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Design and Implementation of a Smart System for Detecting Water Leakage with Dual-Level Monitoring

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Abstract: ***Water leaks in homes and businesses and factories can cause a lot of problems. They waste a lot of water. Cost a lot of money to fix. They also damage the infrastructure. Can be very dangerous. This system is a water leak detection system. It uses the internet to detect leaks and turn off the water. The system has two parts. The first part is for monitoring the water. It uses SCADA and Node-RED to watch the water in time. It can also control the water from away and keep track of what happened in the past. The second part is run by a Raspberry Pi. It checks the sensors all the time to see if there is a leak. If it finds a leak it turns off the water away. The system also has a way to control it locally. It will show if something is wrong. If something goes wrong the system will not start again until it is fixed. We tried this system. It worked very well. It found leaks quickly. Turned off the water fast. It is a good system for homes and businesses and factories to use for their water. The system is very good, for managing water in homes and businesses and factories. Water leaks are a problem and this system can help fix them.***

Index Terms: ***Water leak detection, Internet of Things (IoT), SCADA, Node-RED, Raspberry Pi, real-time monitoring, industrial automation, fault detection, smart water management, supervisory control.***

I. INTRODUCTION

Water leakage is a problem in homes and industries. It wastes a lot of water increases costs, damages buildings and can be dangerous. If leaks are not found or fixed quickly they can cause long-term damage to infrastructure harm the environment and disrupt servicesCurrent leakage detection systems are often simple and not automated. Water leakage systems do not have the ability to monitor and shut down automatically when there is a problem. This is an issue because it can cause a lot of water to be wasted and damage to happen. Many of the water leakage solutions that already exist need to be connected to a network to work. This can be a problem if the network is not working. For example if the network is down the system will not be able to find out if there is a water leak. The new water leakage solution is a control system that has two parts. It has one part for monitoring and controlling the water leakage system from away. This part is very important because it lets us keep an eye on the water leakage system from a distance. The other part, called the field part takes care of controlling the water leakage system and giving us updates on what's happening. This part is also very important because it lets us control the water leakage system directly. This water leakage system can find leaks shut down the system in a controlled way and has ways to override the system if something goes wrong. The main goal of this water leakage system is to respond to water leaks minimize the amount of water that is wasted and protect the infrastructure from water leaks. By using this approach the water leakage system becomes more reliable, safe and flexible. It also gives us a framework for managing water that uses systems to find water leaks. The systems that are already in place to find water leaks become more effective at managing water. They help us manage water by finding water leaks. For instance they can find water leaks quickly. Alert us to take action. The systems that are already in place to find water leaks are very helpful for managing water. They are like a watchdog that keeps an eye on the water leakage system and alerts us if something goes wrong. The part that oversees the system lets us monitor data in time visualize it and control the water leakage system from far away. The field part gives us the ability to operate and control the water leakage system independently. This approach makes the water leakage system more robust. By using this water leakage system we can address water leaks quickly.This minimizes the amount of water that is wasted from water leaks. It also protects the infrastructure from water leaks. The proposed architecture makes sure that we can respond to water leaks. It keeps the water leakage system running continuously. The dual-level control architecture combines monitoring with control of the water leakage system at the field level. This makes the water leakage system more reliable, safe and flexible. Finding and controlling water leaks are crucial for managing water.

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This water leakage solution can be used for water management solutions. It gives us a framework for making the water leakage system more robust. The proposed water leakage system is better than the systems that're already in place. It gives us a way to find and fix water leaks. The water leakage system is designed to respond to water leaks. This minimizes the amount of water that is wasted from water leaks. It also protects the infrastructure from water leaks. The proposed architecture makes sure that we can respond to water leaks. It keeps the water leakage system running continuously. It combines monitoring with control of the water leakage system at the field level. This makes the water leakage system more reliable, safe and flexible. Finding and controlling water leaks are crucial for managing water. We need to take care of the water leakage systems so that we do not have any problems. Water leakage systems are very important for our lives. We use water leakage systems every day so we need to make sure they are working properly. Water leaks are a problem. We need to solve it. The proposed water leakage system is a solution, to this problem.

