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An IoT-Based Framework for Enhanced Construction Material Management and Tracking

Sameer Jain[1], Gustavo Sanchez[2], S. Taruna[3], D.K. Sharma[4]
[*1]Research Scholar, Department of Computer Science and Engineering, Institute of Engineering and Technology, JK Lakshmipat University, Jaipur
*Corresponding author Email ID: samejain1983@gmail.com
[2]Professor, Department of Computer Science and Engineering, Institute of Engineering and Technology, JK Lakshmipat University, Jaipur
Email ID: gustavo.sanchez@jklu.edu.in
[3]Professor, Department of Computer Science and Engineering, Institute of Engineering and Technology, JK Lakshmipat University, Jaipur
Email ID: staruna@jklu.edu.in
[4]Professor, Department of Computer Science and Engineering, Institute of Engineering and Technology, JK Lakshmipat University, Jaipur
Email ID: jaipur.dk@gmail.com

Abstract— Effective inventory management is essential for determining a project's growth and success in the construction industry. Recent studies have revealed that conventional techniques for managing construction materials and components still depend on human capacities, despite the fact that they account for 50%–60% of the entire cost of a typical project. This results in error-prone scenarios including product misplacement, stock replenishment, inappropriate handling, and counterfeiting. Because of this, real-time data collecting using developing technology like RFID (Radio Frequency Identification) is highly desired. In this paper, an Internet of Things (IoT)-based framework for managing and tracking construction materials is presented. It is equipped with a GSM-based GPS module and a number of sensors, including the DHT 11 sensor, and can effectively synthesize all dynamic data regarding the real-time location, ambient temperature, and humidity along the supply chain associated with various types of resources. The prototype of the system uses the aforementioned components to collect the real-time location data. The information gathered using this prototype model enables us to monitor the materials effectively from a distance and provides us with a viable method of deployment for related tasks.

Keywords- Material; Construction Site; GPS; GSM; RFID; Internet of Things

I. INTRODUCTION

Cost of materials typically accounts for up to 50-60% of overall costs in a typical construction project, therefore material management in the construction industry becomes vital given cost and time control. Many construction companies have discovered the importance of employing advanced technologies for better material management. To reduce the efforts of the manpower in collecting the information, and also reduce the chances of errors, projects are required to be served with real-time systems to ensure there is proper monitoring of resources to limit the data errors, time, and cost overruns up to negligible levels. Most researchers have recommended the use of GPS modules for tracking systems for locating the exact position of the concerned materials [1]. Real-time information-gathering technologies have proven vital to the inventory control of construction projects over the past two decades largely [2]. Modern tracking systems allow for quick and easy identification of materials as well as real-time tracking of those materials. The same data can be obtained easily on the mobile phone through SMS and along with that it can be viewed on the Cloud dashboard through IoT [5]. As part of the powered vehicle inspection, an embedded board and Android software are delivered and examined to track school buses from each place A to area B. The proposed framework makes use of GPS and the internet of things (IoT), with GPS sending the current location of the vehicle and IoT transmitting information about the status of the car to any owner or guardian. The suggested system included DHT 11 temperature sensors to address the explorers' safety as well. Additionally, the NEO 6M V2 GPS module will make it possible to broadcast the vehicle's location using a GSM-based system [5].

Logistics and transportation must be able to adjust to the changing nature of construction activities daily due to the intensity and speed of operations. This makes decision-making quick. The creation of a platform for tracking and localizing goods on building sites was the goal. This is accomplished by platform such as Radio Frequency Identification (RFID) technology systems. The paper also describes how the platform was used in a building project. The outcomes demonstrated that the platform assists in reducing costs and saving time while managing material orders. The created platform enables construction managers and contractors to better manage the material procured [7].

In addition to presenting a framework for an automated tracking and monitoring system that will address the necessary transition away from the conventional sensor-and-network-based tracking and monitoring systems for construction materials, RFID tags and ultrasound will be able to provide more accurate positioning performance in measurement than previously observed RFID- and GPS-based technologies used in current construction practices [3].

