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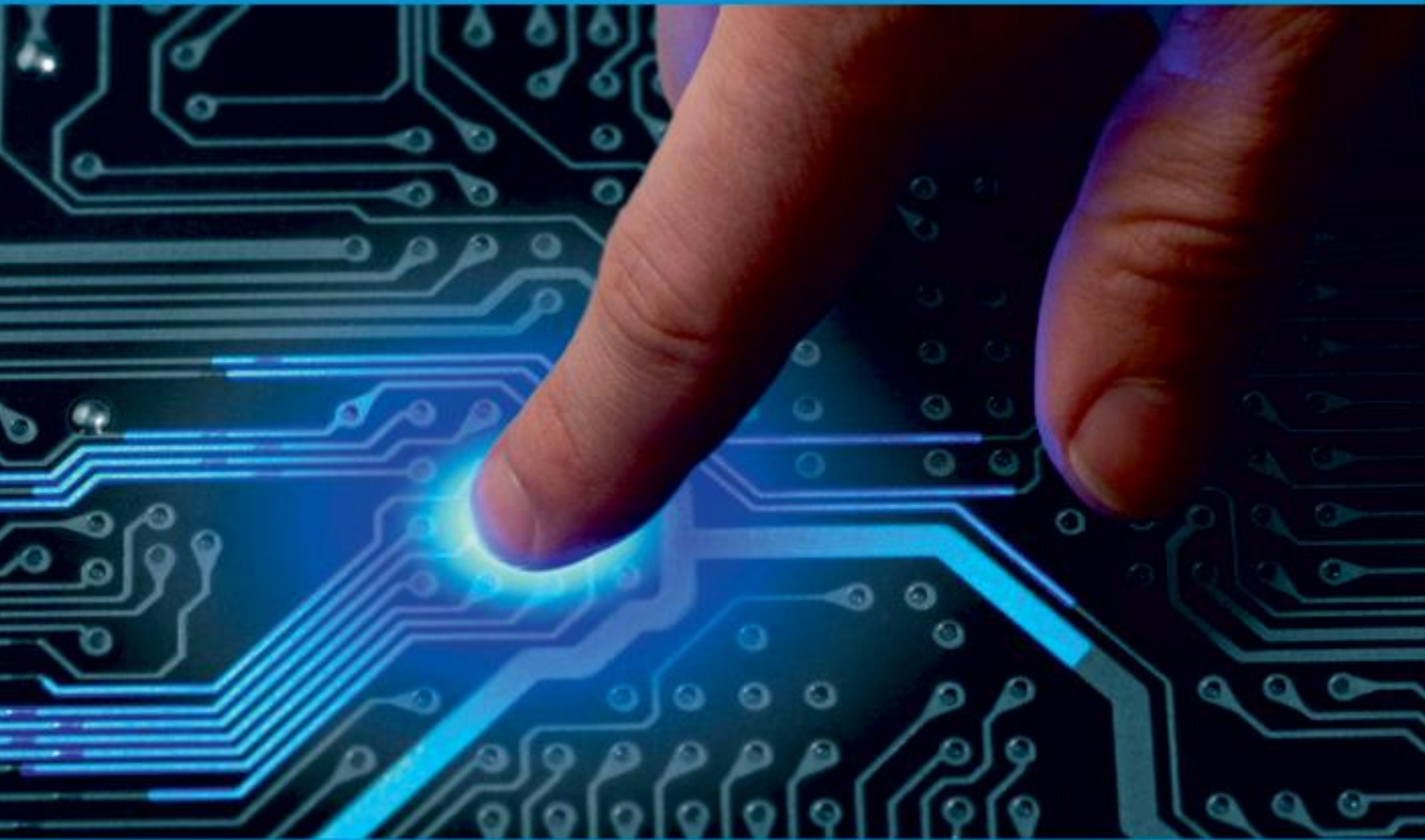

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Design and Development of Data Analytics and Prediction system for beverage filling factory based on IIOT

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ABSTRACT: This project aims to improve manufacturing process through the integration of Internet of Things (IoT) and Industrial Internet of Things (IIoT) technologies. A smart factory framework is introduced that combines an industrial network, the cloud, and several additional control components to produce a beverage. This project involves the collection of real-time data from sensors installed in the factory, which is then analyzed to optimize the production process, improve quality and reduce costs. The system utilizes a range of technologies including sensors, wireless communication, cloud computing and data acquisition and real-time monitoring. The factory is automated, additionally, a graphical user interface (GUI) is included to make any changes manually. The main goal of this study is to create a highly efficient and productive manufacturing facility and decrease production losses by creating a fail-proof IIoT system.

