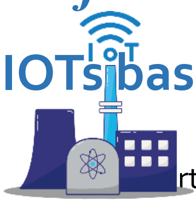
Project Report



IOTs based Nuclear Power Plant Management System (NPPMS)

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Submitted to Professor **Davide Di Ruscio**

Course Titled as **Software Engineering for Internet of Things**

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Purpose

This report provides a comprehensive overview of the system design, using a number of different architectural views to depict different aspects of the system. It is intended to capture and convey the significant efforts which have been made for the system.

Scope

This document provides an architectural & implementation details of the **Nuclear Power Plant Management System (NPPMS)** with the help of Internet of Things.

Tools & Technologies Used

All the content inside this document has been generated using following tools:

Microsoft Word 2013 (*for descriptions and overall report*)

Draw.io (*for Logical Diagrams of Architectures*)

Magic Draw (*for UML Model & Diagrams*)

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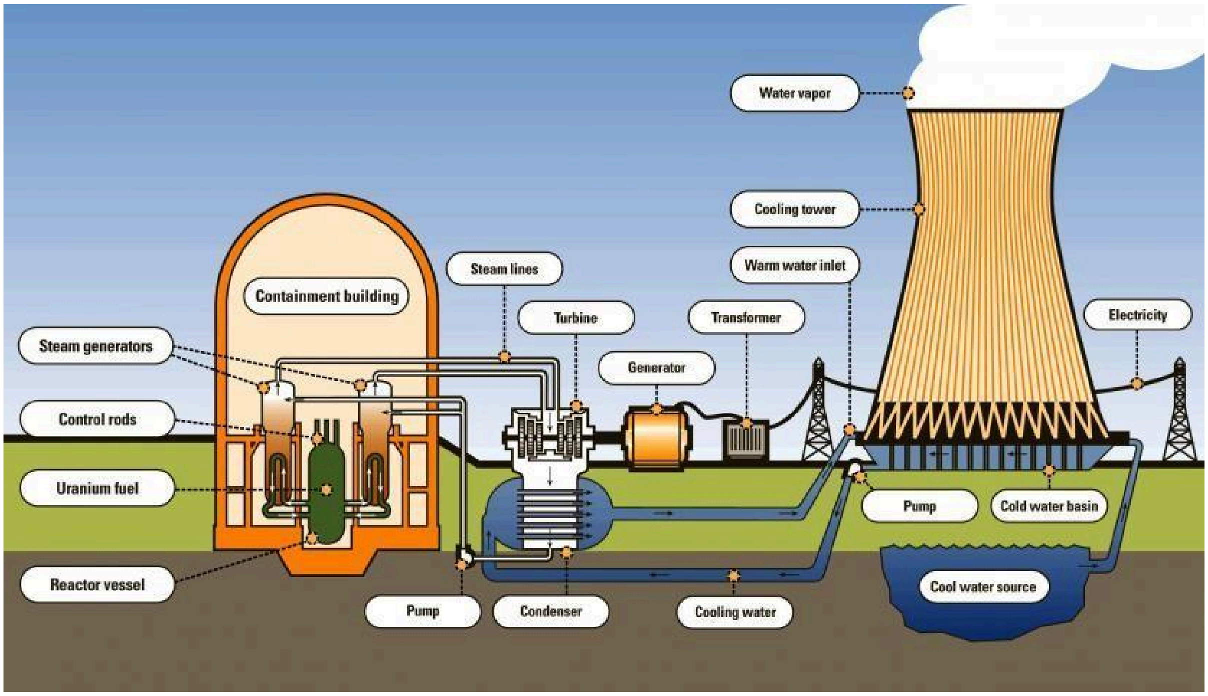
Motivation

A nuclear power plant is a power station that generates electricity by doing chemical reactions in a nuclear reactor using Uranium. During the plant operations, there is the discharge of radioactive elements which are hazardous to the environment, hence there is a dire need to monitor the activities of the nuclear power plant as well as control the devices to ensure the safety of the environment. Due to the nature of the tasks and dangers involved, it is required to monitor such plants remotely as this also ensures the safety of the power plant operator. For the above mentioned reasons, the adoption of IoT technology is handy in such environments to enable stakeholders to remotely monitor and control the day to day business inside the nuclear power plants. Hence IoTs base **Nuclear Power Plant Management System (NPPMS)** is proposed.

