Remote Monitoring, Control and Data Visualization for a Solar Water Pumping System

Omair Ahmed and M. Tariq Iqbal

***Abstract* — Access to clean water is a significant challenge in many regions, including Sukkur, Pakistan. The effective management of water resources is a critical challenge, particularly in areas with limited access to surface water sources. This paper presents a remote monitoring of water pumping system designed to address water distribution challenges in Sukkur, Pakistan. The system utilizes a combination of hardware components, including Arduino Uno, Raspberry Pi 2, ultrasonic sensor, and GSM modules, to enable remote monitoring, control, and data visualization. The system architecture incorporates Node-RED, a powerful flow-based programming tool, to facilitate data communication, storage, and visualization. To enable remote monitoring and control, users can send SMS commands to the Arduino Uno, connected to the GSM module, to query the system's status and control the pump's operation. Additionally, a mobile application developed using the MIT App Inventor platform allows users to interact with the system, visualize real-time and historical data, and receive updates on water levels and pump status. The Raspberry Pi 2 serves as a server and cloud storage for the system.**

***Key words* — Arduino; GSM module; MIT app inventor; MQTT protocol; Node-RED; Raspberry Pi 2; remote monitoring; water management.**

I. INTRODUCTION

Access to clean and reliable water is a fundamental necessity for the well-being and sustainable development of communities, however, many regions across the globe, including Sukkur in Pakistan, struggle with significant challenges in managing their water resources effectively [1]–[3]. These challenges are further intensified in areas with limited connectivity options, where the implementation of modern monitoring and control systems becomes a difficult task [4], [5]. The city of Sukkur, located in the Sindh province of Pakistan, experiences water scarcity due to various factors such as rapid population growth, increasing agricultural demands, and unreliable infrastructure [6], [7]. The existing water supply systems often struggle to meet the demands of the population, resulting in irregular distribution and inadequate access to clean water [8], [9].

In such a scenario, it becomes imperative to develop innovative solutions that leverage renewable energy sources and advanced communication technologies to optimize water resource utilization [10], [11], [12], [13]. The solar-based water pumping system presented in [14] allows for the extraction and distribution of water from underground sources, mimicking the conditions prevalent in Sukkur. In areas where Wi-Fi and 3G/4G connectivity options are limited, traditional methods of remote monitoring and control become impractical. Several works have explored the usability of various technologies to monitor and control solar-based water pumping systems. For instance, author in [15] focuses on the design and analysis of a solar water pumping system for a fish farm in Pakistan. The study examines the performance and efficiency of the system, considering factors such as solar radiation, water demand, and the specific requirements of a fish farm. The findings provide insights into the optimization of solar water pumping systems in agricultural applications. Authors in [16] explore the implementation of an IoT-based fishpond monitoring system to enhance productivity. While not directly focused on solar-based water pumping systems, it provides valuable insights into the integration of IoT technologies for monitoring and controlling water-related systems in agricultural settings. Authors in [17] discuss the application of IoT monitoring for solar-powered pumps in a hydroponic house. It explores the use of sensors and data communication technologies to monitor and control water pumping systems. The findings contribute to the understanding of effective monitoring strategies for solar-based water pumping systems. In [18], the authors focused on the modelling and simulation of a solar water pump using Arduino Uno in Proteus. The study presents a simulation-based approach to analyze the performance and efficiency of the system. [19] presents the automation and control of a solar-powered water pumping system using a microcontroller for aquaculture. The study explores the application of automation and control techniques in solar-based water pumping systems. The findings contribute to the understanding of system optimization for specific applications, such as aquaculture. [20] discusses the development of an economical SCADA system for solar water pumping in Iran. It addresses the challenges and considerations in implementing a cost-effective SCADA system for monitoring and controlling solar-based water pumping systems. The findings contribute to the understanding of SCADA system design and implementation in resource-constrained settings. [21] focuses on the development of an IoT-based open-source SCADA system for PV system monitoring. While not specific to water pumping systems, it explores the integration of IoT technologies and the MQTT protocol for monitoring and control. The paper provides insights into the use of SCADA systems for monitoring solar-based systems. [22] discusses an open source IoT-based SCADA system for remote oil facilities using Node-RED and Arduino microcontrollers. Although focused on oil facilities, it presents insights into the development and

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implementation of SCADA systems for remote monitoring and control.