KEYWORDS: Smart factory, Industrial Internet of things (IIoT), Industry 4.0, Cyber-Physical systems, Data analysis.

I. INTRODUCTION

The Industrial Internet of Things (IIoT) refers to the use of Internet of Things (IoT) in an industrial setting, combining smart technologies such as smart sensors, data collection and storage of data, and cloud-based analytics to produce value-added performance inside an industrial workspace. However, that will necessitate expensive equipment with complicated machinery and high-end software. This may be a problem for small-scale industries with low upfront investments. Not everyone has the means to purchase expensive software and hardware. Here is where our work is put to use. Building factories of tomorrow require technologies of tomorrow. Our project combines the core values of IOT and industry to package bottles using IIOT. We have created software that is simple enough for a layperson to understand and enables reasonably priced machinery to build a fully operational factory.

In this paper we present to you a smart factory framework which is a combination of an industrial network, cloud and various other control elements such as the conveyor belt, flow sensors, level sensors, the product and the machines. This work uses 'Raspberry Pi/Arduino Uno' as we are aiming for a cost-effective system, which is used to control the entire production process as it has a cloud connectivity feature and is also used for controlling and monitoring purposes.

A. Overview

In this paper, we present to you a smart factory framework which is a combination of an industrial network, cloud and various other control elements such as the conveyor belt, flow sensors, level sensors, the product and the machines. This work uses 'Raspberry Pi/Arduino Uno' as we are aiming for a cost-effective system, which is used to control the entire production process as it has a cloud connectivity feature and is also used for controlling and monitoring purposes. To accomplish advanced manufacturing based on network technologies and manufacturing data, it is crucial to develop a smart factory in the framework of intelligent manufacturing. The deployment of a smart factory should also consider the current state of production and other factors. There are still many technical issues that need to be resolved in order to hasten the development of the smart factory due to the differences between the manufacturing and information fields. The main concepts of Industry 4.0 are smart manufacturing and IIoT, where parts, products and machines exchange data in real-time. As real-time data exchange between different devices is a key element of smart factories, this information can be viewed as controls, production status, supplier and customer order confirmation,

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material movement, and simulations. Smart factories provide customers with services and intelligent products that are connected to IoT-based networks. Smart Factory collects and scans data from relevant smart applications and products.

B. Problem Definition

The main goal is to improve the efficiency, quality, and profitability of the factory, while also enhancing the safety and satisfaction of workers and customers alike. The need for real-time data collection and analysis to optimize manufacturing processes and reduce downtime. This can be achieved by interfacing industrial grade sensors into the production process which provide accurate values resulting in favorable analyzing of the data.

The need for enhanced connectivity and interoperability between machines, sensors, and other devices in the factory. The need for predictive maintenance and remote monitoring to prevent equipment failures and reduce maintenance costs. The need for improved quality control and defect detection to reduce waste and improve product quality.

C. Objective

The primary objectives that we will work on in this paper are monitoring the beverage levels in the tank and the bottles, counting the number of bottles being filled through sensors, and interpreting the sensor data that has been acquired. Making sure there is no beverage spill over and overcoming the outdated methods of automation and the cost of labour is alarming, hence, we want to solve it by developing a fail-proof IIOT system that requires little to no human involvement. The goal is to monitor the production line at all times. The main goal of this study is to increase the factory's productivity and decrease production losses such as spillage of drinks while filling the bottles etc. Overall, the objectives of our IIoT-based beverage filling factory revolve around improving operational efficiency, product quality, maintenance strategies, and decision-making processes through the integration of advanced IoT technologies and data-driven approaches.

II. RELATED WORK

The fourth industrial revolution, often referred to as Industry 4.0, as well as the digital transformation of industry are taking place as the 21st century gets underway. Instead of being just a hype, the fourth industrial revolution is a success. Industry 4.0 attracted the attention of business leaders and governments all over the world pretty quickly. Since the first industrial revolution in the 18th century, the world has struggled to supply the demand for products while minimizing harmful environmental and social effects by creating more goods from finite and decreasing natural resources.

