“Electroplating process plant automation and management using emerging automation and communications technologies”

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Abstract:

The Electroplating (EP) process industry is currently facing some challenging process control problems in their production plant due to an insufficient level of automation being applied in the industry; the control is largely manual, and the monitoring of both plant and processes is ad hoc. The requirement for higher production volumes, tighter product tolerances, and the eagerness for better quality with lower cost are forcing the electroplating Companies to automate their processes and develop more responsive process and plant monitoring and control systems. Emerging Automation and communications technologies have now made it possible to effectively implement distributed control system (DCS) based control architecture with hybrid (wired/wireless) communication networks in the industry for achieving both process automation and plant management, offering various advantages such as for real-time process plant monitoring and control, plant visualization and provision of management information for control of production throughout the plant. Electroplating process industries comprising plants with numerous process stages and production operations will particularly benefit from implementing DCS where individual process stages and functions are distributed into computing nodes (i.e., control computers and smart devices) that are physically separated; and all the computing nodes are interconnected by advanced hybrid (wired/wireless)

communications networks. The introduction of less expensive and more functional microprocessors has advanced the state of the art in distributed control system technology. This research aims to develop an integrated advanced process monitoring and plant management system for an electroplating industry using emerging automation and communications technologies.

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Papers published

1. N Venkateshaiah, A Zakeri and O L Iliev, "Developing a self-organised Smart Tank Station for Electroplating Process Plant," *2019 IEEE 5th World Forum on Internet of Things (WF-IoT)*, 2019, pp. 680-685, DOI: 10.1109/WF-IoT.2019.8767176.
2. A Zakeri, N Venkateshaiah, K Burnham, O L Iliev " Real Time Plant Monitoring and Control in Electroplating Industry using ZIGBEE and IoT Technology", International Journal of Industrial Electronics and Electrical Engineering (IJIEEE), Volume-6, Issue-6 (Jun 2018) http://www.iraj.in/journal/journal_file/journal_pdf/11-479-154105529844-51.pdf

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Abbreviations

ARM	Advanced RISC Machine
API	Application Programming Interface
AI	Artificial Intelligence
COA	Centre of Area
CSP	Cloud Service Provider
CoAP	Constrained Application Protocol
CAN	Controller Area Network
CSV	Comma-separated values
CPLD	Complex Programmable Logic Device
CAGR	Compound Annual Growth Rate
DC	Direct Current
DR	Disaster recovery
DCS	Distributed Control System
EC	Electrical Conductivity
EP	Electroplating
ERP	Enterprise Resource Planning
FPGA	Field Programmable Gate Array
FLC	Fuzzy Logic Controller
GPIO	General Purpose Input Output
GHz	Gigahertz
HMI	Human Machine Interface
HTTP	Hypertext Transfer Protocol
IIoT	Industrial Internet of Things
ISM	Industrial, Scientific and Medical
IT	Information Technology
IR	Infrared
IaaS	Infrastructure as a Service
IEEE	Institute of Electrical and Electronic Engineer

IC	Integrated Circuit
I2C	Inter-Integrated Controller
IoT	Internet of Things
LwM2M	Light weight Machine to Machine
LAN	Local Area Network
M2M	Machine to Machine
MCL	Management Control System
MES	Manufacturing Execution System
MATLAB	Matrix Laboratory
MAC	Media Access Control
Mbps	Megabits per second
MF	Membership Function
MQTT	Message Queuing Telemetry Transport
OSI	Open Systems Interconnection
PHY	Physical Layer
PaaS	Platform as a Service
PVC	Polyvinyl Chloride
PLC	Programmable Logic Controller
RPi	Raspberry Pi
RX	Receive
RESTful	Representational State Transfer
RTD	Resistance Temperature Detectors
SSH	Secure Shell
SSL	Secure Sockets Layer
SBC	Single Board Chip
SaaS	Software as a Service
SUDO	Super User Do
SOC	System on Chip
TDS	Total Dissolved Solids
TCP/IP	Transmission Control Protocol / Internet Protocol

TX	Transmit
UHF	Ultra-High Frequency
URL	Uniform Resource Locator
UART	Universal Asynchronous Receiver Transmitter
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network

