Design and Development of Remote Monitoring Predictive Maintenance Dashboard for Reverse Osmosis Water Purification Plant

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***Abstract*— In an effort to digitalize and modernize medical equipment maintenance services in Government Hospitals, remote monitoring dashboard has become indispensable. Monitoring dashboards are often used to monitor, control, improve and maintain the operations of medical equipment as they are a powerful tool that provides an overview of the current status of the operating system. This paper presents the design development of a Remote Monitoring Predictive Maintenance Dashboard via web-based application for the Reverse Osmosis (RO) Water Purification System at Hospital Temenggong Seri Maharaja Tun Ibrahim, Johor, Malaysia. The dashboard monitors real-time data captured from nine sensors located in the RO plant. The real-time data is processed for breakdown prediction of the plant by incorporating the long short-term memory (LSTM) network which will be displayed on the dashboard and produced an alert when necessary. The system development approach practices the 'Waterfall Method' with a combination of the 'Agile Method'. This paper discusses the system requirement specifications, system architecture, system functions and the outcome of the development. The system has been successfully deployed and tested by the stakeholders.**

Keywords—predictive maintenance, health medical equipment, machine learning, analytic dashboard, mHealth

I. Introduction

Visualization of medical equipment performance provides the basis for monitoring, controlling, improving and maintaining the operations of the equipment. Monitoring dashboards are frequently employed for this objective due to its efficacy in compiling and comprising relevant and significant data and information in a user-friendly way and easy to comprehend, usually in the form of graphical overview of the current status of the operating system. Dashboard is defined as a real-time user interface that provides real-time information in a visually intuitive manner, presenting graphical depictions of an organization's Key Performance Indicators (KPIs) to aid in decision-making processes [1]. Dashboards have a variety of uses, and their design, technology, and scope vary according to the following usage scenarios :

- Information radiators are dashboards that are intended to disseminate status information to wide audiences. They are frequently created as information screens put in strategic locations for projects, teams, or organisations.
- Management dashboards, which are generally created as desktop reports with the option to drill-down in the data and are intended to tell managers on the state of the project and its underlying parameters.
- Business intelligence dashboards - These dashboards, which are frequently created as desktop applications with the potential for web-based report access, are designed to assist product managers in accessing, visualising, and analysing data related to product development and its surrounding market.
- Hybrid dashboards, which combine two or three of the aforementioned use cases.

In the healthcare industry, the use of dashboard has become increasingly prevalent for monitoring operational activities and assessing quality in hospital settings as listed in Table I below. A study by Shabestari et al. (2018) demonstrated that the use of a dashboard monitoring system significantly reduced medication errors, improved clinical decision-making, and enhanced patient outcomes [2]. Tajima et al. (2019) showed that implementing a real-time monitoring dashboard in an emergency department resulted in reduced patient wait times, improved staff communication, and enhanced workflow management [3] while Shahzad et al. (2017) highlighted the use of dashboards for monitoring medical device performance, identifying potential failures, and facilitating timely maintenance interventions. This approach led to increased equipment availability and improved patient care [4]. Incorporating Wireless Sensor Networks (WSNs) in the healthcare industry has become a necessity to monitor the health status of medical devices and equipment. In critical applications, one study argues that undesired events have the potential to compromise the reliability of WSNs, necessitating the evaluation of their impacts right from the early stages of development. The author presents heuristic strategies for assessing WSN resiliency using an event-based formal approach, emphasizing the link between resilience, reliability, formal methods, and the significance of the connection between resiliency and coverage. The effectiveness and practicality of the proposed approach are demonstrated through comparisons with related techniques [5].

Nonetheless, there is an absence of literature that discusses on the development of remote monitoring dashboard of IoT-based reverse osmosis water purification plant. Therefore, the purpose of this project is to design and develop a monitoring dashboard framework with a display of input and output data of selected parameters for the predictive maintenance system for the Hemodialysis Reverse Osmosis (PMRO) Water Purification System Plant located at the Hospital Temenggong Seri Maharaja Tun Ibrahim (HTSMTI), Johor, Malaysia. The Haemodialysis Reverse Osmosis Water Purification System serves as the primary provider of filtered water for patients undergoing dialysis therapy treatment at the HTSMTI. Therefore, it is imperative to employ effective maintenance management and employ suitable maintenance procedures in order to ensure the optimal condition of the equipment. An estimation of equipment failure will be predicted in this system by incorporating machine learning. This will allow sufficient time for the device supplier to perform maintenance before the actual breakdown. The development of the IoT-based PMRO system and the formulation of machine learning for the system have been thoroughly explained in previous study in [12]. The paper explained the hardware and software components of the system as well as the machine learning development. Therefore, this paper will extensively cover the monitoring dashboard system that includes (i) the system requirement specifications, (ii) the system architecture, (iii) the system function and (iv) system output.

