IoT Platform to augment Solar Tree as Smart Highway Street Light with Ambient Monitoring Capability

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***Abstract*—The presented work describes an interconnected multi-server IoT network for monitoring and control of smart solar tree. The IoT enabled solar tree is introduced as a smart street light with air quality monitoring capability and has been implemented in the Central Electronics Engineering Research Institute, Pilani. The presented network is a three-layer architecture with a sensor node at the lowermost layer for collecting the sensor data. The solar tree server above it performs the sampling of the data by triggering the software for sensor node. Upon successful data collection, the tree server communicates the same to the central server which is responsible for aggregation, visualization, storage, analysis and control of all the connected solar trees. The paper also discusses the implementation aspect of the network and presents the collected data from the solar tree. The presented IoT network aims for enhancing the capabilities of the solar tree beyond just a power generation device to an application such as security, surveillance, pollution monitoring and many more. At present, the work discussed is towards self-sustained street light with ambient monitoring capability.**

Keywords—Solar Tree, M2M, IoT enabled, IoT network, Monitoring, and Control.

I. Introduction

Harvesting solar energy using solar panel has increased in the past decade realizing the importance of renewable energy sources. This shift in dependence from fossil fuel triggered effective solar panel designs and its smart utilization. Triggered by the development in the IoT domain, smart solutions have been proposed to visualize smart city concepts [1]–[3]. Towards this target, the notion of 'solar tree' has emerged with distributed power generation and utilization creating a chain of self-sustained power generation units. Examples such as rooftop panels, street lights, and standalone solar pumps have been pitched in for independent operation from the grid. With increasing demand in electricity for public lighting due to highway construction and better transportation facilities till the last mile, the concept of off-grid lighting system is coming into picture. Roads are now reaching the villages and local areas, making street lighting an essential need now. Due to such factors, the use of solar trees as smart public lighting system has increased. Street light control based on wireless communication has been presented in multiple works [4], [5]. These works are targeted towards a smart city application proving a comprehensive solution for public lighting. Various lab level demonstration is also reported targeting similar problem based on wireless technology [3], [6].

Technological advancement in connectivity, embedded systems and protocol development provided by the internet of things have greatly enhanced the way we look at devices and deployed systems [7], [8]. Wireless nodes connected to internet are used for data collection, forming the 'internet' in internet of things. The data may be collected for real time assessment or for monitoring the status of deployed system. In any case, the reach of IoT devices are influencing the aspects of system design. Likewise, solar tree is also Turing into an integrated IoT system with panel power generation monitoring using various sensor installed with it. Not only remote monitoring but control and assessment have become a part of smart solar tree development now [9]–[11]. The need for IoT systems for a smart city is now an inseparable entity because of the added advantages such as data management, remote monitoring and control, prediction and big data generation [12]–[15]. Better gateway design analysis for outdoor deployment is being considered for the same [16]. In recent years, enhancement of solar panels with features such as remote monitoring and energy management have been demonstrated through IoT [17]–[19]. Case studies have been presented on the ground level implementation of a solar PV system for different applications such as smart farms and charging stations [20], [21]. However, these IoT frameworks are merely remote monitoring systems that are designed on one to one basis and doesn't include a network which can handle multiple solar tree at the same time.

Apart from stated work, the author has also presented an optimal design approach for increased flexibility in seasonal energy extraction [22], which is a more basic design challenge. The approach describes a data-driven model and genetic algorithm for optimization of solar panel positioning to minimize the shadow losses. The work in now enhanced with IoT integration adding ambient monitoring capability, an addon to the existing novel solar energy harvesting solar tree. The IoT platform and its implementation for augmentation of the solar tree for remote ambient monitoring and street light control are presented in this paper. The presented platform is designed for monitoring and control of multiple solar trees and integrating the data generated by each tree. It consists of a multi-server system with each solar tree as an individual server, interacting with the sensor node and sending the collected data to the central server. The embedded system node at the solar tree acts as the client in this architecture and send data to the base server. A webpage hosted by the central server enables user and admin to visualize the current status of each tree as well as access the entire data set stored in the database. The webpage will show the location of the tree, power generated by the tree during the day, temperature, humidity, CO_2, PM2.5, and PM10 concentration.