In this work [1], a 'Controllino Mega' controller has been used to control the entire production since it has cloud connectivity feature. This will enable communication between various production line components, simplifying real-time control and monitoring of the whole manufacturing process. The article [5], outlines a strategy for industrial automation that eliminates human involvement from online ordering through product shipment. In another work [6], authors presented a way to use a PLC as an Industry 4.0 component, it allows the production domain of Industry 4.0 to effortlessly integrate PLC controllers. The paper [7], provides an overview of smart factories as well as the architecture of IoT-based smart factories. Additionally, the production level was included to help with energy management and to improve the energy efficiency of production systems. To demonstrate the effectiveness of the devised technique for predictive maintenance, the authors have provided a case study [8], and several evaluations on energy conservation have been done. This paper [9] reviews the research done on an existing smart factory and provides the difference between traditional and smart factories, also outlines the different types of sensors used in a smart factory.

III. METHODOLOGY

A. ***Architecture:***

The architecture of the smart factory includes three layers, the physical layer, the virtual layer and the application layer.

- The **Physical layer** consists of the physical devices that are placed at the different workstations in the factory. The workstations include beverage filling work station, bottle capping work station and the packing station. Raw data is collected from the sensors placed, such as an IR sensor, which is used to count the number of bottles being filled, a flow sensor to measure and regulate the flow of liquid filling into the bottle etc.
- The **Virtual layer** consists of the cloud database, where the collected raw data is structured and stored. The data is then analyzed using mathematical algorithms and turns into useful data.

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- The data is then visually represented using a dashboard, this helps us better understand the current status of the factory, the amount of revenue generated from selling the packaged bottles etc comprise the **Application layer**.

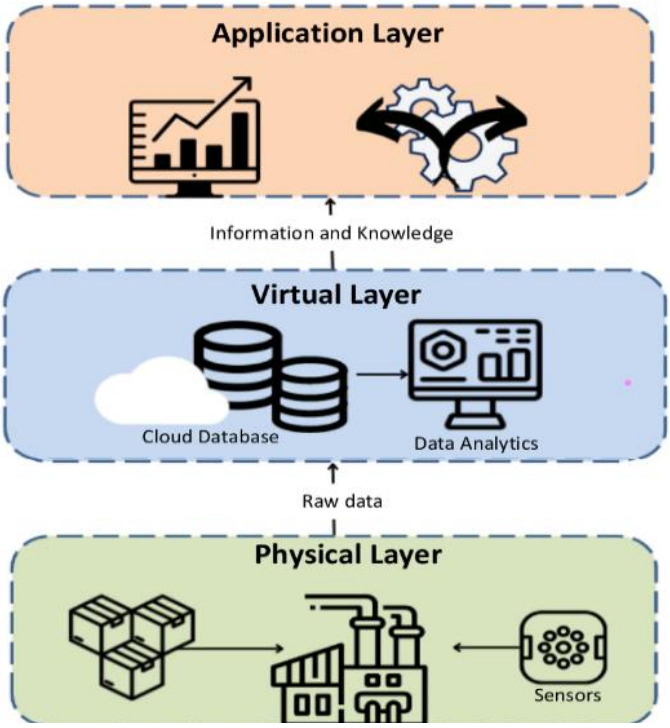

Fig.1. System Architecture

The system design phase involves determining the necessary hardware, software, and network infrastructure, including sensor deployment and connectivity options. Data acquisition and integration are crucial for collecting and integrating sensor data into a central system. The central system, typically a SCADA system, is developed to receive, store, and process real-time data, while analytics and machine learning algorithms analyse the data for optimisation and predictive maintenance. Cloud integration enables scalability, storage, and remote access. Extensive testing and validation ensure system functionality and reliability before deployment. Training is provided to operators and maintenance staff, and continuous improvement is prioritised through data-driven decision making and iterative enhancements.Multiple sensors have been used to monitor the production process such as a IR sensor and a ultrasonic sensor. These sensors are placed in different parts of the production line at different work stations.