TABLE I. USE OF DASHBOARD IN HOSPITAL SETTINGS

Dashboard Type	Description	Ref.
Operational Dashboards	Monitor operational aspects (e.g., patient flow, resource utilization)	[6]
Quality Dashboards	Assess quality metrics and performance indicators	[7]
Financial Dashboards	Track financial performance and budget management	[8]
Clinical Dashboards	Provide patient-specific clinical information and support decision-making	[9]
Patient Experience Dashboards	Track patient satisfaction and engagement metrics	[10]
Executive Dashboards	Provide high-level summary of key performance indicators and support decision-making	[11]

II. DASHBOARD SYSTEM DESIGN

In general, the PMRO system is developed to anticipate breakdowns of the machine, allowing timely scheduled maintenance to be carried out prior to any machine malfunctions. One of the main cores of the project is to display sensor data and breakdown prediction for condition monitoring and fault diagnosis programs to take place. The achievement of high accuracy in fault detection within the predictive maintenance strategy of the PMRO system necessitates the implementation of several measures. These measures encompass the design and development of software, as well as the creation of a dashboard monitoring system. The purpose of this software and dashboard monitoring system is to effectively oversee the actions of the sensors employed throughout the operation of the PMRO system. These are the activities that must be performed under such a development:

- User-friendly and intuitive interface for displaying measurement results and status from sensors as an instructive chart and graphical interface.
- Interfaces can display precise sensor data per microcontroller per seconds to weeks.
- The system is capable of displaying Machine Learning Result notifications and data anomaly alerts.
- Utilizing an interface to transmit a command to a microcontroller (e.g., start or stop a pump).
- The interface can fine-tune the ML parameters for improved results
- To safeguard the system, provide a secure data transmission protocol and encrypted data.

A. *System Requirement*

There are two primary components in the design of a software application:

a. Monitoring : Use for storing data from sensors attached to pipes to monitor RO system (pressure, conductivity and flow rate), processed in microcontroller, then sent to cloud server via wireless connection (Internet), then stored to database server to generate some graphical information via web application interface.

b. Control : Data log from a database server can be utilised as input (data training) for Artificial Intelligence that can be incorporated in a microcontroller (micro AI) and Web-based application for improved analytical results. This output can be used to control actuators on pipes, such as regulating water flow by regulating a valve.

Table II below shows the system requirement of the PMRO system.

TABLE II. SYSTEM REQUIREMENT OF THE PMRO SYSTEM

Requirement	Description
Programming Language	JavaScript (current system) Phyton (when transferring to AWS)
Operating System	Windows
Data Processer	1 CPU, 1 GB RAM, 20GB disk. Monolithic server
Cloud Storage and Server Specification	2 CPU, 2 GB RAM, 20 GB Storage 1 instance for MySQL database
Frontend	HTML, CSS, JS
Backend	PHP connecting Frontend to Database Server. As API server to store data, serve data and process some data for Artificial Intelligence for decision maker.
Data Storage	Mysql / Postgresql / MongoDB (current) To store data from sensors.
User Access	The dashboard can only be accessed by revised administration.