Background

Nuclear Power Plant (NPP) is a thermal power stations which use heat produced during nuclear fission that fueled by uranium **[1]**. NPP consists of numerous buildings and facilities among which the main buildings are containment building, turbine generator building, controlling building, waste storage and disposal called "spent fuel pools". The main process in producing heat starts inside the containment building/compartment which is the house of nuclear reactor. This building usually is designed with two-meters-thick concrete to protect reactor and steam generators from outside intrusion and to protect outside environment from the effects of radiation (in case any malfunction happens). Inside the containment building resides calandria, a large tank known as the heart of nuclear reactor which consists of control rod that can be move up and down to control fission rate of uranium fuels. Meanwhile, turbine generator building contains turbine and generator where the steam produced in the calandria is transported to in order to spin the turbine and generate electricity. For monitoring and controlling nuclear reactor, controlling building is used. Another most important area of NPP is waste storage and disposal place called "spent fuel pools" which is the place to safely store the radioactive wastes after reaction. Spent fuel pools are made of reinforced concrete several feet thick with steel liners that are filled with about forty-foot deep water to serve for shielding the radiation and cooling the rods **[2, 3]**. For understanding how it works; NPP basically uses nuclear fission reaction that produces energy to heat water. This process results in producing steam which is used to spin large turbines to generate electricity **[1]**. **Figure 1**. shows the components which are involved in the energy production process of Nuclear Power Plant (NPP).



(***Figure 1.*** *Components of a Nuclear Power Plant [7]*)

Data Sources & Processing

From **[4]**, it can be simply summarized as Nuclear Power Plants (NPP) belong to a key domain of CPS (Cyber Physical Systems – involves proper monitoring and control of physical processes through computational procedures). The operation of the power plant could be remotely monitored with the help of sensors that provide time-stamped measurements for internal and external parameters. In addition, open-source data analytic tools are used for plant health check and predictive maintenance. **Figure 2**. Shows the types of data sources we get from Nuclear Power Plant (NPP). At the end of the process, all data is used to analyze plant performance, consumption, security monitoring, and a report of final results.

Visual analytics also helps to provide meaningful insights into the time series data. A simple way to visualize a large amount of time-series data is to plot them with a visualization tool.

Brief overview process of data analysis in Nuclear Power Plants:

I. **Sending Data:** Data is sent by the data sources such as Water Chemistry Sensors, Gas and Volatile Sensors, Temperature and Humidity Sensors, and Power Measurement. All those sensors and IoT tools monitor and measure the level of each resource. Afterwards, the data is read by sensor tools.

II. **Processing Data:** In the machine learning pipeline, there are some clusters that help plant operators to understand, visualize, explore, and model the Nuclear Power Plant data by processing, scaling, analyzing, classifying, and plotting the raw data.

III. **Showing Data on Application:** At this state, plant operators can see the data through the application and can perform required operations.

Modality	IAEA Data Sources	Operator Data Sources
Quantitative Sensors	Gamma ray spectrometry (U and Pu isotopics)	Water chemistry (pH, ppm levels, conductivity, hydrogen, oxygen, chloride, fluoride, boric acid concentrations),
	X-ray spectrometry (element identification, container thicknesses)	Primary and secondary loop temperatures, pressures, flow rates, water levels
	Neutron counting (U and Pu amount/enrichment verification)	Accelerometers (vibration FFT)
Operational Signatures	Power monitor (Advanced Thermo-hydraulic Power Monitor)	Ex-core neutron flux (noise shows vibration, phase differences between detectors)
		Reactor power
		Control rod positions
		Steam generator pressures & flow rates
		Valve settings (open/closed)
	Cerenkov radiation viewing	Radiation monitors
		Motor current signature analysis (>350 motors to drive pumps, fans & compressors)
		acoustic emissions monitoring (emitted from equipment and pressure boundaries)
		Odor, burning, fumes
Containment & Surveillance	Camera surveillance	Security cameras
	Load cells (weight measurements)	
	3-D laser range finder	Security personnel
	Seal inspection	RFID tracking
	Containment verification (e.g. laser reflectometry)	
Off-site Laboratory	Destructive Assay (alpha, x-ray, gamma, mass spectrometry, etc.)	Personnel radiation monitors
Environmental Sampling	Particles	Gas effluents
Documentation	Inspector reports, Inventory ledger reconciliation	Maintenance reports, INPO/WANO visits, Regulator event notification reports