Introduction

1.1. Motivation

Many industries such as Automotive, Aerospace, Electronics, Medical, Textile, etc. use electroplated materials to provide long-lasting corrosion resistance and to improve the quality of the material (Giurlani et al., 2018). For example, Bolts and screws are used to assemble thousands of different projects for many industries and applications. If they do not offer their optimal performance, they can cause products to break and jeopardize the safety of the user. In particular, the aerospace, defence, and automotive industries require the highest quality of bolts. As they need to withstand a wide range of technical challenges. Electroplating is an important process for these industries because it provides superior ductility, corrosion resistance, and hardness (Smith, 2015).

A typical electroplating process plant comprises numerous tanks and process stages and operations, the real-time monitoring and control of which would be very difficult if manual monitoring and control operations are employed in the plant (Venkateshaiah, Zakeri and Iliev, 2019). In such cases some delays in response to process changes are inevitable, and this is particularly the case when the operator responsible for monitoring and control is in doubt or the correct instructions are not available to the operator, he/she needs to consult with and seek a decision from the upper-level control manager. As a result, the change that may happen in solution conditions may lead to undesired quality in products, hence the unsuitability of the batch being produced for meeting the customer’s order. The need for automation of process monitoring and control is well recognised in the electroplating industry and the emerging automation and communications technologies can now be effectively used to implement smart control systems in the industry for achieving both automatic process monitoring and control, and real-time management of product quality, production, and plant management (Mir and Rajguru, 2018).

The higher production volume, tighter product tolerances, and the eagerness for better quality with lower cost are forcing the electroplating companies to automate their processes and develop more responsive processes and real-time plant monitoring and control system (Venkateshaiah, Zakeri and Iliev, 2019).

This PhD thesis describes the design and development of an integrated real-time monitoring and control system for an electroplating plant using IoT and cloud technology is described. In an electroplating process plant, the continuous maintenance of the optimum condition of process solution in the process tanks along the production line is essential for achieving the final desired quality of products (Venkateshaiah, Zakeri and Iliev, 2019). However, this is a complex task requiring simultaneous monitoring and control of several variables of the process solution such as temperature, pH, density, conductivity, water level, current and the voltage supplied to the tank. Any variation in the specified values of these variables affects the quality of the product and disturbs the achievement of the scheduled production volume if the changes in process variables are not responded to on time.

In this introductory chapter, the motivation for this PhD thesis is described in section 1.2. The objective of the thesis is presented in section 1.3. The outline of the thesis is described in 1.4. Finally, section 1.5 provides a summary of the thesis contributions.

1.2. Problems

- Large manual work/labour.
- Large wastage (Excess use of material, electrolyte spillage).
- Difficulties in maintaining the consistency of solution conditions.
- Difficulties in controlling and maintaining the process operation.
- Difficulties in maintaining consistency in product quality.

- Undesirable direct exposure of workers to hazardous chemicals and possible accidents.
- Need for great manual intervention to maintain barrels/jobs switching time.
- Difficulties in maximising process capacity utilisation.
- Difficulties in maximising plant capacity utilisation.
- Barriers to increasing plant throughput and productivity.
- And other problems as the study may reveal.

1.3. Objective of the Thesis

This research aims to develop an integrated advanced real-time process monitoring and plant management system for an electroplating industry using emerging automation and communications technologies.

To meet this goal, the following objectives are set:

1. Develop an IoT-based smart tank station for an electroplating process plant.
    - Smart Temperature control system
    - Smart pH control system
    - Smart Level control system
    - Smart Conductivity control system
2. Develop an IoT-based smart process control system

- Plating time management
- Agitation system

1.4. Outline of the Thesis / Organization of the Thesis

This thesis is organized into chapters as follows:

Chapter 2: Literature review
Chapter 3: Current manufacturing environment
Chapter 4: Distributed control system
Chapter 5: Designed architecture / proposed system
Chapter 6: Data Collection
Chapter 7: Conclusion and Future works
References
Appendices

1.5. Thesis Contribution

The main contributions of the thesis are:

- Electroplating tank parameters such as Temperature, pH, Conductivity, plating time, and solution level are measured and recorded in real-time for remote monitoring and management of the production line plating tank solution.
- Conductivity of the water is monitored and controlled remotely.