According to this article, it is technically possible to locate goods in two dimensions using RFID technology in conjunction with global positioning system technology. Analyses based on field experiments show that with this technique, tagged items may be automatically detected and their whereabouts simultaneously tracked in laydown yards and on construction sites. [13], [22].

II. RESEARCH METHODOLOGY

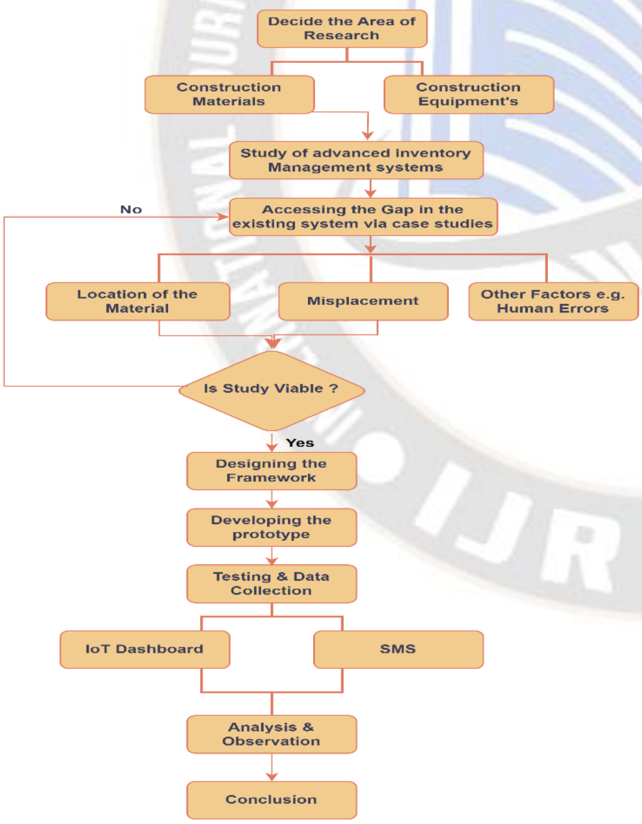

Figure 1. Methodology

- As shown in figure 1, Data collection related to the geographic location of the material in transit or deployed at the site and surrounding atmosphere needs to be obtained at the fingertip.
- Analysis of the collected data through the viability assessment and at the prototype stage
- Analyzing the application of the principles.
- Case studies will include the Technology comparison.
- Benefits for large-scale projects.

2.1 Assessment of the Gap in the study

From the above case studies and review of the literature, it is evident that though several advanced technologies are being implemented for effective management of the materials to be procured for the construction projects it is very important to locate them during the transit and after the deployment.

It is very essential to confirm the location of the material while it is being transported to the construction site or when it is being deployed for the operation. During many of the studies, it was observed that location was not the focus of the study as the vicinity of the project considered was limited and it was easy to locate the material easily and manually. But when the scope and boundaries of the project expand, it is very difficult to access the location correctly but essential.

Along with that, for some specific materials like cement, color/paints, etc. the surrounding conditions of the atmosphere turns out to be the most critical factor to maintain the quality of the concerned material. In this matter, temperature & humidity are the factors under consideration of the study which determine the moisture level of the surrounding atmosphere which will affect the quality of the cement, and temperature in the case of materials like paints, which will adversely affect the quality of these materials.

2.2 Design of the Framework

The basic idea behind designing the model is obtaining real-time data regarding the exact location and information about the surrounding conditions under which the material is being procured is subjected. This will enable the procurement department and eventually the management to ensure the deadlines and assure the quality of the products doesn't get hampered due to inappropriate handling.

To ensure these basic objectives are fulfilled, a framework comprising different IoT devices such as Microcontrollers, sensors, etc. is to be developed to obtain the required data in one place also keeping in mind the financial aspects of the system development for its enhanced acquiring and acceptance tendency by the sector.

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The basic framework as shown in figure 3, is consisting of an Arduino microcontroller, RFID reader and tags, GSM module, GPS module, IOT module, and DHT 11 Sensor.