In a server to server interaction model, each tree can act as a data aggregating node for other trees in the line of sight. This approach minimizes the need to provide each tree with its own internet link and data aggregation can happen using an ethernet to Wi-Fi bridge making one of tree as a hotspot of the nearby trees. Such design allows for resource optimization and stands out from the mentioned approaches in the introduction section. Moreover, the presented work has been implemented on ground inside the institute campus and evaluated for over a year. The designed solar tree is already optimized for maximizing average power output across the year. On top of it, the added features of power monitoring, ambient monitoring using particulate matter count (PM2.5 and PM10), CO_2 concertation, humidity and temperature makes it a complete solution for an integrated IoT enables solar tree. This creates an example of standalone power generation unit capable of environment monitoring and smart street light control. Such a self-sufficient unit is unique and presents a novel idea in the area of smart city applications.

The implementation of the conceptual model is done at Central Electronics Engineering Research Institute, Pilani (CEERI) with two solar trees installed at each of the entrance gates. The hardware node is meant to collect data from the sensors and trigger street lights based on the control signal from the central server. The solar tree server runs the software of the sensor node and ensures communication link. Every solar tree server is connected to the central server via the internet using an MTS modem. Both the tree and the central server is based on Node.js server running in Node-Red and the visualization of data is done by the webpage hosted at the central server. The webpage is designed using HTML, CSS, angular.js, JavaScript and templates from the dashboard.

II. System Description

The designed IoT framework is targeted towards simultaneously monitoring of power generation of the solar panels along with the ambient atmospheric conditions. In order to achieve so, a server to server architecture is formed, where the 'tree server' is installed along with the solar tree and a 'central server' which is remotely located. A solar tree server running inside the tree trunk collects the ambient data and communicates it to the central server.

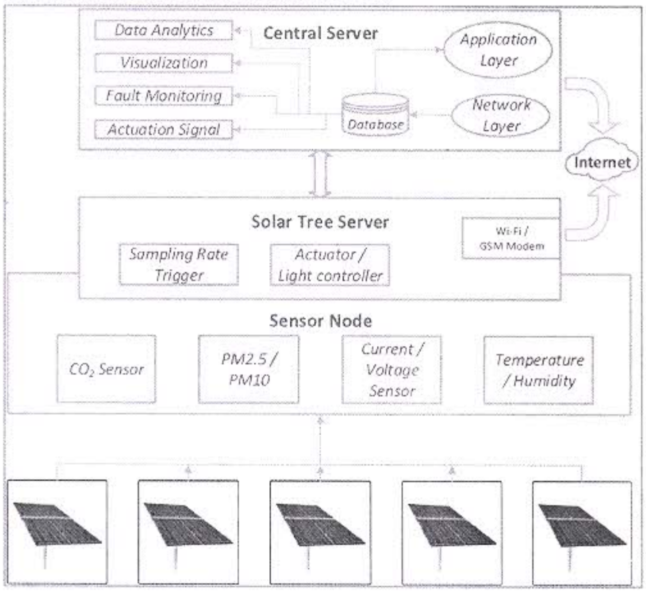

Fig. 1 IoT framework for solar tree

The overall system architecture of interacting multi-server is represented in Fig.1. As shown in the figure, the framework is three-layered, namely, the sensor node, solar tree, server, central server. The sensor node acts as a data acquisition system, collecting sensor data for temperature, humidity, PM2.5, PM10, CO_2, voltage and current. The node is controlled by the solar tree server and is triggered at the sampling rate of 0.05Hz. This sampling rate is still higher considering the rate at which changes occur in the ambient. Still, for testing and data collection, a slightly higher sampling is needed.

The solar tree server acts as a local server for implementing communication and control over the network/internet. The tree server executes the firmware of the sensor node at the specified sampling rate and controls the actuation of a street light, fault monitoring, and error handling. The data communication is handled by a mosquitto acting as a client and sends data to the central server at a specified broker address.

The central server is the main aggregation server, that collects the data from multiple tree servers. Upon collection, the data is timestamped and generated power is calculated and added to the incoming payload. This final data set is stored in the database. The webpage is hosted at the central server and the user can see the visualization of the collected dataset.

III. Field Implementation

A. Solar Tree Server

The solar tree server is build using Node.js inside Node-Red. The main aim of this server is to facilitate the communication and control of the tree. The sensor node which is handled by this server comprises of multiple sensors dedicated for each measurement. For temperature and humidity, the 1wire DHT22 sensor is used and is directly interfaced to the Raspberry Pi3. On the serial communication line, PM2.5/PM10 sensor from adafruit was connected and a software routine is written to read the sensor response. The server triggers the software routine to collect the ambient and power generation data and communicates it to the central server as shown in Fig. 2.