II. LITERATURE SURVEY

Water leakage is a problem in distribution networks every- where. It causes a lot of damage to pipes. This damage costs a lot of money. For example studies found that 30 to 35 percent of treated water is lost due to leaks in pipes. Water leakage in pipes is an issue. It results in a lot of wasted water. Leaks, in distribution networks waste a lot of water. Finding these leaks and keeping an eye on them is very important for managing the water supply.

* Modern research is looking into using technologies like Internet of Things sensor networks, machine learning and cloud-based systems to develop systems that can detect leaks. These systems use sensors like flow sensors, pressure sensors and moisture sensors along the pipelines to monitor the flow of water.

Recently there have been advancements in water monitoring systems that use Internet of Things technology. Many sensors are placed along the pipelines to constantly monitor the flow of water. These sensors send real-time data to platforms where it can be analyzed and visualized. The Internet of Things frameworks help detect patterns like changes in flow rate drops in pressure or unusual consumption patterns that may indicate leaks in the water pipelines.

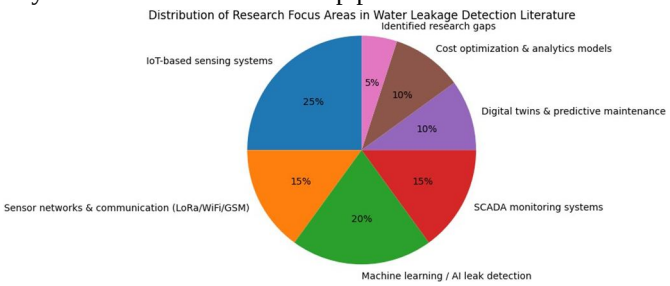


Fig. 1. Pie Chart

Many researchers have suggested using sensor-based sys- tems to detect leaks in the water pipelines. These systems have sensing nodes that are connected through technologies like LoRaWAN, Wi-Fi or GSM networks. This allows the sensors to communicate with the monitoring stations over distances and use very little power. The data that is collected is sent to servers or dashboards where special algorithms evaluate the performance of the water network and detect any faults in the water pipelines

Table I
Distribution of Research Areas in Water Leakage Detection Literature

Research Area	Percentage
IoT-based sensing systems	25%
Sensor networks & communication (LoRa/WiFi/GSM)	15%
Machine learning / AI leak detection	20%
SCADA monitoring systems	15%
Digital twins & predictive maintenance	10%
Cost optimization & analytics models	10%
Identified research gaps	5%

Machine learning and artificial intelligence techniques are also being used to improve the accuracy of leak detection in the water pipelines. Special models like Convolutional Neural Networks and regression models can analyze the patterns of flow and sensor data to identify the locations of leaks in the water pipelines. These systems can find leaks with accuracy of over 95 percent. This shows that using sensor networks and algorithms together is very good for watching the water pipelines. The sensor networks and algorithms are really good at finding leaks, in the water pipelines. The water pipelines are very important. The sensor networks and algorithms help us watch them. Another area of research is making copies and predictive maintenance models for the water infrastructure. These water infrastructure models use sensors and data analysis and simu- lation tools to make a copy of the water distribution systems. The digital copy of the water distribution systems is updated all the time based on sensor data from the water pipelines. It predicts when failures or leaks will happen in the water pipelines. This helps the water utilities plan their maintenance and save money on the water pipelines. Some studies have also looked into using SCADA-based monitoring systems for the water distribution networks. SCADA systems allow people to monitor and control the pumps and valves and sensors in the water infrastructure. By using real-time sensor data from the water pipelines with control software people can detect problems. Turn off the water pipelines in an emergency.

Furthermore modern research is looking for ways to reduce the costs of the water infrastructure while keeping the wa- ter system reliable. Advanced models use data analysis and special algorithms to detect anomalies in the water pipeline networks. These approaches allow utilities to watch the water pipeline networks while saving money on hardware for the water pipelines.

Despite these advancements there are still problems with the existing systems for the water pipelines. Most research focuses on watching the water pipelines from the cloud and analyzing data. It does not fully address the need for control of the water pipelines in time. Many solutions rely heavily on machine learning models for the water pipelines, which require a lot of data and complex computers. Therefore there is still a need for systems that combine sensors and SCADA and visualization and safety features, for the water pipelines.