2.3 Flow Chart

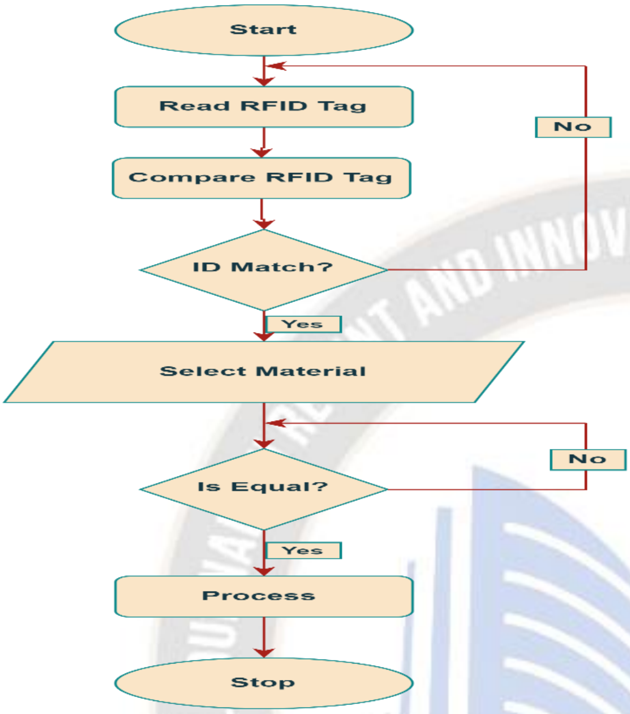

Figure 2. Flow chart of Material Tracking

III. DEVELOPMENT MODEL

The system's operating conditions and power supply requirements were carefully reviewed during the construction of the model, and the components for the prototype were then decided upon in accordance with those findings.

Even though the prototype only considered the Temperature and Humidity sensor and GPS module [14], the sensors may be distinguished and altered, and many outputs can be modified in accordance with the needs of the systems.

The Wi-Fi-based IoT module will process and upload the data to the third-party cloud dashboard, where the data can be easily interpreted and various types of information from the associated sensors may be visualized, such as graphs and plots.

An application framework with a GSM-based system was created to test the viability of applying RFID technology [24] to automate the tracking of materials on construction sites, and the best algorithms and technology were chosen. Through experiments with the available technology, the performance needs and restrictions of the algorithms and technology were also characterized.

- **Working Conditions:**

The GSM-based GPS module, which must be attached to the material itself, will allow real-time access to the location of the material while it is in transit or being delivered to the site. Due to its small size, the GPS module is simple to maintain.

Additionally, the area constraint will be reduced by the use of GSM-based systems, but the GPS module must be kept in an open area in order to broadcast its precise location, which can occasionally be difficult in cases of tunnels, etc.

- Power Supply Requirement: A 12V power supply is needed for the GPS module to function; this can be simply obtained through the battery, power adapter, or solar panel basing system, if possible.

3.1 Block Diagram

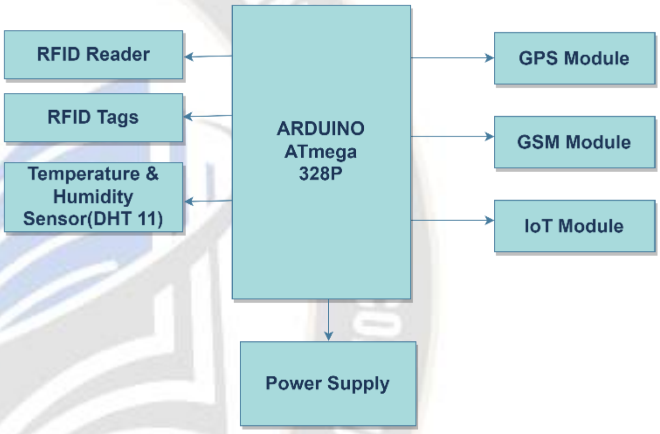

Figure 3. Block Diagram

3.2 Thing speak Dashboard

The Internet of Things (IoT) is a networked system of sensors that are "connected things," and it is managed by a microcontroller unit that has been specially programmed. The items listed in the nomenclature refers to the neighboring devices connected to the internet interface and embedded with an operating system, often the MCU.

