Automation with Smart PLC

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Semester Project for ISE716 (Spring 22') – A Technical Report

Abstract

The recent advancements and evolution of Manufacturing in the fourth Industrial Revolution has resulted in adoption of newer technologies that surround the Smart Manufacturing space. The Industrial Internet of Things takes networked sensors, intelligent devices and puts those technologies directly into the manufacturing floor, collecting data to drive artificial intelligence and predictive analytics. While more interconnected Systems, IIoT has resulted in more and more complexity with multiple system components that are present across the process.

With more sophistication in Process Control, Automation, Data Transfer and Handling, there is a growing need for an Automation System that simplifies the process and at the same time ensures a secure Industrial communication and efficient data handling and control in real-time. We look at a possible solution to this challenge by exploring the Edge Programmable Industrial Controller (Groov EPIC) from Opto 22 which addresses the challenges of Complexity, Security & Cost by connecting directly to field devices, control systems, databases & cloud services.

We demonstrate the Application of the Smart PLC in a Material Handling Automation System involving a conveyor belt and a universal robot. The Smart PLC controls the material handling process by detecting the characteristics of a part, sorting it based on color, constructing efficient data flow and control using Node-RED and MQTT and building a live dashboard indicating the status of the operation and enabling remote control of the system with real-time alerts. An automation system is enabled using the Groov EPIC, without the need for multiple system components in this process and thereby flattening the IIoT architecture.

Keywords

Edge Programmable Industrial Controller; Smart Automation; Programmable Automation Controllers ; PLC with Edge Computing ; Automation Systems with Publish-Subscribe Architecture ; Automation Data Transfer with MQTT ; Groov EPIC Industrial Controller ; Material Handling Automation with Groov EPIC

1. Introduction

The Manufacturing domain, over the last several decades, has made significant progress, advancing through key phases including The Industrial Revolution, Assembly line production, Lean Manufacturing, Computerization, Automation and Robotics. With a giant leap in scientific know-how and various breakthroughs over the last decade, manufacturing has now moved from a Machine-driven Industrial Revolution to Industry 4.0 and Cutting edge of Technology. Industry 4.0 connects embedded system production technologies and smart production processes to pave the way to a new technological age which will radically transform industry and production value chains.

The smart factory evolution is essentially about building upon the advancements of the third industrial revolution by automating the collection of data from machines and applications and transforming that data into immediate insights. This new technology turns the tedious, but critical, process of extracting insights from data into one that is instantaneous, streamlined, and achievable for every manufacturer.

In the previous industrial revolutions, a change in one area usually caused a single disruption to the overall manufacturing process. Today, the intersection of several new technologies allows for an entirely new set of capabilities at any given time [1]. Each technology alone is important, but together their convergence is essential for rapid ground-breaking solutions to emerge. Key technologies such as artificial intelligence, wireless connections, High speed internet and advanced software technologies that seamlessly connect suppliers, manufacturers, and customers, are transforming the way we do business.

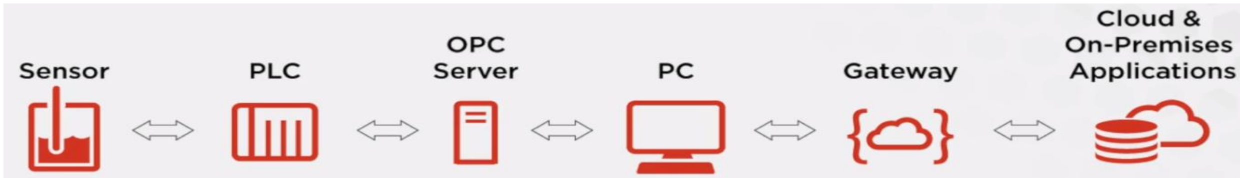
The Industrial Internet of Things is continuing to evolve with progress and focus on Automation & Controls, Cloud Computing, Machine Learning, Data Acquisition and Remote Monitoring. Newer systems are built in the Smart Manufacturing Space leveraging the recent advancements in technologies and computing powers. However, one of the key challenges in New IIoT developments and infrastructure is the complexity of systems that are involved, percolating into various facets including Security, Networking, Legacy Equipment, Licensing, Reliability, and Information technology. [2]

In most cases, Complexity, Cost and Maintaining the systems is one of the biggest hurdles in the Modern Automation setup including a PLC (Programmable Logic Controller). The Modern infrastructure is often plagued with issues in Security, Software Licensing, PC's, Software Updates and Networking [2] resulting in a growing need to

1. Simplify the IIOT systems by reducing the system components
2. Secure Industrial communications easily and efficiently
3. Perform Data handling and control applications in real-time

This Technical paper addresses the existing challenges in a PLC Automation system and how a Smart PLC can eradicate these by seamlessly simplifying Data processing and handling. The demonstration of the technology is implemented through the Opto 22 Epic Groov Smart PLC that is used to control a typical sorting and material handling automation.

Existing System with higher complexity



Simplified setup with Smart PLC

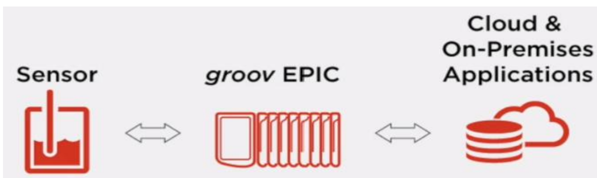


Figure 1: Simplification of IIoT systems with Smart PLC (Groov EPIC)

2. Background & Technology

Programmable logic controllers are small industrial computers. Their design uses modular components in a single device to automate customized control processes. For manufacturing plants, the invention of programmable logic controllers revolutionized the industrial automation process, as its cutting-edge technology replaced a complicated system of electromagnetic relays with a singular controller. In industrial workplaces, PLCs are still the preferred choice over other systems. The system has evolved to incorporate modern technologies, while maintaining the durability of the design to withstand the conditions in a factory setting.

Before the birth of PLC's, automated machines were run by a complex and problematic series of relays. Maintenance costs were high and system configuring took too long to accomplish. In the late 1960's GM's Hydro-Matic division requested a concept from Dick Marley. In 1968, the concept that would the PLC was born. It was then called the standard Machine Controller. Marley's new company MODICON introduced the 084 Model in 1969 starting the race to perfect this new technology [3]

From the first commercial success with MODICON 184 Model to the Simantic S5 – Siemen's four CPU design. Advanced Automation grew rapidly through the 1980's and 1990's. With the advent of Profibus and Ethernet, newer PLC's including the Simantic S7 came into the market towards the end of 1990's. Over the two decades, with motion control, Tag based addressing and various advancements in automation have resulted in the next generation of PLC's including the ControlLogix and CompactLogix platforms. Modern Technology has led us into the new revolution of Smart Manufacturing. While it is possible to achieve advanced operational analytics limited only by our imagination, it is important to look back to see our progression and how many of these classic PLC's will be replaced or upgraded in order to stay relevant in the modern manufacturing market place. [3]

The Biggest challenge with the existing PLC's is getting data from the edge of the network - from the sensors and actuators in factories, buildings, and remote sites, to the software and people who would be using this. It takes a chain of middleware to translate data between these systems and move it to the desired place. Hardware, drivers, parsers, and custom software are costly to purchase, install, and maintain, and every link in the chain opens security concerns.