*(**Figure 2.** Types of data sources typically used by the IAEA; and typical data sources used by civilian reactor operators [4])*

Limitations & Project Scope

Due to time constraint and unavailability of hardware devices, all sensor data are simulated. However, if there are real sensors and devices, they can still be easily integrated into the system.

Things to be monitored in this project are:

- Temperature
- Pressure
- Water chemistry
- Flow rate
- Radiation

NOTE: Sensor layer and the Device layer are being implemented via code just for simulation purposes, since there are no physical sensors then there's no need for physical devices.

System Requirements & Usecases

Following main requirements are defined for the system under discussion:

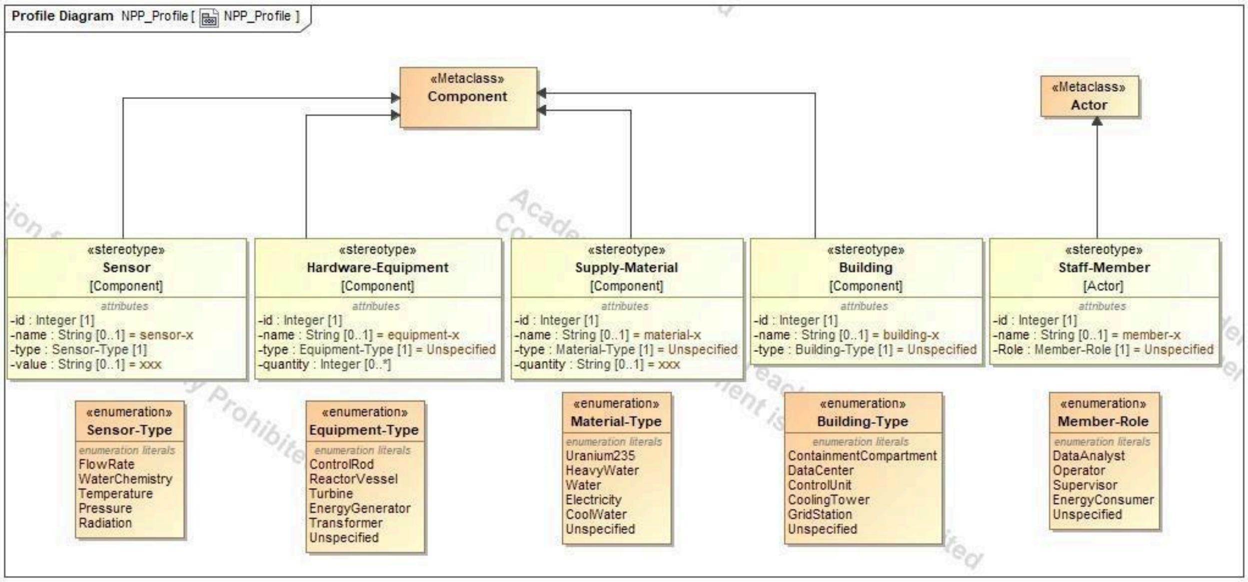
- Sensors should be able to collect data from the different buildings of the power plant.
- The IoT system should be able to process the data fetched from the sensors.
- The administrative dashboard should be able to display both historic and real time data collected by the sensors being installed inside.
- System should be able to send important emails to the Administrator when there are abnormalities.

In this **NPP** system, we have focused on the most important functionality which is given below serving the requirements of the course of "**Software Engineering for Internet of Things**" studied during the semester. Some additional details are incorporated only at the UML Modeling level but the core focus is given to IoTs instead of other business domains i.e. user management etc.