- A smart level control system is built for remote monitoring and control of the electroplating tank level.
- A smart temperature control system is installed in the Nickel-plating tank solution and its output (the temperature reading) is monitored via ThingSpeak web-based platform in real-time.
- A smart pH control system is installed in the Nickel-plating tank solution and its output (the pH readings) is monitored via ThingSpeak web-based platform in real-time.
- Measured plating tank parameters are controlled and maintained using actuators with fuzzy logic techniques. Which has reduced maintenance costs.
- The temperature range can be altered remotely and it can be set to any desired range according to the product specification.
- The Smart sensors are calibrated and tested for tolerance for extreme environments.
- A reliable temperature sensor is used and tested to withstand corrosion or other damages.
- By the installation of smart sensors and actuators in the plating bath the variable parameters are optimized and the quality of the solution is maintained, hence Manufacturing Efficiency is enhanced and the plating conditions are optimized.
- The current manual data-entry process and paperwork which is manually updated by the operators about the changing parameters

in the production line is replaced with real-time monitoring and record system. This eliminates manual labour.

- The control of production line parameters enhanced manufacturing efficiency, production profitability and increased machine utilisation.
- Plating tank parameters plays important role in determining the quality of the plating product and the productivity of the plating process plant. Hence, by monitoring and controlling these variable parameters the plating quality is assured, which in turn increased customer satisfaction.
- The real-time remote monitoring and management of the production line plating tank solution have helped with an on-site analysis of failures.
- The real-time remote monitoring and control of the hoist will reduce onsite accidents such as getting knocked into the plating solution because of the momentum of the hoist.

Contribution to the knowledge:

- This research would shed light on how IoT product system features can help in Electroplating Process Plants.
- This research is one of the first empirically tested impacts of IIoT-enabled digitalization capabilities in the Electroplating industry.

- This research also contributes to the discussion on the role of digitalization in electroplating production line control.
- The cloud storage technology is used to collect and record production line data in real-time for remote monitoring and control.
- Wireless sensors and actuators are used for automation.

Literature Review

2.1. Electroplating Process

There is a demand for adaptable manufacturing processes in the metal processing industry for a wide range of applications. One of the most important applications is metal surface engineering which determines product functionality. A few different techniques are being used such as physical vapour deposition (Puippe, 2021), laser technology (Salvietti et al., 2018) (Tassin et al., 1996), thermal spray and electroplating process (Khedekar et al., 2016) (Zangari, 2015), the latter is one of the most effective ones. Electroplating gained interest starting in 1840, in Birmingham, England (Ramanarayanan and Chun, 2008). This led to the establishment of Birmingham as the industrial centre for electroplating. Electroplating technology has been rediscovered after the Second World War with the discovery of semiconductors and the growth of the electronics industry, especially in the metallization of printed wiring boards. In a recent development, due to a deeper knowledge of the electrochemical process theory as well as research on new materials and emerging technologies this technology is moving towards a more flexible and interconnected production. In 2015 electroplating represented around 37% of the total market share within the metal finishing sectors and it is expected to increase at a compound annual growth rate of 3.7% over the forecast period of 2016–2026, projecting revenues of over US

$21 billion by the end of 2026 (Kang et al., 2016) (Venkateshaiah, Zakeri and Iliev, 2019).

Electroplating is an electrochemical process for depositing a layer of metal upon a metallic or another conducting surface to enhance the appearance or properties of the component and provide a protective coating (Fotovvati, Namdari and Dehghanghadikolaei, 2019). Electroplating is a form of electrodeposition.

The electroplating process essentially involves two electrodes, the electrode which is positively charged is known as the anode and the other electrode which is negatively changed is the cathode (Mittal, 2020). The electric current is passed between two electrodes immersed in an electrolyte, the electrolyte contains electrically charged particles or ions. When a voltage is applied between the electrodes these ions migrate towards the electrode with the opposite charge; molecules from the positively charged ions move to the cathode and negatively charged ions to the anode. Once the electrical current starts flowing, it results in the transfer of electrons between the electrodes. The electrical energy is supplied by a DC power source such as a rectifier (Mittal, 2020).

