



Machine Learning-Based Solar-Powered LoRa-IoT System for Irrigation and Salinity Advisory

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KEYWORDS

Smart irrigation, LoRa, IoT, Machine learning, Solar power, Soil salinity, Precision agriculture.

ABSTRACT

This paper presents a Machine Learning-based Solar-Powered LoRa-IoT system designed for efficient irrigation management and soil salinity advisory in agriculture. The proposed system integrates soil moisture, salinity, temperature, humidity, and water-level sensors with a low-power microcontroller and LoRa long-range wireless communication. The complete field unit is powered using a solar panel and battery, ensuring autonomous operation in remote and off-grid agricultural areas. Sensor data collected from the field is transmitted through LoRa to a base station, which forwards the data to a cloud server for storage and analysis. Machine learning algorithms analyse environmental parameters to predict irrigation requirements and provide actionable advisory to farmers. A mobile application enables farmers to remotely monitor field conditions and manually control the irrigation pump when required. The system offers a low-cost, energy-efficient, and long-range solution that reduces water wastage, improves crop yield, and supports sustainable, data-driven agriculture.

INTRODUCTION

Agriculture plays a vital role in economic development and food security, yet traditional irrigation practices are still widely followed in rural areas[1]. These practices rely heavily on manual observation and experience, often resulting in over-irrigation or under-irrigation, water wastage, increased energy

consumption, and reduced crop productivity. With increasing population and shrinking water resources, there is a growing need for intelligent irrigation systems that optimize water usage based on real-time field conditions.

The Internet of Things (IoT) has enabled continuous monitoring of agricultural parameters such as soil

moisture, temperature, humidity, salinity, and water levels using distributed sensors. However, conventional wireless technologies such as Wi-Fi, Bluetooth, and cellular networks are not suitable for large-scale or remote farms due to limited range, high power consumption, and dependence on internet connectivity. LoRa (Long Range) communication addresses these limitations by providing low-power, long-distance data transmission without requiring continuous internet access.

Machine Learning (ML) further enhances smart irrigation systems by enabling predictive decision-making based on historical and real-time sensor data[2]. By integrating IoT sensing, LoRa communication, solar energy, and ML-based prediction, the proposed system delivers a reliable, cost-effective, and sustainable solution for modern agriculture.

LITERATURE SURVEY:

Recent research in smart agriculture has focused on wireless sensor networks, IoT-based monitoring, and automated irrigation systems. Early systems employed Bluetooth and ZigBee technologies for short-range communication, which limited scalability and field coverage. ZigBee-based systems provided low power consumption but were constrained to small areas and mesh network complexity. Santoshkumar, et al.[4] in their research, select various sensors and methods for precision agriculture such as temperature sensor, humidity sensor, and Arduino (ATMega328) microcontroller board with the wireless sensor network system. The role of WSN is to sense the remote data from the desired location and transmit through the wireless network which can be viewed by the receiver. M. Dholu, et al.[5] proposed and designed an IoT for precision agriculture application. This proposed system consists of various components like humidity & temperature sensor, soil moisture sensor, and a microcontroller unit (MCU) along with the Wi-Fi module, using the Wi-Fi router uploaded the sensed data on Thingspeak cloud and finally displayed it on the mobile application. Researchers highlighted LoRa's capability to cover several kilometres with minimal energy consumption. Recent studies have introduced machine learning into irrigation systems to improve decision accuracy, but many implementations remain costly or

internet-dependent. These limitations motivate the development of a solar-powered, LoRa-enabled, ML-based irrigation and salinity advisory system. D. Davcev, et al. [6] design an IoT agriculture system based on LoRaWAN. As discussed, RF technology was replaced by Bluetooth technology, and Bluetooth was replaced by ZIGBEE technology, And ZIGBEE has replaced by LoRa technology. D. Davcev, et al. Y. Kim, et al. [7] designed remote sensing and control of an irrigation system using a distributed wireless sensor network. In this proposed system [7], communication signals from the sensor network and irrigation controller to the base station were successfully interfaced using low-cost Bluetooth wireless radio receiver [7]. A. Hanggoro, et al. [8] proposed and designed a greenhouse monitoring and controlling using an android mobile application, which was a complete system designed to monitor and control the humidity inside a greenhouse. It used an android mobile phone, connected using Wi-Fi to a central server which connects via serial communication to a microcontroller and humidity sensor. According to them, Wi-Fi has been implemented all over the world, and 802.11g was the third modulation standard for wireless LANs. P. Gangurde, et al. [9] designed a novel approach for precision agriculture using a wireless sensor network. In their research, they propose different topologies for precision agriculture. The development and deployment of WSNs have taken traditional network topologies in new directions [9]. Different WSN topologies are Bus, Star, Ring, and Grid [9]. According to them, delay in star case was much less than the delay in a bus, grid, and ring topology [9].