Smart PLCs like the Groov Epic (Opto 22) solves the challenges of Complexity, Security & Cost by connecting directly to field devices, control systems, databases & cloud services.

With Smart PLC's,

1. There is one Industrial Unit that takes the place of all the Middleware

Figure 2: Groov EPIC Smart PLC (Source: Opto 22)

2. Presence of a more secure system with Encryption, User Authentication & Communication. From Operating System, Network interfaces, firewalls to Data communication options, Smart PLC's have an enhanced Security across the elements of System Architecture. Below is a typical system architecture [4]

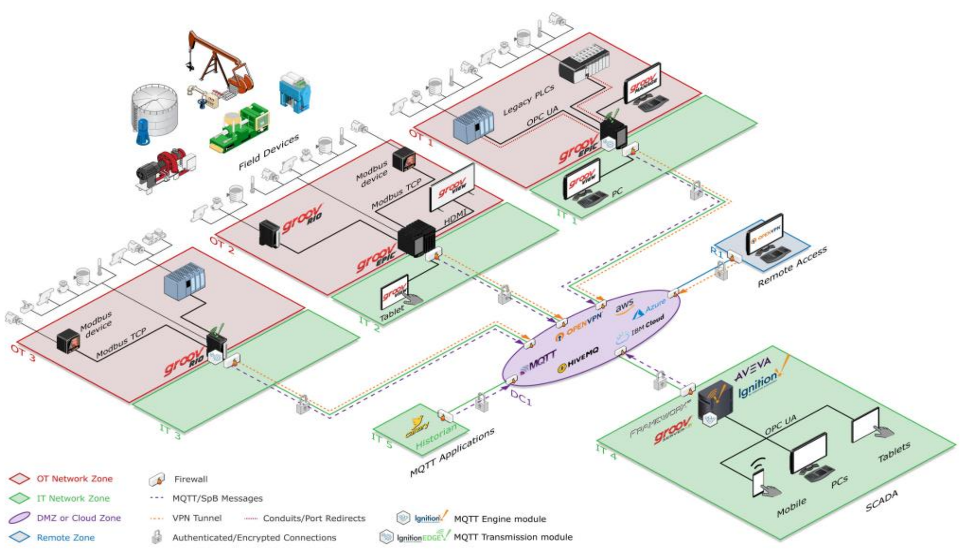


Figure 3: Typical System Architecture with a Smart PLC (Source Opto22)

3. Retrieve data faster and efficiently with built-in software and a compatible architecture. For example, the Groov EPIC incorporates MQTT Sparkplug making IIoT implementation much simpler with a Publish/Subscribe architecture, Enables Node-Red that builds simple flows to move data to and from databases, cloud applications, and APIs

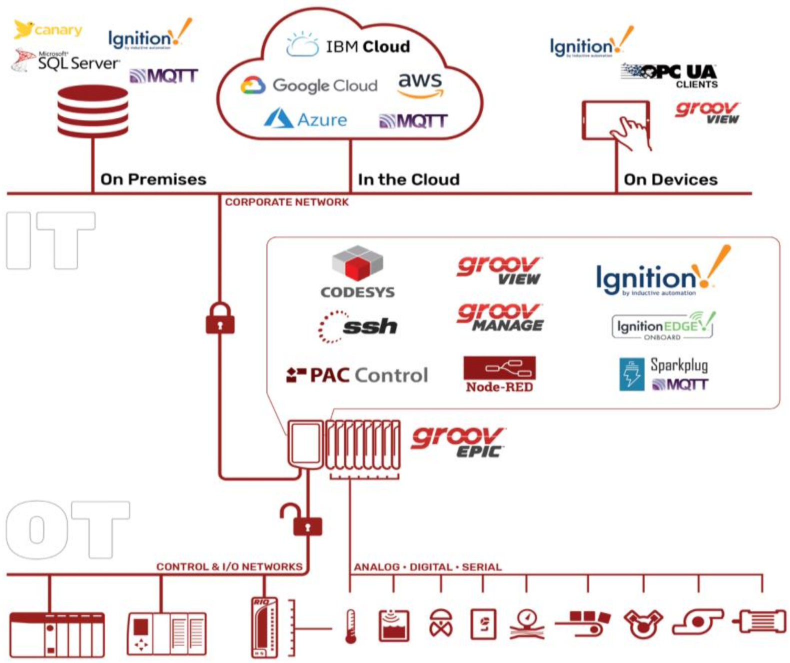


Figure 4: Compatible Packages including MQTT and Node-RED aiding efficient data transfer process with Smart PLC's (Source Opto22)

With the capability of a Smart PLC, Material Handling Automation can be made Real-time, enabling manufacturing and production teams to identify efficiency for different parts, defect type and rates and various other associated metrics relevant to the industry.

3. Industrial Automation, PLC' Markets and Technology Trends

Statista Market research (2021) estimates the size of the global industrial automation market reached 175 billion U.S. dollars in 2020. The market is expected to grow at a compound annual growth rate (CAGR) of around nine percent until 2025. In 2025, the size of the global industrial automation market should reach roughly 265 billion U.S. dollars [5]

Among the Control Systems Market, Grand View Research (US) estimated a roughly equal share between PLC, DCS (Distributed Control Systems), SCADA (Supervisory control and data acquisition) and Others.

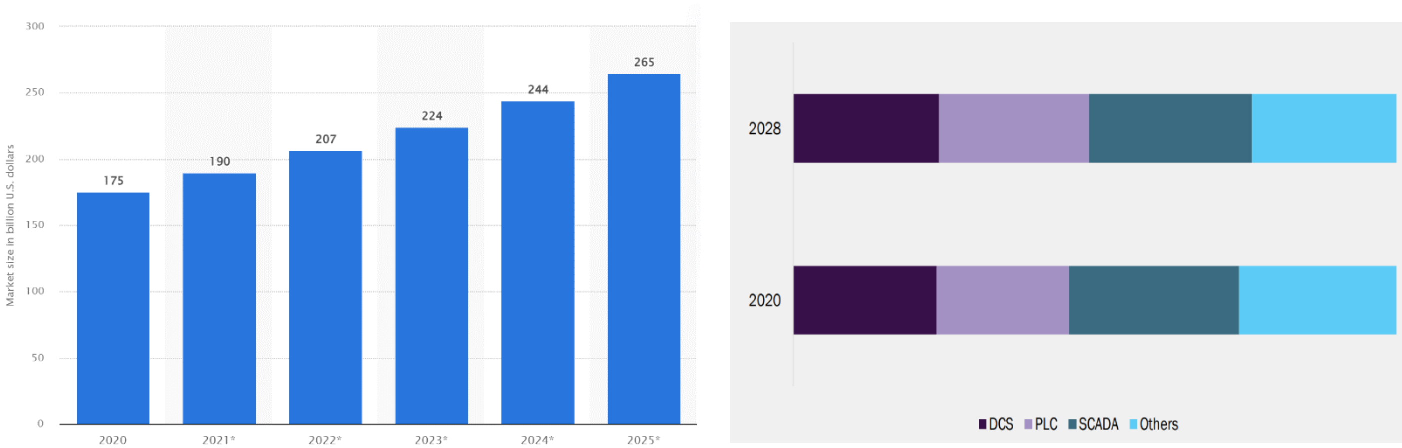


Figure 5: Left - Global Industrial Automation Market estimated to be 265 Billion US Dollars (Source: Statista) ; Right – Global Split of Control Systems Market with approx. 25% share with PLC (Source : GrandView Research)

The rapid shift of industries toward smart manufacturing is a key factor responsible for spurring the market growth. Industries that adopt automation systems largely prefer to leverage proven standards and technologies to ensure safe, secure, and consistent operations. Furthermore, the advent of Industry 4.0 has resulted in the manufacturing sector experiencing a rapid acceptance of new and augmented networking architectures and systems. [6]

However, issues such as high deployment costs of these systems, privacy and security concerns, lack of standards and regulations pertaining to Industry 4.0 are some of the major challenges posed before the industry players. Technologies like the Smart PLC, when implemented within an Automation process, eliminates the need to have middleware technologies and systems and thereby flattens the IIoT architecture to a great extent.

