

Литература

1. Дефекты 3D печати – Попробуем ввести классификацию – URL: <https://3dtoday.ru/blogs/leoluch/defects-3d-printing-will-try-to-introduce-a-classification> (дата обращения: 02.03.2026).
2. Кэлер, А. Изучаем OpenCV 3. Разработка программ компьютерного зрения на C++ с применением библиотеки OpenCV / А. Кэлер, Г. Брэдски. – М. : ДМК Пресс, 2017. – 826 с.
3. Обзор технологий трекинга: AR маркеры – URL: <https://habr.com/ru/articles/563666/> (дата обращения: 02.03.2026).

SENSORS FOR INTELLIGENT OIL CONDITION PREDICTION SYSTEM**Wang Hao, Zhang Nan***Sukhoi State Technical University of Gomel, the Republic of Belarus*

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Lubricating oil degradation seriously impairs the operational stability and service life of industrial machinery. Traditional manual sampling and laboratory detection methods for oil condition monitoring suffer from low efficiency, high cost, and inability to capture early degradation anomalies. To solve this problem, this paper designs and implements a low-cost and scalable intelligent oil condition prediction system based on ESP32 microcontroller. The system uses a distributed telemetry framework to collect multi-dimensional oil parameters via temperature, torque, viscosity, and light sensors, transmits data wirelessly over MQTT, and runs moving average filtering, adaptive outlier detection, and real-time visualization on a Python server. This small article systematically expounds the research purpose, technical methods and experimental results of the system. The constructed multi-sensor monitoring scheme can realize continuous real-time perception of oil health status, which provides a feasible technical reference for industrial equipment predictive maintenance and intelligent oil condition monitoring.

Keywords: ESP32 microcontroller, intelligent oil condition prediction, multi-sensor telemetry, MQTT protocol, data processing, real-time monitoring.

Research Purpose

Lubricating oil undertakes core functions such as friction reduction, heat dissipation, wear resistance and contamination isolation in industrial mechanical operation. Long-term service will lead to oil aging, oxidation and particle contamination under the influence of thermal stress and mechanical load, resulting in the decline of lubrication performance, and further inducing equipment overheating, mechanical failure and unplanned downtime. Traditional telemetry monitoring schemes represented by commercial industrial controllers and cloud IoT platforms [1] have high deployment cost, complex licensing mechanism and strong dependence on external infrastructure, which are not suitable for small-scale deployment, prototype verification and educational application scenarios.

It is necessary to develop an open, low-power and scalable distributed telemetry system based on microcontroller. The research objectives are as follows: firstly, construct an edge sensing platform compatible with multiple sensors to obtain multi-dimensional data reflecting oil state; secondly, establish a stable MQTT wireless transmission and server data processing pipeline to ensure reliable data interaction and efficient analysis; thirdly, realize real-time data visualization and threshold anomaly early warning, so as to provide decision basis for oil degradation evaluation and equipment fault prediction, and reduce the operation and maintenance cost of industrial equipment.

Research Methods

The system adopts a layered architecture of edge sensing node, wireless transmission

network and server-side data processing, taking ESP32 as the core control unit. The overall framework of the system is shown in the fig. 1.

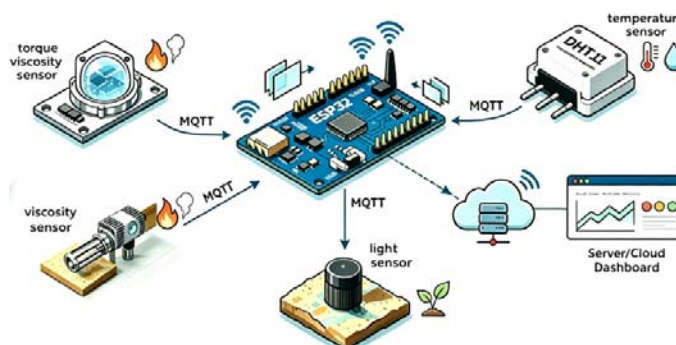


Fig. 1. Architecture of the prediction system

Hardware Platform Configuration

ESP32 microcontroller is selected as the edge sensing node, which is equipped with dual-core Xtensa LX6 processor with main frequency up to 240 MHz, built-in Wi-Fi and Bluetooth modules, 520 KB RAM and 4 MB flash memory, and integrates 12-bit ADC and rich GPIO, I2C and SPI interfaces, without additional communication peripheral modules. The module has the characteristics of low power consumption (0.06–1.25 W), small size ($25 \times 50 \times 10$ mm) and low cost (\$5–10), which is suitable for large-scale deployment of sensor network.