PROPOSED SYSTEM AND WORKING METHODOLOGY:

The proposed system integrates solar power, IoT sensing, LoRa communication, and machine learning to create a smart irrigation and salinity advisory solution. The system is divided into two main units: a field station and a base station.

A) Field Station Unit The field station consists of soil moisture sensor, salinity (EC/TDS) sensor, temperature and humidity sensor, and water-level sensor. An ESP32/Arduino-based microcontroller collects sensor data and controls a relay connected to a water pump. The entire unit is powered by a solar panel with battery

backup. Sensor data is transmitted to the base station using a LoRa (SX1278) module.

B) Base Station Unit The base station uses a NodeMCU/ESP8266 with a LoRa module to receive data from the field station. The received data is forwarded to a cloud server via Wi-Fi for storage and visualization. The base station also sends control commands back to the field unit when required.

C) Machine Learning-Based Prediction Machine learning algorithms analyze historical and real-time sensor data to predict irrigation requirements. Parameters such as soil moisture, salinity, temperature, and humidity are used as input features. The trained model determines whether irrigation is required and provides advisory to farmers, improving water efficiency and crop health.

D) User Interface and Control A mobile application allows farmers to monitor field conditions in real time and manually control the water pump based on ML predictions. Alerts and historical trends support informed decision-making[10].

E) BLOCK DIAGRAM

The block diagram illustrates the integration of sensors, microcontroller, LoRa transmitter and receiver, cloud server, and mobile application. The workflow begins with sensor data acquisition, followed by LoRa transmission to the base station, cloud processing, ML-based prediction, and pump control through relay actuation.

Transmitter Section:

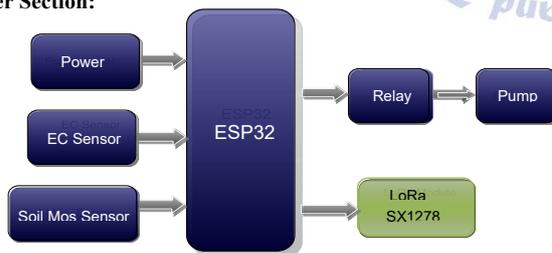


Fig. 1. Block Diagram of Proposed Smart Irrigation System

Receiver Section:



Fig. 2. Block Diagram Base Station

F) WORKFLOW DIAGRAM

The workflow diagram illustrates the sequential execution of the proposed system, beginning with system initialization followed by continuous monitoring

of environmental and occupancy conditions. The process starts once the Raspberry Pi is powered ON[11]. The sensors are initialized and begin capturing temperature, humidity and illumination values, while the camera simultaneously detects human presence within the room. All acquired parameters are fed into the machine learning inference module, where they are evaluated in real time to decide whether appliances need to be activated or turned OFF.

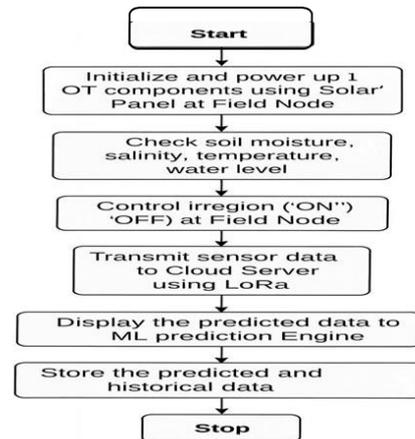


Fig. 3. Workflow Diagram of Smart Irrigation System

RESULT:

The implemented prototype successfully monitored real-time field parameters and transmitted data over long distances using LoRa. The solar-powered system operated reliably in off-grid conditions. Machine learning predictions enabled timely irrigation, reducing water wastage[12]. Remote monitoring and control through the mobile application reduced manual effort and improved irrigation efficiency.