Some of the Major players in the PLC market have come up with solutions that try to address the problems including complexity, cost and maintenance as discussed so far. Edge Controllers, for example, have been a talking point and can provide advantages in many applications where traditional industrial controllers have been used. Modern consumer and commercial computing experiences are ripe for merging into industrial products. Internet of Things (IoT) devices are becoming commonplace, and many are looking at incorporating Industrial IoT (IIoT) devices into automation systems. Digital transformation requires connecting with many data sources, collecting and storing the data, visualizing and analyzing it, enabling optimized operations [7]

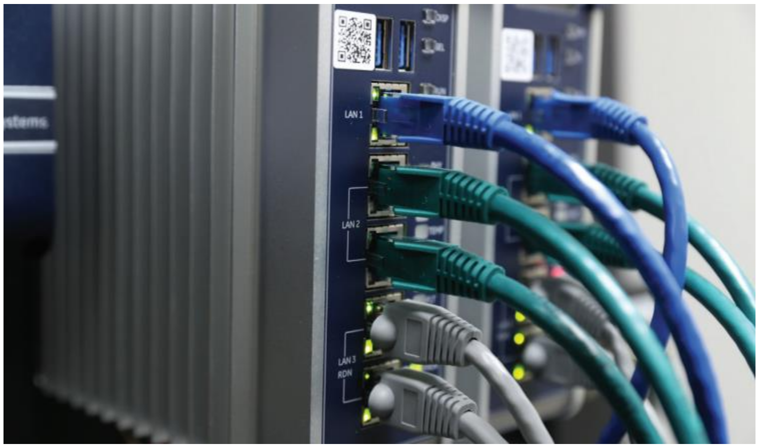


Figure 6: Edge Controllers such as those offered by Emerson, combine deterministic control like a PLC/PAC and independent general-purpose processing like a PC (Image Courtesy Emerson)

PLCs and PACs are good technologies developed in different eras. Edge controllers can update or replace PLCs and PACs and offer advantages by implementing carefully designed OS's for addressing OT and IT needs for control, communications, and application development. [8] PLCs used to be isolated or communicated with slow and cumbersome serial links. PACs included better industrial protocol implementation and Ethernet for improved connectivity and interoperability. Edge controllers deliver these advantages and can perform in an increasingly IT-connected environment. When users only need a PLC/PAC feature set, they can still specify an edge controller to fill that role. Standard IEC-61131-compliant programming methods can be used, or even commercial languages like C. These users never need to access the general-purpose OS features if they choose not to. The Challenge, however, is the need for edge controllers offering a native toolbox of IT-friendly features such as Linux OS, a Python interpreter, secure sockets, an embedded database and OPC Foundation OPC UA support which is still not an offering from many of the Major PLC suppliers.

Similarly, to have controllers that are high performing, robust and modular, and have onboard high-level communications, standard/open connectivity, and simple integration with PC applications and model-based simulation, Siemens introduced the SIMATIC ET 200SP2 Open Controller. This Controller is a modern “multi-tasking” controller, combining functions of a PC-based software controller with visualization, PC applications (Microsoft Windows or Linux), and central input/output connections in one compact device.[9]

Applications for these optimized controllers include series machine manufacturing and for machines with distributed architectures. Such modular controllers minimize space and can be accommodated in compact control boxes on the machine, improving the cost-performance ratio. An industrial flat panel connected through the graphics interface can provide visualization, optionally with multitouch functionality. Since the PC is built in, no separate PCs are required. For commissioning, mouse and keyboard can be connected via standard onboard USB interfaces. At the same time, the gigabit Ethernet interfaces support high-performance connection to higher-level networks [9]

While the above two cases march towards flattening the IIoT architecture, The Groov EPIC from Opto 22 offers a more holistic and complete package that connects the OT and IT seamlessly and ensuring essential security features.

4. Related Work

The power of Smart PLCs in the field of Automation and Industry 4.0 is endless. The following are some of the examples of the how Smart PLCs, in this case Groov EPIC, has been implemented

4.1 Retrofitting a CNC Milling Machine with EPIC RIO

In a time when automation is driven by increasing connectivity, there is still plenty of everyday equipment that is simply not designed to communicate with various other devices and networks. The CNC Milling machine generates huge amounts of Data which can be used to know how well it's working, how much energy it's using and how often it's put to work. Leveraging that data to build an OEE or predictive maintenance program is often an untapped source of potential savings.[10]

With three measurements including vibration, temperature, and current, the system could detect a variety of problems and indirectly measure power consumption, giving the users a reliable reading of overall system health and usage

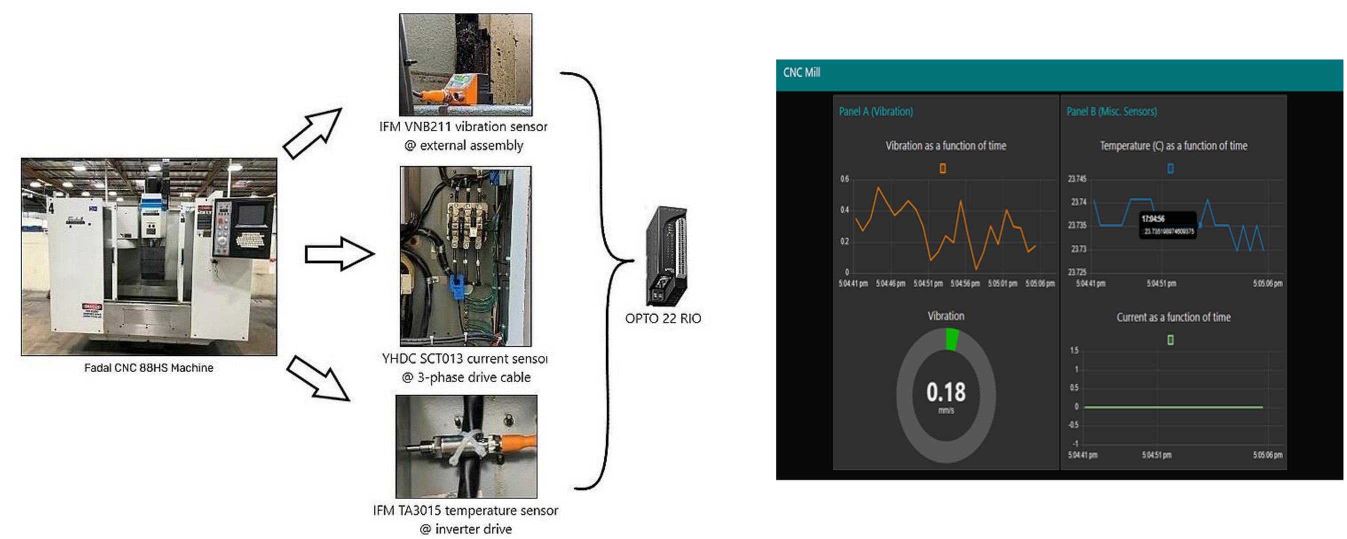


Figure 7: Left - System Architecture for Data Extraction (Source Opto22 Blog); Right – Node-Red Dashboard