III. METHODOLOGY

A. Overview of the System Architecture

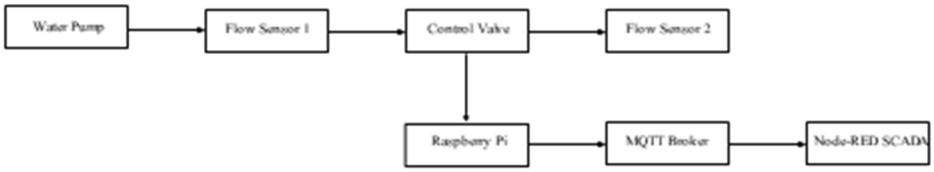


Fig. 2. System Architecture of IoT-Based Flow Monitoring and Control System

With an MQTT broker. This is how it works: the Raspberry Pi and the MQTT broker work together to get things done. The broker then sends this information to applications that are supposed to get the information from the Raspberry Pi. Our system uses the Internet of Things to make all of this happen. We have sensors and edge computers in our system that work with the Raspberry Pi. The Internet of Things technology really helps our system to find leaks and figure out what the risks are in systems that use the Internet of Things.

The Raspberry Pi and the Internet of Things technology are really important, for our system because they make it work properly. The Control and Supervision Layer lets operators monitor the system and view data on a dashboard created with Node-RED. This dashboard displays flow measurements, anomalies, alerts and historical trends over time. This architecture makes the system scalable, efficient and able to alert operators to leaks.

The Internet of Things technology is used to build the system. The system architecture is designed to provide real-time leak detection and risk assessment, with Internet of Things technology. The Internet of Things technology enables data processing. Allows operators to monitor pipeline conditions closely.

The system provides system monitoring and visualization through a dashboard. The dashboard shows real-time flow measurements, detected anomalies, alert notifications and historical data trends.

B. Leak Detection Algorithm

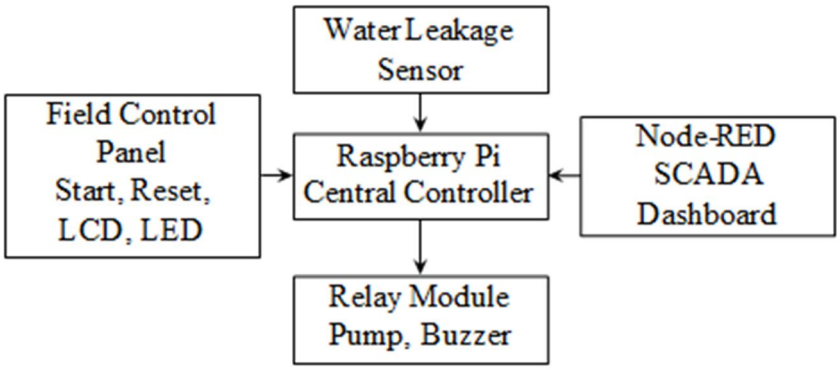


Fig.3. Block diagram of the proposed dual-level water leakage detection system

We want to create a system that finds leaks and iden- tifies risks in distribution systems using Internet of Things technology. Our system has parts: sensors, edge computers, communication methods and control systems. These parts work together to check the pipelines condition and find flow patterns.

The system has four parts:

- The Sensing Layer is connected directly to the pipeline. Uses flow sensors to measure water flow.
- These sensors create signals that show the flow rate and send this information to a processing unit for analysis.
- The Edge Processing Layer uses a Raspberry Pi to collect and process sensor data remotely.
- It analyzes the flow data processes it and compares it to identify changes that could indicate a leak.

The Communication Layer helps send data from the edge device to the monitoring platform using the MQTT protocol. The Raspberry Pi shares the information it has processed

The leak detection algorithm is used to find flow conditions in the pipeline. It does this by comparing the flow rates at two points in the pipeline. We have two flow sensors, one at the start of the pipeline and one at the end. A Raspberry Pi. Processes the information from these sensors.

Normally the amount of water flowing into the pipeline should be the same as the amount flowing out. The system calculates the difference between the two flow rates all the time. It uses the equation to find this difference: the difference in flow rate is equal to the value of the flow rate going in minus the flow rate going out. If this difference is too big the system thinks there might be a leak.