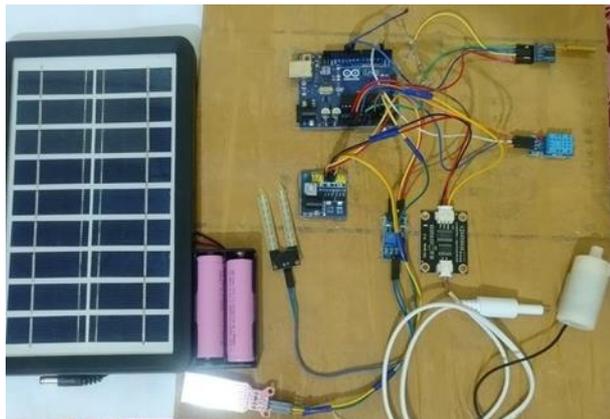
A. HARDWARE RESULT-PROTOTYPE IMPLEMENTATION OF LORA-IOT IRRIGATION SYSTEM

The complete hardware prototype of the proposed Machine Learning-Based Solar-Powered LoRa-IoT irrigation system was successfully designed and implemented. The field station consists of soil moisture sensor, soil salinity (TDS/EC) sensor, temperature and humidity sensor, and water level sensor interfaced with an Arduino UNO microcontroller[13]. A LoRa (SX1278) transceiver module is connected to the microcontroller to enable long-range, low-power wireless data transmission.

A relay module is integrated to control the irrigation water pump, allowing ON/OFF operation based on user

commands and advisory outputs. The entire field unit is powered using a solar panel with battery backup, ensuring uninterrupted operation in remote agricultural locations without grid power[14].

The base station consists of a NodeMCU (ESP8266) integrated with a LoRa receiver module, which successfully receives sensor data packets from the field node and uploads them to the cloud server through Wi-Fi connectivity. Stable power supply, reliable sensor readings, and continuous LoRa communication confirmed the robustness of the implemented prototype.



Field station

Fig. 4. Prototype setup with ESP32, sensors, relay module and pump



Base station unit

Fig. 5. Prototype setup with NodeMCU, LoRa module
B. PRACTICAL WORKING OUTPUT – LIVE IRRIGATION PUMP CONTROL

The practical operation of the system was validated by controlling a real irrigation water pump connected through a relay module [15]. Based on sensor readings and user commands received from the mobile/web application, the pump was switched ON and OFF in real time.

During dry soil conditions, the system recommended irrigation, and the pump was activated remotely via the application interface[16]. When sufficient soil moisture

was detected, the pump was switched OFF, preventing over-irrigation. This confirms that the LoRa-based communication and control mechanism works reliably over long distances with minimal latency.

The successful live control of the irrigation pump demonstrates the feasibility of remote farm management, reducing manual effort and enabling timely irrigation decisions.

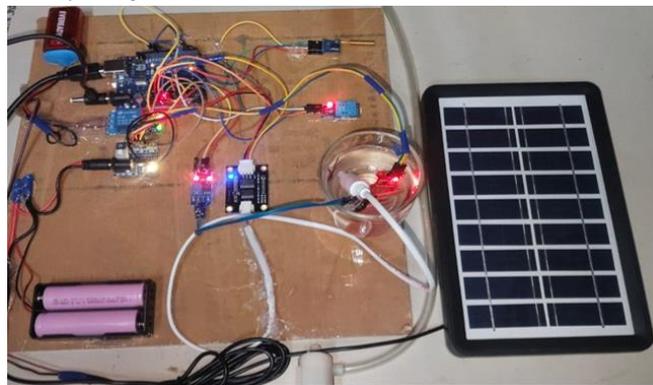


Fig. 6. LIVE PUMP IRRIGATION CONTROL
C. REAL-TIME MONITORING AND PREDICTION DISPLAY

A real-time monitoring dashboard was developed to visualize sensor parameters such as soil moisture, salinity, temperature, humidity, and water level[17]. The dashboard also displays machine learning-based irrigation prediction results, indicating whether irrigation is required or not.