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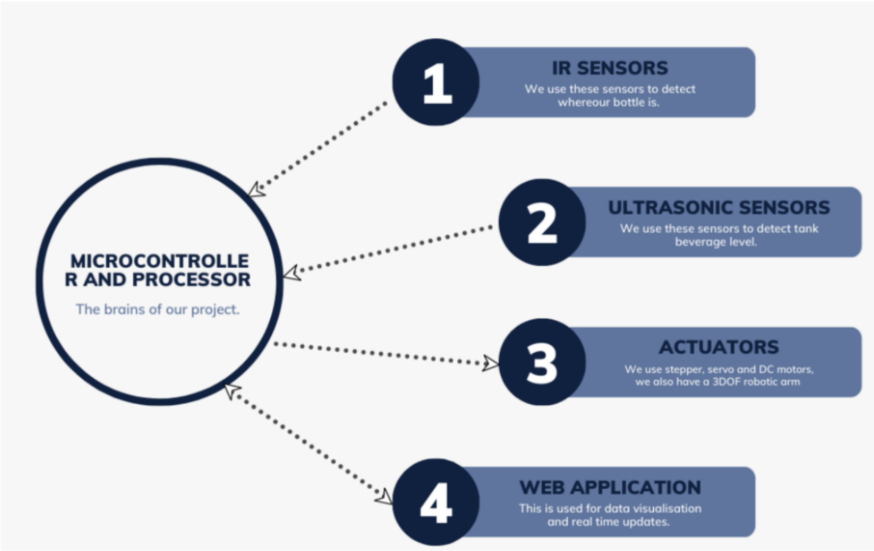

Fig.2. Block Diagram

B**. *Sensors:***

Multiple sensors have been implemented in the factory to monitor the production process, such as a liquid level sensor, flow sensor, temperature sensor and industrial grade photo sensors. These sensors are placed at multiple parts of the production line at different work stations.

- A liquid level sensor is used to monitor the amount of liquid remaining in the tank. The data about the amount of liquid present in the tank is constantly sent to the cloud app that we have built. The operator receives a message through the app to refill the tank when the liquid level drops below a specified threshold.
- A conveyor belt transports the empty bottles to the bottle filling work station. Photo sensors are used to detect empty bottles, once the bottle is detected, the conveyor belt stops moving and the bottles are filled with liquid.
- A flow sensor is placed near the nozzle that fills the bottles. This flow sensor helps in both monitoring and precisely filling the beverage into the bottle. Additionally, this information is uploaded to the application we created.
- The temperature sensor is an electronic device that monitors the temperature of its surroundings and transforms the input data into electronic data, this is used to communicate temperature changes to the operator. The beverage must be kept at 39-65 degrees temperature at all times. Anything above or below these temperatures will compromise the quality of the beverage, which is something we do not desire.

IV. DESIGN AND IMPLEMENTATION

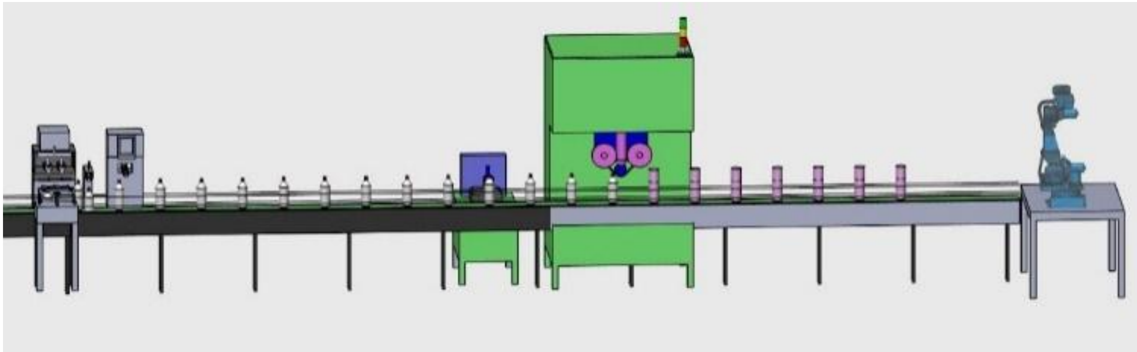

Fig.3. Autodesk model of the factory

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I. Hardware

The main tools that will be discussed are:

- **Conveyor:** A conveyor is a mechanical handling device that is used to transport materials or products from one place to another within a factory or other industrial setting. The conveyor typically consists of a belt or chain that moves continuously along a set of rollers or other supporting structures, carrying the materials or products along with it. The conveyor is a meter long in length and 10 cm in width, and Nema17 stepper motors are mounted to wheels on one end of the conveyor and dummy wheels on the other end. The chassis that holds these components is made out of wood. A belt made up of nylon and rubber has been used as the conveyor belt which is wrapped around the two ends of the conveyor. Running the stepper motors will make the conveyor belt move. The conveyor belt can carry 6 empty bottles effortlessly at a time.