After instrumenting the signals that need to be collected, the system wires are connected to a *groov* RIO edge I/O module. Using RIO's embedded Node-RED IoT engine, a real-time mobile dashboard can be created which can be hosted on mobile, browser and on the Groov Display and the data can be pushed to OSI PI using REST calls. The OSI PI system is used to generate email notifications based on sensor values and to connect data to Grafana for more detailed dashboard designs [10]

In this implementation, power of Node-Red and Groov is combined to create dashboards in different platforms. As an open platform, it's easy to build connections to dozens of different database systems, cloud services, and more.

4.2 Warehouse to Enterprise: Emerald 66/NACI

When the demand of Hand sanitizers rose during the pandemic, Emerald 66 Enterprises used the smart manufacturing capabilities of Opto 22 to manufacture more than 1 million bottles of hand sanitizers a week by renovating an empty denim processing plant. To deal with the challenges, an unique architecture was proposed that enabled separate control systems to function together and also laid a foundation for E66's data acquisition goals [11]

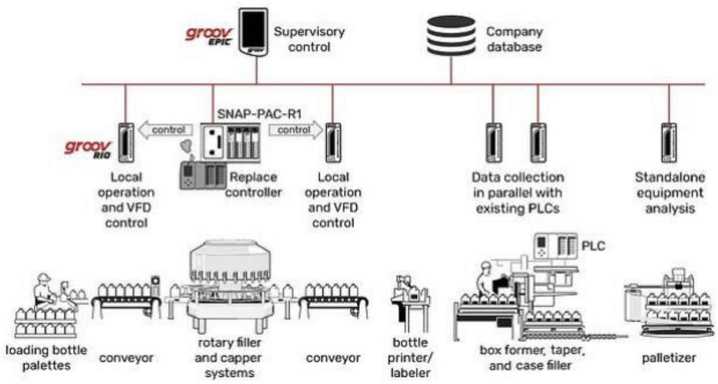


Figure 8: System Architecture

At the top level, groov EPIC edge programmable industrial controller was used to supervise the process lines and connect disparate devices through REST APIs. Equipment that arrived with defunct control systems was integrated into this network as remote I/O through SNAP-PAC-R1 controllers, which also provided specialty I/O options. NACI then used groov RIO edge I/O modules to loosely integrate any functional control systems. As each new unit came online, NACI dropped in one of these PoE-powered modules and used its software-configurable channels to identify the kinds of signals the unit provided. NACI mirrored these I/O signals in parallel with the existing PLC I/O connections and integrated them into the groov EPIC network [11]

5. Methodology and Process

Machine Vision is an important element in Industry 4.0. Using Cameras, Sensors, Actuators with Computer vision and Machine Learning enables Industries to improve their production and inspection lines. It helps industrial automation systems in numerous ways such as increasing efficiency by improving inventory and detecting faulty products and improving manufacturing quality. As data analytics capabilities progress, the high volume of data accessible through vision equipment will be used to identify and flag defective products, understand their deficiencies and enable fast and effective intervention in the industry 4.0 factory.

Before understanding how Machine Vision is implemented in Smart Factories, it is imperative to understand the tools used in this framework and their implementation.

5.1 Using MQTT

Included with groov EPIC is MQTT communication, with both string and Sparkplug B payloads. MQTT is a publish-subscribe (pub-sub) protocol that's suited to many IIoT applications because of its architecture.

In a pub-sub architecture, a central server called a broker handles all data. MQTT clients can publish data to the broker or subscribe to get data from it (or both). Clients who publish data send it only when the data changes (report by exception). Clients who subscribe to data automatically receive it from the broker only when it changes. With device-originated connections, once the connection is initiated, data can travel in both directions. For example, whether a groov EPIC is publishing or subscribing to data, the EPIC initiates the connection - an outbound connection, which the firewall would allow. Once the connection is made, data can travel bidirectionally.[12]

MQTT Transmission with either a strings payload or Sparkplug-B payload, available through groov EPIC, offers advantages for both on-premises and remote data communication. As depicted in the below figure, groov EPIC systems in industrial areas connect to sensors and actuators through their own I/O and through other PACs, PLCs, and RTUs, and publish and subscribe to data through the MQTT broker. At the main site, Ignition Edge and a groov EPIC also publish and subscribe data through the broker, while providing database connectivity and system visualization.[13]

This Pub-Sub can be used to control actuators which are connected on to the network and the advantage of using MQTT is the ability to modify code which gives the user flexibility to adapt the conditions based on the requirements. MQTT is also used to publish Data being generated from the Factories on to the Broker which can be streamed real-time on a subscriber who might be located. We use QOS level 0 in this application to stream binary output from the PC based on the camera and use that binary data from the Groov EPIC

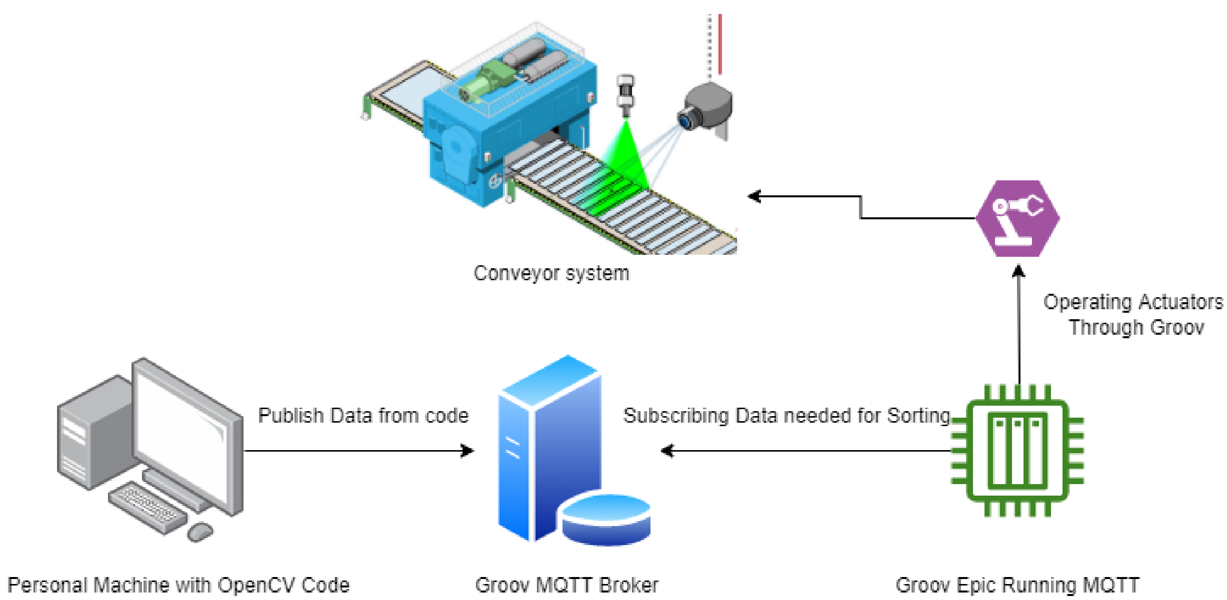


Figure 9: Proposed Flow Diagram of implementation

In the Material Handling Automation that we are looking to execute, Multiple Sensors including a temperature sensor (Detects the temperature of the system) and a CMOS sensor (to detect the color of the incoming part) is connected to the EPIC groov smart PLC. The Conveyor system that carries the part, The Groov EPIC and other devices connected in the Shop floor, publish, and subscribe data through a MQTT broker, while providing database connectivity and system visualization in real-time

