

A Smart IoT System for Remote Refrigeration Monitoring

B Padmaja (✉ b.padmaja@gmail.com)

Associate Professor, Department of CSE, Institute of Aeronautical Engineering, Hyderabad, India

Vijayakumar Ch

Assistant Professor, Department of IT, Institute of Aeronautical Engineering, Hyderabad, India

E Krishna Rao Patro

Associate Professor, Department of CSE, Institute of Aeronautical Engineering, Hyderabad, India

B Shashirekha

Assistant Professor, Department of CSE (AI & ML), Institute of Aeronautical Engineering, Hyderabad, India

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A Smart IoT System for Remote Refrigeration Monitoring

^{1,*} B Padmaja, Associate Professor, Department of CSE, Institute of Aeronautical Engineering, Hyderabad, India, b.padmaja@gmail.com

² Vijayakumar Ch, Assistant Professor, Department of IT, Institute of Aeronautical Engineering, Hyderabad, India, veejaymtech@gmail.com

³E Krishna Rao Patro, Associate Professor, Department of CSE, Institute of Aeronautical Engineering, Hyderabad, India, patrosir@gmail.com

⁴B Shashirekha, Assistant Professor, Department of CSE (AI & ML), Institute of Aeronautical Engineering, Hyderabad, India, b.shashirekha@iare.ac.in

Abstract: The realm of refrigeration industry has marked its significance for storing food and beverages. Refrigeration warehouses are extensively used to store various combinations of large fresh food stock at favourable temperatures to maintain its quality. Any deviations from these favourable temperatures pose negative impacts on the cold stock. Hence, it is essential to minimize the margin of these potential risks that can incur huge loss to the cold-storage industries. On-site evaluation can be reliable to address these risks, but it is time consuming and an inefficient process as human intervention can be prone to manual errors. The paper, therefore, proposes a methodology to build a smart IoT system to remotely monitor and evaluate the refrigeration warehouses seamlessly at one's fingertips using a mobile or laptop through dashboards. Furthermore, this paper addresses the difficulties in managing and analysing the large sensory data which are the result of seamless monitoring by unleashing the power of edge computing and cloud computing.

Keywords: Internet of Things; Refrigeration Monitoring; Temperature Analysis; Edge Computing;

I. Introduction

A network of things such as sensors, devices, embedded boards, computing resources, vehicles, systems connected with each other to inter-communicate using the Internet as medium. IoT has enabled communication and exchange of information among things and people in an easier way. All these connected things are called as Smart Objects. IoT has expanded its significance in all major spheres of our lives. Smart Home, Smart City, Smart Grid, Wearables, Smart Retail and Logistics, Health Care, Smart Agriculture and Farming are evident use cases of the impact made by Internet of Things. All these applications brought a new value to our lives. Majority of challenges faced in the logistics sector are addressed by the required use of IoT. Newer developments in technologies with the incorporation of IoT shaped the future of logistics allowing businesses to expand and be flexible with changes in industry demands. Continuous tracking of logistics, remote tracking of logistics, asset monitoring, predictive asset monitoring, optimization of warehouse loads (inventory control), optimization of routes, vehicle management and fleet management collectively contribute to the deployment of Smart Logistics concept. In order to reduce the logistic expenses and avoid spoiling of goods during transportation, continuous and remote monitoring of temperature and humidity is essential in containers during transportation. A GUI helps in analyzing and supervising the essential parameters during food transportations. Figure 1 depicts the industrial IoT eco system and its major applications.

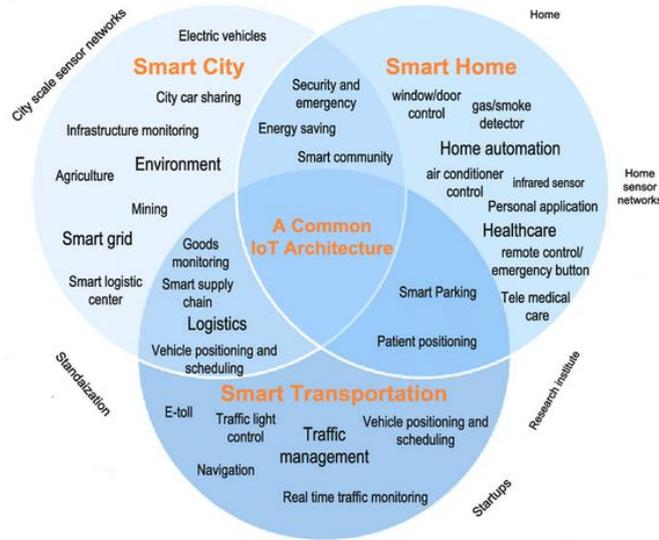


Figure 1. Industrial IoT Ecosystem and its applications

Refrigeration warehouses in cold storage industry are generally used for storing fresh stock ranging from variety of food. These places are artificially cooled to from a negative to positive degrees of Celsius based on the requirements. These warehouses are usually located far away from the living life. Hence, any drastic changes in the temperatures lead to negative result on the stored stock. These unprecedented situations can be triggered unknowingly anytime. Hence, it is necessary to address that everything stored are in the permissible limits of the temperature. Monitoring the temperature and logging the temperature during all instances will be an ideal way for being vigilant before any immeasurable loss. With the enhanced evolution of Internet and sensors, it is now achievable to address any problem. Henceforward, this paper proposes a methodology to build a smart IoT system to remotely monitor and evaluate the refrigeration warehouses seamlessly at one's fingertips using a mobile or laptop through dashboards.

The remainder of the paper is organized as follows: Section II presents the related literature in IoT based monitoring systems, Section III presents the importance of Edge Computing in designing the proposed system, Section IV presents the proposed system architecture, Section V elaborates the proposed system in the experiment study performed, Section VII elaborates the technology stack used, followed by Conclusions in Section VI.

II. Related Work

This section gives an overview of smart IoT monitoring solutions developed in the fields of smart refrigeration, smart healthcare, smart city, smart environment, smart office, and other smart oriented use-cases.