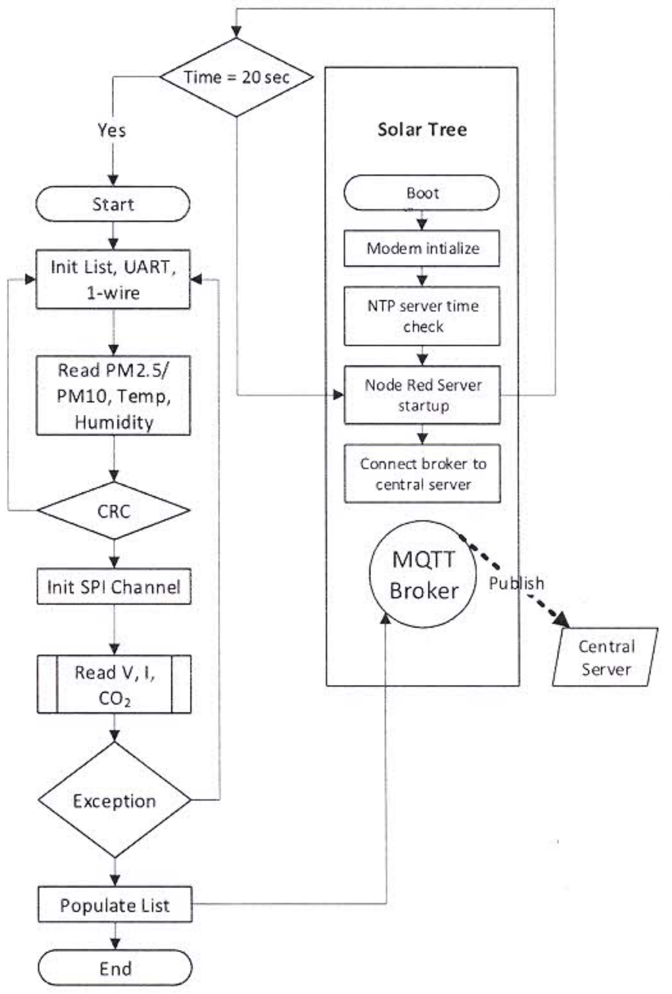

Fig.2 Flowchart for the sensor node software routine running at the solar tree

Upon bootup, the Raspberry Pi first initializes the modem for internet connection. Once the connection is established, the NTP server checks for the time and later, the Node.js server is initialized. The mosquitto broker is triggered and the connection to the central server is established. The software routine is triggered to read the data from the sensors. The PM2.5/10 counter is ensured for correctness by CRC and the entire software routine is run in try/exception mode for correct data gathering. Since the readout time from the sensor node is much higher than the sampling rate, this gives us ample amount of time for re-iterating the software is there is an exception while reading the sensors. Once all the data are fetched correctly, the list is populated and passed to the server where it is directed to the central server through the MQTT broker in a data packet. Each packet consists of three headers and 7 sensor data as payload aligned in a sequence shown in Fig.3. The broker publishes the data to a specified location maintained by the global central server.

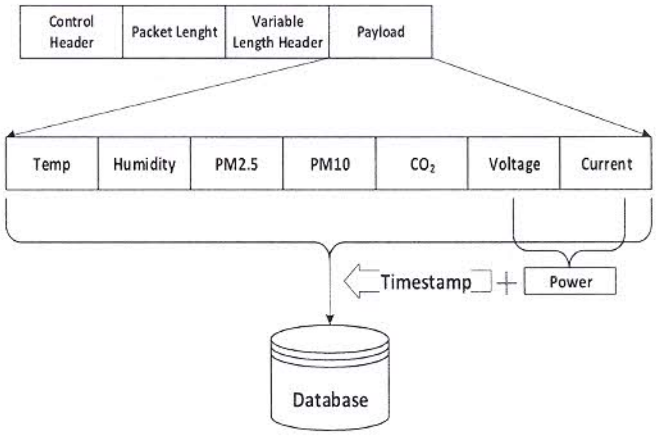

Fig.3 Data packet and payload details

As seen from the packet structure, the payload consists of data for temperature, humidity, PM2.5, PM10 CO_2, voltage and current. The complete payload is attached to the timestamp at the server and stored in a database at the server. The parsing script at the server separates out each payload using the index of each data. The last two indexed value is used to calculate power generated by PV panels for visualizing in the webpage.

B. Central Server

The central server is also a Raspberry Pi3 running a Node.js server inside Node-Red. The central server facilitates data visualization through a webpage, database management, decision making, actuation signal generation, and data analytics. Each solar tree upon bootup connects to a central server and gets registered with their respective IP addresses. For every tree, a unique address for message passing is created, which is maintained by the MQTT broker. The central server aggregates the incoming data, attaches the timestamp and power generated by the solar panels and then stores it in a database. Every tree is given its own database for storage and analysis. The overall concept is shown in Fig. 4.