5.2. Using Node-RED

Node-RED, an open-source software program you can use to wire together devices, databases, cloud applications, and APIs (application program interfaces) with simple logic flows. Node-RED takes advantage of pre-programmed, reusable code blocks called nodes. These nodes make IIoT application development simpler, easier to repeat, and faster to scale. Built on the popular Node.js JavaScript runtime, Node-RED benefits from a large Node-RED library—containing over 600 prebuilt and ready-to-deploy nodes—allowing IIoT application developers to leverage existing software code and deploy it directly into their applications. [14, p. 22] Node-Red is applied here by using nodes to stream data through MQTT and use it as a subscriber on the Groov Epic to operate Logics needed for the Machine Inspection. Node RED also lets us control different actuators, lights, sensors, etc. from remote locations which reduces the complexity of wiring [15]

5.3 Groov View for Dashboards

Groov View is Opto 22’s operator interface tool that is simple, browser-based, and connected to automation systems, software, databases, and devices of all kinds. Groov View aids in building live dashboards which can reduce a lot of complexity in an otherwise world, where the data has to be sent to a user computer and use Python Libraries to build dashboards.

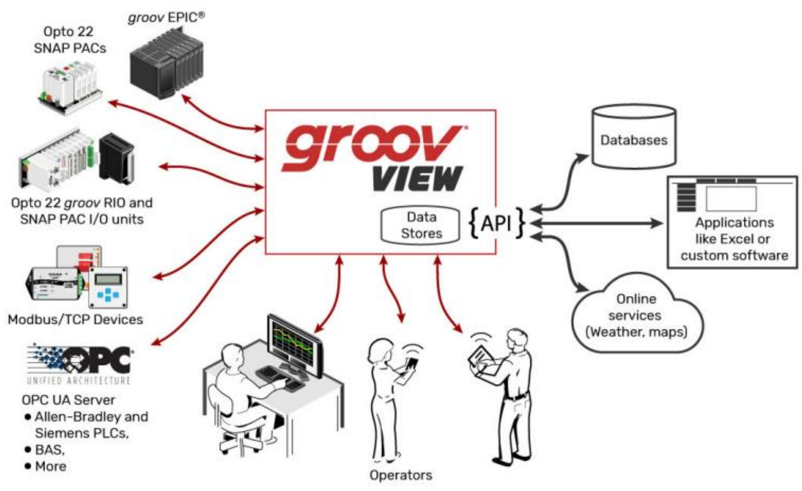


Figure 10: Groov View Capabilities

The building interface involves drag, drop, and tag. There is no tag limits and no user licenses required. Set up authorized users and groups. Define events based on one or more conditions, and automatically alert selected personnel anywhere when events occur. Groov View can augment existing human-machine interfaces (HMIs) and SCADA systems by making specific data visible to authorized users at any time and in any location. [16]

The key to IoT usefulness is getting the data out of where it's trapped and into the systems and software where it's needed. Groov lets the user use standard Internet and IT-compatible tools to manipulate and move data between things in the real world and computer systems and software on premises or in the cloud.

Groov logs events that a user configures. Each event that is configured is based on one or more conditions, such as a value equal to a value you specify, or a value outside a range you determine. When a user sets up multiple conditions for one event, the event can be configured to occur when all of them are true or when any one is true. These event-based notifications are sent via email (or text message, through most carriers) [17]

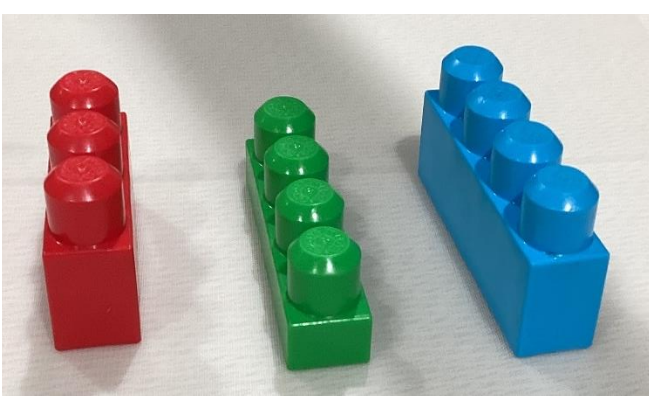
Event messages can be customized and sent to groups or individuals. Messages can include equipment data, time/date stamps, other key information, and even links back to the groov operator interface for one-click access to real-time, visual data for further investigation. For example, if a machine overheats, stops working, or otherwise meets or exceeds one or more predefined criteria, a maintenance technician can receive a notification and click right to the groov screen for more data. With email available at almost any time or location thanks to mobile devices such as smartphones, notifications can get critical data into the right hands right away.

6. Results and Execution

6.1 Python OpenCV - Color detection

OpenCV is a Python open-source library, which is used for computer vision in Artificial intelligence, Machine Learning, face recognition, etc. OpenCV was used to detect the color of a block in this material handling automation demonstration.

Since the blocks had set colors (Red, Green and Blue), a set of lower and upper thresholds were decided experimentally for the three colors. The Thresholds involving Hue, Saturation and Value (HSV) – Hue being the color portion of the model, expressed as a number from 0 to 360 degrees, Saturation being the amount of gray in a particular color, from 0 to 100 percent and Value working in conjunction with saturation and describes the brightness or intensity of the color, from 0 to 100 percent, where 0 is completely black, and 100 is the brightest and reveals the most color. Therefore, the HSV color space describes colors (hue or tint) in terms of their shade (saturation or amount of gray) and their brightness value



```
_, frame = cap.read()

hsv = cv2.cvtColor(frame, cv2.COLOR_BGR2HSV)

l_r = np.array([0, 201, 113])
u_r = np.array([62, 255, 255])

l_g = np.array([43, 68, 0])
u_g = np.array([85, 255, 255])

l_b = np.array([75, 186, 75])
u_b = np.array([153, 255, 255])

mask_red = cv2.inRange(hsv, l_r, u_r)
res_red = cv2.bitwise_and(frame, frame, mask=mask_red)
mean_red = np.mean(res_red)
```

Figure 11: Colored Blocks used for Pick and Place (Left); HSV Thresholds using OpenCV for color detection (Right)

6.2 Operating Conveyor belt with Python API

The Conveyor used in the automation system was a Vention belt conveyor that supports Python programming for control from a computer system. Vention systems developed a standard MachineMotion Python API that can be run using pre-installed libraries. With this setup, any IDE can be used, programming can be done when the system is not connected to MachineMotion and the communication is vastly simplified as multiple devices can have the computer as the communication hub. [18]

```python
from platform import machine
from MachineMotion import *
import time
ip = "192.168.10.12"

machine_motion_example = MachineMotion(machineIp=ip)
print ( "Controller connected" )
machine_motion_example.moveContinuous(1, -50, 50)
#time.sleep(30)
#machine_motion_example.stopMoveContinuous(1, 100)
```

```python
broker = "192.168.10.4"
port = 1883
def on_publish(client, userdata, result):
    print('Data Published \n')
    pass

client2 = paho.Client("ashwathpc")
client2.on_publish = on_publish
client2.connect(broker, port)
```

Figure 12: Python Scripts for Conveyor Control (Left) ; Python Scripts for MQTT connection (Right)

The Python program enables to start and stop the conveyor by addressing it with the IP address. This opens up a plethora of opportunities to design control logics to operate the conveyor via the python code. In our case, when the python code is started, the conveyor is started with a fixed speed and acceleration. When a colored block is detected by the camera, the code stops the conveyor after a short wait time to enable the robot to pick up the block.