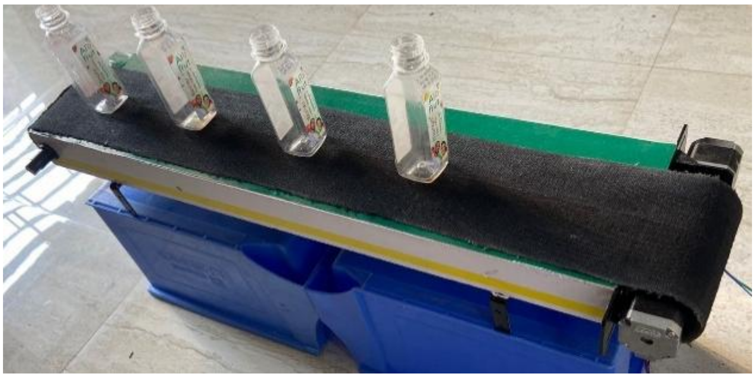
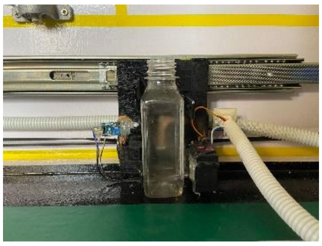


Fig.4. Conveyor Belt

- **Pump:**A food grade industrial beverage hose connected to a submersible pump is used as the pumping mechanism to fill bottles with beverage. The submersible pump is placed inside the tank filled with the beverage. On detecting a bottle near the beverage filling station, the pump activates for 5 seconds and fills the 250 ml bottle and turns off. The hose is supported with a clamp to keep it in place. The tank also has a sensor that monitors the amount of liquid in the tank and can be monitored using the dashboard. The pump stops when the liquid level drops down the threshold level.
- **Linear Actuators**: The bottles are transported to the filling station using the conveyor and then the bottle is transported to other work stations using the linear actuators. These linear actuators are also controlled by stepper motors for accuracy and precise movements of the bottle and are supported by sliders for frictionless movement. The above-mentioned mechanism is horizontal linear actuation. There are two types of linear actuators used in this work, horizontal linear actuation and vertical linear actuation.The capping mechanism also uses linear actuators. When the bottle reaches the capping station, the capping mechanism, made out of a slider, stepper motors, and a 3-D printed part, slides down, the motor runs clockwise and the bottle is capped. Then the capping mechanism slides up using the same linear actuators and this process repeats. This is called Vertical linear actuation. During the actuation, the wires may hinder the actuation, so flexible conduit pipes are used to keep the wires together in place.



(a) **(b)**

Fig.5. (a)Carriage/Slider (b)Capping Mechanism

- **Robot Arm:** A 3-DOF (Degrees-of-freedom) robotic arm made with the help of a stepper motor which is used for revolute motions, a dc motor is used for revolute up and down motions and gears used for the

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actuation and the movement of the robot. A gripper is placed at the end of the robotic arm. This robotic arm is placed at the very end of the production line. It opens its gripper, holds the bottle, closes its gripper, picks up the bottle and moves towards a box, fine motion downwards, the gripper releases the bottle and goes back to its initial position and waits for another bottle to be picked up. 6 bottles are packed in each box.

Fig.6. Robotic arm

II. Software

The set of programs that assist you in carrying out tasks such as data collection, processing, storage, and evaluating instructions based on the processed data form the IoT Software. Examples of this type include middleware, operating systems, firmware, and applications.

- **Firmware:** Firmware can be defined as the program that is embedded in the hardware devices that is essential for the hardware to function. Firmware is also called embedded software. In this case, the microcontroller used is the Arduino Mega 2560 which is coded in C++ programming language. Header files such as AccelStepper, Servo, Time etc have been put to use to build the program which is used to run the factory.
- **Data Acquisition/Middleware:** Data collected from the hardware devices and sensors is sent to the database using a Raspberry Pi. A Python program is coded using SQL queries to update or insert the values obtained from the hardware into the database. This can also be called as serial communication between the hardware and the software. Python libraries such as Serial, mysql.connector and time etc have been used for this application.