Use case Name	***Data Visualization in NPP***
Actor	Staff Member (Role: **Data Analyst**)
Precondition	Relevant data is available in the database
Post-condition	All sensor related data is visualized successfully on dashboard
Main Scenario	While performing different operations in power plant, all sensors send the data to the data layer, which make that data available for performing analytics and visualizations so that desired actions can be performed

Architecture Diagrams

Figure 4. represents UML profile diagram of NPP. There are two Meta classes: ***Component*** and ***Actor*** which required stereotypes so that we don't have to create those elements again and again and to reuse the predefined stereotypes in our model. It consists of four stereotypes which are ***Sensor***, ***Hardware-Equipment***, ***Supply Material***, and ***Building***. Meanwhile, there is just one stereotype for Actor Meta class which we named as ***Staff-Member***. There are five ***enumerations*** that are used as tagged values for each one of the above mentioned stereotypes. The enumerations give us understanding about what type of ***sensors***, ***equipment***, ***material***, and ***building*** we use as well as provide some information related to the role of the ***Actors***. **Table. 1** shows the function of each enumerations.



*(**Figure 4.**Profile Diagram for Nuclear Power Plant Management System - NPPMS)*

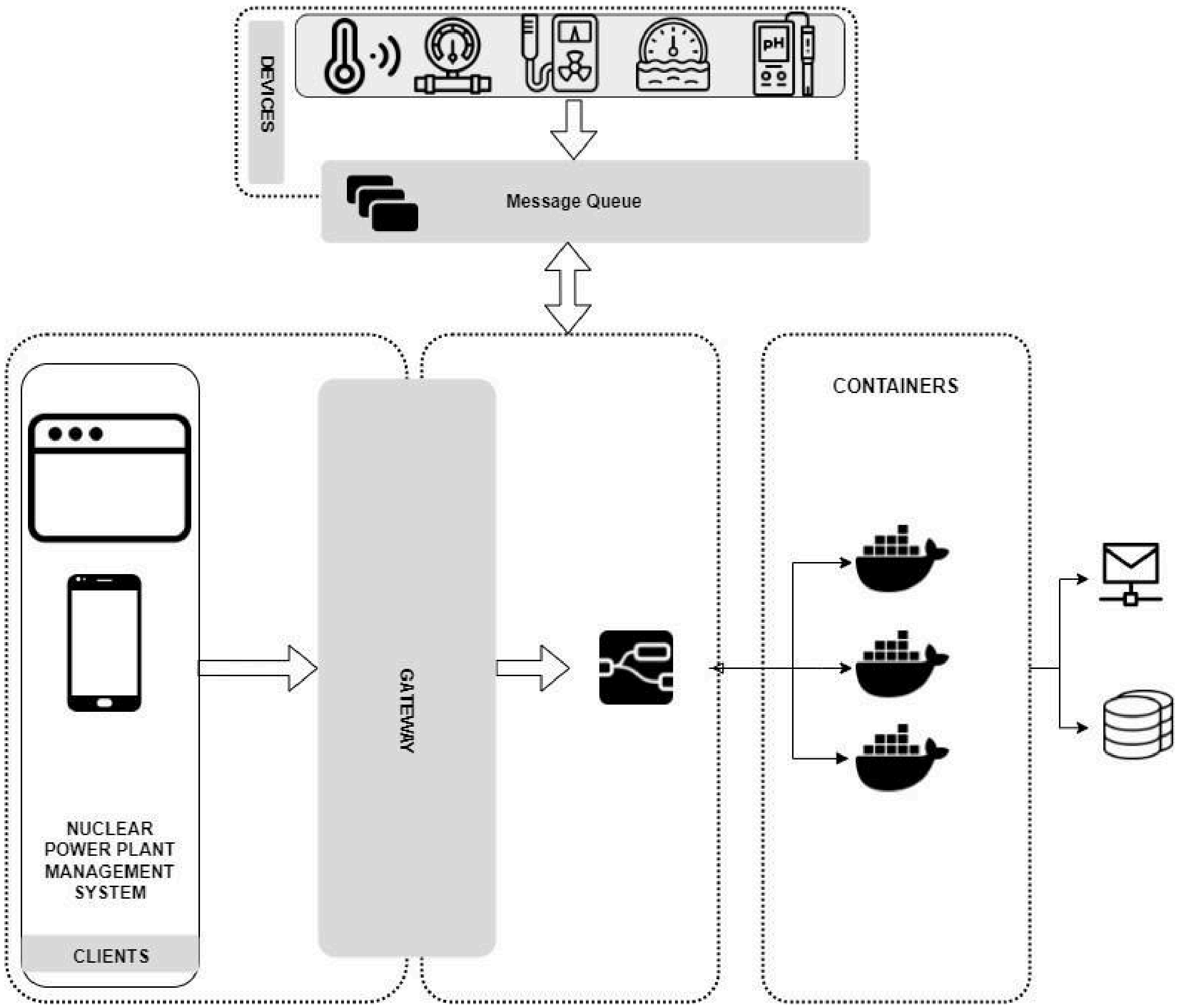
Meta class	Stereotype	Enumeration	Function
Component(s)	*Building(s)*	Containment compartment	house for reactor vessel and control rod
		Control and monitorin g unit	place where the staff in charge do the monitoring and control process
		Data center	where all the data received by sensors being stored
		Cooling tower	building to transfer exhaust heat into the air instead of into a body of water
		Grid station	to transport electricity from the power plant to customers
	Material(s)	Uranium 235	the fuels to produce electricity
		Heavy water	it is used as a moderator in nuclear reactors
		Water	to convey heat from the reactor core to the steam turbines
		Electricity	energy to start the process and provides power for monitoring unit
	Equipment(s)	Control Rod	to control fission reaction inside reactor vessel
		Reactor vessel	containers that hold nuclear fuel when the reactors operate