Wu et al. [1] used an IoT based system to check the internal temperature of the refrigerators used in transportation system. This system used RFID, temperature sensors, GPRS system to monitor food safety in cold chain logistics. Heidmann et al. [2] proposed a supervision unit using low-power UHF / LF sensor system using wireless low power sensor nodes for freight quality monitoring. The authors used a web-based interface along with a virtual network to monitor the container and its essential control parameters using the data received by sensor nodes. Mambou et al. [3] developed a simple and powerful monitoring system for pharmacy stores using sensors to control the refrigeration temperature and medication search. The authors claimed their sensor-based approach is cheaper than software-based system and useful for deprived area. Nasir et al. [4] merged the idea of IoT and smart kitchen to develop a smart refrigeration system which consists of 3 modules such as sensing, control and transmission module. All modules together determine the food quality and condition of the refrigerator by notifying via SMS or email. Edger et al. [5] designed a PCB based monitoring system to check

the faults in a chain of refrigerators or cold chain which runs on conventional compressors. The authors used cloud platform to send data and alarms to or from the cold storages using Sigfox wireless communication. This system checks the operational failures, voltage, current and power consumption. It also controls and measure the temperature inside the freezer. Song et al. [6] developed an IoT based smart controlling system to reduce energy consumption of air conditioners (AC) to improve power efficiency. It includes three modules such as smart meter, gateway and cloud. Smart meter performs the real-time monitoring of temperature in the AC's and the readings are stored in a cloud server via gateway. Meimei et al. [7] designed a food cold chain monitoring system using ZigBee, GPS, GPRS, GIS, embedded system and a remote database. This system performs real-time monitoring of location information using a remote network. Faz et al. [8] proposed a low-cost IoT system for monitoring temperature in freezers using a Wi-Fi microcontroller along with temperature sensors. Authors used clod platform to store and analyze data and helps in supervising various parameters such as light, energy consumption etc.

Furthermore, Othman et al. [9] proposed an edge-computing based smart energy solution which monitors the performance of a small-scale standalone PV plant. The edge-device used was responsible to acquire desired data, perform required processing and then display data for remote performance monitoring of this PV plant. Desired data included voltage, current, ambient temperature. Baumgartner et al.[10] studied environment monitoring using a wide variety of sensors acquiring different forms of data on different kinds of edge computing devices ranging from microcontrollers to microprocessors. Sinha et al. [11] studied the use of edge devices in smart home solutions by monitoring the total power consumption of domestic appliances and allowed the user to set up the limits for power consumption for every appliance. Katalina et al. [12] proposed an edge-computing based smart environment solution which monitors the real-time air quality and classifies quantitative interpretation of air quality as fresh air, low pollution, medium pollution, high pollution and very high pollution based on by processing the data acquired and using a metric. This solution uploads a new data entry into the cloud if there is any deviation observed from the known classifications. The applications of IoT along with edge and cloud computing are endless. Table 1. depicts some of the important details about the use of computing devices, sensors and its applications.

Table 1. Overview of components and applications used in the state-of-the-art literature

References	Edge Controller	Sensors	Applications
[1]	8051 Micro Controller	RFID, Temperature measurement module (RF SoC NRF9E5 and digit temperature sensor DS18B20), GPRS, Wireless Infrared Sensors,	Monitoring the internal temperature of the Refrigerated Transport Vehicles
[2]	Wireless Low-power UHF / LF sensor network	A base station, OSGi-framework, UHF transceiver, an additional 3D-LF interface	Intelligent Container Monitoring System
[3]	Raspberry Pi	Ambient sensors, EN15251 module, Comfort Box	IoT based Indoor Personal Comfort Levels Monitoring System
[4]	Arduino UNO	Load cell, odor sensor, LCD module and Wi-Fi module	IoT based Smart Refrigerator System to reduce Food spoilage
[5]	SigFox Module	Temperature Controller, Electronic Paper Display (EPD)	Designed to monitor faults in chain of refrigerators or freezers.
[6]	Zigbee Module	Smart Meter (Temperature, humidity sensor, the integrated infrared controller, the electrical switch, the	IoT-based Smart Controlling System to save electricity

		power monitor, the Zigbee end node)	consumption of air conditioners
[7]	ARM	ZigBee, GPS, GPRS, GIS	Remote Food Cold Chain Monitoring System
[8]	ESP-8266-Wi-Fi microcontroller	DS18B20 temperature sensors, ThingSpeak IoTplatform	Remote supervision of light control, energy efficiency of refrigeration in the food chain
[9]	Raspberry-Pi	A voltage divider, Current Sensor (ACS 712 – 30A), Temperature Sensor (LM35)	Smart Energy Solution monitoring the performance of PV Plant.
[10]	Microcontrollers & microprocessors	Wide Range of Sensors	Evaluative study of low-cost hardware and wireless communication for environmental monitoring.
[11]	Beagle-Bone Blackboard	Hall Effect Sensor (ACS712)	Smart Home Solution monitoring the total power consumption.
[12]	Raspberry-Pi	Grove Pi, Grove Dust Sensor, Grove Air Quality Sensor	Smart Environment Solution monitoring the real-time air quality.

III. Edge Computing

IoT has made things such as computing devices, mechanical machines and smart devices connected via the internet and enabled the ease of communication with each other. Al-Fuqaha et al. defined IoT as the interconnectivity of real-world smart objects with the global network of sensors and computing devices communicating through standard protocols to share the information [13, 15]. Generally, most of the IoT devices are equipped with sensors to detect and monitor the changes in the environment by using the data which is generated by these devices. According to CISCO, the number of things connected to the internet is growing at an unprecedented rate and it is expected that there will be a total number of 50 Billion number of IoT connected devices [14, 16]. These multiple devices with multiple sensors which can sense the changes, collects and produces a huge amount of continuous data. Analysis on the IoT based Big Data helps to give meaningful and instantaneous insights to facilitate real-time monitoring of things by using techniques machine learning and deep learning approaches. It requires high computational capability to pre-process, analyse and find the hidden patterns to make sense of Big-Data. In this regard, the involvement of Cloud Computing to deploy the above techniques compensates high operational and computational requirement. Cloud Computing is a platform to leverage the use of physical and virtual resources, storage capabilities, infrastructure, and many more services provided based on the requirement of the end-users such as firms and organizations. Cloud based computing systems can perform CPU and GPU intensive computation in an unbelievable rate. Therefore, it is necessary to transport the data to the central Cloud for using the analytical techniques to meet computational costs. Transporting the huge amount of data which is generated at every instance to cloud constantly demands good Internet connectivity, low latency, high bandwidth, and large storage capacities. This results in a very huge transportation cost to the user.

Transportation costs can be fairly reduced by adopting the new paradigm which focuses on shifting away the heavy workloads from Cloud to IoT nodes of the network. This new paradigm is called as ‘Edge-Computing’. Edge Computing can briefly be defined as the distributed real-time data processing concept deployed at the edge of the network to address the low-latency communication. The shift of adopting edge-computing from conventional ways is already observed in many of the researcher’s studies along with industrial implementations.