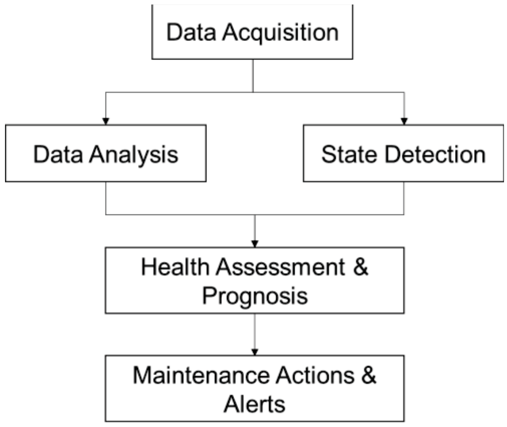

Fig. 1. PMRO dashboard system flow chart

B. System Architecture

An effective system design for predictive maintenance should encompass features that, when integrated holistically, facilitate the effective integration of predictive maintenance as a comprehensive system. The system's functioning is launched through the process of data acquisition, wherein data from several sources is captured in real-time and stored in a database. The data collected from the data collection system is utilised for the purposes of data analysis and the detection of system states. The data obtained by the data collecting system serves as a comprehensive account of the system's performance and characteristics across a certain period. A range of methodologies can be utilised in the process of data analysis to uncover faults, errors, and other similar issues. The data will be subjected to analysis by either the grouping of distinct parameters or the separate analysis of each individual parameter. The data that is provided for the purpose of data analysis is sent simultaneously to the block responsible for state detection. This facilitates the visualisation of the system's state in real time and enables the early discovery of issues. The outcomes of the data analysis are applied to the evaluation and forecasting of the current status of the system. Once predicted results become accessible, it will be possible to determine the appropriate maintenance tasks to be executed based on the affected parameter of the system, and afterwards schedule the necessary jobs or provide warnings to avert a system failure. The operational characteristics of each system block, as illustrated in Figure 1, can be outlined beginning with the process of data acquiring.

A business Architecture has been developed according to the Enterprise Architecture (EA) approach where it describes the alignment of systems which includes Business, Data, Application and Technology (BDAT). Business architecture is an all-encompassing system description. It defines the nature of their interaction and identifies its purpose, vital functions, active components, and critical processes. Business architecture consists of a collection of distinct, yet interdependent platforms that create a modular, multidimensional system [13]. The overview of the whole Business Architecture is as in Fig. 2.

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In this architecture, the type of service medium is the remote and online monitoring dashboard. The users for the system consist of:

i. **Internal users** : Engineering Service Division (EDS) or Ministry of Health Malaysia (MOH) and Hospital Temenggong Seri Maharaja Tun Ibrahim, Kulai Johor (HTSMTI) to ensure the smoothness and completeness of hospital operations and medical equipment functionality.

ii. **External users** : Concession companies (MSB/AP) and Universiti Teknologi Malaysia (UTM) to monitor, evaluate and verify the data representations.

The main services of this dashboard are the data visualization and daily data log of the sensors that are connected to the RO Water Purification plant. The dashboard will also provide forecasting and prediction on the equipment breakdown based on the machine learning algorithm implemented in the system. By doing so, it will alert the users by warning indications.

For the data layer, there are 2 categories of data sources i.e internal sources and external sources. Internal sources are from all three sensors used in this project i.e conductivity sensor, pressure sensor and flow sensor. Meanwhile, the external source is the data analysis from the machine learning algorithm. The system architecture also identifies the data monitoring and data provider. The data monitoring is performed by the EDS and HTSMTI while the data providers are the concession companies and UTM.