		Turbine	convert the energy from the steam produced by fission reaction in to

			mechanical energy in the form of shaft rotation
		Energy Generator	producing electricity from turbine's kinetic movements
		Transformer	boost the voltage for purposes of long-distance transmission to reach consumer
	Sensor(s)	Flow Rate	measuring the amount of a liquid, gas, or steam flowing through or around the flow meter sensors
		Water Chemistry	to check many chemistry components inside water (pH, conductivity, hydrogen, oxygen, chloride, fluoride, etc.
		Temperature	to check the air, liquid, and solid temperature inside the buildings and equipment
		Pressure	to measure the pressure in gases or liquids inside the buildings and equipment
		Radiation	to measure the level of radiation from nuclear reaction
Actor(s)	*Staff Member(s)*	Operator	operating the equipment from control and monitoring building
		Data Analyst	analyzing data received from database
		Supervisor	responsible for the operation and maintenance of staff and plant
		Energy Consumer	consumer that use the electricity from NREP

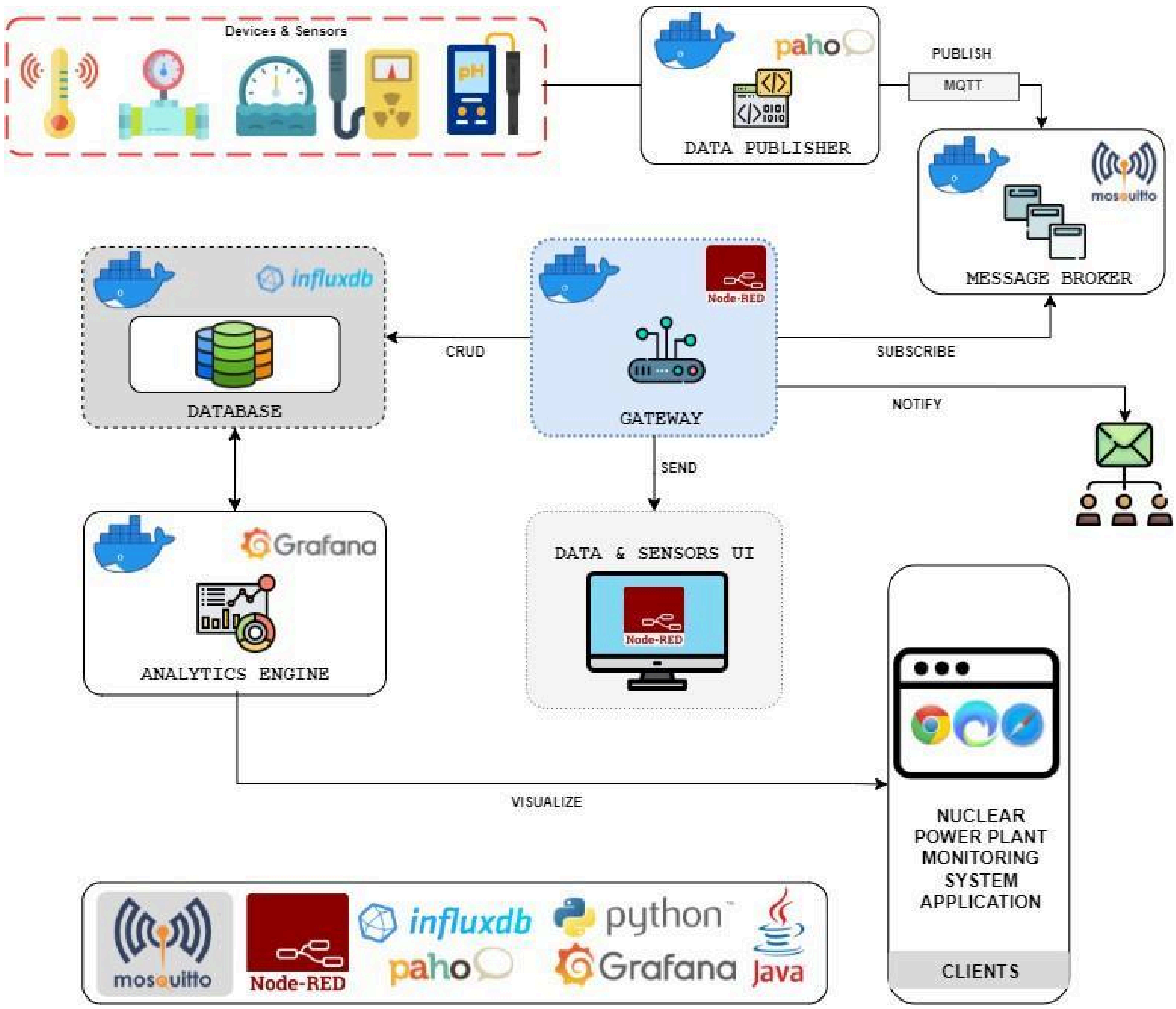
*(**Table 1.**Functions of Enumerations)*

Figure 5. represents conceptual layered diagram of NPPMS.



*(**Figure 5.** Layered Diagram for Nuclear Power Plant Management System - NPPMS)*