Edge computing processes data on IoT network that is located close to the point of data creation. In short, it does minimal pre-processing of huge data at the edge of the network before transporting data into cloud service. This way it creates an impact on transportation cost by reducing the needs of high bandwidth and low latency. World is adopting ‘Edge-computing’ as part of their IoT solutions and it is evident in research reports [17,18].

Edge Computing aims in handling a certain amount of workload at the edge-nodes of the network. These nodes are generally the devices to which sensors are attached to or gateway devices which are close to the sensors. Offloading the infrastructure load to the edge of the network immensely reduces the latency, communication overhead and related issues. IoT based Edge Computing infrastructure can be deployed to the existing IoT networks by introducing computational capacity to the end nodes, which communicate to the Cloud via one or more gateways as shown in Figure 2. Edge nodes in the figure comprises of variety of sensors, micro-controllers, single board computers and other radio frequency transmitters. Gateways are wireless data receivers, routers, switches and other computational resources. Cloud is the computing infrastructure, which is provided by various technology giants like Amazon, Google, Alibaba, Microsoft, etc. Based on the requirement, computation can be carried at the gateways as well. The computation at the middle layer that is at gateways is called as ‘Fog Computing’.

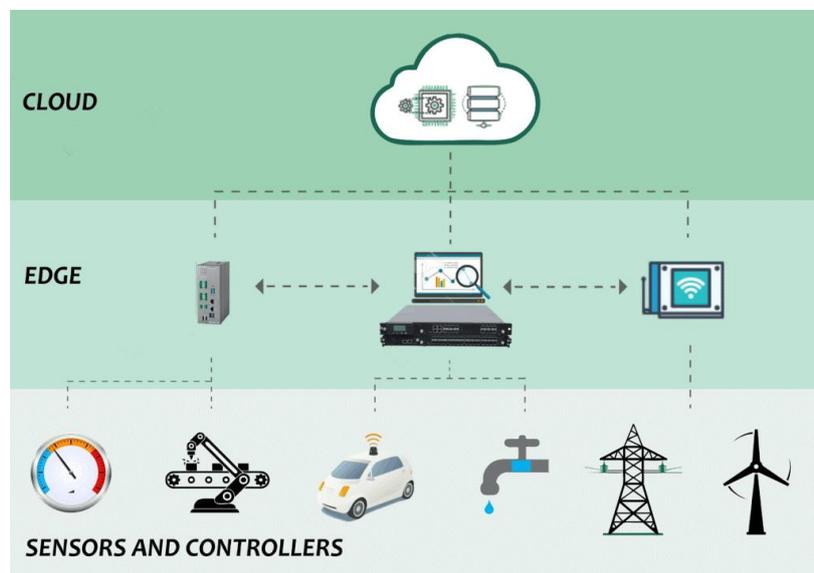


Figure 2. Edge Computing in IoT Systems

IV. Proposed System Architecture

Sensors generate data and scaling up the sensors to a distributed environment in a large cold-storage warehouse results in generation of huge amount of data. Therefore, the proposed system aims in the use of Edge Computing by handling a certain amount of workload at the edge-nodes of the network enabling the use of decentralization. Amalgamating the concepts of ‘Internet of Things’ and ‘Edge-Computing’ in a novel way to meet remote monitoring, this paper uses a three-tier architecture as shown in Figure 3 for the proposed IoT System.

The three layers are as follows:

- (i) Edge Layer (ii) Server Layer and (iii) Application layer.

Edge Layer comprises of nodes or things such as sensors, actuators, microcontrollers, microprocessors and other devices deployed in remote regions. Components in this layer are responsible for sensing, actuating, and performing edge-computing operations to pre-process the large data generating rapidly.

Server Layer comprises gateways or routers which are intended to collect the pre-processed data from all sensor nodes and transport it to cloud and visualizations. Components in this layer are the access-points for the data to enter the internet of applications.

Application Layer comprises of the cloud services, user end-devices such as mobiles, tablets, etc. providing visualized dashboards containing analysis and reports of remote monitoring.

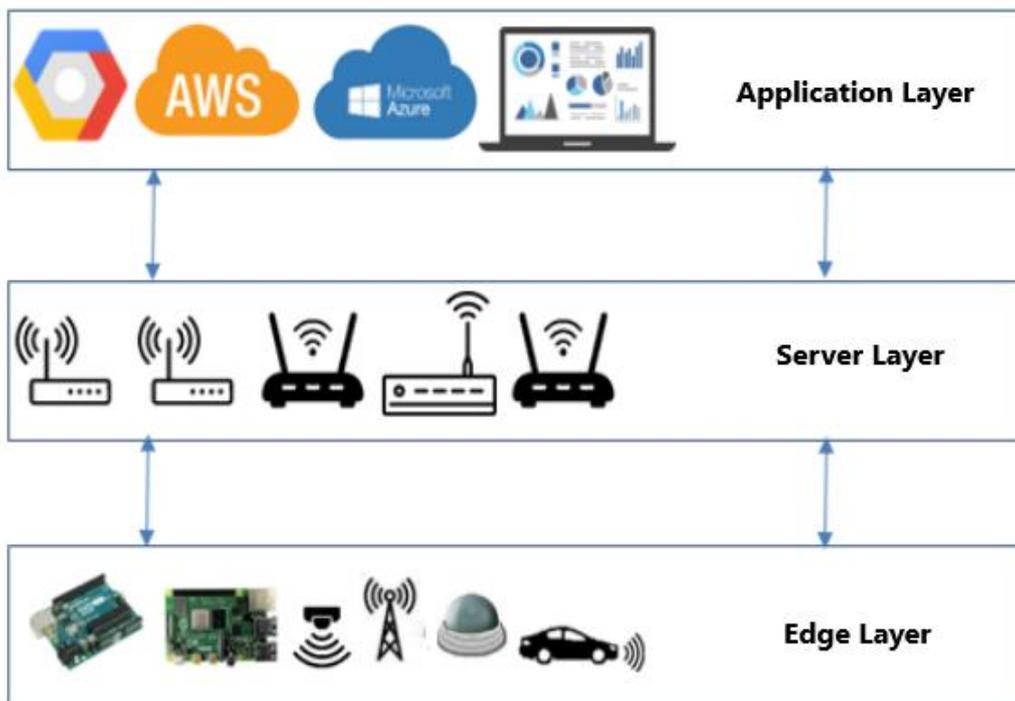


Figure 3. Three-tier architecture for Remote Monitoring

V. Experiment

The proposed IoT system for refrigeration monitoring used in the experiment has two nodes in a network and a gateway deployed at a warehouse. The system involves two important stages namely:

- i. Edge Computation of temperature readings on nodes.
- ii. Communication between nodes and gateway.
- iii. Visualisation of monitoring the warehouse in a dashboard.

a. Edge Computation of temperature readings on nodes:

Each node of the system is set to record the temperature data for every 0.1 sec. The system can be extended to have a larger number of nodes to cover the complete warehouse, then logging this sensory data for every 0.1 sec from each node to the cloud results in expensive node to cloud communication. The faster generation of these data points from various nodes accumulates huge amount of data resulting in cumbersome management and analysis of data. Furthermore, at times of poor internet connectivity, it is highly probable that the transmission of the data fail. The transmission failure cannot be afforded by refrigerator warehouses as the

data is utmost essential to make any analysis, if required. Hence, this stage uses the strategy of ‘window segmentation’. Each window has a length of 300 units, each unit corresponds to temperature data reading collected for every 0.1 sec. Hence, each window is a span of 30 sec. Adding further, these windows are segmented into statistical parameters such as mean, median and standard deviation by edge-computing.

Mean plays its significance in the system by displaying a value which wholly represents the window of temperature readings. It is a compact form of representing the span of 30 seconds. The deviations of mean value readings from the threshold temperature of the warehouse (the temperature at which the warehouse should be operated) triggers the warnings in form of messages or emails. Mean is also helpful to compare the operation of other nodes i.e. it can be implied if they are operating correctly. The mean of the window is edge computed at the nodes as given in equation 1.

$$Mean = \frac{Sum(Window(X))}{300} \quad (1)$$

Where,

$$Window(X) = [x_1^\circ, x_2^\circ, x_3^\circ, \dots, x_{300}^\circ] \quad (2)$$

Median plays its significance in the system by indicating the presence of outlier temperature readings (the readings which are deviated to far apart). It is because mean is affected the most in the presence of outliers. Hence, the greater difference in mean and median of a window indicates that temperature is fluctuating signing the importance to pay attention to the space of warehouse where this certain node is deployed. Timsort which is a hybrid of merge and insertion sort is used to sort the window as given in equation 3 prior to the edge computation of median of the window at the nodes as given in equation 4.

$$Window(X) = Sort(Window(X)) \quad (3)$$

$$Median = \frac{x_{15}^\circ + x_{16}^\circ}{2} \quad (4)$$

Standard deviation plays its significance in the system by giving an approximate view of the spread of data readings in the window around the mean. The higher standard deviation indicates that the temperature readings of the window are widely spread implying that readings are less reliable. The lower standard deviation indicates that the temperature readings of the window are clustered closely implying that window of readings are more reliable. This parameter judges the trust of readings giving the user higher confidences of the system. The standard deviation of the window is edge computed at the nodes as given in equation 5.

$$Standard\ Deviation = \sqrt{\sum_{i=1}^{300} (x_i - Mean)^2 / 300} \quad (5)$$

b. Communication between nodes and gateway:

The edge-computed data of the windows from all the nodes is sent to the gateway (access-point) using Message Queuing Telemetry Transport (MQTT), an IoT Communication Protocol. MQTT follows Publish-Subscribe Model. Publish-subscribe model consists of three components namely Broker, Publisher and Subscriber. Broker is the central point in the architecture, which is responsible for filtration and segregation of

messages which are published by a publisher. A publisher is responsible for posting data onto a topic into the broker, whereas a subscriber is responsible to receive data from the broker on a subscribed topic without always requesting the broker for information. In the stage, nodes are publishers, gateway is the broker and dashboards along with cloud services are subscribers.

c. Visualisation of monitoring the warehouse in a dashboard:

The dashboard visualisation of each node of the system deployed in the warehouse is pointed by the IP and ports of the nodes. Each node has a separate dashboard as shown in Figures 6 and 7. Every dashboard displays mean, median and standard deviation of windows spanning for 30 seconds. It also displays a graph of mean versus time, where, mean is on y-axis and time is on x-axis. The presence of spikes on the graph indicates the extensive variation of temperature readings. The user will also be triggered by a message or an email in those unprecedented situations. The three lines on the left of dashboard are used to view the dashboard of different nodes. Furthermore, the edge computed data for all nodes along with time stamps is logged in cloud services concurrently.