The basic electrical circuit for electroplating is shown in Figure 1 (Nickel Institute, 2014), where the product to be plated is made into an anode submerged in the plating bath, and the cathode is the plate metal (i.e., nickel for nickel plating). A DC is applied on them to the plate. The following reaction is occurring at the poles.

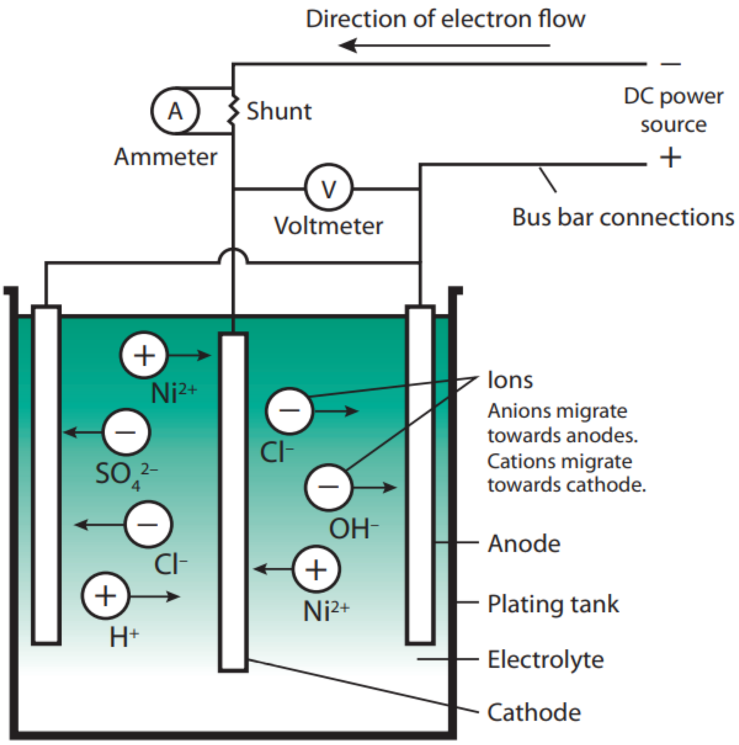


Figure 1: Basic electrical circuit for electroplating (Nickel Institute, 2014).

Although a wide range of metals can be electrodeposited, this thesis is restricted for the discussion on nickel plating.

2.1.1. Factors affecting electrodeposition

According to (Kumar, Pande and Verma, 2015) parameters such as current density, temperature, agitation system, bath pH, bath concentration and plating time play important roles in determining the quality of the plating product and the productivity of the plating process plant.

Variable parameters and the operating conditions that affect the electroplating process of nickel solution and the quality of the finished product are given in the Table below:

Table 1: Variable parameters and operating conditions of nickel solution.

Variable Parameters	Operating Conditions
Temperature	50 - 65 °C
pH	3.5 – 4.5
Level of the solution	The barrel must be completely immersed in the solution
Time	1-hour 10 minutes
The conductivity of the water used	0.1
The density of the solution	50 – 56 TW
Current supplied	Depends on the material and load size.

The effects of electroplating parameters are described below,

Effects of Temperature:

An increase in bath temperature increases solubility and thereby the transport number, which in turn leads to increased conductivity of the plating solution and decreases the viscosity of the solution, thereby replenishing the double layer relatively faster. In general, this increases the crystal size. The hydrolysis of nickel sulpha-mate produces sulphate and ammonium ions which greatly increases the tensile stress of the deposit (Nickel Institute, 2014). Hence, it is vital to maintain the temperature below 65°C to avoid hydrolysis of the nickel sulpha-mate. If the temperature decreases the hardness and tensile strength increase and decreases the ductility. To maintain the required grain size for the metal deposit it is necessary to maintain the temperature between 50 to 65°C (Kumar, Pande and Verma, 2015).

Effects of pH:

The pH is a measure of the hydrogen ion concentration, or more simply the acidity, of a solution. In the case of nickel solutions, pH has an important influence on bath performance. The pH can affect the bright plating range, cathode efficiency, effects of impurities, throwing power, stress, as well as the physical properties of the deposit (Nickel Institute, 2014).