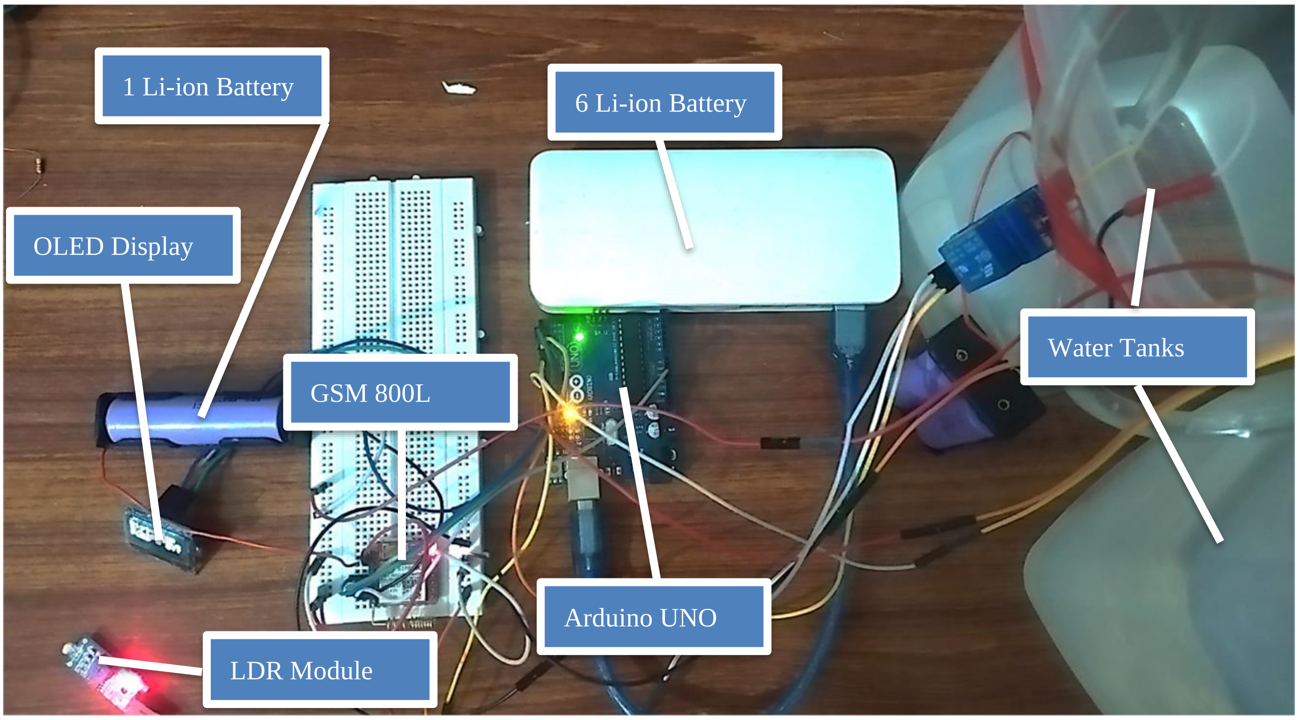


Fig. 1. Test Hardware Setup of the proposed system.

This paper presents a control and monitoring of the solar-based water pumping system employing GSM technology for SMS communication between the system components. An Arduino Uno microcontroller, a Raspberry Pi 2, and an app developed using the MIT App Inventor platform. The app, equipped with GSM and MQTT functionalities, enables users to send commands, query system information, and receive updates on the water pumping system's status.

The paper is structured as follows: Section II presents the overall system architecture and hardware setup. Section III presents the software aspect of the study. Section IV explores data communication and management of the work. Section V presents and discusses the results and Section VI concludes the study.

II. System Architecture And Hardware Setup

The system architecture and hardware setup of the solar-based water pumping system comprise a pumping system controlled by an Arduino Uno microcontroller with a GSM module, a Raspberry Pi 2 acting as a server and cloud storage unit, and a user app developed using the MIT App Inventor platform. The following subsections explored each aspect of the hardware setup.