The IoT Service, a fundamental programme and communication protocol, is what powers the entire system. The sensors and other components need unique communication protocols in order to function, gather data, and interact with one another and analyses the data collected. They cannot operate and perform on their own. Can connect to other items to the fullest extent possible to do this.

IoT systems must be connected to the internet either directly or through the use of additional devices like IoT module (Node MCU). This unit will transfer the data

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gathered by the built system to a third-party dashboard where it will be used for analytics and data visualization as needed.

Thing Speak is a platform that offers free services for various data analysis, monitoring, and visualization capabilities. For project prototyping, it is freeware.

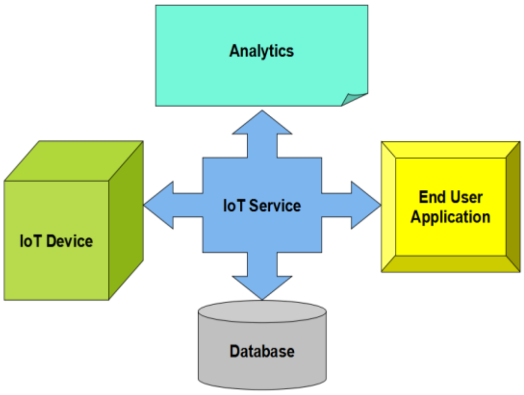

Figure 4. IoT Working Principle

In order to structure IoT applications and prototyped projects, Thing Speak offers a number of services. Real-time data visualization and collection capabilities allow it to display the data in a variety of ways, including charts, graphs, and other visual representations. The user can also develop plugins and other partnerships using web services and API keys.

The "Thing Speak Channel" is the primary feature that allows users to view data that has been differently visualized. It consists of the following components and stores the data that is sent to Thing Speak:

With the usage of these various fields, data gathered from associated sensors can be stored in the Thing Speak Cloud. There is a maximum of 8 fields available for storing data of any kind.

- Three location fields can be used to hold navigational information, such as the latitude, longitude, and elevation of moving sensors or devices.
- One status field, which contains a succinct statement outlining the channel's data.
- The information gathered can be exported from Thing Speaks to a.csv file, which creates an excel file with the necessary fields, the date and time the information was gathered and recorded in the Thing Speak fields, and the serial number of the event.