Sensor data received through the LoRa gateway is continuously updated on the screen, enabling farmers to monitor field conditions from anywhere. The prediction output dynamically changes with sensor variations, providing instant feedback and decision support[18]. This real-time display enhances transparency and improves farmer confidence in adopting smart irrigation practices.

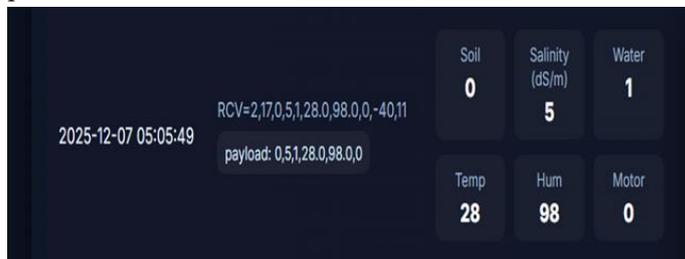


Fig. 7. UI output –Motor 1→Motor ON.

D. MACHINE LEARNING-BASED IRRIGATION AND SALINITY ANALYSIS

Machine learning techniques were applied to analyze the collected environmental data and predict irrigation requirements[19]. Historical sensor data containing soil

moisture, salinity, temperature, and humidity values were used to train the prediction model.

The trained model successfully classified irrigation needs under varying field conditions. During real-time operation, the model accurately identified dry soil conditions and recommended irrigation, while avoiding unnecessary watering during adequate moisture levels.

Salinity data analysis also helped in identifying high salt concentration conditions, supporting better soil health management[20]. The results demonstrate that machine learning enhances the intelligence of the system by enabling data-driven irrigation decisions rather than fixed threshold-based control.

E. IRRIGATION AND SALINITY ADVISORY SYSTEM RESULTS

Based on machine learning predictions and real-time sensor inputs, the system generates irrigation and salinity advisories for farmers[21]. The advisory messages indicate irrigation status such as "Irrigation Required" or "No Irrigation Needed", along with salinity condition alerts.

These advisories help farmers optimize water usage, reduce salinity stress on crops, and improve overall crop productivity[22]. The advisory mechanism transforms raw sensor data into meaningful and actionable information, making the system farmer-friendly and practical for real-world deployment.

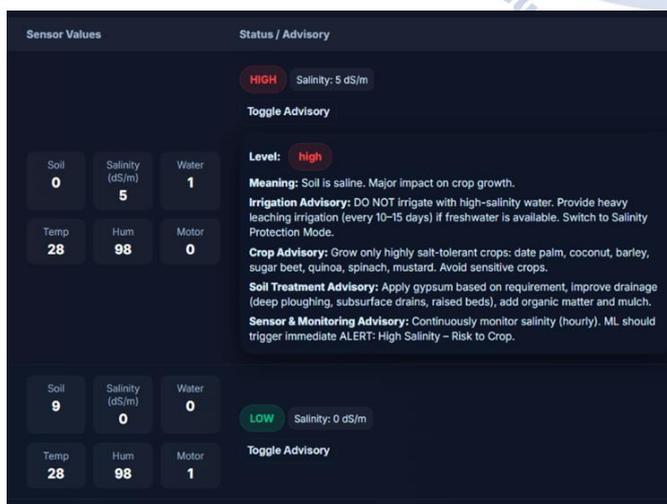


Fig. 8. HIGH → high salinity indication → gives advisory.

F. WEB APPLICATION (HTML/CSS) AND SECURE HTTPS RESULT SUMMARY

A web-based application was developed using HTML and CSS to display real-time sensor data, prediction results, and irrigation status[23]. The application is

hosted on a secure HTTPS platform, ensuring data privacy and secure remote access.

The webpage provides a summarized view of field conditions, including moisture levels, salinity values, pump status, and machine learning recommendations. This centralized monitoring platform allows farmers to manage irrigation efficiently without physically visiting the field[24].