A. Arduino Uno and Control Setup

The overall Arduino based hardware setup is illustrated in Fig. 1. The hardware consists of and Arduino UNO R3 microcontroller. The controller is connected with a light dependent resistor (LDR) module that measure the available sunlight. The Arduino is also connected to an ultrasonic sensor that measure the water level in one of the two tanks, mimicking the underground water tank and outer water tank. The Arduino is power by a power bank that consist of Li-ion battery cells and provides 5V DC power to Arduino using a step-up DC-DC converter of 3.7V to 5V. The Arduino has a GSM connectivity using a SIM800L module. The Arduino Uno processes incoming SMS commands and sends responses containing relevant information, such as current water levels and pump status.

B. Raspberry Pi 2 and Node-RED Integration

The Raspberry Pi 2 is used to work as a server and cloud storage unit and illustrated in Fig. 2. Since this setup presents a solar-based water pumping system in remote areas where limited connectivity is available, the Raspberry Pi 2 has been connected to another GSM module to communicate with the Arduino. It is connected to the Arduino Uno via another GSM module, establishing communication between the two units. The Raspberry Pi 2 is also connected to the internet through Ethernet, enabling connectivity for remote access and data exchange. This provides the connectivity to the end-user android mobile app.

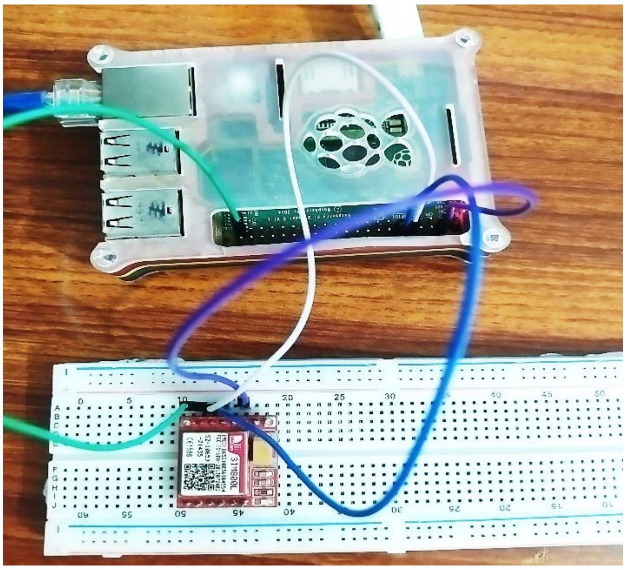


Fig. 2. GSM module connected with Raspberry Pi 2.

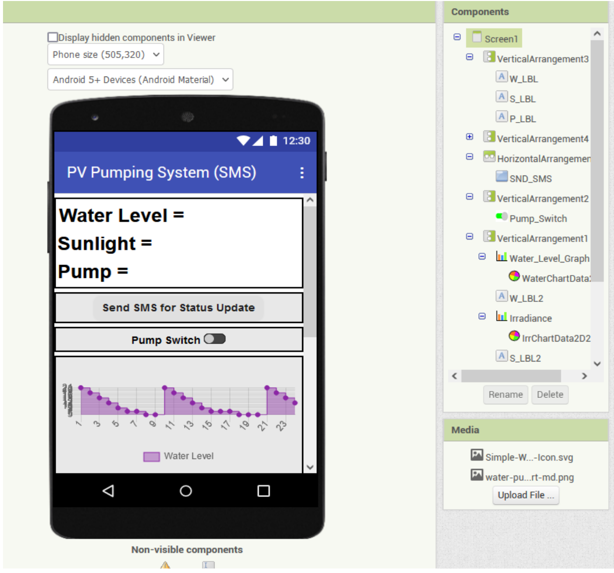


Fig. 3. An android mobile app is designed using MIT App Inventor.

