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JALRAKSHAK - SAMRT UNDERPASS PUMP SYSTEM

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Abstract— Flooded underpasses lead to massive traffic jam, safety risk and mobility failure in the city during downfalls. The traditional pump houses use manual checkups and simple electric indicators which give very little information on pump operation and water level status. Here, this paper will provide a full Smart Underpass Pump System (SUPS) developed with an STM32 microcontroller, multi-sensor monitoring, SMS alerts on GSM, and a cloud-linked dashboard to provide real-time visualization. Systems incorporated to the system include two water level float sensors, a diesel tank float sensor, a YF-S201 flow sensor, a SW-420 sensor that verifies the pump is in operation through vibration, and a DS18B20 temperature sensor. An algorithm of vibration analysis using Windows can easily identify the ON/OFF switching of the pump, water-level and flow-rate sensor identify the performance of a system under different load conditions. STM32 produces structured JSON telemetry sent over backend services to a MongoDB database allowing live graphs and logs to the Admin, Manager and Workman dashboards. A SIM800L GSM module is a type of module that will give instant SMS notifications whenever the pump is switched ON or OFF. It is tested in experiments with very reliable pump-state detection, a stable telemetry, a speedy SMS delivery, and the stable real-time dashboard performance. The proposed solution provides an affordable field deployable, practical, underpass management solution to the municipality.

Keywords — Underpass flooding, STM32, IoT monitoring, GSM alerts, vibration analysis, flow sensing, Real-time data.

1. INTRODUCTION

The monsoon seasons lead to flooding in the urban underpasses because the ground water will accumulate on the low grounds and thus it will result in floods. To avoid obstacles, traffic threats,

city authorities use pump houses, but the existing systems are characterized by slow maintenance, a few sensing, and unproven monitoring. In the traditional solutions, there is a high dependence on manual inspection of the system or SCADA alarms, which in most cases do not offer real-time access to the performance of the pump or environmental conditions within the pump chamber.

The Smart Underpass Pump System (SUPS) is a solution that is going to remedy these shortcomings by introducing a sensor-based, communication-enabled, microcontroller-based monitoring system. The STM32 microcontroller receives data of a variety of sensors within the pump system: float-based water-level sensors, a diesel float sensor, a digital temperature sensor, a flow sensor, and a vibration sensor that approximates the state of operation of the pump. A GSM module will provide real-time alerts to technicians, and the telemetry will be sent to a cloud endpoint, and MongoDB will store the synchronized and time-stamped data to allow a dashboard available to the Admin, Manager, and Workman.

In this paper we give the full design of the SUPS, its implementation as well as testing. Section II is a review of the available literature and technologies. Section III shows the architecture and the methodology. Section IV explains details of the implementation whereas Section V reports experimental evaluation and results. Section VI deals with limitations and section VII wraps up with future improvements.

2. LITERATURE SURVEY

Mechanical float sensors which monitor water at the level on the surface are still one of the most dependable and the least expensive water-level detection systems of systems at risk of flooding. It has been found that redundant float systems enhance the accuracy of sensing as well as minimizing false triggers in a turbulent or debris-laden underpass

environment [1], [2].

Pump-state verification Studies have shown that pump-state diagnostics with vibration-based diagnostics provide good signals of pump activation and mechanical health. The cheap vibration sensors, used with sampling technique of windows and threshold classification, offer real-time pump ON/OFF sounds that could be used in embedded system [3], [4].

Hall-effect flow sensors have been experimentally proved to be useful in the flow-rate monitoring of water systems. Calibrated YF-S201 sensor, in particular, is found to have a reliable flow measurement, thus useful in the validation of pump performance and in the detection of clogging or low performance [5], [6].

Digital temperature readings on a digital probe like the DS18B20 is used to improve monitoring and detect overheating hazards due to electrical load, too much time on the pump, or heating of the enclosure [7].