Four kinds of sensors are matched for oil state monitoring:

1. Temperature sensor: Real-time monitoring of oil temperature, which is an important physical parameter affecting oil viscosity and oxidation rate.
2. Torque moment sensor: Collecting mechanical friction torque changes, characterizing the matching degree of oil lubrication performance and equipment operating state.
3. Viscosity sensor: Directly detecting oil viscosity value, which is the core index to judge oil degradation degree.
4. Light sensor: Identifying oil transparency changes caused by particle pollution and additive attenuation, and indirectly reflecting contamination degree.

ESP32 regularly collects multi-sensor signals, completes preliminary noise filtering, and encapsulates the original data into JSON format for wireless publishing.

Wireless Communication Protocol

MQTT publish-subscribe protocol is adopted for data transmission, which is lightweight and oriented to resource-constrained IoT devices and unstable wireless communication environment. Compared with HTTP/REST and CoAP protocols, MQTT has compact message header, complete QoS quality of service mechanism and message persistence function, which can effectively reduce network load and improve transmission reliability under intermittent wireless connection. JSON is used as data payload format, which has good readability and parsing convenience, and is compatible with most high-level programming languages, avoiding the complex configuration of binary encoding schemes.

Server-Side Data Processing and Visualization

Python server is built to realize MQTT message subscription, data verification, statistical processing and human-computer interaction visualization. The core algorithm adopts moving average method combined with adaptive outlier filtering: firstly, deserializing JSON data and verifying data validity; secondly, using fixed sliding window to calculate

moving average to suppress high-frequency noise; then setting threshold constraints to judge sensor state, and dividing into Normal, Warning and Error levels; finally, updating visual interface and triggering early warning prompts.

The system adopts multi-threaded architecture to separate MQTT background message receiving and UI main thread rendering, which avoids interface stalling caused by network delay and data processing block. The time series visualization algorithm constructs dynamic curve charts through circular buffer and adaptive axis range, with timestamp log recording function, realizing traceable display of monitoring data.

Research Results

1. A multi-sensor edge acquisition platform based on ESP32 is developed successfully. It supports synchronous access to temperature, torque moment, viscosity and light sensor signals, with stable data collection, low power consumption and flexible scalability, which can meet the deployment requirements of industrial oil condition monitoring nodes.

2. The MQTT-based wireless telemetry transmission link is verified to be stable. It maintains low-latency and high-reliability data transmission in complex wireless environment, and JSON format simplifies subsequent data parsing and secondary development.

3. The server-side data processing and early warning system operates reliably. The moving average filtering algorithm can effectively suppress environmental noise; the configurable threshold parameters can be adjusted without recompiling the code. The multi-threaded design ensures smooth response of the visual interface and real-time performance of abnormal alarm.

4. The combined detection scheme of four sensors can comprehensively characterize the degradation, pollution and lubrication performance changes of lubricating oil, which replaces the traditional manual sampling detection mode and has good practical application value.

The constructed intelligent oil condition prediction system realizes low-cost, real-time and reliable whole-process monitoring of lubricating oil state. It has the advantages of open architecture, strong customizability and easy expansion, which can provide technical support for industrial equipment predictive maintenance and subsequent intelligent oil state prediction research.

References

1. Wu J. Edge computing-based IoT architecture for machine condition monitoring and fault diagnosis. *IEEE Internet of Things Journal*, 2023, no. 10 (12), pp. 10689–10700.

ARCHITECTURE OF INTELLIGENT WEAR PREDICTION SYSTEM

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To address the shortcomings of traditional offline monitoring for rotating machinery friction pairs, such as strong lag, high deployment costs, and dependency on external networks, a friction condition intelligent prediction system based on a three-layer IoT architecture using the ESP32 controller was designed. The system adopts a local offline deployment model, capable of real-time acquisition of multi-source parameters of friction pairs, wear feature extraction, and remaining life prediction. It features lightweight design, easy scalability, and high reliability, meeting the online monitoring requirements of industrial friction pairs.

Keywords: friction prediction, three-layer IoT architecture, ESP32, Intelligent identification; real-time monitoring; machine learning.