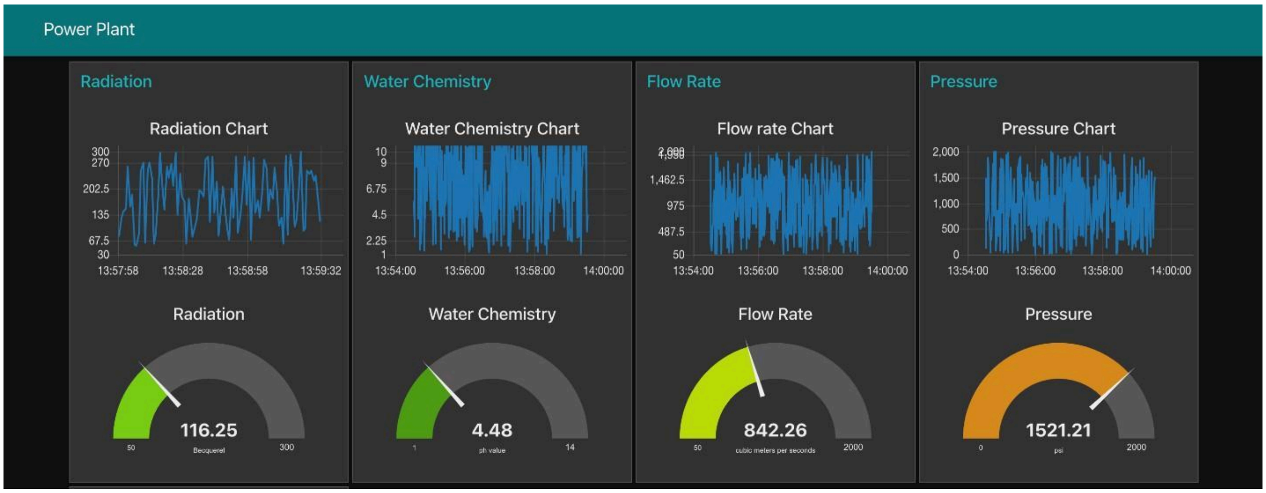
Figure 6. represents detailed architecture diagram of NPPMS. All the components are deployed in dedicated ***Docker*** containers. The ***physical layer*** shows the devices & sensors being used in our system for monitoring i.e. *Temperature sensor, Pressure meter, Flowrate meter, Radiation sensor & Water chemistry sensor*. Due to unavailability of actual devices, the data is randomly generated by using Python client for Paho and then ***published*** to the dedicated topic in messaging queue. The protocol used by Mosquitto broker is ***MQTT***. The back bone of the system is gateway and backend which is controlling whole flow of the system. It is made using Node Red and it acts as a ***subscriber*** for the queue mentioned above. After getting the data from the message broker, it's saved in the ***database*** and for that purpose Influx DB is used. In case of sensor values crossing a specific threshold, automated emails are sent by using Node Red client. Grafana is used to show the ***analytics*** and time series data by fetching every single second from Influx DB.



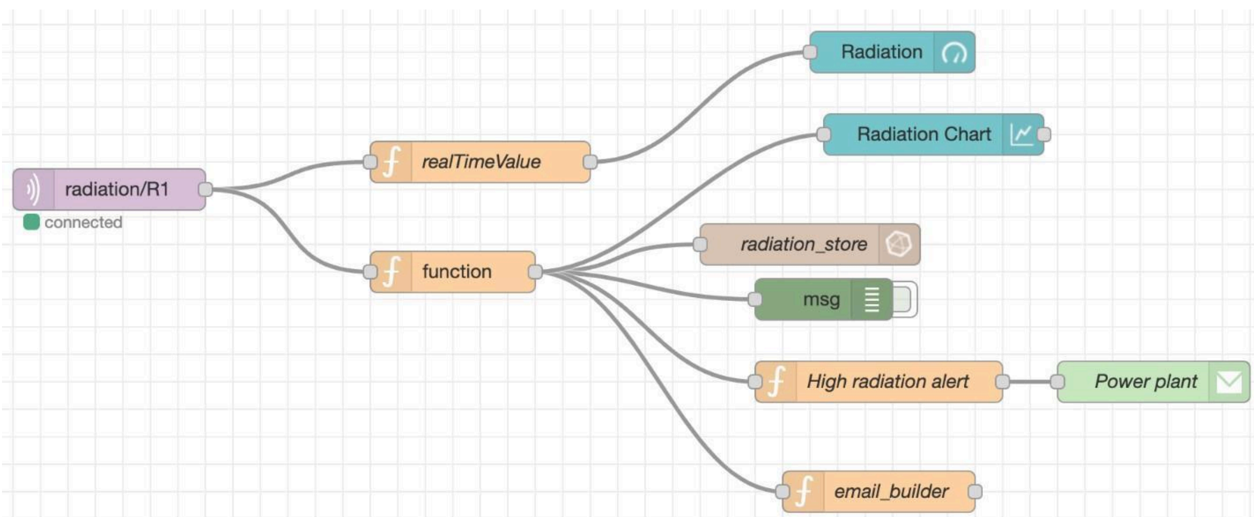
*(**Figure 6.** Architecture Diagram for Nuclear Power Plant Management System - NPPMS)*