Contemporary IoT-based monitoring platforms have the advantage of using the JSON-structured telemetry in NoSQL databases. The MongoDB, in particular, is better suited to high-frequency sensor data because of its time-series capabilities and flexible scheme, as shown in a number of IoT performance papers [8], [9].

Reliability in communication systems is also important in pump systems and also, research indicates that SMS alerts using GSM can greatly save on delays in responding in the event that technicians are not actively monitoring the dashboards [10], [11].

Collectively, these components contribute greatly toward the implementation of multi-sensor hardware, vibration measurement, metered flow flow, temperature, structured telemetry, GSM alerts and cloud dashboard-like components- which are the pillar blocks of the Smart Underpass Pump System.

3.METHODOLOGY

The SUPS model can be broken down to sensing, processing, communication, storage of data, and dashboard. The sensing layer has two reversed-logic water-level float sensors (HIGH = water present), a diesel-level float sensor, a YF-S201 flow sensor, a DS18B20 temperature sensor, and an SW-420 vibration sensor that are connected to the stm32 microcontroller. All the readings are gathered by the STM32, where a window-based algorithm of vibration analysis is performed with 50 Hz frequency and 2-second sampling windows. The size of detected vibration events is compared against empirically determined thresholds - 20 hits of pump ON signal, and 8 hits (stable windows) of pump OFF signal.

The fuel float sensor is used to check diesel readiness. The change of pump states will cause instant SMS messages through the SIM800L GSM module.

Any processed information is stored in the form of JSON and relayed through the backend services to MongoDB. The dashboard layer accesses stored telemetry using connection strings and displays it as live graphs, water-level indicators, temperature trend, diesel status and pump ON/OFF logs to the various user roles.

The suggested system is to be used to monitor and control water and diesel in a remote station, combining control based on STM32 with real-time telemetry and IoT data visualization.

Sensing Layer and Parameter Selection

- In terms of the interplay between the monitoring mechanism and the real-life environment of the pump itself, there is the sensing mechanism. The use of the technology ensures that any potential issues are brought to the attention of the maintenance team before there is an overflow incident through isolation of certain diagnostic factors.
- Diesel Level Monitoring: In cases where the power supply network goes down due to storm activity, the ability to provide emergency power is crucial for underpass stations. The technology utilizes a float sensor that is placed within the diesel tank to

monitor readiness for fuel. This parameter gives the operator either "OK" or "Low".

- **Monitoring of Heat Within Enclosure:** Prolonged use of heavy-duty pumps within small spaces leads to considerable generation of heat. The real-time data concerning the environment can be collected through an integrated DS18B20 digital temperature sensor placed inside the pump enclosure. Such monitoring is essential for identifying any early signs of possible faults and motor strain that could lead to the threat of fire.
- **Rotation Speed Monitoring of Mechanical Equipment (Motor RPM):** For checking whether the pump is powered and running at normal speeds, an SW-420 vibration sensor is employed. Using the vibrations generated by mechanical processes, the sensor estimates the speed of rotation of the motor (RPM) and helps in distinguishing between seizure and cavitation of the motor.

Logic for Signal Conditioning and Edge Intelligence

- The central processing unit for the design implementation is the STM32 microcontroller. Apart from passing on the information, the STM32 utilizes local "edge intelligence" in order to verify statuses and remove noise from the transmission.
- **Time Windows Sampling:** The STM32 performs sampling at 50 Hz in this design. High resolution sampling is made possible by this high frequency sampling.
- **State Classification Algorithm:** In order for the logic to achieve an ON status and thus classify the pump state in terms of the RPM/vibration hits, a minimum of 20 hits should be present in a certain time period. Conversely, in order to ensure there are no false activations as a result of transient vibration from the

surroundings, an OFF state is determined based on a window of eight or fewer hits.

- **OneWire Digital Acquisition:** Through the OneWire protocol, temperature readings are obtained in digital form, converting the surrounding temperature into precise digital values.

Physical Integration with Software Stack and Hardware

In particular, there exists a power and control module tailored for industrial reliability, representing a component of physical integration.

