

Machine Learning for Predictive Maintenance: A Cloud Computing Architecture and Lessons for a Healthcare Context

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Abstract

In recent years, hospitals have invested substantially in new medical technology to guarantee medical devices' precision, reliability, and requisite performance. Despite technological developments revolutionizing medical devices, antiquated maintenance practices persist in healthcare services and infrastructure. Maintenance plans frequently need to be created for a combination of cutting-edge and outdated technology utilized in medical devices. Many hospitals have encountered the issue of identifying equipment-related risks that have been mitigated by implementing appropriate integrity monitoring techniques. The incessantly increasing volumes of extensive data streams gathered from actuators and sensor assemblies integrated into network-capable detectors and chips of medical devices necessitate a scalable platform construction to facilitate the requisite storage and immediate data processing for device tracking and upkeep. This study examines the maintenance of medical devices via an Internet-of-Things (IoT)-enabled autonomous quality monitoring system for gadgets that provide extensive real-time data within healthcare settings. The suggested construction, comprising an integrity surveillance system and a data analysis module, guarantees comprehensive insight into medical equipment and enables the prediction of potential problems before their occurrence.

Keywords: Predictive Maintenance, Machine Learning, Cloud Computing, Healthcare.

Introduction

In the past few years, cloud computing has garnered significant attention in healthcare applications because of its capacity to deliver various medical services via the Internet. Cloud computing enables apps to provide infrastructure services to numerous stakeholders with diverse and constantly changing needs. Cloud infrastructure comprises data centers, hosts, virtual machines, resources, and related components (Abdelaziz et al., 2018). Data centers encompass a substantial array of resources and a diverse assortment of applications. Servers consist of many Virtual Machines (VMs) to store and retrieve various medical resources for users (Teixeira et al., 2020). The cloud employs virtualization technology, enabling the distribution of a single physical server or software instance among multiple users and organizations. It achieves this by assigning an abstract name to a substance and supplying a link to that tangible asset upon request.

Specific industries have implemented sophisticated repair and tracking procedures to detect component wear and failure and to discover early indicators of possible issues before system failure. Various systems for machinery monitoring, including Condition-Based Maintenance (CBM) (Strang, 2020), have proven efficient in minimizing downtimes and equipment failures. CBM is a strategy that continuously monitors components and assists in determining whether to repair or replace them based on their existing or anticipated state. Many sensors are utilized throughout medical equipment to constantly monitor the status of every part in real-time or near real-time. This produces a substantial volume of log data at elevated rates, presenting a research challenge in big data analytics due to the multitude of medical devices utilized in medical facilities (Levitin et al., 2015). There is a paucity of work examining big data analysis in medical facilities about the tracking of devices and their states.

This article, thus, examines various categories of health data gathered by health surveillance equipment. The integration of routine upkeep, self-integrity tracking, and big data analysis constitutes an optimal strategy for timely predicting equipment breakdowns and safeguarding healthcare service delivery. This aids in estimating the remaining lifespan of the gadgets and addressing the technical factors involved in retrieving necessary data.

Background

Electronic structures, such as health surveillance gadgets, have several interacting components to execute specific duties that necessitate upkeep. Maintenance encompasses all technical measures undertaken to get back the required functionality of an industrial unit, whether planned (preventative) or unplanned. A repairable structure, which can be restored to its original operational state post-failure without requiring complete replacement, is monitored periodically and non-periodically throughout its lifespan (Huq et al., 2016). Scheduled inspections are conducted to adhere to fundamental principles of safety, precision, and dependability, ensuring operations meet the necessary performance standards by identifying latent faults and implementing suitable measures. One suitable course of action is rectifying the underlying causes of latent failures if an element exhibits problems or implementing preventative care if no issues are identified to avert potential shortcomings (Laghari et al., 2021). Most health institutions adhere to the maintenance protocols established by equipment makers.

The medical sector confronts challenges such as escalating operating expenses and significant equipment malfunctions. Medical professionals have begun to amass vast quantities of structured, semi-structured, and unstructured data in preparation for unforeseen circumstances, presenting new issues. More effective approaches are required to leverage medical information fully to address these escalating expenses. Current surveillance techniques and procedures for medical device repair are deemed inflexible in addressing various equipment integrity issues. The current systems do not conveniently detect element levels of efficiency or failures.

Emerging technological innovations, such as the Internet of Things (IoT) (Maktoubian & Ansari, 2019) present fresh possibilities to improve the collection and processing of health information across every area of health care. The IoT paradigm enables ongoing tracking of all items, including health monitoring devices in a medical setting. Various segments within a typical medical company are characterized as data generators. These encompass treatments, diagnosis, assessment, tracking, avoidance, and therapy. The information is gathered from 5k to 10k types of medical gadgets. Insufficient emphasis has been devoted to the significance of the information being gathered, which could impact the upkeep of specific medical equipment, particularly real-time surveillance systems. A connected device platform enables diverse healthcare equipment to collect numerous kinds of data, which are subsequently transmitted via the Internet for upkeep.