To facilitate data storage and visualization, the Raspberry Pi 2 incorporates Node-RED, a flow-based programming platform. Node-RED provides a user-friendly interface for configuring data flows and creating a dashboard to visualize the collected data. The Raspberry Pi 2 receives SMS updates from the Arduino Uno at regular intervals, processes the data, and stores it in a CSV file. Node-RED's capabilities allow for the creation of a visually appealing and informative dashboard that displays real-time water levels, historical trends, and system performance metrics.

C. User App Developed with MIT App Inventor

To enable user interaction and provide an interface, an app is developed using the MIT App Inventor platform. The designed app is illustrated in Fig. 3. The app is equipped with both GSM and MQTT functionalities, allowing users to send commands and receive updates through SMS or MQTT protocol. The user app provides users with the ability to query system information, request status updates, and send specific commands for actions such as starting or stopping the pump. It also includes data visualization features, displaying the last 25 values of water levels and pump status communicated over GSM or MQTT. The app enhances the system's usability by providing users with remote access to monitor and control the water pumping system through their smartphones.

III. Software Implementation

The software implementation of the solar-based water pumping system encompasses the programming and integration of various components, including the Arduino Uno, Raspberry Pi 2, and the user app developed using the MIT App Inventor platform. This section provides an in-depth overview of the software implementation, outlining the control logic, data management, and visualization aspects of the system.

A. Arduino IDE

The Arduino Uno serves as the central controller of the system, responsible for monitoring water levels, receiving SMS commands, and sending responses. The code written for the Arduino utilizes the Arduino programming language,

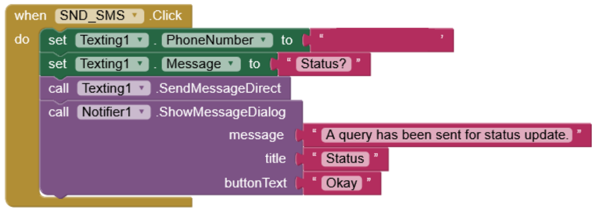


Fig. 4. A design block in MIT App Inventor when a query is generated from user app.

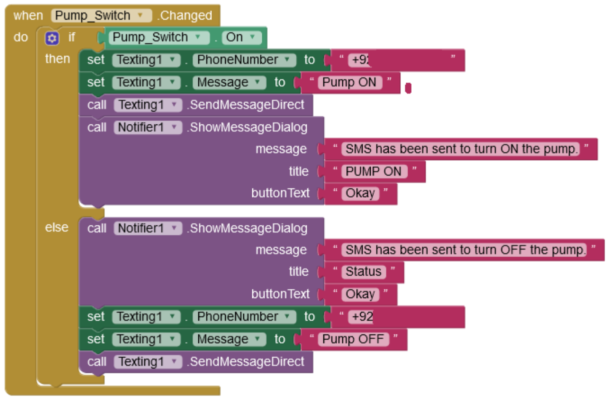


Fig. 5. MIT App Inventor design block to turn on and turn off the pump on user discretion.

Fig. 6. A section of MIT App Inventor design block when text is received from Arduino and processed to display on app dashboard.

which is based on C/C++. The control logic implemented in the code ensures that the pump operates efficiently based on the water level readings from the ultrasonic sensor and sunlight readings from LDR module. When the water level in the outer tank falls below a certain threshold, the Arduino triggers the pump to extract water from the underground tank and fill the outer tank provide there is sufficient sunlight to power the system. Additionally, the Arduino is programmed to respond to SMS commands from the Raspberry Pi or user queries, providing relevant information such as current water levels and pump status.

B. Node-RED

On the Raspberry Pi 2, the Node-RED platform is utilized to handle data storage and visualization. Node-RED provides a visual programming interface that allows for easy integration and flow-based programming. Fig. 7 shows the steps and flows used to provide storage capability and communication between Raspberry Pi 2 and Arduino, as well as between User App and Raspberry Pi 2. Fig. 7 (a) presents a SIM800 GSM module that is included in the flow of Node-RED to communicate with the GSM hardware module. Fig. 7 (b) shows the module is used to get the SMS from the