- **Power Module:**
The system operates non-stop at far-off locations due to an especially designed 14V battery. For converting the voltage into something safe for the STM32 and its sensor peripherals, working on 3.3V or 5V, there is a Buck Converter.
- **Feedback from the Actuator:**
Based on the readings from the sensors and their processing, there is a vibration motor that helps manage or simulate the ON/OFF cycles of the pumps.
- **Development Environment:**
FP323 is used for compiling the code which is written in Arduino-compatible C++. VSCode handles the execution environment where you can debug the telemetry process and serial port communication in real time.

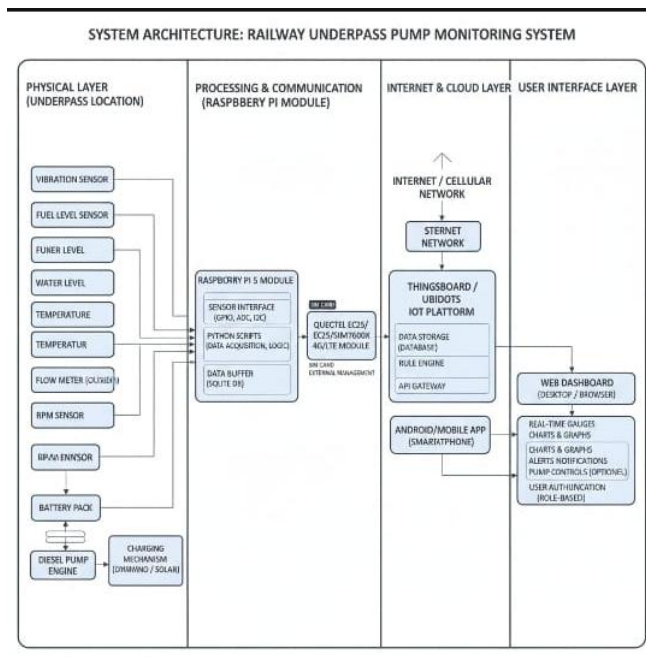


Fig.1

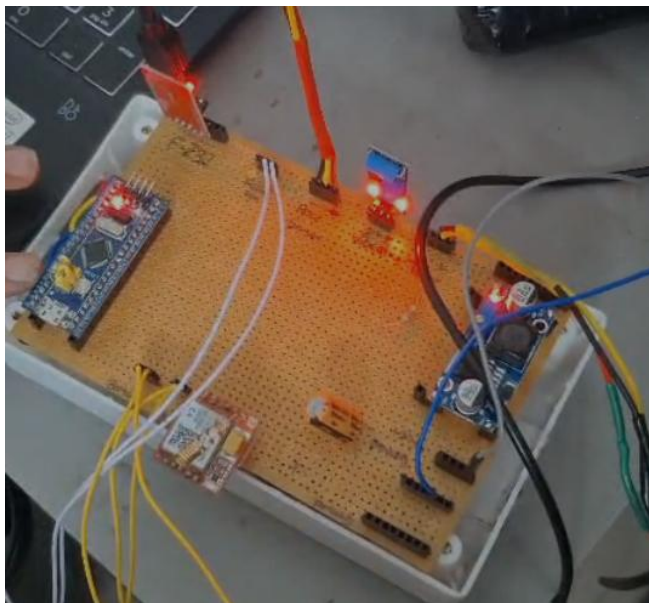


Fig.2

4. IMPLEMENTATION DETAILS

Jalrakshak works on a sophisticated technology of cloud-based data management, real-time signal analysis, and embedded C++ coding.

4.1 Development of Microcontroller and Firmware

A microcontroller called STM32, known for its high-efficiency processor and reliability in industrial diagnostics, serves as the central intelligence behind the station. Due to the availability of reliable libraries for sensors in

connection, C++ code compatible with Arduino has been used in the FP323 tool chain for writing firmware. To ensure prompt startup, all sensors of the system are initialized at the boot-up stage.