Like the tree server, the central server also follows the same boot sequence and ensure NTP synchronization, internet connection, MQTT broker service, and Node.js server to be available and running. This boot sequence ensures that upon any malfunction of the power supply, the entire IoT network is auto reconfigured without any manual intervention just as shown in Fig. 4. The webpage for the solar tree is accessible globally and is protected by a login page. For users, a default login ID and password is created and a separate login for the admin is created. The MQTT messages are encrypted by TLS and password protected so that any other intruder cannot send or receive the sensor data. The central webpage for data visualization is shown in Fig. 5.

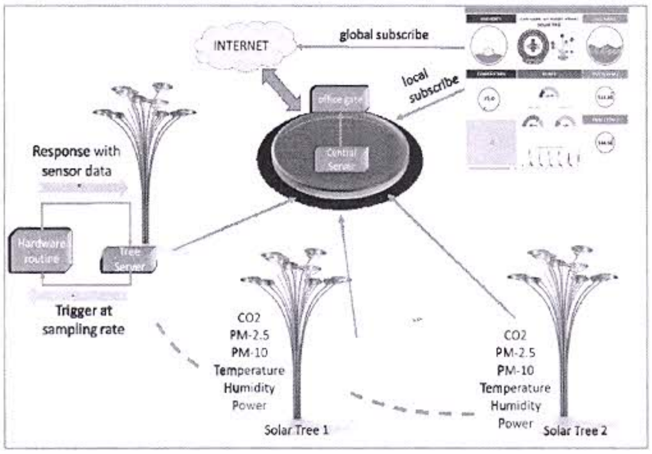

Fig.4 Overall conceptual representation of the implemented IoT enabled solar tree

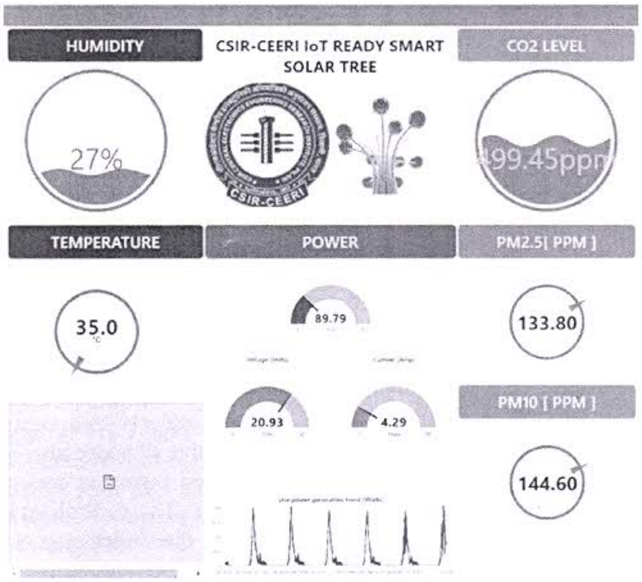

Fig. 5 Webpage designed for data visualization of sensor data

IV. Results and Discussion

The first step towards the establishment of the solar tree was to optimize the positioning of the panels based on the latitude and longitude of the location. This was carried out by a software algorithm development by our team and described in [22]. Based on the calculation for 5 solar panels, two solar trees were designed and installed at the entrance of the institute's gate. The sensor node interfaced with Raspberry Pi was placed with the solar tree and provided an internet connection using an MTS modem. The final installed tree is shown in Fig. 6. The power generated by the solar panels is controlled by MPPT controllers to optimize loading and power curve and is stored in a 200AH lead acid battery. This battery is used for powering up the local server, LED street light and the sensors attached to the solar tree.

Fig. 6 Installed solar tree at the institute entrance with the IoT system

This self-sustained model of the solar tree is up and running and the year-long data is stored in the central server. The street light is also automated and the control signal is generated by the central server. The logic for the street light trigger is made based on the fact that summer has longer daylight and so the power generation continues even after 6 pm and winter have shorter daylight so power generation stops well before 6 pm. Combing these factors the street light actuation is done by the server by combing the time and value of the current signal from the tree.

The collected data from the solar tree helps in evaluating the performance of the solar tree and also helps in monitoring the ambient conditions. Since the dataset is huge, a sample of 4month power generation is shown in Fig.7.