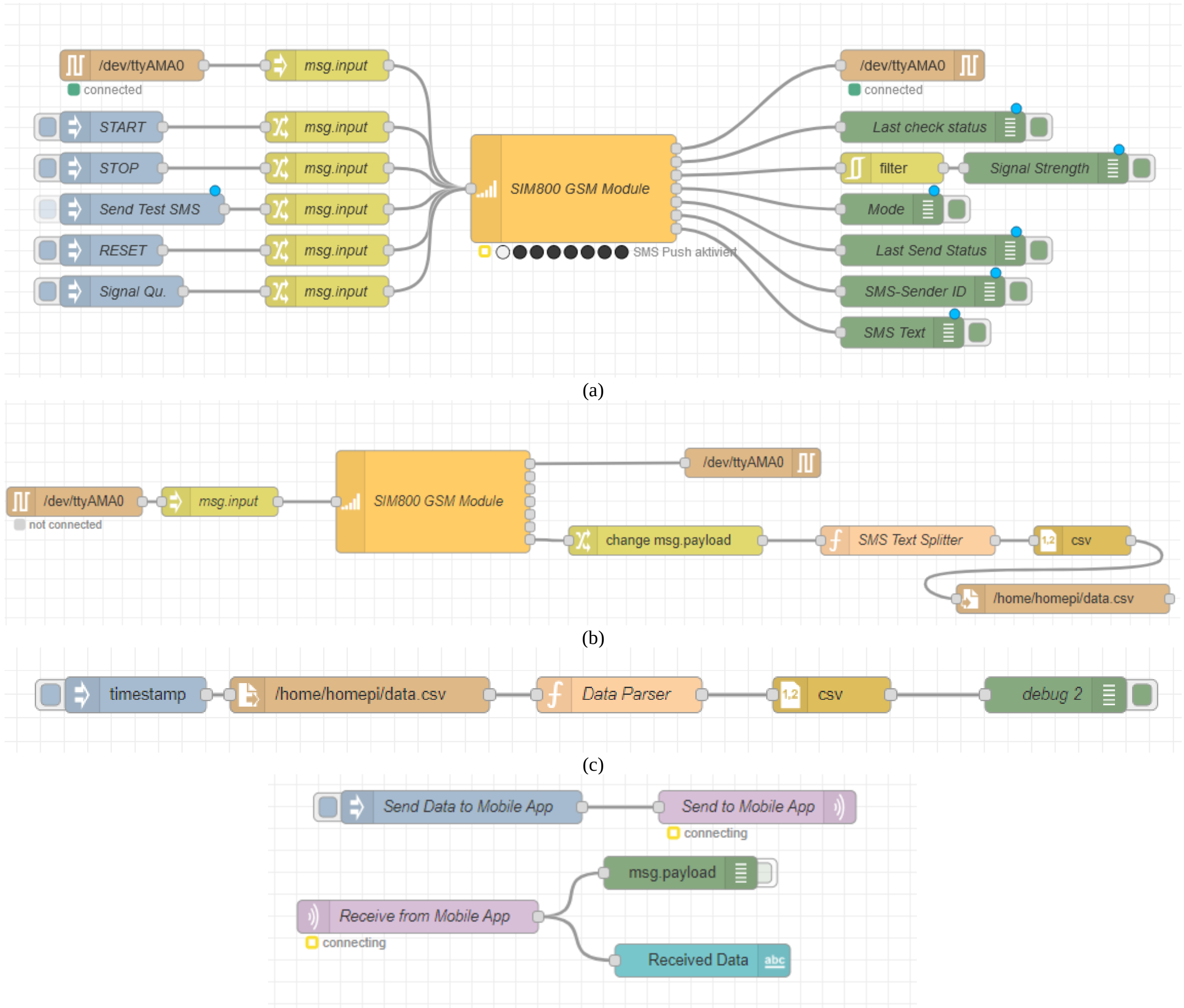


Fig. 7. A Node-RED setup followed in this setup. (a) A SIM800 GSM module is included in the flow of Node-RED to communicate with the GSM hardware module. (b) The module is used to get the SMS from the Arduino, and then splits the text in meaningful data by using a function of text splitter. The data is then stored in CSV file on the raspberry pi storage. (c) The stored data is then used to display on the dashboard of the Node-RED. (d) The data is also communicated with the user app via MQTT protocol.