The leak detection algorithm looks at the flow rates measured by the two flow sensors and checks if the difference is bigger than a limit. If the leak detection algorithm finds that the difference is bigger than this limit it sends a warning signal to the people monitoring the pipeline. This helps us find leaks quickly and avoids sending out warnings when the sensors get a little mixed up. The leak detection algorithm is really important for finding leaks in the pipeline it checks the pipeline for leaks. The algorithm is key, to detecting leaks and sending warnings to the people. The leak detection algorithm is good at finding leaks, in the pipeline.

C. Hardware Implementation



Fig. 4. Hardware Implementation

The system has a lot of parts that work together. It has devices that sense things, a unit that processes information and modules that help with communication. All of these parts help the system monitor everything in time and detect leaks.

1) Flow Sensors

There are two flow sensors that are put in spots in the pipeline. These sensors measure how much water is flowing through the pipeline. They send signals that're like electrical pulses and these pulses are related to how much water is flowing. The sensors always send information about the flow. This information is used to see if there are any changes that might mean there is a leak.

2) Raspberry Pi Controller

The Raspberry Pi is like the brain of the system. It gets signals from the sensors. Uses them to do things. The Rasp- berry Pi uses scripts to process the information it gets and it does all of this in real time. It does calculations runs the leak detection algorithm and sends the information it processes to the monitoring platform.

3) Control Valve

The system also has a control valve that helps regulate the water flow in the pipeline. If the system detects a leak or something is not right it can take action. For example it can close the valve to stop water from being lost and to prevent more damage.

4) Network Connectivity

The Raspberry Pi can connect to the network using Wi-Fi or Ethernet. This helps it talk to systems that are monitoring things. The Raspberry Pi can send the information it processes to the cloud or to a platform called SCADA.

D. Data. Iot Integration

The system uses a protocol called MQTT to send infor- mation. This protocol is often used in Internet of Things applications because it is simple and does not need a lot of bandwidth.

In this system the Raspberry Pi sends information to a server called an MQTT broker. The broker helps get the information to the places. The system works like a publisher and subscriber.

1) The Raspberry Pi sends information about the flow and the systems status.
2) The MQTT broker gets this information. Sends it to the right places.
3) The monitoring dashboard gets the information it needs to show what is happening.
4) This way of doing things helps the systems parts talk to each other in a way that's reliable and can be scaled up.

E. Monitoring and Visualization

The system uses a tool called Node-RED to keep an eye on things and make sense of them. Node-RED is really useful for Internet of Things projects. The system has a dashboard that shows what is going on now. This dashboard shows things like:

1) How much water is flowing according to the sensors.
2) If there are any changes in the flow that could mean there is a leak somewhere.
3) Any warnings that we need to know about.
4) Whether the control valve is working properly.

The Node-RED dashboard is easy to look at because it uses pictures and graphs. So it is simple for people to see what is happening with the Node-RED system and fix any problems quickly using the Node-RED system. The Node-RED system can also show us information, about what has been happening over time with the Node-RED system. This helps people understand what is going on with the Node-RED system and make the Node-RED system work better.

F. System Operation Workflow:

The water leakage detection system works in a series of steps to keep an eye on the pipeline and make sure it is safe to use.

1) System Start

When we turn on the water leakage detection system all the hardware parts, like the Raspberry Pi flow sensors pump control system, buzzer and LED indicators are ready to work with the Node-RED system.

2) Controller Initialization

The Raspberry Pi sets up all devices and communication modules. This includes setting up flow sensors deciding on threshold values for finding water leaks and connecting with the MQTT broker and Node-RED dashboard. The water leakage detection system is set up correctly before it starts monitoring the pipeline.