When insoluble anodes are used, the pH of the solution in the vicinity of the anodes will fall due to the liberation of hydrogen ions from the oxidation of water at the anode surface. At the same time, oxygen and/or chlorine will be released. These can oxidise some organic additives in the solution. Chlorine can also lead to health concerns. These effects become significant when more than 20% of the total bath current passes through insoluble anodes (Panizza and Cerisola, 2004).

Across the full spectrum of metal finishing operations from pre-treatment, through plating, to wastewater treatment, pH is a critical indicator of the chemical processes. In several processes, pH level ranks among the critical values that influence plating rate and throughput. In others, such as environmental regulation, accurate pH monitoring is essential to documenting regulatory compliance. Surprisingly, many individuals responsible for ensuring product quality, resource efficiency, regulatory compliance, and plant profitability, may simply take pH testing for granted (Joseph, 2003).

pH measurement is essential to making up baths that function as expected. Equally importantly, the optimal replenishment of individual bath chemistry components needs to deliver consistent operation hour after hour, day after day. Timely and accurate pH monitoring enables the most tightly controlled replenishment strategy, helping to avoid wild swings in bath composition and avoiding the risk of “poisoning” a bath from adding too large a quantity of a chemical. The criticality of maintaining proper pH varies with the plating operation. In the rinse tank for a wide range of plating operations, extreme pH values can result in a product that is undesirably spotty or uneven in finish, colour, or texture (Kumar, Pande and Verma, 2015) (Nickel Institute, 2014).

Effect of Plating time:

According to Faraday’s Law of electrolysis “*the quantity charge flow, ‘Q’ in the solution is proportional to the current flow, ‘I’ and also the Flow time, T”* as shown in the equation below: (Dahotre and Sudarshan, 1999)

$$Q = I \times T \qquad \text{--- Equation (1)}$$

Where,

Q = Quantity charge flow

I = Current flow

T = Time

The plating thickness is directly proportional to the plating time and current/amperage supplied (Kumar, Pande and Verma, 2015).

Effects of Conductivity of water used for electroplating:

Raw water as it comes from a lake, river, or tap is rarely suitable for industrial use. The water contains contaminants, largely ionic, that if not removed will cause scaling and corrosion in plant equipment, particularly in heat exchangers, cooling towers, and boilers. The demineralization process is adopted to remove all or nearly all the contaminants. The main goal is to remove only certain contaminants, such as hardness ions like calcium and magnesium (Rosemount Analytical, 2010).

The measurement of conductivity is important in the electroplating industry, it is the capacity a solution has for conducting an electrical current. The conductivity of water is an indication of the number of ions and/or free-flowing electrons that are present for the conduction of electricity (Cloete, Malekian and Nair, 2016) (IC Controls, 2017). Conductivity is a measurement of the total concentration of ions in a solution for the determination of impurities in the solution (Kumar, Pande and Verma, 2015).

Effect of Solution Level:

The plating solution level must be maintained at the required level, Optical level sensors are used to control the solution level of the plating tank. When the barrel is moved from one tank to another it alters the level of the solution, if the level of the solution is not maintained, the load immersed in the tank might not be completely covered with the solution, resulting in uneven plating (Venkateshaiah, Zakeri and Iliev, 2019).

Effect of Agitation:

Agitation provides sufficient mixing of a metal salt by which the chemical reagent becomes intimate and reacts with each other. It replenishes metal salts or ions at the cathode and reduces the thickness of the diffusion layer. Agitation reduces the gas bubble and helps to increase the operating current density and thereby permitting a higher operating current density. Maintaining a proper agitation system can greatly improve the plating performance (Venkateshaiah, Zakeri and Iliev, 2019) (Kumar, Pande and Verma, 2015).