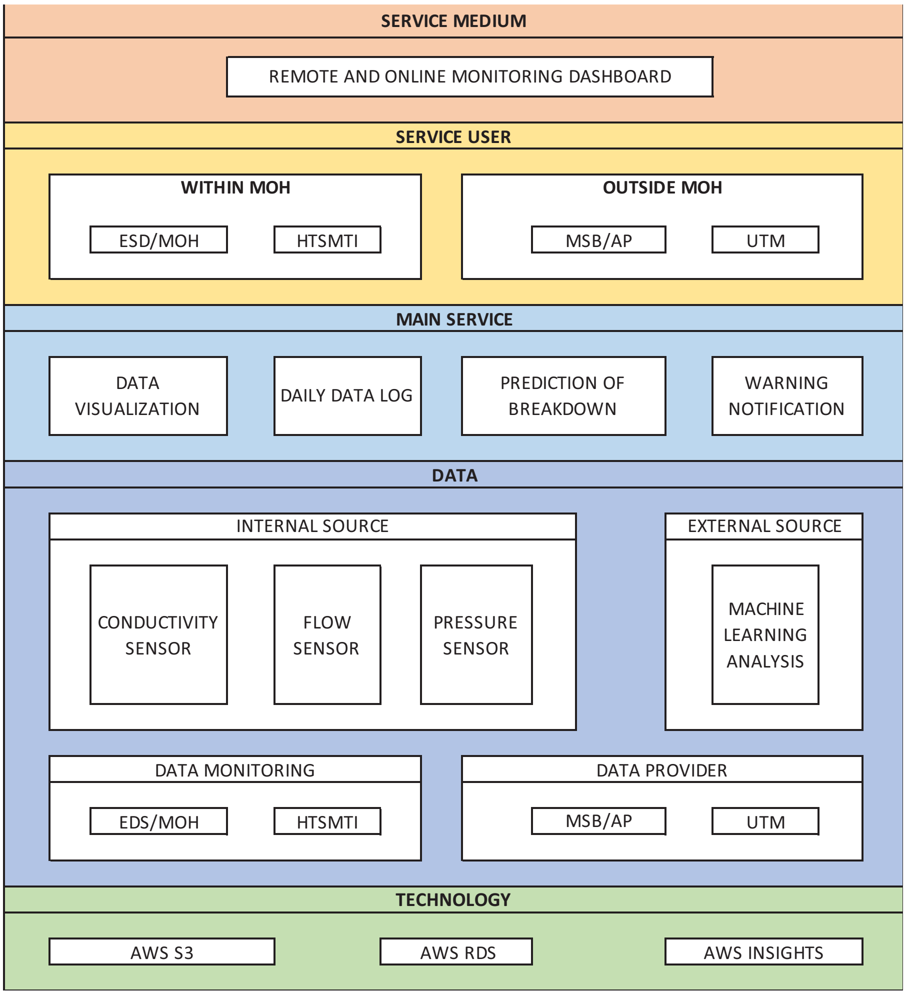

Fig. 2. PMRO dashboard system architecture

For the technology layer, all infrastructure will be using the Amazon Web Services (AWS) Cloud as subscribed by the National Institutes of Health (NIH) and comprises of [14]:

i. **Amazon Simple Storage Service (Amazon S3)** is a highly scalable object storage service that offers exceptional levels of data availability, security, and performance, making it a leading solution in the industry. Customers from various industries and of different scales have the opportunity to store and safeguard an extensive amount of data for a wide range of purposes. These purposes encompass data lakes, cloud-native apps, and mobile devices. By leveraging cost-effective storage classes and implementing user-friendly administration capabilities, it is possible to effectively manage expenses, efficiently arrange data, and define precise access limitations to align with specific business, organisational, and compliance requirements.

ii. **Amazon Relational Database Service (Amazon RDS)** is a comprehensive suite of managed services designed to streamline the process of deploying, managing, and scaling databases inside a cloud environment. Users can choose from a range of seven commonly used engines for their deployment needs. These options include Amazon Aurora with MySQL compatibility, Amazon Aurora with PostgreSQL compatibility, MySQL, MariaDB, PostgreSQL, Oracle, and SQL Server. Additionally, users have the option to install their chosen engine on-premises using Amazon RDS on AWS Outposts.

iii. **Amazon CloudWatch Application Insights** makes the applications and underlying AWS resources more observable. It assists in configuring the optimal monitors for the application resources to continuously evaluate data for indications of application faults. Application Insights, which is powered by SageMaker and other AWS technologies, delivers automatic dashboards that display possible issues with monitored applications, allowing the user to swiftly isolate ongoing issues with the infrastructure and apps. Application Insights' greater visibility into the health of the applications reduces the mean time to repair (MTTR) required to troubleshoot application faults.

However, at this stage of the development, all data are stored, processed and analysed using a paid server. The transfer of the server and all its data will be performed after all users are satisfied with the outcome of the system.