6.3 MQTT Publish and Subscribe

The crucial element of an automated system is the communication protocols that are enabled in the connecting devices. In this context, one of the biggest advantages with a smart PLC like the Groov EPIC is the access to MQTT protocol that makes industrial communication faster, easier and effective. From the local system via the Python program, the information on the color of the block is received (as detected via OpenCV codes). The next step is to send this data to the EPIC Groov controller and enable the further sequence of operations. Through the same python program, we publish the color data (as “Red”, “Green” or “Blue”) to a local MQTT broker under a specified topic name. With this setup, the required data is published real-time as the camera detects the block and the subscribing devices to this topic receive the data that enables the control and flow for this automation

6.4 Node-Red for Control Logics and Integration

With the python scripts publishing the information to the local broker, the EPIC Groov controller needs to receive this information by subscribing to the same topic. This is enabled via Node-Red. Node-Red specifically enables MQTT in and out nodes that can be used to both publish and subscribe to a broker. These nodes need to be installed to the Node-Red dashboard which comes in-built with the Smart PLC.

The Server address of the broker is setup within the MQTT node, and the topic is specified to ensure that the nodes publish/subscribe to get the required information. Once the node is setup, these can be deployed in the Node-Red flows. As given in the below figures, the local broker was setup to be “192.168.10.4” and the topic to which the node was subscribing was given to be “ashwath33/python”. Any data published to this broker via the topic mentioned will be visible from the node configured in the Groov EPIC system. Groov EPIC can also act as a local broker and this setup can be explored as desired by obtaining the license for Ignition Edge [19]

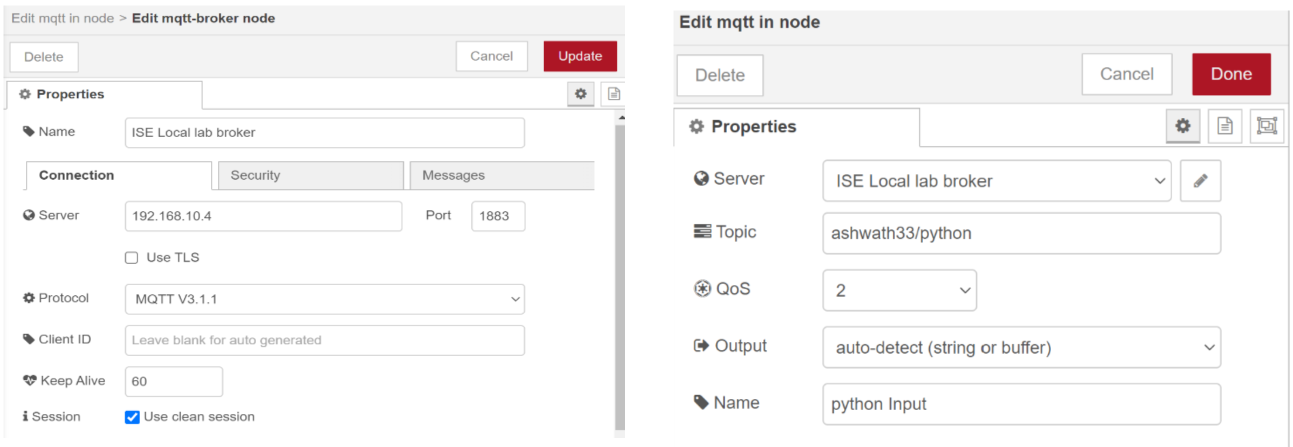


Figure 13: Setting up of MQTT Node in Node-Red

Node-Red, being a flow-based programming enables a host of control features that makes it easier for a user to design and construct various control logics for the automation system. In this case, with MQTT nodes enables, we connect these nodes to various other control nodes to logically sequence the operations for robot picking, signaling and information flow.

A virtual wiring flow was created with control established between the Smart PLC and the Universal Robot. The Python MQTT Input node subscribes to the topic and broker and receives information. This MQTT node is connected to a function node that checks the color of the block. The Python MQTT node connects to three different function nodes (for the three different colors) from where further control is established.

The messages that pass through a flow are plain JavaScript objects that can have properties set on them. They usually have a payload property - this is the default property that most nodes will work with A number of nodes also treat “msg.topic” as having special meaning. It might be used to identify the source of the message, or to identify different ‘streams’ of messages on the same flows. It also gets displayed in the Debug sidebar with every message. For example, the MQTT In node will set “msg.topic” to topic the message was received on. [20]

For example, in case of the red flow, the first function node checks if the information published was “Red”. We build an if-else logic within the function node and pass the relevant information to the subsequent node based on this condition. Groov EPIC also has specific module and channel nodes that can be downloaded from other packages and used in the Node-Red flows. We use these Groov nodes to switch on the controller channels based on logics created using the function nodes. In the example of Red, the function node sends information to the Groov node and allows to turn on/off the channel (in each module) that was used to setup the Groov Node. In case the detected color is Red, the channel 5 in output Module 1 is turned ON. We introduce another function node that converts the Channel ON/OFF information from the Groov node to pass on a binary Zero or One value that is sent to the Modbus Node (depicted as “pick Red”)

The figure below shows the flow program that was created for this automation. We use a mix of msg.payload and msg.topic properties across different function, MQTT, delay, Groov and Modbus nodes to establish the sequence of control.