Arduino, and then splits the text in meaningful data by using a function of text splitter. The data is then stored in CSV file on the raspberry pi storage. Fig. 7 (c) illustrates the stored data is then used to display on the dashboard of the Node-RED. Fig. 7 (d) shows the data is also communicated with the user app via MQTT protocol. Using Node-RED, the Raspberry Pi 2 receives SMS updates from the Arduino at regular intervals. The received data, including water levels and pump status, is processed and stored in a CSV file for future reference and analysis. Furthermore, Node-RED enables the creation of a user-friendly dashboard to visualize the collected data. The dashboard can display real-time water levels, historical trends, and system performance metrics, providing users with a comprehensive overview of the water pumping system's operation.

C. *MIT App Inventor*

The user app, developed using the MIT App Inventor platform, plays a crucial role in enabling users to interact with the solar-based water pumping system. Fig. 4, Fig. 5, and Fig. 6 present the design blocks used in designing the core functionalities of the user app. The app features both GSM and MQTT functionalities, allowing users to send commands and receive updates through SMS or MQTT protocol. The app's interface is designed to be intuitive and user-friendly, providing options to query system information, request status updates, and send commands for specific actions. Additionally, the app incorporates data visualization capabilities, displaying the last 25 values of water levels and pump status communicated over GSM or MQTT. This feature allows users to monitor the system's performance and make informed decisions based on the displayed information.

IV. Data Communication And Management

Effective data communication and management are crucial aspects of the solar-based water pumping system. This section delves into the details of how data is exchanged between the components, specifically focusing on the communication between the Arduino Uno, Raspberry Pi 2, and the user app. Furthermore, it explores the data management processes, including storage, retrieval, and visualization of the collected data. Fig. 8 provides the overall communication between the three nodes.

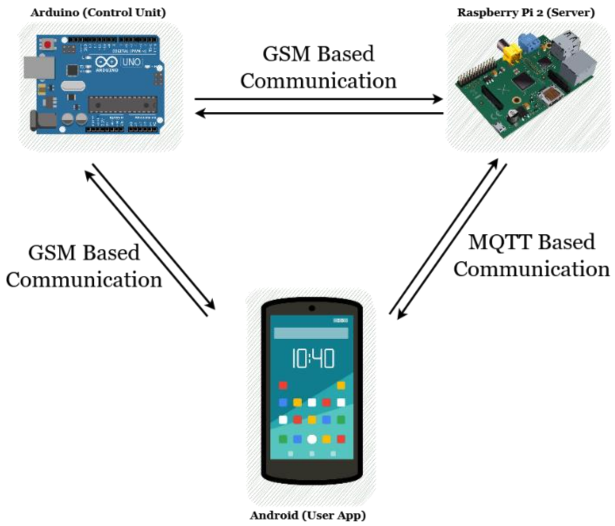


Fig. 8. Communication protocols among the three devices: Arduino, Raspberry Pi 2, and Android Application.

A. Communication between Arduino Uno & Raspberry Pi

The Arduino Uno and Raspberry Pi 2 establish communication using GSM modules. The Arduino Uno, equipped with a GSM module, sends SMS updates to the Raspberry Pi 2 at regular intervals. These updates contain vital information such as water levels in the outer tank and the status of the pump. The Arduino Uno processes the incoming SMS commands from the Raspberry Pi 2 and responds accordingly, providing real-time data to the Raspberry Pi 2 for further processing.

The Raspberry Pi 2, upon receiving SMS updates from the Arduino Uno, utilizes the Node-RED platform for data processing. The Node-RED flow is configured to process the incoming SMS messages, extract relevant data, and store it in a CSV file for future analysis. This data includes timestamps, water level readings, and pump status information. The use of Node-RED's visual programming interface simplifies the data processing tasks and ensures seamless integration with the storage and visualization components of the system.