2.2. Raspberry Pi

The Raspberry Pi platform has become a very interesting choice for IoT applications since it provides a very powerful/low-cost platform with good hardware expansion capabilities (different ports, General Purpose Input/output (GPIO), pins) and standard connectivity (Ethernet, Wi-Fi interfaces) (Calvo et al., 2016) (Balasubramaniyan and Manivannan, 2016). Even though alternative Single-Board Computers (SBC) providing similar characteristics are available in the market, the price of the Raspberry Pi is very competitive because it is a credit card-sized Linux computer initially designed for education, but it has become a mass product (Calvo et al., 2016) (Venkateshaiah, Zakeri and Iliev, 2019).

The smart tank will include both smart sensors and smart actuation, this way it self-regulates and organizes itself. Multiple sensors and actuators can be connected and controlled at the same time due to these GPIO pins. GPIO (General Purpose Input Output Pins), allows the user to make the pins as input or output according to the necessity.

2.2.1. Software and programming language

The Debian-based Linux Operating System (Raspbian) is used as recommended by the Raspberry Pi Foundation. Raspberry Pi uses AMR-based Broadcom BCM2711 System on a Chip (SOC) with a 1.5 GHz 64-bit quad-core ARM Cortex-A72 processor, with a 1 MB shared L2 cache. Raspberry Pi Foundation specifically selected Python as the main language because of its power, versatility, and ease of use (The Raspberry Pi Foundation, 2022). Python is preinstalled on Raspbian. There are many different options for writing python on the Raspberry Pi, PuTTY is one of the simplest. It is a software application that can run from the desktop or laptop computer to access the Raspberry Pi command-line interface. It uses SSH (secure shell) to open a terminal window on the computer, which can be used to send commands to the Raspberry Pi and receive data from it (Circuit Basics, 2020).

2.3. IoT

The IoT is coined in 1999 by Kevin Ashton, an expert on digital innovation. The first version of the Internet was about the data created by people, while the next version is about data created by things. The best definition for the IoT would be:

> *"An open and comprehensive network of intelligent objects that can auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment"* (Madakam, Ramaswamy and Tripathi, 2015)

The internet of things (IoT) is a system of interconnected digital devices, machines, objects, animals or people equipped with radio frequency identification chips and similar technologies with unique identifiers and the ability to transmit and share data over the network without the need for human interaction (Gillis, 2022). IoT represents the next evolution of the Internet, taking a massive leap in its ability to gather, analyse, and distribute data that can turn into meaningful information. IoT can also be referred to as the "Internet of Objects".

The internet is a global system of interconnected computer networks that use the standard internet protocols suite (TCP/IP) to serve billions of users worldwide. It is a network of networks that consists of millions of private, public, academic, business, and government networks, of local to global scope, that are linked by a broad array of electronic, wireless and optical networking technologies (Madakam, Ramaswamy and Tripathi, 2015). in the big data era, recording from several such environments and users is extremely valuable from a statistic as well as a business and economic point of view. Due to the decreasing cost of implementation of the IoT device and the increasing demand, the IoT paradigm has a huge impact on both consumers' lives and business models. As shown in Figure 2 (Capra et al., 2019) the IoT trend is expected to increase rapidly (ForgeRock, 2021).