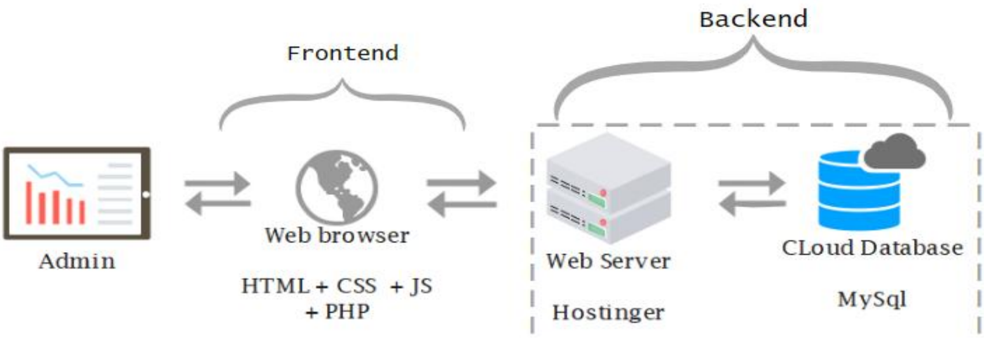

Fig.7. Frontend and Backend Connectivity

- **Dashboard:** A website has been built using HTML, CSS, Javascript and PHP where the collected raw data is pictorially represented using graphs. This dashboard is accessed by the factory's admin to monitor the production process and also have some insights on the revenue being generated, sales etc. It gives you a report of all the events that took place in a particular time period. The dashboard also shows you the live status of the factory such as the conveyor belt's status, tank level, filling status, bottle capping and packing too. The sales and the revenue generated from selling the bottles can also be seen in the dashboard. This website/ dashboard can be accessed from anywhere as it is hosted on the cloud. We have chosen Hostinger as a web hosting server to host our website which also provides us with 100GB of storage space which is an ample amount of space to store all the data collected from the factory. The backend includes the web server and the cloud database in which the data is accessed, stored and manipulated using SQL queries in phpMyAdmin. The data is also analysed and represented graphically using jQuery. Ajax has been used to auto update the website to show the live updates without having to refresh the whole page.

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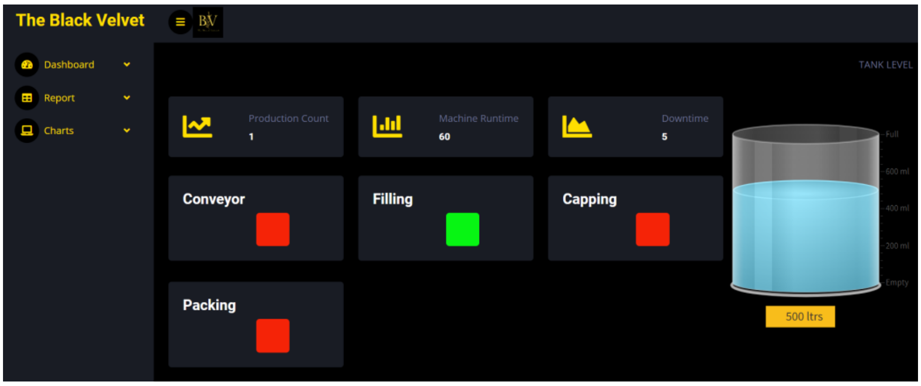

Fig.8. Live status of the factory on the dashboard

V. Results and Discussion

The data collected from the sensors in the IIoT-based beverage filling factory is uploaded to the cloud for efficient storage, organization, and analysis. By leveraging cloud-based services and tools, the collected data can be processed and managed in a centralised database, allowing for easy retrieval and analysis. Once in the cloud, the data can be transformed into meaningful insights through various analytical techniques. Advanced algorithms and machine learning models can be applied to uncover patterns, trends, and correlations within the data. This analysis can provide valuable information about the production process, enabling optimization and improvement of various aspects.