B. Data Storage and Retrieval with Node-RED and Raspberry Pi 2

Node-RED, running on the Raspberry Pi 2, facilitates data storage and retrieval. As the system receives updates from the Arduino Uno, the data is logged and stored in a CSV file. This file serves as a repository for the collected data, enabling historical analysis and monitoring of the system's performance. The CSV file can be accessed and queried for specific data points, such as water levels at different timestamps or pump status during specific intervals. Node-RED provides the flexibility to retrieve data from the CSV file using various data manipulation and filtering techniques. Users can retrieve the stored data based on their requirements and gain insights into the system's behavior over time.

C. Data Visualization through Node-RED Dashboard and User App

The Node-RED platform, in conjunction with the Raspberry Pi 2, offers powerful visualization capabilities. It enables the creation of a user-friendly and interactive dashboard that displays real-time and historical data about the water pumping system. The dashboard provides visual representations of water levels, pump status, and other relevant metrics. The Node-RED dashboard presents the collected data in the form of charts, graphs, and gauges. Users can monitor the system's performance, track water level trends, and analyze pump behavior through intuitive visualizations. This empowers users to make informed decisions and take necessary actions based on the displayed information. In addition to the Node-RED dashboard, the user app developed using the MIT App Inventor platform also includes data visualization features. The app can display the last 25 values of water levels and pump status communicated over GSM or MQTT. This feature provides users with a quick overview of the system's recent performance and allows them to monitor the water pumping system's status remotely through their smartphones.

V. Results and Discussion

Fig. 9 shows the Android mobile application developed using the MIT App Inventor platform. To ensure its functionality and validate its performance, the application was installed on two mobile phones, undergoing comprehensive testing and evaluation. The application's primary function is to facilitate communication between the user and the Arduino Uno microcontroller as well as user and raspberry pi. By simply sending a text SMS with the keyword "Status?" to the Arduino, users can obtain real-time information about the system's status. The Arduino promptly responds with a detailed message containing essential data regarding the water level, sunlight availability, and pump status. Some possible responses received from the Arduino are as follows:

- "Water Level = Low, Sunlight = Low, Pump = Off" indicates that the water level in the tank is low, sunlight availability is low, and the pump is currently turned off.
- "Water Level = High, Sunlight = High, Pump = Off" signifies that the water level in the tank is high, there is sufficient sunlight available, and the pump remains switched off.

Fig. 10 shows the prompt and responses received from Arduino and User Application. To query the status of the pumping system, a prompt SMS was sent to the Arduino Uno, as depicted in Fig. 10 (a). This SMS command requested information about the current status of the pump and the water levels in the outer tank. Fig. 10 (b) and 10 (c) illustrate scenarios where prompt SMS commands were sent to the Arduino Uno to either turn on or turn off the pump. These commands allowed users to manually manage the operation of the pump, ensuring efficient water distribution. As shown in Fig. 10 (d). The response was transmitted back to the user through the GSM module connected to the Arduino. It contained relevant information, such as the current water levels and the pump's operational status. This real-time feedback enabled users to stay informed about the system's performance and make informed decisions regarding water management. Users can also query the Raspberry Pi 2 via the MQTT protocol over a Wi-Fi connection. Upon receiving the query, the Raspberry Pi 2 promptly processes the request and generates an appropriate response. The response includes vital information such as current water levels, historical data trends, and system performance metrics. This seamless communication between the mobile application, Arduino Uno, and Raspberry Pi 2 ensures that users have access to comprehensive and up-to-date information The integration of the mobile application, Arduino Uno, and Raspberry Pi 2 through these communication channels represents a significant achievement in remote monitoring and control. The combination of SMS commands and MQTT queries provides users with multiple avenues to access relevant system information, enabling effective decision-making and ensuring optimal water distribution.