3.3 Circuit Diagram

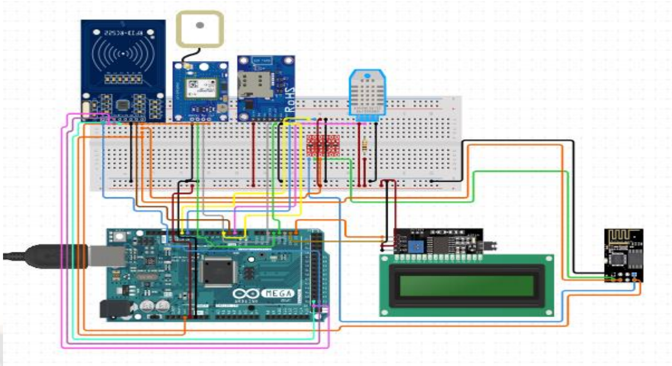

Figure 5. Circuit Diagram

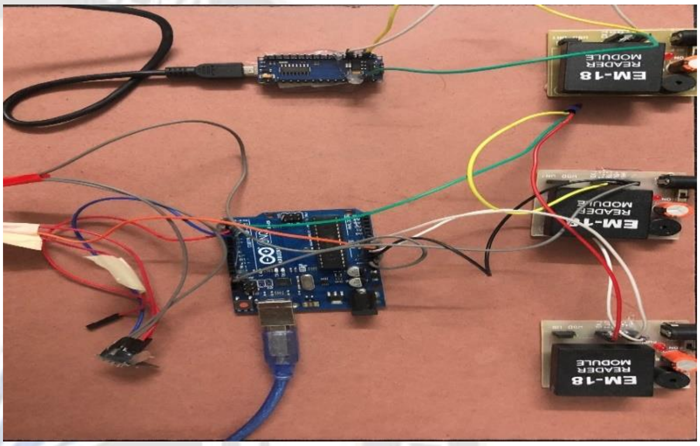

Figure 6. Actual Implementation Circuit

Figure 7. Output of the Thinkspeak cloud for Main site

Figure 8. Output of the Thinkspeak cloud for Site A

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Figure 9. Output of the Thinkspeak cloud for Site B

3.3.1 Data Collection

The prototype needs to be used in the field for data collection, assuming that the GPS module and Temperature & Humidity sensor serve as the transmitter devices and the other parts serve as the data collector. In the real-world scenario, the transmitter is controlled by a wireless system that is run independently. It transmits data to the MCU via GSM functionality, then to the recipient via SMS functionality and, finally, via IoT to the Thing Speak dashboard.

The system is designed so that, upon each oscillation of the RFID tags, the reader will send an SMS to the registered mobile number with the temperature and humidity readings for the area as well as a link to the material's GPS location, i.e., its location if the store department or quality department needs to locate the item on-site or while it's in transit and access the surroundings.

Along with it, the temperature and humidity data will be transmitted to the Think Speak dashboard via the IoT module's connectivity to display the data by date.

Additionally, using the Think Speak dashboard, an excel file with the real-time data, which includes the temperature and humidity readings, as well as the location's latitude and longitude, date, and time stamp, may be exported for further study.

3.3.2 Turning on the System

The system is activated by performing the subsequent steps:

- Put the SIM card inside the GSM module and connect the 12V power supply. Wait until the red LED on the module begins to flicker at 2-second intervals. It suggests that a connection has been made.
- Then Connect the Arduino MCU board's 5V power source, then wait a short while for the system to synchronize.
- Wait for the SMS to arrive on the registered phone after placing the RFID tag on the RFID reader for roughly 3 seconds.
- Next, attach a USB cable to the ESP8266 IoT module so that it may receive electricity. Utilize a mobile hotspot to connect it to the Wi-Fi.
- Watch for sensor data to appear on Thing Speak Dashboard graphs. Use the SMS you received to confirm the same.
- Download the.csv file for the tabulated, cumulative data that has been gathered and saved in the cloud from the Thing Speak dashboard.

3.3.3 SMS System

The system is set up to send an SMS to the registered cellphone number that contains the data gathered by the sensors and GPS module. The SMS will also include a link to Google Maps regarding the location of the GPS module as well as the temperature and humidity values in degrees Celsius and percentages, respectively.

Upon detecting the RFID tag or by merely sending the letter "L" as a reply to the same broadcasting system, the registered user presuming it to the procurement department or quality department will be able to access the instantaneous message-based data which will contain the necessary information.

It will send the data whenever the department requests it for the purpose of assessing the location and exposure circumstances of the content to be evaluated.

