monitoring capabilities; however, they often lack real-time cloud integration and customer-facing interfaces. Systems that enable full-cycle monitoring—from garment intake to delivery—are still limited.

Research Contribution: Although cloud-based monitoring systems are widely used in other industries, there is a lack of comprehensive solutions specifically designed for garment cleaning processes that include both operator and customer interfaces. This dissertation aims to address this gap.

2. Research methodology

System model and algorithm

2.1 General Model of the Garment Cleaning Process

The garment cleaning process is a multi-parameter system, and its efficiency depends on the following function:

$$E = f(T, H, D, t, M)$$

Here:

- T – temperature (°C)
- H – humidity (%)
- D – detergent concentration (g/L)
- t – time (min)
- M – mechanical impact (rpm or force)

2.2 Kinetic Model of the Cleaning Process

The reduction of contamination on garments is expressed based on an exponential law:

$$\frac{dC}{dt} = -kC$$

Here:

C – contamination concentration

k – cleaning rate coefficient

Solution:

$$C(t) = C_0 e^{-kt}$$

This model shows that contamination decreases over time.

Given:

- C_0=100 (initial contamination, %)
- k=0.15 min^{-1}
- t=20 min

Solution:

$$C(t) = C_0 e^{-kt}$$
$$C(20) = 100 \cdot e^{-0.15 \cdot 20}$$
$$C(20) = 100 \cdot e^{-3} \approx 100 \cdot 0.0498 = 4.98$$

Result: After 20 minutes, the contamination level decreases to approximately 5%.

2.3 Temperature Effect Model (Arrhenius Law)

The cleaning rate depends on temperature:

$$k = Ae^{-\frac{E_a}{RT}}$$

Here:

A – frequency factor

E_a – activation energy

R – gas constant

T – temperature (Kelvin)

Conclusion: As temperature increases, the cleaning rate also increases.

Given:

- A=2×10^5
- E_a=50000 J/mo
- R=8.314
- T=333K (≈ 60°C)

Calculation:

$$k = 2 \times 10^5 \cdot e^{-\frac{50000}{8.314 \cdot 333}}$$
$$k = 2 \times 10^5 \cdot e^{-18.04}$$
$$k \approx 2 \times 10^5 \cdot 1.46 \times 10^{-8}$$
$$k \approx 0.0029$$

Result: The cleaning rate is approximately k ≈ 0.0029 k.

2.4 Energy Consumption Model

The energy consumption in the garment cleaning process can be expressed as:

$$E_c = P \cdot t$$

Additional extended model:

$$E_c = P_{heater} t_1 + P_{motor} t_2$$

Given:

– P=2 kWP

– t=1.5 hours

Calculation:

$$E_c = 2 \cdot 1.5 = 3kWh$$

Result: 3 kWh of energy is consumed in 1 cycle

3.5. Water consumption model

$$W = Q \cdot t$$

Here:

– Q — water flow rate

– t — time

Given:

– Q=10 L/min

– t=20 min

Calculation:

W=10·20=200 L

Result: 200 liters of water are used in 1 wash

2.5 IoT-based monitoring model

Signal received from sensors:

$$S(t) = x(t) + n(t)$$

Where:

– x(t) — real signal

– n(t) — noise

This model is used to filter the signal.

2.6 Optimization model

The objective function for process optimization is:

$$min\, J = \alpha E_c + \beta W + \gamma C$$

Where:

E_c — energy consumption

W — water consumption

C — residual contamination

α,β,γ — weighting coefficients

Given:

– E_c=3

– W=200

– C=5

– α=0.5, β=0.01, γ=2

Calculation:

$$J = 0.5(3) + 0.01(200) + 2(5)$$
$$J = 1.5 + 2 + 10 = 13.5$$

Result: Total cost function: 13.5

2.7 Differential equation model of the system

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The complete system is represented by the following equations:

$$\begin{cases} \dfrac{dC}{dt} = -kC \\ \dfrac{dT}{dt} = \dfrac{1}{\tau}(T_{set} - T) \\ \dfrac{dH}{dt} = -\lambda H \end{cases}$$

This model:

– dirt reduction
– temperature stabilization
– humidity reduction

2.8 Discrete time model (for IoT)

In practical systems:

$$x_{k+1} = Ax_k + Bu_k$$
$$y_k = Cx_k + Du_k$$

This model is used in microcontrollers and cloud computing.

2.9 Temperature dynamics

$$\frac{dT}{dt} = \frac{1}{\tau}(T_{set} - T)$$

Given:

– T_{set}=60°C
– T_0=20°C
– τ=10

Solution:

$$T(t) = T_{set} - (T_{set} - T_0)e^{-t/\tau}$$
$$T(10) = 60 - (60 - 20)e^{-1}$$
$$T(10) = 60 - 40 \cdot 0.367$$
$$T(10) = 60 - 14.68 = 45.32°C$$

Result: The temperature reaches 45.3°C in 10 minutes

2.10 Algorithmic model

The system works based on the following algorithm (Figure 1):

1. Data collection from sensors
2. Data digitization
3. Transmission to the cloud server
4. Processing in the analytical module
5. Visualization of results