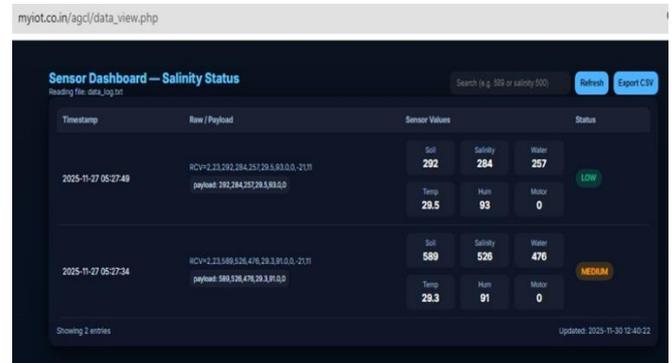


Fig. 9. Web Application.

G. SUMMARY OF RESULTS

The experimental evaluation of the proposed system confirmed reliable performance across all functional modules. The hardware prototype operated stably under solar power, and all sensors provided consistent and accurate real-time measurements[25]. LoRa communication successfully transmitted sensor data over long distances with minimal packet loss and low power consumption.

The live irrigation pump control was executed effectively through relay actuation, validating the practical applicability of remote farm management[26]. The real-time monitoring interface displayed sensor values and prediction outcomes without noticeable delay, ensuring continuous visibility of field conditions.

The machine learning model demonstrated accurate irrigation prediction under varying soil moisture and environmental conditions, reducing unnecessary irrigation cycles and promoting efficient water usage[27]. Salinity monitoring and advisory functionality further enhanced soil management capability. The secure HTTPS-based web application provided centralized access to all system outputs, offering a user-friendly and reliable platform for decision support[28].

Collectively, these results validate the technical feasibility and functional reliability of the proposed LoRa-IoT-based smart irrigation and salinity advisory system.

CONCLUSION:

The successful design and implementation of the Machine Learning-Based Solar-Powered LoRa-IoT System for Irrigation and Salinity Advisory demonstrate the effectiveness of integrating IoT sensing, long-range wireless communication, renewable energy, and machine learning for modern agricultural applications. The developed system addresses the limitations of traditional irrigation practices by providing real-time field monitoring, intelligent irrigation prediction, and remote-control capabilities in a single unified framework[29].

The deployment of multiple environmental sensors enabled continuous monitoring of critical agricultural parameters such as soil moisture, soil salinity, temperature, humidity, and water level. The use of LoRa communication ensured reliable, low-power, long-range data transmission from the field station to the base station, making the system suitable for remote and rural agricultural environments where internet connectivity is limited or unavailable[30]. Solar-powered operation further enhanced system sustainability by enabling uninterrupted functioning without dependence on grid electricity.

The incorporation of machine learning significantly improved decision-making by analyzing historical and real-time sensor data to predict irrigation requirements accurately. Unlike conventional threshold-based irrigation systems, the proposed model adapts to changing environmental conditions and reduces unnecessary water usage[31]. The salinity advisory component provides additional value by helping farmers identify and manage high salinity conditions that could adversely affect soil health and crop productivity.

The web-based monitoring platform and mobile interface enabled farmers to remotely visualize field conditions, receive actionable advisories, and control irrigation equipment from any location. This reduced manual labour, improved operational efficiency, and supported timely irrigation decisions[32]. Overall, the system successfully demonstrates a cost-effective, energy-efficient, scalable, and intelligent smart irrigation solution that supports sustainable agriculture and data-driven farming practices.