Proposed ML-based CBM

Technology can fail in two primary ways: (1) by producing erroneous readings that deviate from exact and calibrated values or (2) by ceasing to function altogether. Due to the significance and sensitivity of medical equipment, both lead to serious adverse outcomes. This article defines integrity surveillance as the suggested building's capacity to deliver prompt alerts to healthcare device administrators when a device is deemed untrustworthy for its intended purpose. Given the innovations, procedures, and tools accessible through the IoT stack, a reliable surveillance architecture depicts the transmission and tracking of data produced by medical equipment through IoT Gateways. Integrity checking requires that each device identifies erroneous measurement inputs and/or malfunctions before the outputs are compromised and/or terminated. The reliability monitoring techniques are tailored to individual device types; hence, the proposed structure embodies a comprehensive IoT-centric solution. The gadgets are presumed to employ a local integrity-checking mechanism that reports the functioning state of each device.

Fig. 1 illustrates that actuators and sensor devices transmit substantial amounts of real-time and near-real-time information, necessitating delivery to databases and their processing elements. Therefore, in the initial phase, a linkage is necessary among the huge data platform and controls for which the IoT gateway is accountable. In addition to enabling interactions, the IoT gateway securely prepares and aggregates data at the network's edge. This will enhance reaction time and information transfer efficiency. The peer-to-peer networking paradigm, exemplified by the Data Distribution Service (DDS) procedure, commonly employed in intricate and mission-critical structures, is a suitable option for the gateway component.