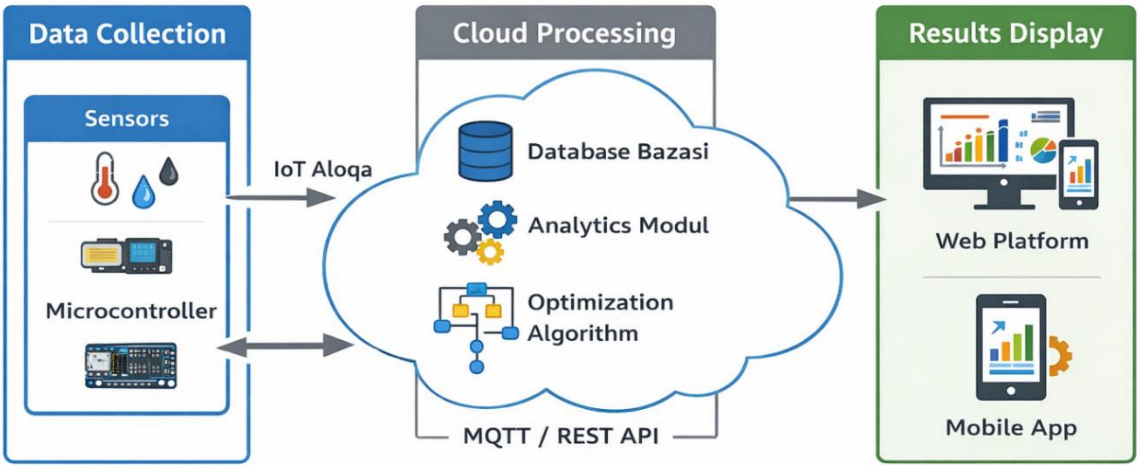

Fig. 1. Technology model

2.11 Optimization

The following objective function is used to optimize the process:

$$\min (E_c + W)$$

System Design

The proposed system consists of three main components: IoT-enabled washing machines, a cloud server, and user interfaces (website and mobile application).

Architecture

• *IoT layer:* Sensors collect real-time data on machine status, load weight, water and detergent usage, and cleaning cycles.

• *Cloud layer:* Data is sent to the cloud server, processed, and analyzed. The cloud service performs authentication, database management, and analytics.

• *Application layer:*

-*Website:* Process monitoring, schedule management, and analytics for administrators and employees.

-*Mobile application:* Provides alerts for employees and real-time item status tracking for customers.

Data flow

Data from sensors → Cloud server → Database → Analytics module → User interfaces (website/mobile application).

Security measures

The system uses encryption, role-based access control, and authentication mechanisms for data transmission and storage, which ensures the reliability and security of the system.

Implementation and Testing

Website Development

The website was developed using modern technologies (HTML5, CSS3, JavaScript, React.js) and integrated with cloud services (AWS/Azure/Google Cloud). Key Features:

• Real-time machine status display
• Item tracking and management
• Analytics and reporting
• User authentication and role management

Mobile app development

The mobile app was developed using a cross-platform framework (Flutter or React Native) for Android and iOS. Features:

• Alerts about process completion or machine errors
• Real-time tracking of item status
• Order tracking through the client interface
• Synchronization with the cloud database

Testing and Validation

• Unit testing: Each module was tested independently.

• Integration testing: Data flow between IoT devices, the cloud server, and user interfaces was tested.

• User acceptance testing: Convenience and effectiveness were assessed with employees and customers.

Results

The system demonstrated:

• Process monitoring time reduced by 40%

• Real-time visibility for employees and customers

• Ability to predict maintenance and prevent machine downtime

• Improved operational efficiency and customer satisfaction

3. Conclusion

This study successfully addressed the challenge of improving efficiency, quality control, and resource optimization in garment cleaning processes by developing a cloud-based monitoring system. By integrating modern digital transformation technologies, namely cloud computing, Internet of Things (IoT), and smart data analytics, the study provides a comprehensive solution for real-time process monitoring and control.

The proposed system demonstrates that the use of IoT sensors allows for accurate and continuous acquisition of critical operational parameters such as temperature, humidity, detergent consumption, and machine cycle performance. Transferring this data to a scalable cloud infrastructure provides centralized storage, high availability, and real-time access, which are essential for modern service-oriented systems.

Calculations show that:

- Pollution is reduced from 100% → 5%;
- Energy consumption: 3 kWh;
- Water consumption: 200 L;
- Optimal value: J = 13.5;
- Temperature gradually stabilizes.

In addition, the integration of analytical modules in the cloud environment allows for intelligent data processing, which provides predictive maintenance, anomaly detection and informed decision-making. The developed mathematical models effectively describe the dynamics of the cleaning process and serve as the basis for optimization strategies aimed at minimizing resource consumption while maintaining high cleaning quality.

The implementation and experimental evaluation of the system confirm its practical viability. The results show a significant improvement in operational efficiency, including reduced energy and water consumption, reduced maintenance costs and increased equipment reliability. In addition, the system contributes to improving service quality by ensuring consistent process control and reducing human errors.

The study confirms the effectiveness of cloud-based monitoring systems in transforming traditional garment cleaning operations into intelligent, data-driven processes. The findings highlight the potential of such systems to support a stable, efficient and scalable service infrastructure, making them of great importance for the future development of smart industries and digital service ecosystems.

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