3) Monitoring Leakage Sensor

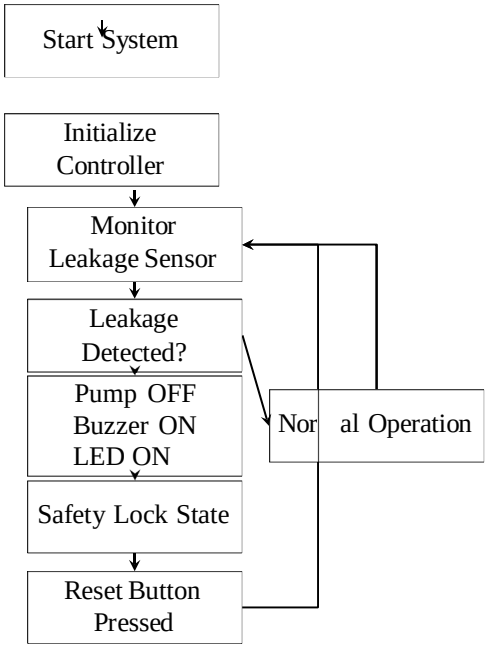


Fig. 5. Methodology flowchart with safety interlock logic

4) Data Processing and Flow Comparison

The Raspberry Pi looks at the information from the sensors. Compares flow values from points in the pipeline to find big differences. If there is a difference it might mean there is a water leak in the pipeline.

5) Leakage Detection Decision

The water leakage detec- tion system checks if the difference in flow values is more than a limit. If the difference is okay the water leakage detection system keeps working and monitoring the sensors. If the difference is too big the water leakage detection system decides there is a water leak in the pipeline.

6) Emergency Response and Safety Interlock

When a water leak is found the safety interlock mechanism kicks in. The water leakage detection system turns off the water pump turns on the buzzer and turns on the indicator. This safety mechanism stops water from being wasted prevents equipment damage and avoids dangers.

7) Safety Lock State

The water leakage detection system goes into a safety lock state. The pump stays turned off to prevent it from being turned on by mistake while the water leak's still there. The water leakage detection system waits for someone to fix the water leak.

8) Reset Button Operation

To get the water leakage detection system working again the person in charge presses the reset button after fixing the water leak. This resets the safety lock. Lets the water leakage detection system go back, to monitoring the pipeline.

9) Normal Operation Loop

If no water leak is found the water leakage detection system keeps working. It keeps monitoring the flow sensors and looking at the information. This creates a loop that keeps the pipeline safe.

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10) IoT Data Communication

The Raspberry Pi sends information and water leak warn- ings to the MQTT broker. The Node-RED dashboard gets this information. Shows it in real-time. Users can check the pipelines status and system warnings from afar.

The water leakage detection. The Raspberry Pi work together to make this happen. The water leakage detection system is a part of keeping the pipeline safe.

IV. SYSTEM ARCHITECTURE

The water leakage detection system starts monitoring the pipeline. The flow sensors constantly measure the water flow rate in the pipeline. Send this information to the Raspberry Pi. This lets the water leakage detection system keep track of the pipelines condition.

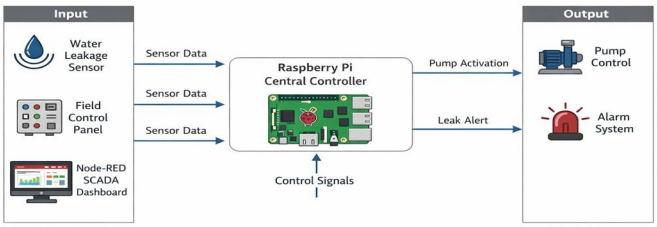


Fig. 6. System Architecture of the Proposed Water Leakage Detection System

The system we are talking about has a centralized control architecture. In this system the Raspberry Pi is the brain that makes all the decisions. It gets all the information from the parts of the system. Processes it. The important information comes from the water leakage sensor. This water leakage sensor is always watching the pipeline to see if there is any water where it should not be.

We also get information from a control panel that's out in the field. This control panel lets us watch what is going on reset the system by hand and control how the system works. The Raspberry Pi looks at all the information it gets from the sensors. The Raspberry Pi decides if everything is okay or if there is a water leak. If the Raspberry Pi finds a leak it acts fast. The Raspberry Pi turns off the water pump. The Raspberry Pi turns on the alarm. The alarm has a buzzer and a flashing light to get someones attention. At the time the system sends information, about what's happening to the Node-RED SCADA dashboard. The system uses the MQTT protocol to send this information. This lets us watch what is going on in time and see the status of the water pipeline system from else. By putting all the information from the sensors the control panel and the monitoring system together in one place we can find water leaks quickly fix prob- lems fast and make the water pipeline system more reliable. The Raspberry Pi and the Node-RED SCADA dashboard work together to make this happen. The Raspberry Pi and the Node- RED SCADA dashboard use the MQTT protocol to talk to each other.