A detailed report can be generated based on the analysed data. This report provides a comprehensive overview of the production count, total revenue, downtime, rejection count, revenue loss, run-time, total batch count, and other relevant metrics. These reports can be generated on a daily, weekly, monthly, and yearly basis, allowing for trend analysis and performance evaluation over different time periods. This information helps management and stakeholders understand the production performance and make informed decisions.

Report

ID	Date	Time	Shift	Message	Value	Timestamp
590	2023-05-23	16:00:00	B	Capping	False	2023-05-23 16:00:00
589	2023-05-23	16:00:00	B	Filling	True	2023-05-23 16:00:00
588	2023-05-23	16:00:00	B	Tank_level	500	2023-05-23 16:00:00
587	2023-05-23	16:00:00	B	Conveyor_status	False	2023-05-23 16:00:00
586	2023-05-23	16:00:00	B	Downtime	5	2023-05-23 16:00:00
585	2023-05-23	16:00:00	B	Machine_runtime	60	2023-05-23 16:00:00
584	2023-05-23	16:00:00	B	Production_count	60	2023-05-23 16:00:00

Fig.9. Report of the activity

Real-time monitoring of the components of the beverage machine is another valuable capability of the cloud-based system. The status of various components, including the conveyor belt, nozzle, capping mechanism, and end product inspection, can be continuously monitored. Any deviations or anomalies can trigger immediate alerts or notifications to relevant personnel. This allows for timely intervention, preventive maintenance, and quick resolution of issues, reducing downtime and maximising productivity. The cloud-based system also enables historical data analysis, which helps identify long-term trends and patterns. By analysing data over an extended period, the system can identify recurring issues, bottlenecks, or areas for improvement. This information allows for proactive decision-making and continuous process optimization.

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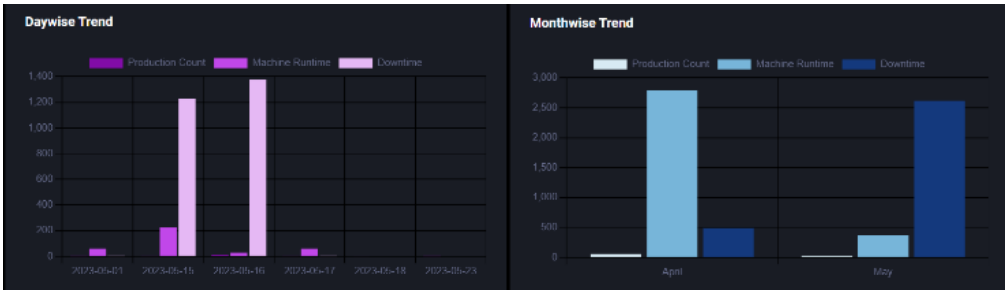

(a) (b)

Fig.10. (a)Daily trend (b)Monthly trend

VI. CONCLUSION

After a thorough assessment of the challenges faced by the beverage filling industry, an IIoT(Industrial Internet of Things) solution was developed to address the issues and enhance the efficiency and hygiene of the bottling process. The implementation of this solution not only resulted in cost reduction but also identified critical areas for improvement within the industry. The design and implementation of the production process in the beverage factory involved extensive automation, guided by insights from sensors strategically placed throughout the facility. The primary objective of this study was to boost productivity, minimize production losses (such as drink spillage during the filling process), and improve overall operational efficiency.

Additionally, sensors were strategically positioned along the carriage to monitor the movement of bottles, ensuring proper alignment and minimising the risk of jams or bottlenecks. By continuously collecting data on bottle movement, the system could identify any issues and provide immediate alerts to operators, allowing for quick intervention and resolution. The collected sensor data was transmitted to a centralised cloud platform, where it was processed, organised, and analysed. Advanced analytics techniques were applied to gain valuable insights into the production process. This analysis enabled the identification of patterns, trends, and inefficiencies, paving the way for data-driven decision-making and process optimisation.

In conclusion, the application of IIoT technology in the beverage filling industry resulted in a more efficient and hygienic production process. By utilising sensor data and advanced analytics, the factory experienced increased productivity, decreased production losses, and improved operational efficiency. The automation and real-time monitoring capabilities provided by the IIoT solution allowed for precise control, proactive maintenance, and continuous improvement. The successful

implementation of this solution sets a benchmark for the industry, showcasing the potential for transforming traditional manufacturing processes into smart, efficient, and sustainable operations.

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