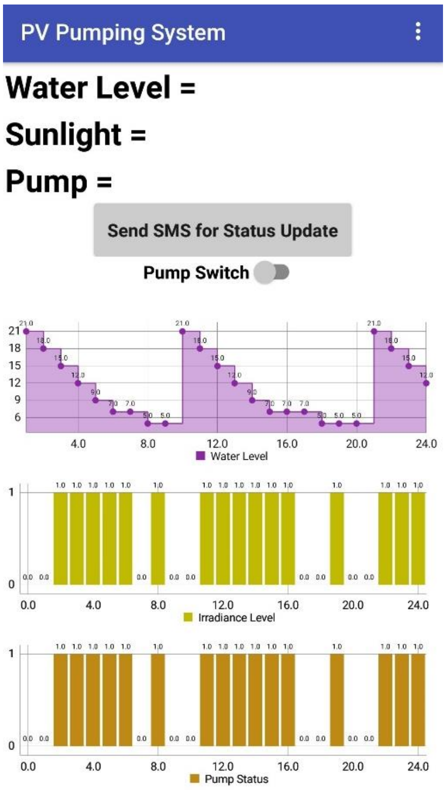
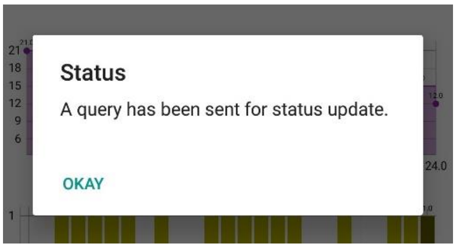
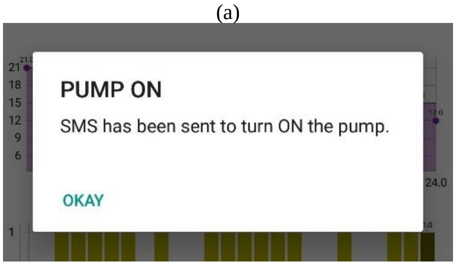


Fig. 9. User Application designed in MIT App Inventor.



(a)



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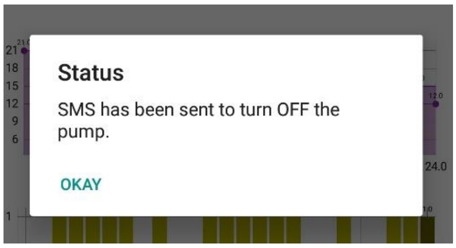
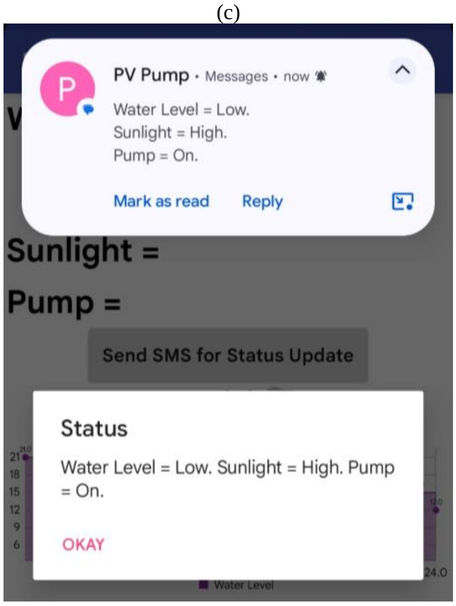


(c)



(d)

Fig. 10. Working of User Application. (a) A prompt SMS is sent to Arduino to query the status of the pumping system. (b) and (c) A prompt SMS is sent to either turn on or turn off the pump. (d) A response received on the Application from the Arduino.

VI. Conclusion

This research presented a solar-based water pumping system designed to address water distribution challenges in Sukkur, Pakistan. The system demonstrated its effectiveness in remote monitoring, control, and data visualization, offering a practical solution for areas with limited access to surface water sources. The integration of hardware components, including Arduino, Raspberry Pi 2, and GSM modules, enabled efficient water management and remote operation. The software implementation, such as the MIT App Inventor-based user app, Node-RED, and data communication protocols, provided user-friendly interfaces and reliable data visualization.

While the system presented in this paper has demonstrated promising results, there are several areas for future work and improvement. Implementing predictive analytics and machine learning algorithms can enable the system to anticipate water usage trends and make intelligent decisions in real-time. Additionally, expanding the scalability of the system to accommodate larger water pumping requirements and multiple pump configurations would be beneficial. This could involve integrating multiple pumps and tanks, along with developing sophisticated control strategies to ensure optimal water distribution and pressure management.

Conflict of Interest

Authors declare that they do not have any conflict of interest.

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