V. EXPERIMENTAL RESULTS AND DISCUSSION

The system we made was built using a Raspberry Pi, a sensor that detects water leaks a circuit to control the pump and a control panel that is installed in the field. We tested this system in a controlled environment to see if it could find water leaks and automatically respond to problems. When we were testing it we made leaks near the sensor to see how the system would behave. When the sensor found water it sent a signal to the Raspberry Pi, which looked at the signal and figured out that there was a leak. Soon as it detected the leak the system turned off the pump by using the relay module, which stopped water from flowing and prevented damage. At the time the system turned on the warning lights and sounds: the light on the control panel came on and the buzzer made a noise to warn people nearby that there was a leak. The system also sent updates and warnings to the Node- RED dashboard in time using a special way of communicating called MQTT. The dashboard showed the status of the system and any warnings, which meant that people could monitor the pipeline from afar.

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Our tests showed that the system works well responds quickly to leaks. Combines local safety features with internet-based monitoring, which makes managing water pipelines safer and more efficient.

We used the Raspberry Pi and the water leakage sensor module and the relay-based pump control circuit and the field- mounted control panel to make the system. The system was. It worked.

1) The Raspberry Pi got the signal, from the sensor. Turned off the pump.
2) The system sent warnings to the Node-RED dashboard.
3) The dashboard showed the status of the system and any warnings.

The system is good because it responds quickly to water leaks and it helps people monitor the pipeline from afar. The Raspberry Pi and the sensor and the circuit and the control panel all work together to make the system work.

VI. CONCLUSION

This research is about a system that finds water leaks in pipes. It has two levels of control to make sure the water system is safe and reliable. The system uses sensors to check the water flow in time and a computer to control everything. It uses two flow sensors placed at locations in the pipeline to monitor water flow rates. The sensors keep an eye on the water flow. They send this information to a Raspberry Pi computer. If there is a leak between the sensors the Raspberry Pi computer figures it out because the water flow rates, from the sensors do not match. The system uses a tool called Node-RED to keep an eye on things. It helps make sense of them. Node-RED is really useful for Internet of Things projects. The system has a dashboard that shows what is happening now.

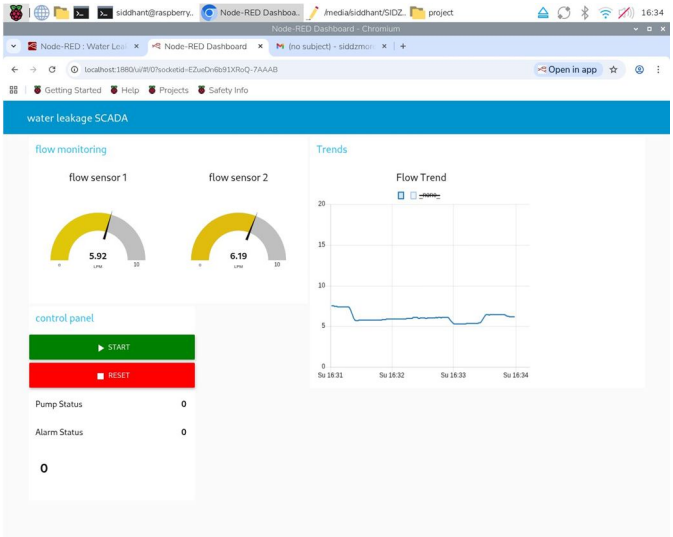


Fig. 7. Real-time leakage alerts were visualized on the Node-RED SCADA dashboard during testing

This dashboard shows things like:

1) How much water is flowing according to the sensors.
2) If there are changes in the flow that might mean there is a leak.
3) Any warnings we need to know about.
4) If the control valve is working properly.