System Developed

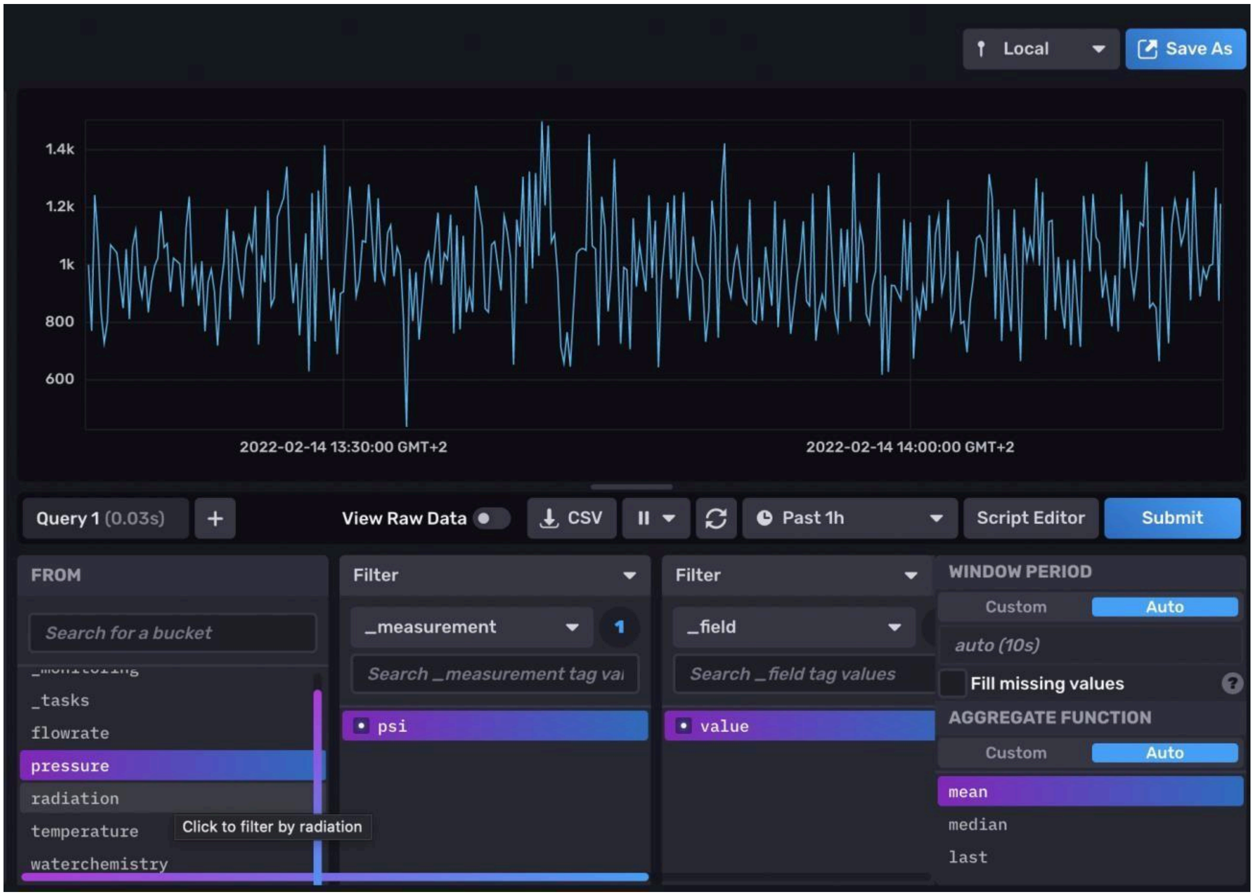
Following screenshots show the final outcome of the system developed:



*(**Figure 7.** Node Red UI Dashboard Showing the Data from the Sensor in NPPMS)*



*(**Figure 8.** Node Red Radiation Sensor Flow in NPPMS)*



*(**Figure 9.** Influx DB Dashboard: Querying Pressure Sensor Data in NPPMS)*

*(**Figure 10.** Grafana Dashboard Showing the Data from Influx DB in NPPMS)*

Bibliography

[1] Eia (U.S. Energy Information Administration), “Nuclear explained nuclear power plants.” [Online]. Available: https://www.eia.gov/energyexplained/nuclear/nuclear-power-plants.php

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[4] D. R. Farley, M. G. Negus and R. N. Slayburg, “Industrial Internet-of-Things Data Analytics for Nuclear Power Safeguards,” Sandia Report, 2018.