Conflict of interest statement

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

REFERENCES

- [1] "Arduino LoRa Tutorial: Interfacing SX1278 (Ra-02) LoRa Module with Arduino." <https://circuitdigest.com/microcontroller-projects/arduino-lora-sx1278-interfacing-tutorial> (accessed Nov. 27, 2019).
- [2] "Certification | LoRa Alliance®." <https://loro-alliance.org/lorawan-certification> (accessed Jul. 20, 2020).
- [3] "lora comparison - Google Search." https://www.google.com/search?q=lora+comparison&sxsrf=ACYBGNRa9EsJ4w1grb5vRir4gcJdPWDABQ:1574843836978&source=lnms&tbm=isch&sa=X&ved=2ahUKEwi6-Oq7_onmAhXw7HMBHQwFBN8Q_AUoAXoECA4QAw&biw=1536&bih=792#imgc=tC4H51VJnlB50M: (accessed Nov. 27, 2019).
- [4] Santoshkumar and Udaykumar R.Y, "Development of WSN system for precision agriculture," in 2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS), Mar. 2015, pp. 1–5, doi: 10.1109/ICIIECS.2015.7192904.
- [5] M. Dholu and K. A. Ghodinde, "Internet of Things (IoT) for Precision Agriculture Application," in 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI), May 2018, pp. 339–342, doi: 10.1109/ICOEI.2018.8553720.
- [6] D. Davcev, K. Mitreski, S. Trajkovic, V. Nikolovski, and N. Koteli, "IoT agriculture system based on LoRaWAN," in 2018 14th IEEE International Workshop on Factory Communication Systems (WFCS), Jun. 2018, pp. 1–4, doi: 10.1109/WFCS.2018.8402368.
- [7] Y. Kim, R. G. Evans, and W. M. Iversen, "Remote Sensing and Control of an Irrigation System Using a Distributed Wireless Sensor Network," *IEEE Trans. Instrum. Meas.*, vol. 57, no. 7, pp. 1379–1387, Jul. 2008, doi: 10.1109/TIM.2008.917198.
- [8] A. Hanggoro, M. A. Putra, R. Reynaldo, and R. F. Sari, "Green house monitoring and controlling using Android mobile application," in 2013 International Conference on QiR, Jun. 2013, pp. 79–85, doi: 10.1109/QiR.2013.6632541.
- [9] P. Gangurde and M. Bhende, "A Novel Approach for Precision Agriculture Using Wireless Sensor Network," p. 8, 2015.
- [10] I. Săcăleanu, R. Popescu, I. P. Manciu, and L. A. Perișoară, "Data Compression in Wireless Sensor Nodes with LoRa," in 2018 10th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), Jun. 2018, pp. 1–4, doi: 10.1109/ECAI.2018.8679003.
- [11] R. N. Rao and B. Sridhar, "IoT based smart crop-field monitoring and automation irrigation system," in 2018 2nd International Conference on Inventive Systems and Control (ICISC), Jan. 2018, pp. 478–483, doi: 10.1109/ICISC.2018.8399118.
- [12] G. Sushanth and S. Sujatha, "IOT Based Smart Agriculture System," in 2018 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), Mar. 2018, pp. 1–4, doi: 10.1109/WiSPNET.2018.8538702.
- [13] M. Ashifuddin Mondal and Z. Rehena, "IoT Based Intelligent Agriculture Field Monitoring System," in 2018 8th International