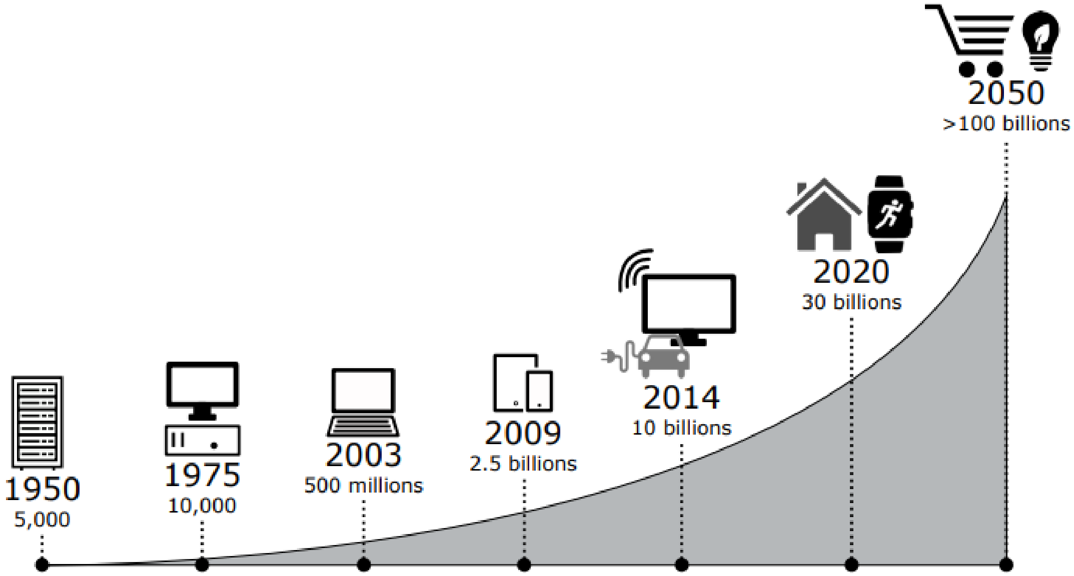


Figure 2: Expected adoption growth of IoT devices (Capra et al., 2019).

Gartner's Chart, the world's leading company in research and advisory fields has stated that IoT Technology is among the top 5 technologies (Sailaja and Kumari, 2021). A recent report projects the number of

Internet of Things (IoT) devices worldwide is forecast to almost triple from 8.74 billion in 2020 to more than 25.4 billion IoT devices in 2030 (Vailshery, 2022). IoT devices are used in all types of industry verticals and consumer markets, with the consumer segment accounting for around 60% of IoT-connected devices in 2020. This share is projected to stay at this level over the next ten years. Figure 3 (Vailshery, 2022) shows the number of IoT-connected devices worldwide from 2019 to 2030.

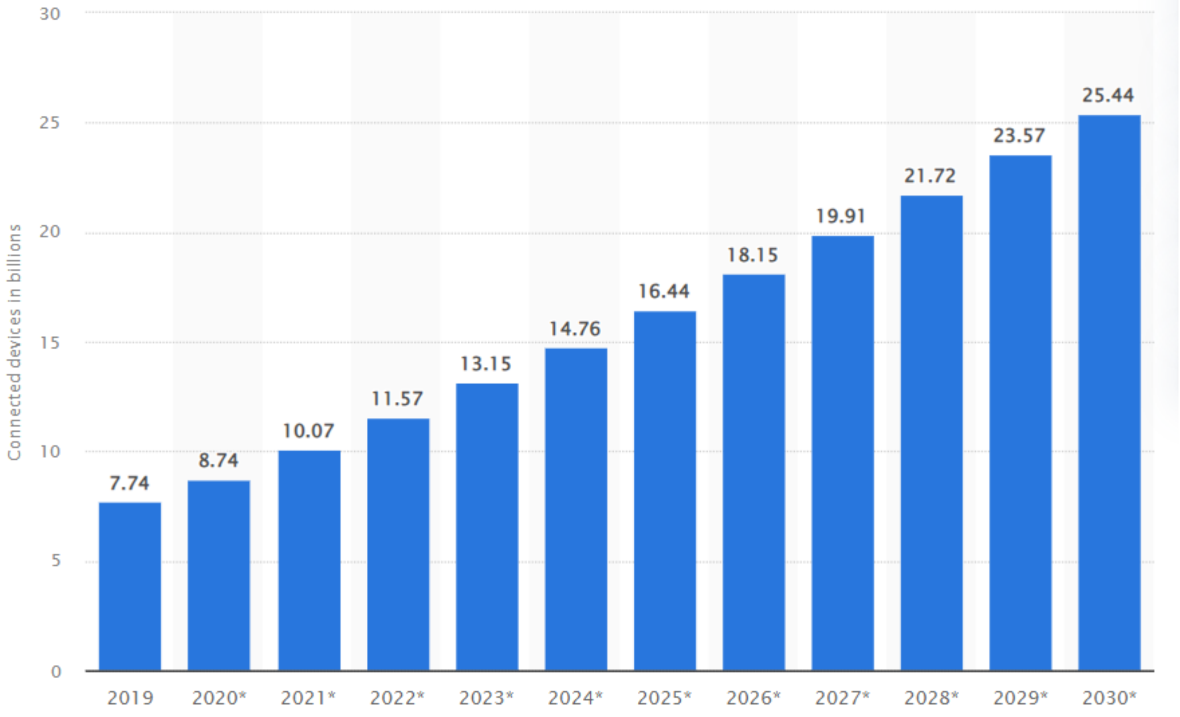


Figure 3: Number of IoT-connected devices worldwide from 2019 to 2030 (Vailshery, 2022).