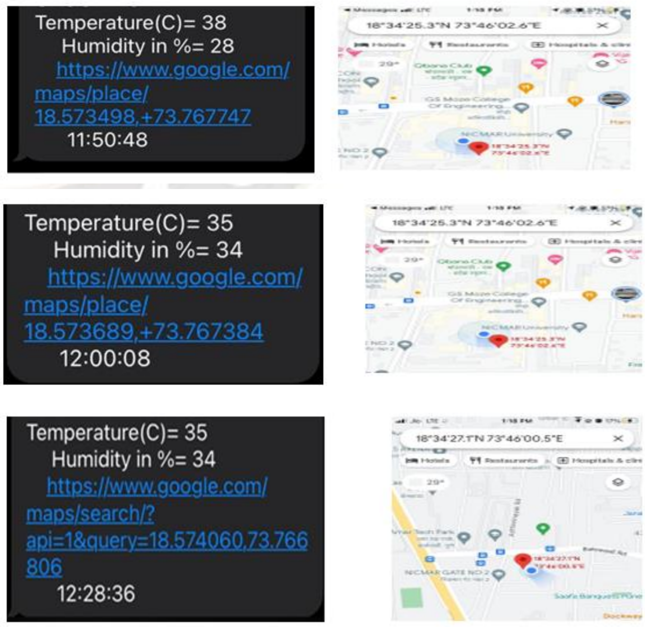

Figure 10: Output of the SMS System

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IV DATA ANALYSIS

In order to access and control the movement of the material in the chosen area and, simultaneously, gain control over the conditions to which the material is exposed, the analysis and interpretation of the data are carried out when it is determined that the report's objectives have been met.

The following table displays the data analysis performed to determine the material's distance from the reference point at the location with coordinates (18.574249,73.766794), which is illustratively thought of as the site's store. In analytics, the following formula is used to determine the distance:

Distance in meters = 1609.34*6371*ACOS (COS (RADIANS (90-A)) * COS (RADIANS (90-B)) +SIN (RADIANS (90-A)) *SIN (RADIANS (90-B)) *COS(RADIANS(C-D)))/1.609

Where,

A stand for the Latitude of Reference Point, B for the Latitude of the Location Being Considered, C for the Longitude of Reference Point, and D for the Longitude of the Location Being Considered.

4.1 Analysis of Distance

The distance between the material at the site under consideration and the reference location specified is shown in the following table. Additionally, it returns the material's status, indicating whether it is "Within the Range" or "Out of Range." The maximum permitted distance for the material to travel from the reference location is assumed to be "100 m" for analysis purposes.

Aside from this, the data gathered for the temperature and humidity will have the upper limits that can be tolerated while still maintaining the quality of the material exposed. The department can effectively monitor the exposure conditions since the graphs will show the peak value obtained.

Table 1. Sample Data

Sr No	Time Stamp	Temperature (°C)	Humidity (%)	Latitude	Longitude	Distance (Meters)	Status
1	2023-01-15T01:53:35+05:30	29.3	47	18.57473	73.76643	66.11	Within the Range
2	2023-01-15T01:53:51+05:30	28.9	47	18.57473	73.76643	66.11	Within the Range
3	2023-01-15T01:54:10+05:30	28.9	49	18.57473	73.76643	66.11	Within the Range
4	2023-01-15T02:01:01+05:30	29.3	61	18.57473	73.76643	66.11	Within the Range
5	2023-02-01T11:48:46+05:30	32.9	41	18.5735	73.76775	130.66	Out of Range
6	2023-02-01T11:49:26+05:30	32.4	42	18.5735	73.76775	130.66	Out of Range
7	2023-02-01T11:50:48+05:30	35.8	34	18.5735	73.76775	130.66	Out of Range
8	2023-02-01T11:51:34+05:30	35.9	33	18.5735	73.76775	130.66	Out of Range
9	2023-02-01T11:59:41+05:30	35.5	35	18.57369	73.76738	88.02	Within the Range
10	2023-02-01T11:28:36+05:30	36.8	31	18.57406	73.76681	21.06	Within the Range
11	2023-02-01T11:29:11+05:30	35.8	33	18.57406	73.76681	21.06	Within the Range
12	2023-02-01T11:30:29+05:30	35.6	33	18.57406	73.76681	21.06	Within the Range
13	2023-02-02T12:48:39+05:30	24.9	51	18.57372	73.76787	127.93	Out of Range
14	2023-02-02T12:49:09+05:30	25	51	18.57372	73.76787	127.93	Out of Range
15	2023-02-02T12:49:29+05:30	24.9	51	18.57372	73.76787	127.93	Out of Range
16	2023-02-02T12:51:33+05:30	25	51	18.57372	73.76787	127.93	Out of Range
17	2023-02-02T13:00:33+05:30	25.1	52	18.57371	73.76622	84.57	Within the Range
18	23-02-02T13:02:46+05:30	25.2	51	18.57371	73.76622	84.57	Within the Range