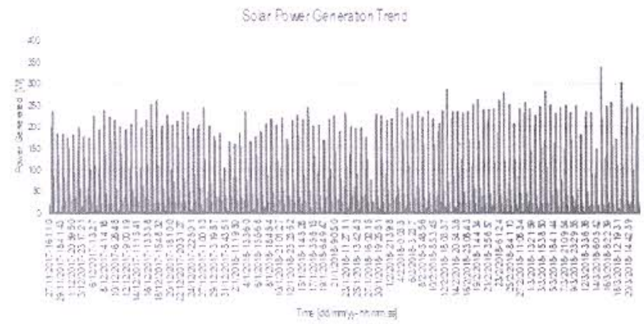

Fig.7 Solar power generation trend collected from the IoT server over a period of 4 months.

An insight power generation trend can be seen in Fig. 8 shows a typical power curve for two different days. From the curve is can be noted that the battery is fully charged by 10 am to 11 am and so the mppt controller operates at a lower power curve of the solar panel. This is to ensure that the solar panels deliver power as per the load attached to it.

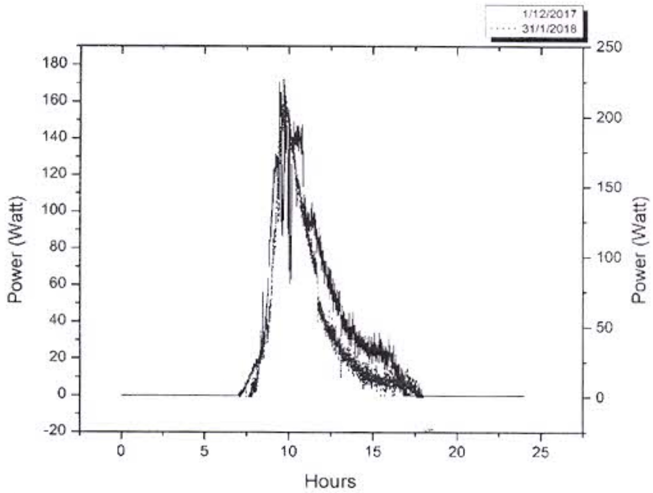

Fig.8 Typical power generation curve from the solar tree

Extracting the data from the collected payload at the central server we can see the trend of ambient parameters such as PM2.5, PM10, and CO_2 concentration. The solar trees were installed in November 2017 and have been functioning since then. We have collected data for over a year now and a sample of data is shown in Fig.9. The graph shows the variation trend in PM2.5 and PM10 averaged for each day.

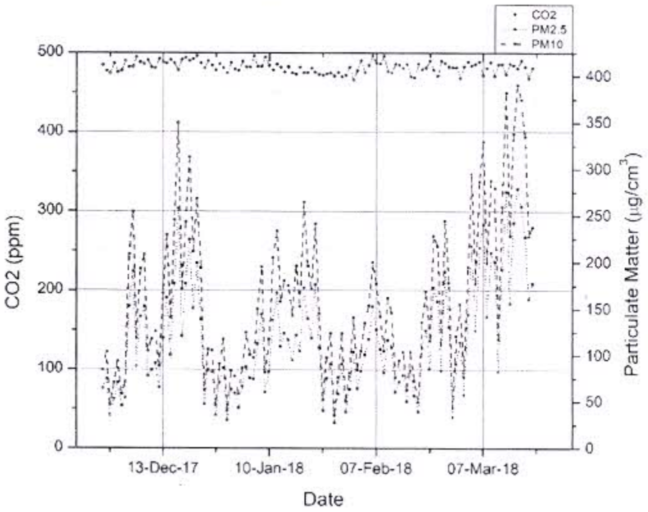

Fig.9 PM2.5, PM10 and CO_2 concentration trend shown as a daily average over a period of 4 months

The collected data is within a close accuracy with the Central Pollution Control Board (CPCB) data. Although, this data is assumed to be more accurate as this is a direct measure of pollution inside the campus and far from the CPCB installed stationary monitoring stations. The CO_2 is also near the global average value for an open environment and fluctuates below the 500ppm level mark. A slightly higher CO_2 level is observed during the traffic hours and is evident from the curve show in Fig.9.

V. Conclusion

The paper presents an IoT framework for solar tree based on interacting multi-server architecture. The architecture is 3-layered with sensor node at the bottom for collecting the data from the solar tree and environmental data. Running on top of this node is the solar trees server which runs the software of the sensor node and communicates data over the internet. The final layer is the central server that aggregates data from all the connected solar trees and stores them in their respective database. The central server also hosts for a web interface for the user to visualize the data and location of the solar trees. IoT based remote monitoring and control enhances the capability of the solar tree. The conceptual model is implemented in the Central Electronics Engineering Research Institute with two such tresses placed at the entrance gates. The presented model of IoT enabled solar tree can serve multiple functionalities such as EV charging stations, surveillance and security systems, PA systems, street lights and much more. The authors believe that such implementation will contribute towards the smart city vision.

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