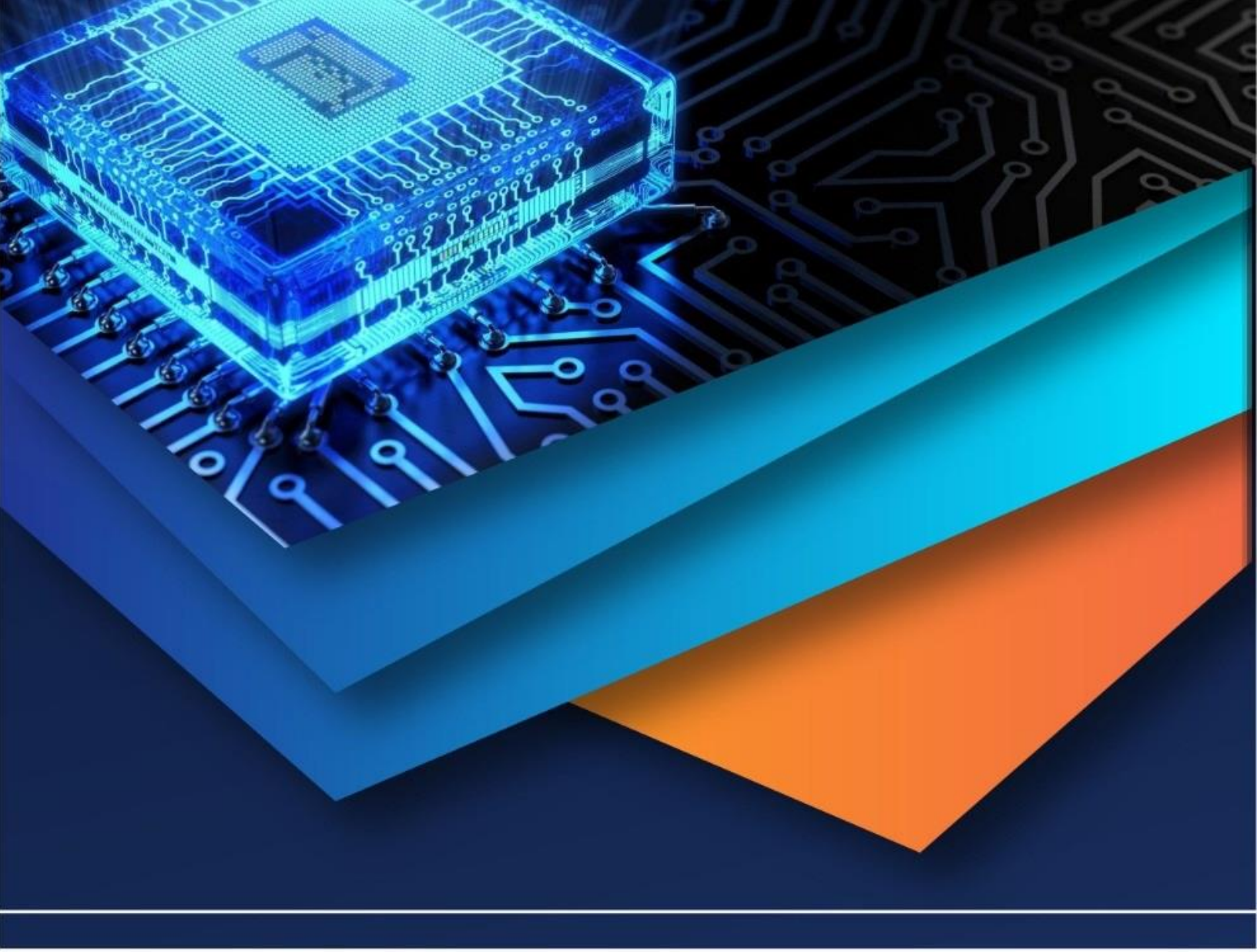
The Node-RED dashboard is easy to look at. It uses pictures and graphs. So it is simple for people to see what is happening with the Node-RED system. They can fix problems quickly. The Node-RED system shows information about what has been happening over time. This helps people understand the Node-RED system. They can make the Node-RED system work better. The dashboard helps people see Node-RED sys- tem problems and fix them. The Node-RED system provides information to make it work better. People use the Node-RED system to monitor and control things. The Node-RED system is useful, for Internet of Things projects.

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