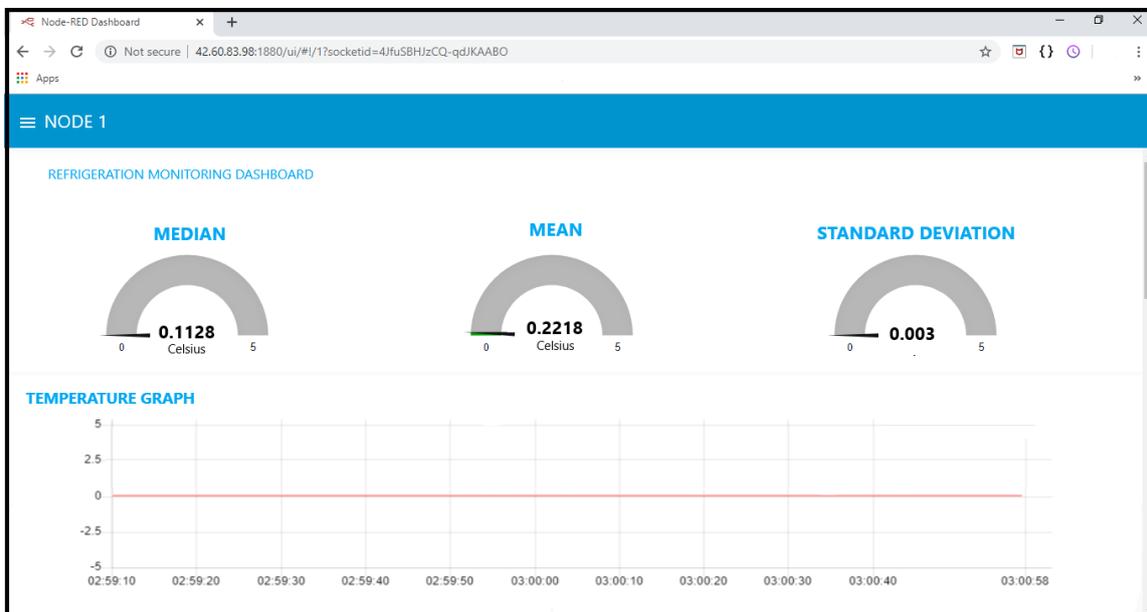


Figure 4. Node One Dashboard

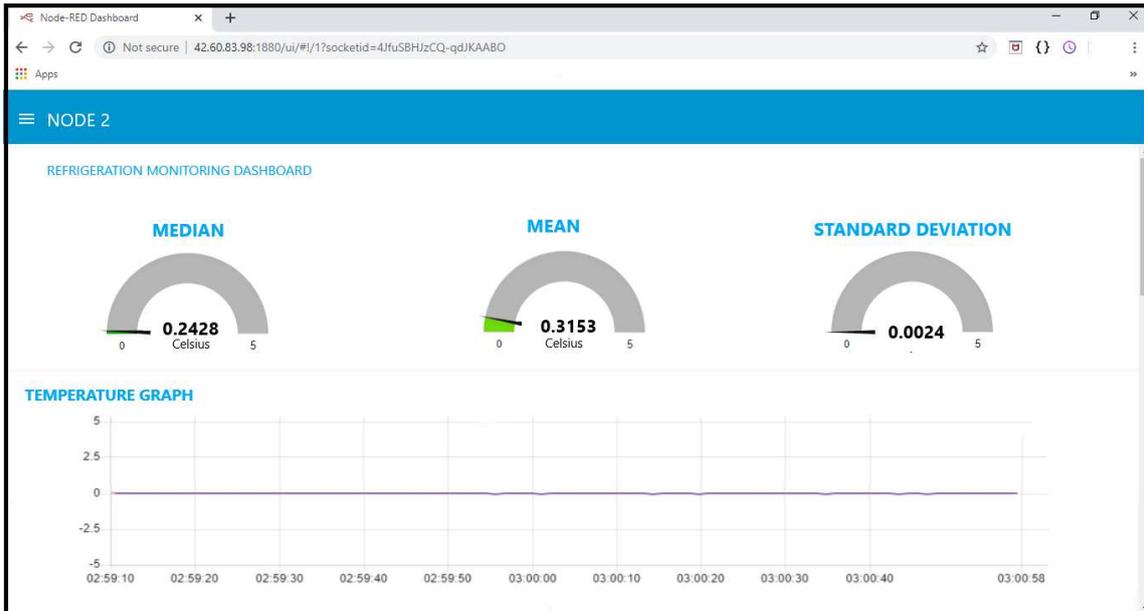


Figure 5. Node Two Dashboard

VI. Technology Stack

This section of the paper briefs about sensor selection, hardware stack and software stack used in the implementation for the proposed system in the experiment.

a. Sensor Selection:

The most essential criteria for remote refrigeration monitoring system is sensor selection. Sensor is the heart of complete system as it boils down to data generation by detecting the changes and variations. DS18B20 as shown in Figure 8 is the sensor module used. It has a temperature range of -55°C to 125°C at an operating voltage of 3.0V to 5.0V. It further has a sampling rate of 750ms.

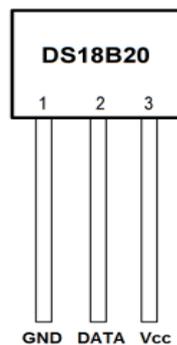


Figure 8. DS18B20 Sensor Module

b. Hardware Stack:

Nodes and gateway are important components. Nodes require the power to sense and compute. Gateway requires power to collect and transport the data from edge devices of the network to applications. Hence, Raspberry Pi is used for the study.

c. Software Stack:

System uses Python as the programming language in all levels as it is a highly interpreted and general-purpose programming language offering the scope for high customizability. MQTT is used for Data Transfer Communication (between Nodes and Gateway). Node-RED which is a flow-based programming tool is used to create the dashboards along with interconnecting the flow of network. Finally, AWS provided by Amazon Inc. is used as the Cloud Service because of its wide range of cloud services and good support. Dynamo DB Service which has a huge number of users had been selected as the service.

VII. Conclusions

Food safety is always the foremost concern and refrigeration industry has significant importance for storing food and beverages. Refrigeration warehouses are widely used to store various food items by maintaining appropriate temperature level to maintain its quality and freshness. Therefore, it is vital to have a low cost and flexible IoT based automatic monitoring system for easy tracing and monitoring of food quality in the cold storages. Hence, this paper proposes a low cost, real-time remote refrigeration monitoring system for food items in refrigeration warehouses.

Scaling up the proposed system with many nodes will help the industrialists to monitor the parameters of interest (such as temperature, voltage, mean, median and standard deviation) and can provide an instantaneous real-time observation through customized dashboards of cold storages. This approach also works as an alarming system and trigger alerts before real damage happens to food items.

The use of edge computation for statistical calculations on the data from 'window segmentation' strategy in the experiment study of the proposed system made remote monitoring powerful in the following ways:

- i. High frequency data is minimised into reliable window segments of data reducing the expensive node-cloud cost.
- ii. Mean parameter ensures the variation of warehouse temperature around threshold through warnings, if sensed and make comparisons with other nodes to assure their active working functionality.
- iii. Median parameter ensures the presence of outlier data readings in the window.
- iv. Standard Deviation ensures the reliability of data readings of a window.

Furthermore, the paper intends to motivate other researches in various to further improve the solutions or implementations leveraging the power of IoT and edge computing as per the requirements.

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Availability of data and material: Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Code availability: Available, if required it will be supplied

Authors' contributions: B Padmaja (BP) contributed and conducted experiments for remote refrigeration monitoring, Ch Vijayakumar (CHVK) contributed in literature survey and data gathering, E Krishna Rao Patro (EKRP) supervised and helped to draft the manuscript, Shashirekha B(SRB) contributed in writing and fine tuning the paper without plagiarism.

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Author Biography

Ms. B. Padmaja is a faculty member in the Department of Computer Science, Institute of Aeronautical Engineering, Hyderabad, Telangana, India. She has received her B.Tech from North Eastern Regional Institute of Science and Technology (NERIST), Arunachal Pradesh, India in 2001. She completed her M.Tech from School of IT, JNTUH, Hyderabad, India. Currently she is pursuing her research in “Reality Mining: Smart Phone Based Human Behavior Analysis” from JNTUH, Hyderabad. She is a member of ISTE and CSI. She has more than 18 years of teaching experience and published 20 research papers in various International Journals and Conferences.