C. *System Functions*

There are 5 system functions that have been identified for the development of PMRO system monitoring dashboard. The functions are categorized into several sub-functions based on users' requirements. The system functions are as follow:

i. **Data Log Management** : To acquire, process and display the data from all nine sensors (pressure sensors, flow rate sensors and conductivity sensors) installed in the RO plant. The data is a real-time data and transmitted to the cloud every 2ms. The data management will be monitored by the technician on site from the concession company.

ii. **Data Visualization Management** : To represent and display the sensors' data in the form of line and gauge chart for better understanding of the data. The data can be accessed by all service users

iii. **Breakdown Prediction** : To process, predict and display the estimation for device failure. The prediction is made using Machine Learning algorithm based on previous data entry from the sensors. The ML algorithm is monitored by UTM but the prediction is accessible to all service users.

iv. **Warning Alert Notification** : To detect and display data anomalies based on sensors' data. A warning notification will pop up when anomalies are detected. The notification is visible for all service users.

v. **Administration Management** : To perform registration, generating report and search activities within the dashboard system. This module can be accessed by the administration of the system i.e. EDS and MSB.

D. System Development Approach

The system development approach practiced is the 'Waterfall Method' with a combination of the 'Agile Method'. The justification for choosing the Waterfall Method is because it is easy to plan and easy to manage. More emphasis is given to the needs analysis phase especially for the transformation of manual business processes to digital and the development of this system is the first to be implemented. Waterfall Method' is also very suitable to implement for smaller projects with clear requirements such as this PMRO System. Whereas, the Agile Method approach is practiced at each phase in the Waterfall Method to ensure that each activity can be implemented quickly, at shorter phases, interaction and feedback with customers can be implemented periodically according to the phase. This is to avoid inaccuracy of expectations between the system development team and the customer.

III. Results and Discussion

This section exhibits the graphical interfaces of the PMRO system monitoring dashboard. The monitoring dashboard interface exhibits real-time visualisations of data from pressure sensors, conductivity sensors, and flow rate sensors. Figures 3 and 4 depict the line graph and gauge chart, respectively, illustrating the data obtained from the sensors. The line graph in Figure 5 allows users to readily see any anomalies or discrepancies in the data while the HRO system is in operation. The abnormalities or the sudden rise or drop in the data can be due to several reasons such as leaking at the pipe fittings, no or little water flow and water contamination, to name a few. When faced with such irregularities as shown in Fig. 6, technicians can conduct an inspection of the equipment and make necessary adjustments if needed.

Another function of this system is to predict the time to failure of the device. The ML algorithm implemented in the system will continuously run and calculate the prediction. The ML algorithm has been discussed in [12] previously. Once the calculation is complete, a notification indicating the success of the prediction will appear as shown in Fig. 7. The time to failure or breakdown of the device is displayed in the front page as in Fig. 8. The daily data log of the sensors can be found in Data Log tab. It can display the data in 10, 50 or 100 entries. The most recent data log is on the last page of the module. Fig. 9 shows the data for 5 pressure sensors while Fig. 10 shows the data for flow rate sensors and conductivity sensors.

The dashboard has been presented to the stakeholders and received approval for migration to the AWS server for better security and performance. The migration to the AWS server will require extensive remodification of the system requirement as it requires Phyton as the programming language. This will be explained in future publications.