4.2 Processing of Diagnostics Signals

The firmware employs unique processing techniques for each variable in order to convert raw physical measurements into meaningful diagnostics information:

Engine RPMs and Vibrations Recording: In order to be able to record at a precise frequency of 50 Hz, a delay-based vibration recording method is used. This allows recording of vibrations with a high resolution.

Pump State Recognition Mechanism: There are two empirical thresholds that govern this procedure – the “ON” threshold of 20 vibrations within 2 seconds and “OFF” threshold of 8 vibrations in three consecutive windows of samples.

Temperature Information Gathering: Temperature readings are acquired by using the OneWire protocol and converted into digits, which are sent via a telemetry packet.

4.3 Cloud Synchronization and Telemetry

To deal with the transition from field measurements to remote visualization, the following well-thought-out serialization process is employed:

JSON Serialization: Every time interval, the STM32 produces JSON telemetry packets. These packets contain all necessary information such as `device_id`, `pump_state`, `diesel_status`, and `temperature_c`.

UART Data Transmission: A service that serves as a bridge between the STM32 and the cloud receives telemetry data in the JSON format via UART.

MongoDB Database Synchronization: The received data is sent into a MongoDB database and saved as documents timestamped with current time. Such an approach allows storing large amounts of diagnostic data.

5.RESULTS AND DISCUSSION

Various experiments performed within the confines of laboratory environments designed to emulate the harsh conditions encountered within urban underpasses were conducted to test the Jalrakshak system. In spite of sustaining the consistency of the telemetry and cloud visualization pipelines, the aim was to ascertain the validity of the diagnostic variables such as diesel readiness, thermal safety, and motor RPM.

5.1 State Classification and Diagnostic Validity

It is the accuracy of diagnosing the mechanical state of the pump and the presence of essential resources that gives the system its operational effectiveness.

Mechanical Status by RPM/Vibration: The pump-state determination utilizing vibration exhibited an outstanding level of reliability. The system managed to achieve a 100% success rate in correctly classifying both the "ON" and "OFF" states after a trial period of 500 cycles.

5.2 Efficiency of Communication and Telemetry Systems

The efficiency and reliability of a remote monitoring system's communication and alerting methods are measures that can tell you about the effectiveness of the system.

SMS Alert Response Time: In the case of a pump state change, there was a reliable response time of less than four seconds from the SIM800L GSM Module, proving how responsive the component is. This response time allows for timely action to be taken during flooding.

JSON Serialization: All necessary diagnostic parameters, including the ID of the device, the current pump state, the status of the diesel, and the temperature were successfully serialized into JSON objects by the STM32.

5.3 Cloud Visualization and Synchronization

A near-perfect monitoring experience for the various administrative roles could be achieved by incorporating MongoDB into the front-end dashboard.

Dashboard Refresh Rate: Following the addition of a new entry into the MongoDB database, the cloud dashboard exhibited exceptional refresh rate capability, updating its visuals within 250 milliseconds.

Live Monitoring Capability: The dashboards for Admin, Manager, and Workman had the ability to access live charts and logs. System monitoring in real-time could be achieved through visualization, which accurately captured the physical state of the remote pumping station.