Mr. E Krishna Rao Patro is a faculty member in the Department of Computer Science, Institute of Aeronautical Engineering, Hyderabad, Telangana, India. He has received his MCA from Anna University, Chennai in 1997. He completed his M.Tech from, JNTUH, Hyderabad, India. Currently he is pursuing his research in “Web Intrusion Detection System using Machine Learning Approach” from Vel Tech University, Chennai. He has more than 20 years of teaching and industry experience and published 10 research papers in various International Journals and Conferences.

Figures

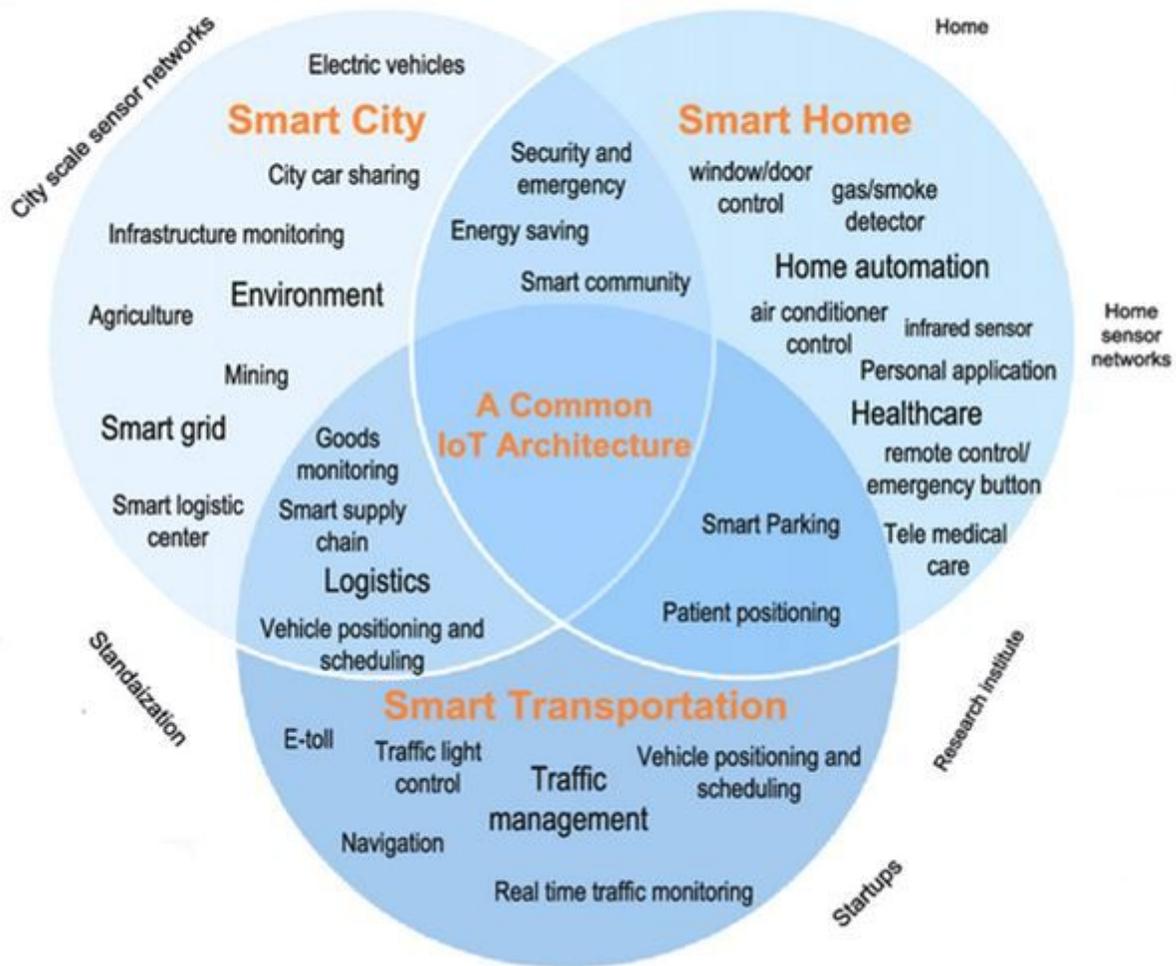


Figure 1

Industrial IoT Ecosystem and its applications

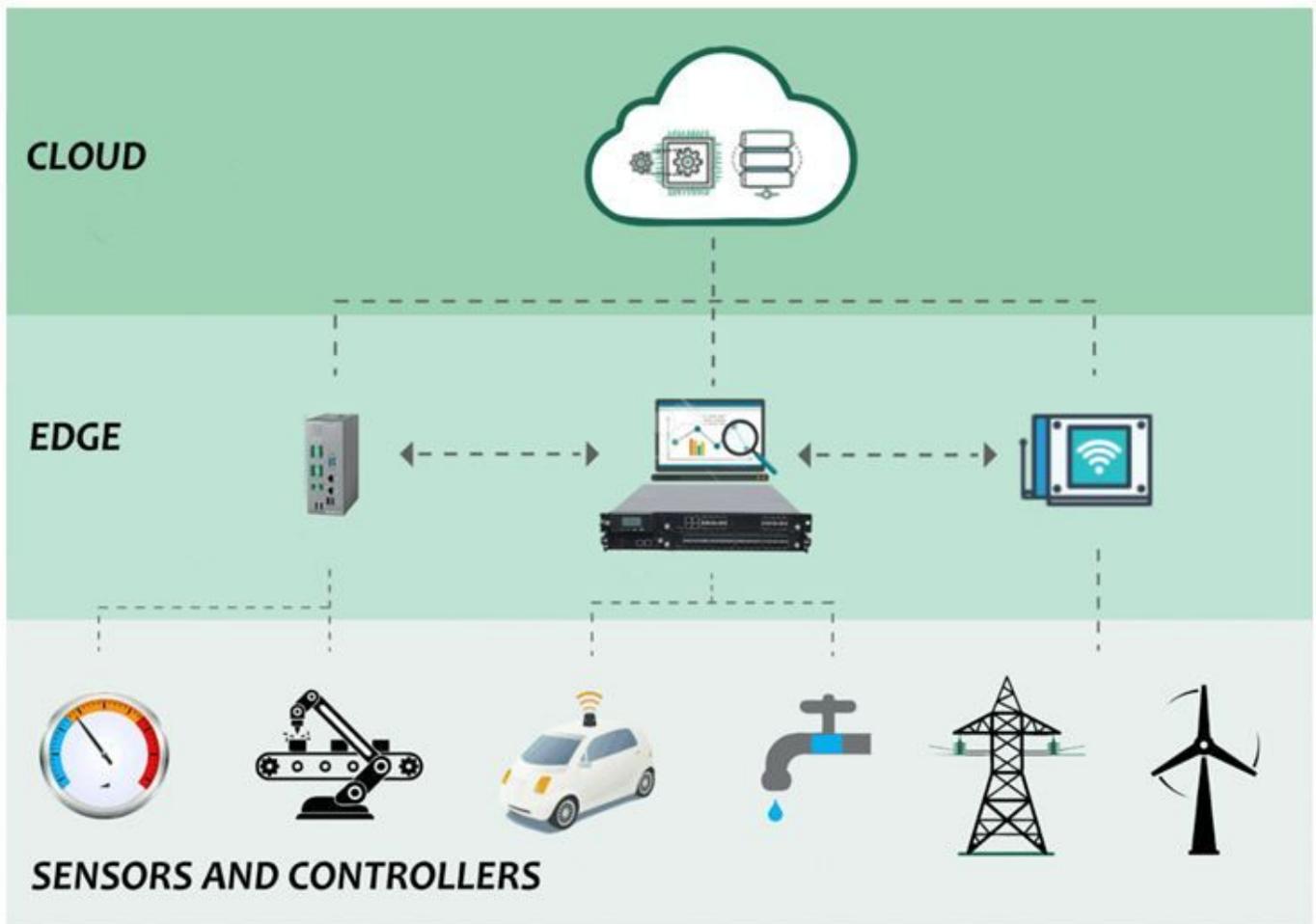