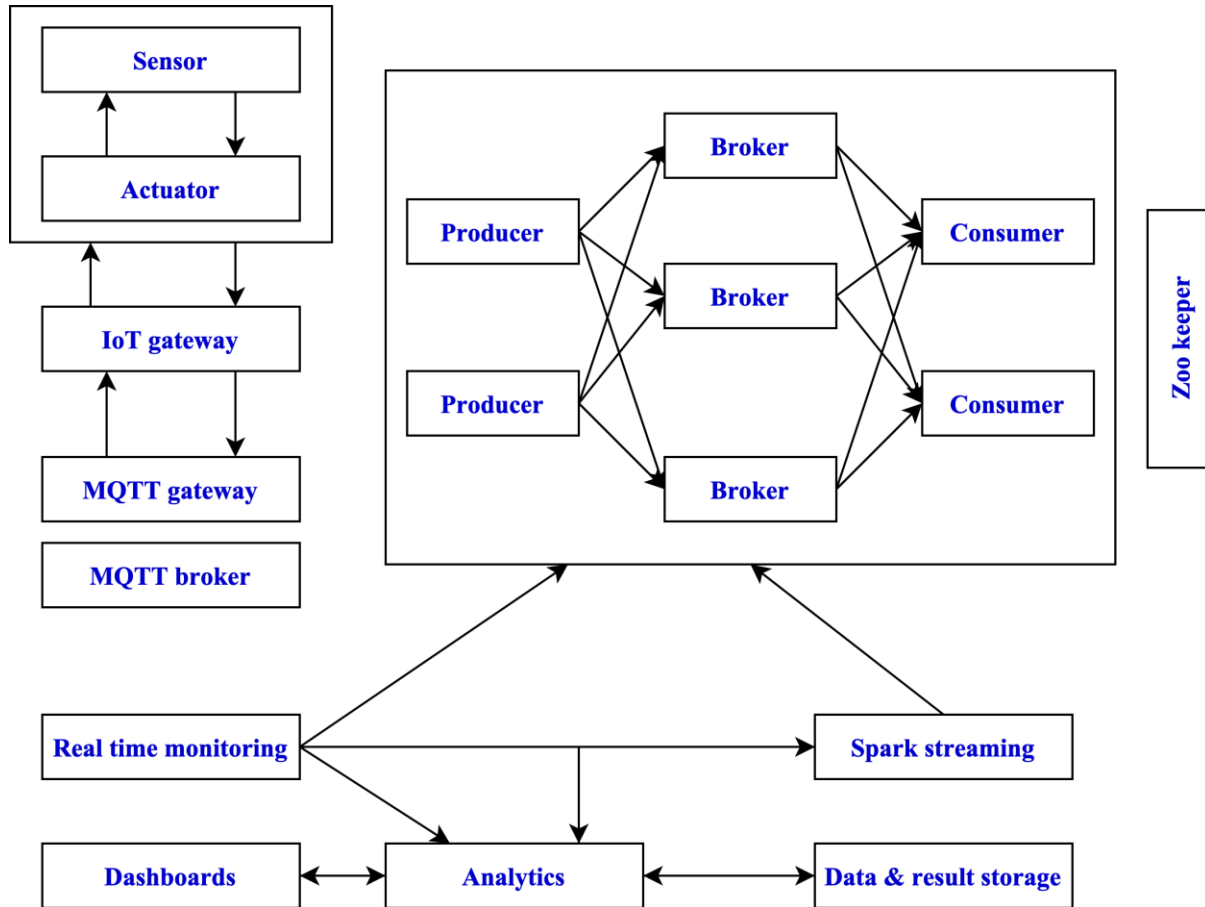


Fig. 1: Architecture of the Model

Client-server models suitable with IP systems are the ideal method for the entry point since they offer synchronous functioning, enable Quality of Service (QoS), and mitigate latency limits and security threats while managing multiple devices. Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocols (CoAP) exemplify client-server systems. The MQTT broker is situated at the network periphery to link several devices via the web, facilitate real-time message transmission, and ensure delivery of messages.

Hive MQ and Mosquitto are prominent message brokers suitable for the suggested design. A significant issue within this process is the buffering capacity, which affects the system's sustainability. To resolve this issue, a decentralized streaming service like RabbitMQ or Apache Kafka (AK) should be utilized as an intermediary messaging platform. AK is a publish/subscribe streaming processing technology capable of handling significant volumes of real-time data per minute from multiple customers. AK persistently gathers data and prepares it for storage in surveillance, interpretation, and analysis systems. AK utilizes Zookeeper to handle and organize brokers and consumers.

Empirical Investigation

An extensive analytical structure for preventative care is required to examine the failure mechanisms of various motors. Preventative care aims to facilitate decision-making for maintenance planning by diagnosing problems and estimating the residual service life of engines. Utilizing information on condition monitoring obtained from specific sensors, diverse analysis of information and processing methodologies can be employed to derive various aspects, including statistical examination, frequency analysis, and model evaluation. The traditional method involves gathering all raw sensing information and transmitting it to a centralized server for processing. This strategy generates substantial communication traffic, particularly in the era of Big Data. Conversely, the proposed mobile agent-based methodology encodes the feature extraction methods into the mobile representatives, dispatches them to the cloud locations for immediate raw data processing, and transmits the recovered features to a centralized server. This novel strategy could significantly diminish data transfer, hence enhancing system efficiency. Various feature extraction algorithms are employed based on the characteristics of the signal. This study selects five statistical characteristics, three frequency characteristics, and a coefficient of the autoregressive model from the vehicle's current envelopes for motor defect diagnostics.

Obstacles

The advantages of the portable agent-based model lie in minimizing data transfer and improving system adaptability. Achieving cloud-based predictive maintenance entails various obstacles that require further investigation.

1. Dynamic allocation of resources and independent agent management. Computing assets, specialized expertise, artificial intelligence computations, and equipment tracking information are essential for executing cloud-based maintenance predictions. Investigation into adaptive resource allocation and independent agent control methodologies is necessary to enhance service delivery and facilitate effective utilization of resources and integration within the cloud.
2. Diverse data storage and processing. Contemporary maintenance planning systems are typically designed for structured information from sensors. As the number of tracked objects of interest rises in the dynamic production environment, diverse multi-modal sensing measures are gathered. The problem lies in storing and analyzing this data using effective predictive maintenance methods.
3. Security of communications. Ensuring user confidentiality and service safety remains a formidable challenge in cloud computing. To provide a safe cloud repair service, handling information safety, network safety, information locality, data integrity, identification, and authorization is essential. Specifically, intrusion detection inside a mobile agent architecture is a critical concern. Encoded forecasting methods' security and analytical outputs must be effectively handled during the traversal of mobile sensors across the intranet.

Conclusion

This article introduced a real-time monitoring framework for examining and maintaining healthcare products within healthcare institutions. Due to the rising quality and number of medical equipment in hospitals, traditional maintenance procedures have been considered inefficient or unworkable. The suggested architecture employs big data and IoT technologies to detect component damage or failure and monitor healthcare device conditions. This design utilizes advanced integrated technology to monitor device parts for scheduled upkeep. It features real-time device tracking abilities, leading to lower operating expenses and enhanced efficiency in the supply chain. Data analysis is conducted at multiple phases of device operation and subsequently arranged in various formats that propose activities for the upkeep and functioning of medical devices. Accumulated data facilitate the comprehension of factors such as asset-degradation trends and performance under diverse operational settings. The amalgamation of big data technology with IoT principles facilitates enhanced precision tracking of medical equipment. Historically, scientists and engineers could oversee a limited number of gadgets simultaneously; a more significant percentage of healthcare equipment can now be continuously monitored in real-time with the suggested integrity surveillance architecture. This research does not address local integrity-checking approaches for specific medical devices; the structure suggested would enhance the accuracy of medical equipment and their service schedules by minimizing unplanned disruptions.

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