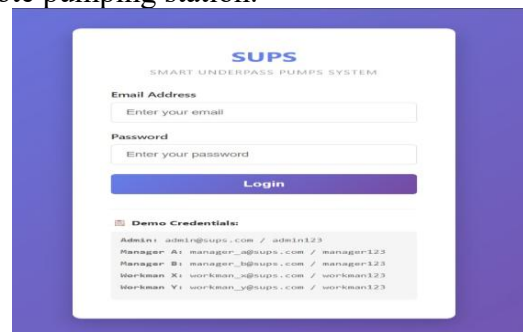


Fig.3

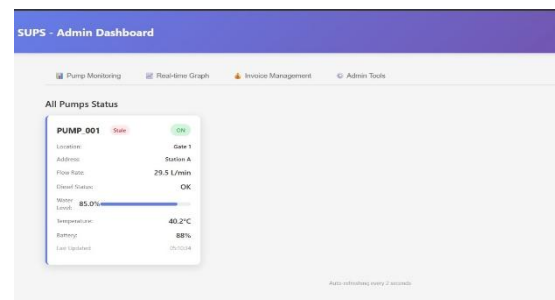


Fig.4

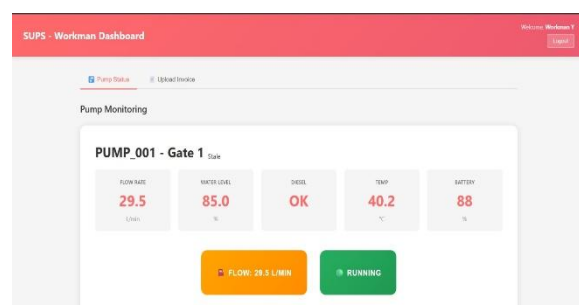


Fig.5

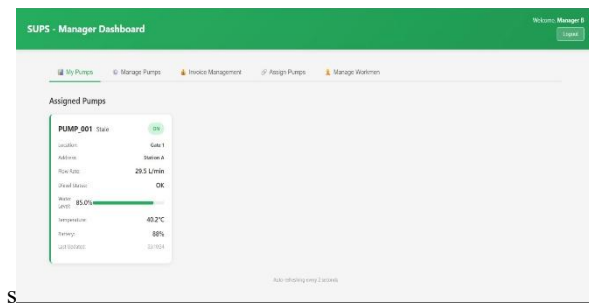


Fig.6

6. CONCLUSION

In particular, the Jalrakshak project demonstrates how a highly sophisticated diagnostic monitoring Smart Underpass Pump System (SUPS), utilizing the capabilities of the STM32 microcontroller, can be designed. In this context, the framework provides comprehensive and immediate readings on essential health parameters, including the diesel level readiness, enclosure temperature, and motor RPM through vibration analysis, as opposed to traditional approaches that rely on physical inspection.

It has been proven that this approach is reliable and efficient in practice, judging from experimental results:

Diagnostic Accuracy: During over 500 experiments, the vibration-based detection algorithm demonstrated a perfect accuracy of identifying the pump's state -100% was achieved.

Communication Effectiveness: The GSM SIM800L module ensured that critical status updates were transmitted via SMS in less than 4 seconds.

7. FUTURE SCOPE

While the "Jalrakshak" system currently provides a solid foundation for monitoring the health of the pumps in underpasses, there are several areas where technological advances could boost its reliability and usability:

Advanced Electrical Monitoring: The use of a pump-specific current sensor will allow accurate electrical monitoring, thus allowing quick detection of winding problems or instances when the pump is overloaded.

Improved Power Management: With the use of the STM32 ADC to measure battery voltage, accurate prediction of the amount of time left before exhaustion of energy storage can be achieved, as well as proper assessment of the health of emergency batteries.

Mobile Ecosystem Development: Telemetry and notifications would be available instantly from the smartphone when developing an application for monitoring the underpasses' pumps.

8. LIMITATIONS

While the Jalrakshak system is very reliable when tested experimentally, there are still several problems that must be addressed before the system can be implemented on a large scale in cities:

Communication Constraints: Since the generation of real-time pump notifications largely relies on GSM connection, there might be problems such as delay or loss due to bad signal in areas where there is low connectivity or heavy rainfall during monsoon season. **Maintenance Issues:** Since the sensors for water and fuel level control are mechanical sensors, there could be some deposits of sediment, necessitating their regular cleaning to ensure continued precision in detection.

Sensitivity to Contaminants: The presence of contaminants within the pipe might have a significant effect on the performance of the flow rate sensors.

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We are currently in our second year of undergraduate studies at Vishwakarma Institute of Technology (VIT), Pune, where we completed this work as part of the Department of Instrumentation and Control Engineering.

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