- Conference on Cloud Computing, Data Science Engineering (Confluence), Jan. 2018, pp. 625–629, doi: 10.1109/CONFLUENCE.2018.8442535.
- [14] "Arduino - Introduction." <https://www.arduino.cc/en/guide/introduction> (accessed Jun. 27, 2020).
- [15] "Arduino Uno," Wikipedia. Jun. 04, 2020, Accessed: Jun. 27, 2020. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Arduino_Uno&oldid=960701078.
- [16] "arduino image - Google Search." https://www.google.com/search?q=arduino+image&sxsrf=ACYBGNTVJptchmLm4c8MgRrl-O6CrZYs0A:1574842640177&source=lnms&tbm=isch&sa=X&ved=2ahUKEwju550B-onmAhXIIIcAHWeWBk8Q_AUoAXoECA4QAw&biw=1536&bih=792 (accessed Nov. 27, 2019)
- [17] [4nmAhXy7HMBHZVBBfIQ4dUDCAs&uact=5](https://www.google.com/search?q=nodemcu+board&sxsrf=ALeKk03_w5ZTkFaXlZlpqZQB3CDI7z5w1A:1593215478375&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiNk46V1qDqAhXFIOYKHV9OBC4Q_AUoAXoECBkQAw&biw=1536&bih=754#imgrc=Jm9WX4IV4msaDM) (accessed Nov. 27, 2019). "nodemcu board - Google [Search.](https://www.google.com/search?q=nodemcu+board&sxsrf=ALeKk03_w5ZTkFaXlZlpqZQB3CDI7z5w1A:1593215478375&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiNk46V1qDqAhXFIOYKHV9OBC4Q_AUoAXoECBkQAw&biw=1536&bih=754#imgrc=Jm9WX4IV4msaDM)
- [18] "dht sensor - Google Search." <https://www.google.com/search?q=dht+sensor&oq=dht&aqs=chrome..69i57j69i59l2j69i60l3.2048j0j7&sourceid=chrome&ie=UTF-8> (accessed Nov. 27, 2019)
- [19] "moisture sensor image - Google Search." https://www.google.com/search?biw=1536&bih=792&tbm=isch&sxsrf=ACYBGNQ07RIkIa5hdhunjVpBuGnygXSl_Q%3A1574843238923&sa=1&ei=ZjPeXc3wN-bYz7sP1cqIyAc&q=moisture+sensor+image&oq=moisture+sensor+image&gs_l=img.3..0j0i5i30.11209.15152..15334...2.0..0.308.3277.0j6j8j1.....0....1..gws-wiz-img35i39j0i7i30j0i24j0i8i30.WL6rmVjvJds&ved=0ahUKEWjNu9Se_InmAhVm7HMBHVUIAnkQ4dUDCAc&uact=5#imgrc=pqWVRFyp5ICIGM: (accessed Nov. 27, 2019).
- [20] "LoRa – A survey of recent research trends - IEEE Conference Publication." <https://ieeexplore.ieee.org/document/8400161> (accessed Jan. 09, 2020).
- [21] "What is LoRa? | Semtech LoRa Technology | Semtech." <https://www.semtech.com/lora/what-is-lora> (accessed Jan. 09, 2020).
- [22] "PHP Introduction." https://www.w3schools.com/php/php_intro.asp (accessed Jun. 28, 2020).
- [23] "XAMPP," Wikipedia. Jun. 26, 2020, Accessed: Jun. 28, 2020. [Online]. Available: <https://en.wikipedia.org/w/index.php?title=XAMPP&oldid=964658334>.
- [24] "XAMPP Installers and Downloads for Apache Friends." <https://www.apachefriends.org/index.html> (accessed Feb. 19, 2020).
- [25] "Arduino - Environment." <https://www.arduino.cc/en/guide/environment> (accessed Jun. 28, 2020).
- [26] S. Mistry, [sandeepmistry/arduino-LoRa](https://sandeepmistry.com/arduino-LoRa). 2020.
- [27] "Installing ESP8266 in Arduino IDE (Windows, Mac OS X, Linux)," Random Nerd Tutorials, Jul. 05, 2019. <https://randomnerdtutorials.com/how-to-install-esp8266-board-arduino-ide/> (accessed Jun. 28, 2020).
- [28] "LoRa SX1278 & ESP8266 Transmitter Receiver with DHT11 Sensor," How To Electronics, Feb. 15, 2020. <https://how2electronics.com/lora-sx1278-esp8266-transmitter-receiver/> (accessed Jun. 28, 2020).
- [29] "bluetooth range - Google Search." <https://www.google.com/search?q=bluetooth+range&oq=bluet&aqs=chrome..69i59j69i57.1537j0j7&sourceid=chrome&ie=UTF-8> (accessed Jun. 29, 2020).
- [30] "wifi range - Google Search." https://www.google.com/search?sxsrf=ALeKk01klBnzqAvOJkNW-XUI5DnNn1bllw%3A1593385191134&ei=5yD5XuXhB9jE4EPm7yWyAk&q=wifi+range&oq=wifi+range&gs_l=IFCAAQkQIyCggAELEDEBQQhwlyAggAMgIIADICCAyAggAMgIIADICCAyAggAMgIIADoECAAQRzoECAAQDVFJlJVUmDJW2gAcAN4A1AB2guIAbgPkgEJMC4xLjEuNy0xmAEAoAEBqgEHZ3dzLXdpeg&client=psy-ab&ved=0ahUKEwil8bqyzqXqAhVY4jgGHRueBZkQ4dUDCAw&uact=5 (accessed Jun.29, 2020).
- [31] "zigbee range - Google Search." <https://www.google.com/search?q=zigbee+range&oq=zigbee+range&aqs=chrome..69i57.4280j0j7&sourceid=chrome&ie=UTF-8> (accessed Jun. 29, 2020).
- [32] "Free Web Hosting with PHP, MySQL and cPanel, No Ads." <https://in.000webhost.com/> (accessed Nov. 27, 2019).