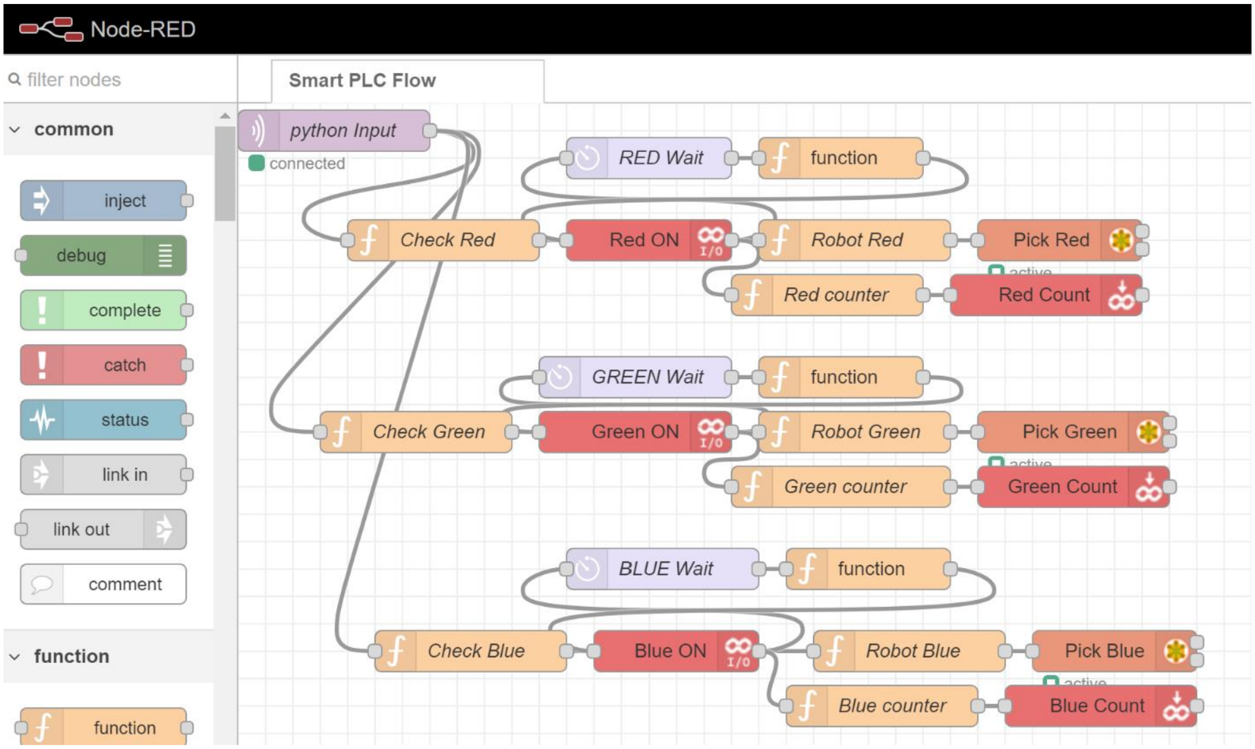


Figure 14: Node-Red Flow used in the Automation

6.5 Modbus-TCP/IP as Communication protocol

Modbus uses TCP/IP and Ethernet to carry the data of Modbus message structure between compatible devices. Modbus TCP/IP combines a physical network (Ethernet), with a networking standard (TCP/IP), and a standard method of representing data (Modbus as the application protocol) [21]. MODBUS bases its data model on a series of tables which have distinguishing characteristics.

For each of the primary tables, the protocol allows individual selection of 65536 data items, and the operations of read or write of those items are designed to span multiple consecutive data items up to a data size limit which is dependent on the transaction function code. The 'read and write general reference' function codes are defined to carry a 32 bit reference number, and could be used to allow direct access to data items within a very large space. [22] The Modbus protocol exchanges information using a request-reply mechanism between a master (client) and a slave (server). The master-slave principle is a model for a communication protocol in which one device (the master) controls one or more other devices (the slaves) [23]

In our scenario, Groov EPIC acts as a Modbus client (Master) and the Universal Robot acts as a Modbus Server (Slave). The Controller requests information from the Universal Robot and the Robot responds/sends back information to the client (response). Before enabling the read/write of modbus address registers, it was important to know the available address registers on the Slave that can be used for data read/write request.

The Address registers on the Universal Robot vary from input discretes, output discretes, input registers and output registers. Each address serves a specific function of the robot action. However, there are also general purpose 16-bit address registers from 128-255 that are unused. We identify these general-purpose address registers in the Universal Robot to use them in the automation control.

First the identified tag addresses are setup in the Groov EPIC controller by feeding the IP address of the slave, address registers and the type of register. In this case, we use address registers from 128 to 133 and input these values in the Modbus setup on Groov. The identified 16-bit registers are read/write enabled which means that these can be read as well as modified using the controller. Similarly address registers are configured in the Universal Robot so that these variables/values can be used in Robot program as required.

Through Node-Red, we send a binary value to the Modbus node that already has the address registers setup. This essentially means that the input to the modbus node is transferred to the actual address register thereby modifying the values. In a way, a communication is established between the Smart PLC and the robot with the Modbus TCP/IP protocol and enabled by the Node-Red flow programming.

The Address registers used in the Universal Robot are referenced in a separate Robot program. For example, the address register 128 is labelled as variable 'Red' in the modbus setup window of the Robot. This variable can be used in various Robot programs and various condition logics referencing the value of this address register. We use If-else conditions in the program referencing these variables and program the robot to perform actions based of the input.

The Entire process flow is explained though an example. A green block detected by the camera, publishes the data (as "Green") to the local MQTT broker under a specific topic. The controller subscribes to this topic as enabled by the Node-Red MQTT nodes. The MQTT node sends data via a function node to turn ON a specific channel in the controller. The state of channel is converted into binary values again through a function node and sent to the Modbus TCP/IP node. The Modbus node, which is configured and setup with the relevant registers and IP, received this information and sends the data to the registers. In this case, since the block detected is 'True' for a green block, a value of 1 is sent to the address register 129 (as configured). Now, the address register 129 holds a value of 1 instantaneously. We program the robot in a way to perform the action of picking up a Green Block and dropping it in a green basket if the referenced variable (for address 129) is changed to 1. In this way, a communication is established between the controller and the Universal Robot enabling the pick and place motion.

6.6 Groov View for Real-time dashboards

With the automation control established by various features supported by the Smart PLC including MQTT, Node-Red and Modbus TCP/IP, it is important to add a visualization element to the data that is collected from the automation system. This is particularly important in a real-world manufacturing shopfloor which is dynamic and needs to be responsive in real-time. The Groov EPIC supports Groov View, a browser-based interface that makes visualization simple by building various dashboards. The user can build, deploy, and view effective operator interfaces for an automation system on a PC or a mobile device.

The Automation system in our case demands a real-time update on various inputs including the status of the block that is being picked up, the count of different blocks that have been picked, the production rate of each of the blocks and other measures of the system. With Groov View, the tags used for Modbus devices can be referenced to dashboards and this helps to use the Modbus tags created for the Universal Robot directly into the Groov View dashboard.