Figure 2

Edge Computing in IoT Systems

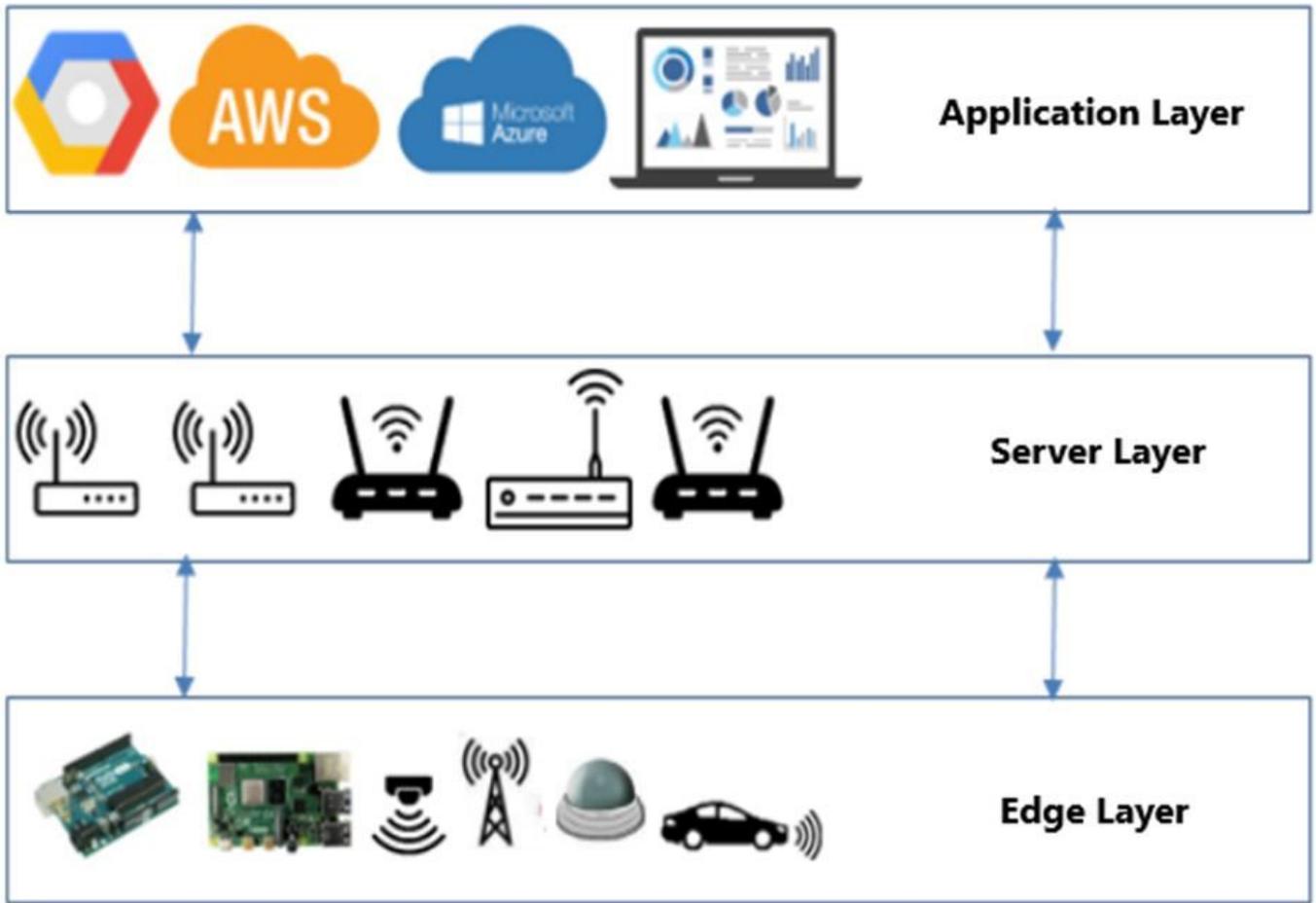


Figure 3

Three-tier architecture for Remote Monitoring

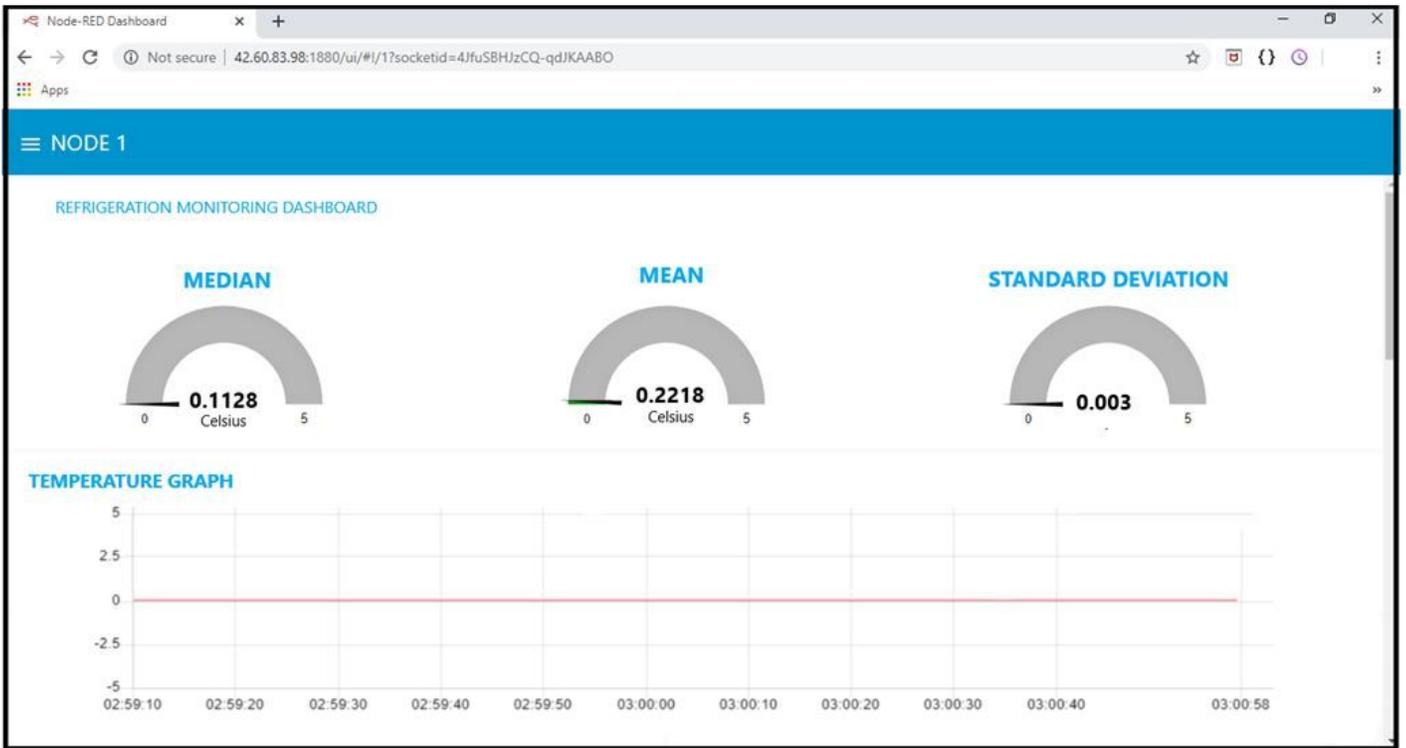


Figure 4

Node One Dashboard

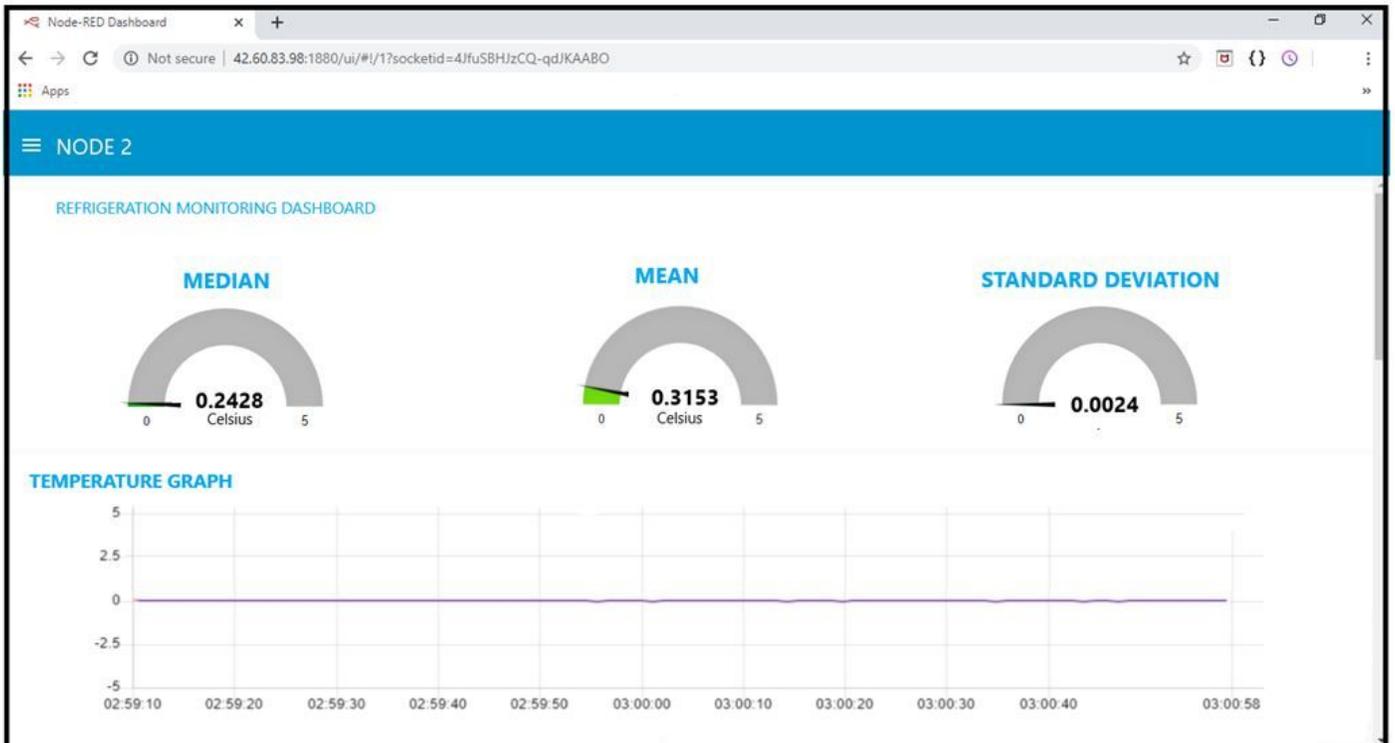


Figure 5

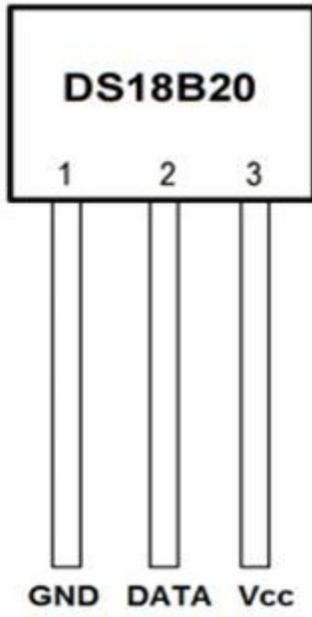


Figure 6

DS18B20 Sensor Module