4.2 Temperature & Humidity Graphs

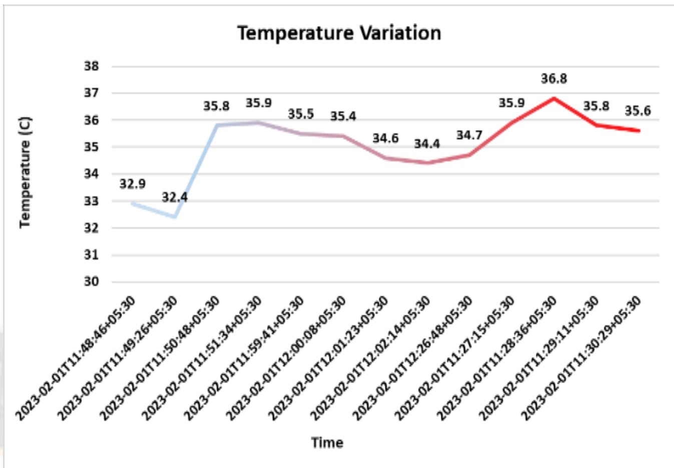

Figure 11. Temperature Graph

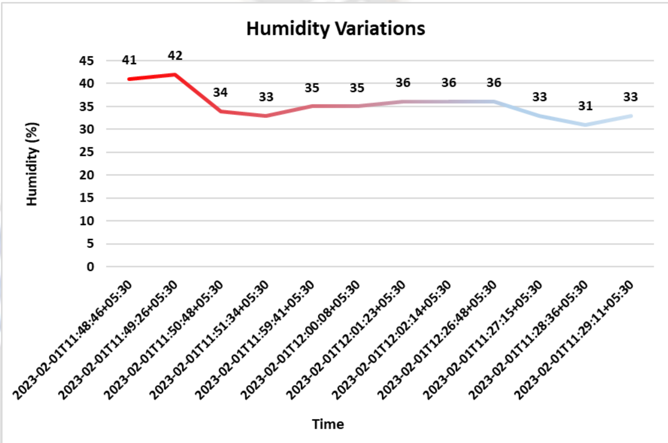

Figure 12. Humidity Graph

V CONCLUSION

This research work has established and studies how a real-time tracking system based on RFID technology, the GSM Platform, and the Global Positioning System (GPS) may be applied to various construction projects, more specifically to the management of the materials where the project's overall cost is highest. In order to evaluate the location and exposure conditions, the study is being conducted. The tracking system's data collection and accuracy were evaluated, developed, and discussed, which made a substantial contribution to lowering the need for human intervention in the data collecting process and lowering the likelihood of data collection and analysis errors.

The study found that real-time tracking systems based on RFID and GSM technology may be used to create prototypes for instantaneous data with automation and perform the analysis of the same to stop the misuse and misplacement of concerned materials in real-time and in a remote location, preferably the store of a construction site or as required. Managers must, however, build a suitable tracking device called a detector for sensing the RFID tags mounted on either the vehicles carrying the materials or the materials themselves as appropriate if they want to adopt this system.

The vehicle entry or exit may be followed for every exit and site where it is practical to install detectors, and the site boundary fixation can be used to determine the range of material movement. The analysis is premised on the belief that if a vehicle or item exceeds the limitations, this will be reflected in the system and may be tracked. It is a very advanced technology that will allow for real-time, scalable assessments of the material's presence at workplaces during transportation or after deployment, as well as academic prototype and field implementation.

From a research perspective, low productivity and prone to mistake data will be introduced by measuring the effects of building material management or personnel intervention, but the deployment of this technology at an advanced level will assist minimize them to a base level. In complicated projects, the true value of tracking expensive resources may out to be quite important. In addition to navigation, the exposure condition would be crucial in determining the quality needed to meet the project's standards for high-cost products. The system's sensors will deliver data on temperature and humidity as well as previously gathered information with a timestamp.

As a prototype, the system simply has temperature and humidity sensors and a GPS location; additional sensors can be added as and when needed.

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