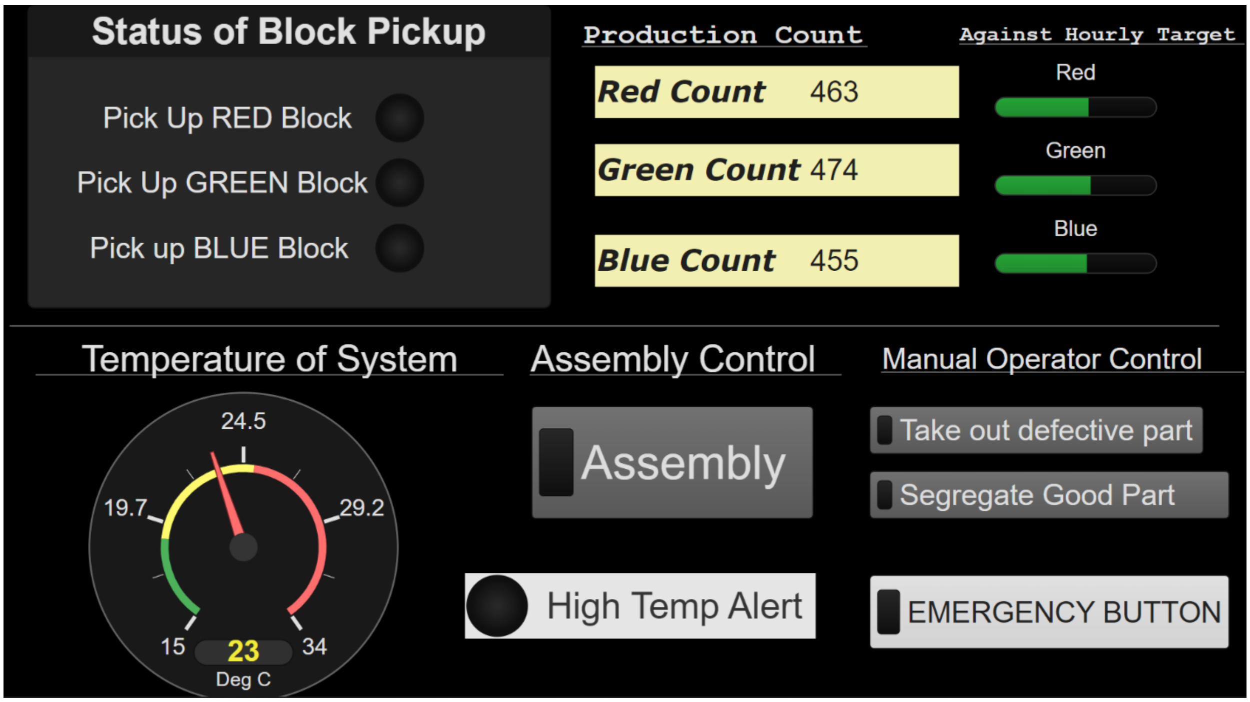


Figure 15: Groov view Dashboard built for the Material handling automation

The above diagram depicts a dashboard created with Groov View for the automation system. The Dashboard includes Status of the Block (Indicated by the respective colors), Production count of the respective blocks, Productivity rate against hourly target for each of the blocks, Temperature of the system (using a Dial Chart), an assembly control button, Alert signals including High temperature and Emergency status and other Manual Operator control options.

The Status of the Block is tagged using the various channels that have been toggle ON/OFF from the Node-Red Flow. As the color of the block is detected, the information is sent via MQTT to the function nodes which in turn toggles the respective channels for each of the colors. These channel tags are referenced in the Groov View Dashboard. So, when a blue block is detected, the subsequent flows in the Node-Red programming turns a specific Channel ON, which when referenced in the Groov View dashboard shows that the green block is being picked up until the channel is OFF. Since the channel needs to be turned OFF after the action is performed, a wait timer is input in the Node-Red flow. This given time delay accounts for the time taken by the robot to complete the pick and play action. Once the delay time is reached, a function node toggles the channel OFF again. Therefore, the status of the block is active only for a given time until the Robot completes the pick and place action.

For the Production count, we have a function node installed in the Node-Red flow that counts the colored blocks every time the channel is ON. This ensures that the count is incremented by 1 when the respective colored blocks is detected and picked by the Robot. The counter has also a reset option wherein the user can reset the count of the blocks if needed. A text box indicating the count of each block is displayed using this function. The Text box is referenced to the output of the node from where the count of the block is obtained. An actual vs hourly target chart also supplements this indicating the efficiency of the production

The Temperature of the system is captured with a temperature sensor that displays data with a Dial Chart. The Dial Chart is input with safe, alert and danger regions as indicated by green, yellow and red colors in the dial chart. The temperature chart also comes with a temperature alert alarm which is turned ON if the temperature value exceeds the danger threshold set by the user. If the danger threshold is exceeded, an event is created such that the alarm button is toggled ON. One step further, we also configured username, email ID's and mobile numbers of different users who would get a text or email alert as soon as the temperature threshold is reached.

With a Smart PLC enabling a host of technologies, it was also important to have a real-time control of the robot by a user not being right in front of the machine. To execute such a scenario, a assembly control option was given in the dashboard. The Assembly control option lets a user to click or tap the assemble button which in turn communicates to the robot to perform a set action. The Communication to the robot is achieved by the Modbus TCP/IP protocol which was explained earlier. A particular address register in the robot is referenced in the Groov view dashboard and the click of the button enables a change in the value of address register which triggers a robot action. With this feature, remote monitoring of automation system is possible, helping operators and production teams to be able to control machines even when they are away. Similarly, various other manual control options including taking out a defective part and segregating a good part are given for the users.

6. Discussions and Future Work

Through the demonstration, it was evident that the capabilities of the Smart PLC like the Groov EPIC is enormous especially from an IIoT standpoint. While the major features of Groov EPIC have been covered, a few including Secure Shell Access, Codesys and OPCUA can still be explored further.

SSH helps to build custom applications using known languages and run them on an open, Linux based automation system such as the Groov EPIC. The SSH protocol provides a secure remote login from one computer device to another. With strong authentication options (including passwords and public key authentication, SSH offers secure access for both users and automated processes. [24] This potentially has a good use case in the Groov EPIC in various automation control directly via the Secure Shell.

Codesys when installed in Groov EPIC supports in using IEC 61131-3 compliant languages including Ladder Diagram (LD). A typical PLC involves using one of the IEC compliant languages and with Ladder Diagram, many of the control logics can be designed and executed with the help of Codesys. In our demonstration, the control logics were largely created through Node-Red, however ladder diagrams can also be effectively used especially when integrating with multiple sensors, actuators, and legacy PLC's

The Ignition and Ignition Edge platforms installed in Groov EPIC supports OPC UA. OPC Unified Architecture (OPC UA) is a cross-platform, open-source, IEC62541 standard for data exchange from sensors to cloud applications developed by the OPC foundation. [25] With Ignition Edge, OPC UA drivers including Allen Bradley PLC's, Siemens PLC's, Modbus TCP devices are supported. Since Codesys supports OPC UA servers and Node-Red can accommodate OPC UA nodes, there can be tag exchanges between these two powerful features in Groov EPIC. These can be seamlessly integrated with groov view as well.

There are other capabilities including live video recording that can be implemented with the Groov EPIC. Node-Red Flow programming can further be extended by connected to various databases for data retrieval and storage. Node-Red also supports interaction with SAP which opens up various possibilities in integrating a Smart PLC with an internal system. Legacy PLC's can be integrated into the Smart PLC. This feature in particular is extremely useful for organizations that have been dependent on legacy PLC's for a long time and do not want to shift to new controllers at a large scale. The Integration is much simpler, and this is enabled by the various support features like the Ignition Edge.

7. Conclusion

The various capabilities of a Smart PLC like Groov EPIC were demonstrated through this report. Smart PLC supporting a host of features like MQTT, Node-Red, OPCUA, Modbus TCP/IP, Codesys, Secure Shell Access, Web-based Visualization feature like Groov View enables a complete automation system that flattens the IIoT architecture to a great extent simplifying the system and securing industrial communications easily and effectively. With remote monitoring and real-time control getting more and more traction in the smart manufacturing space, a smart PLC could execute these critical real-time features seamlessly.

In the last couple of years, PAC and Smart PLC's have been in demand especially with Industrial companies looking to capitalize on digital advancements and Industrial Internet of Things. With more and more connected devices, Smart PLC's could possibly fill a big gap that has existed in the automation system.

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