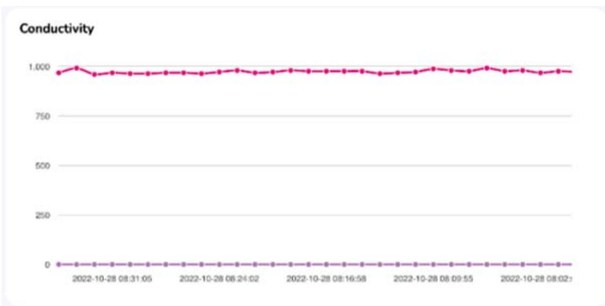

Fig. 3. PMRO dashboard system architecture

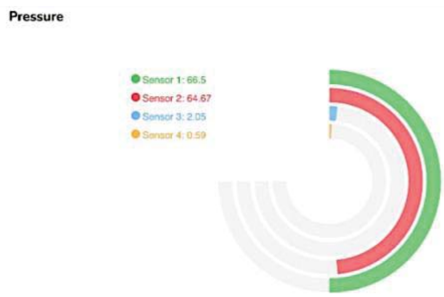

Fig. 4. PMRO dashboard system architecture

Fig. 5. Abnormalities readily observed in the PMRO dashboard system

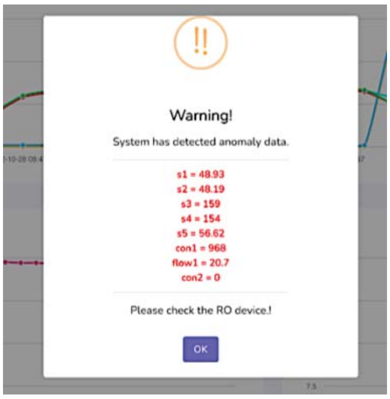

Fig. 6. Abnormalities detection and alert notification

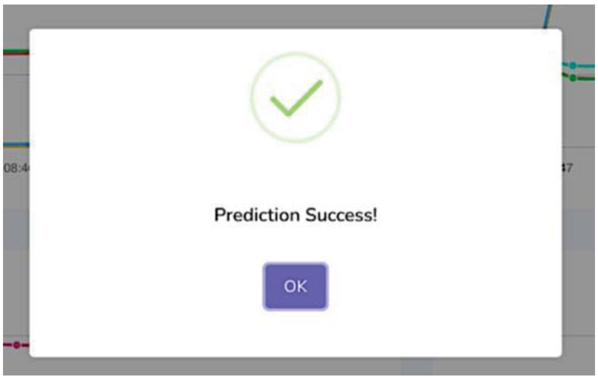

Fig. 7. Successful prediction notification

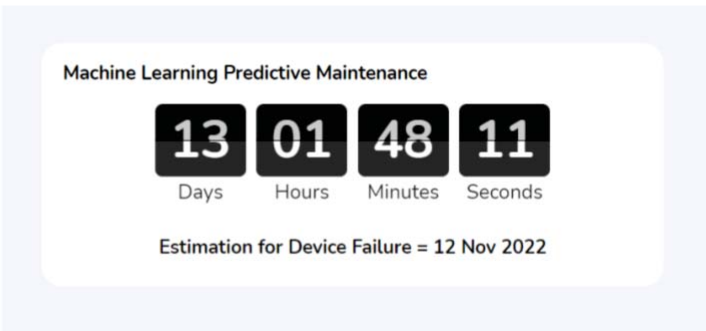

Fig. 8. Estimation of device failure

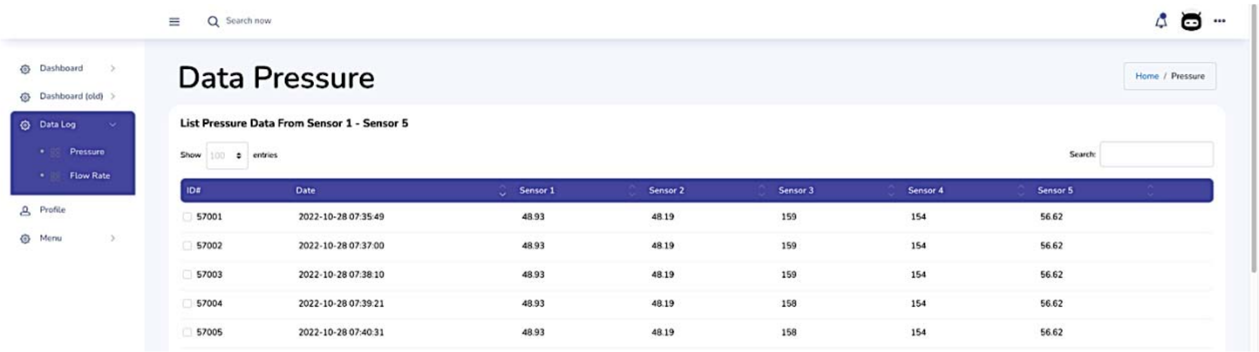

Fig. 9. Data log of pressure sensors

Fig. 10. Data log of flow rate sensors and conductivity sensors

IV. Conclusions

The main purpose of the dashboard monitoring system is to enable the monitoring, controlling, improving and maintaining the operations of the equipment. The dashboard is also equipped with the prediction of breakdown of the reverse osmosis water purification plant using machine learning method. The estimation of equipment failure is displayed in the dashboard and alert will be issued to respective administration for further assessment. At the end of this project, we have successfully managed to design, develop, implement and deploy the monitoring dashboard system to be utilized by MOH and benefitted by the stakeholders.

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