A report from Emergen Research projected that the global Internet of Things (IoT) connectivity market size reached USD 5.91 Billion in 2021 and is expected to register a revenue CAGR of 24.1% through 2030 (Newsdesk, 2022).

2.3.1. Background of IoT

To make the IoT work there are multiple layers of software or processes which are known as the IoT technology stack; they are,

a) Device hardware, which acts as an interface between the real and the digital world. These devices can be turned into connected devices with the addition of necessary instrumentation by adding sensors or actuators along with the appropriate software to measure and collect the necessary data (Tournier et al., 2020) (Madakam, Ramaswamy and Tripathi, 2015).

b) Device software, is used to implement the communication with the cloud, for collecting data, integrate devices as well as performing real-time data analysis within the IoT network (Tournier et al., 2020).

c) Communication, includes both physical connectivity solutions (Cellular, satellite, LAN) and specific protocols used in varying IoT environments like ZigBee, Thread, Z-wave, MQTT, LwM2M). Choosing the relevant communications solution is one of the vital parts of constructing every IoT technology stack since it determines how the data is sent or received from the cloud and also how the devices are managed and how they communicate with third-party devices (Tournier et al., 2020).

d) Platform, is the place where all of the data collected from the device hardware and software through the communication layer is gathered, managed, processed, analysed and presented in a user-friendly way (Tournier et al., 2020).

In this research, the MQTT data protocol is used to transfer data from the Raspberry Pi microcontroller to ThingSpeak cloud storage. MQTT is much broader and it warns the user if the data is not being transmitted successfully.

Protocols for IoT qualified devices: IoT protocols and standards are broadly classified into two separate categories i.e., IoT data Protocols, and Network Protocol for IoT.

Protocols

TCP/IP:

The Transmission Control Protocol/Internet Protocol (TCP/IP) suite has become the industry-standard method of interconnecting hosts, networks, and the internet. It is seen as the engine behind the Internet and networks worldwide (Parziale et al., 2006). The TCP protocol expects that addresses be written in terms of an IP address and a port number. An IP address is a 32-bit identifier that uniquely identifies a network interface connected to the Internet. Every network interface that is connected to the Internet has an IP address (Medhi and Ramasamy, 2018). The TCP and IP are two separate protocols operating at different TCP model layers and OSI levers.

The IP standard defines the behaviour of the packet, it commands the packets where to go and how to get there. Whereas the TCP is responsible for synchronous and reliable data transmission over Internet connection networks. The TCP is a connection-oriented protocol, which means a connection is established and maintained until the client and server have finished exchanging the data with each other. It is safer to use TCP/IP protocol since the transmitter gets proper acknowledgement whether the packet is being delivered or not (Parziale et al., 2006).

MQTT:

MQTT is a lightweight message queueing and transport protocol. It is suitable for the transfer of telemetry data such as sensors and actuators. It is very lightweight and suitable for M2M (Machine to Machine), WSN (Wireless Sensor Networks) and IoT (Internet of Things) scenarios where sensors and actuator nodes communicate with applications through the MQTT message broker. MQTT is a publish/subscribe model that runs over TCP/IP sockets or Web-Sockets (Hunkeler, Truong and Stanford-Clark, 2008). It receives subscriptions from clients on topics, receives messages from clients and forwards these, based on clients' subscriptions, to the interested clients.

MQTT minimises network bandwidth and device resource requirements and also attempts to ensure reliability and delivery. This approach makes the MQTT protocol particularly well-suitable for connecting machine-to-machine, which is a critical aspect of the emerging concept of the IoT. MQTT over Web-Sockets can be secured with SSL. SSL (Secure Sockets Layer) is a security protocol that creates an encrypted link between a web server and a web browser (Soni and Makwana, 2017).

HTTP:

HTTP uses the Transmission Control Protocol (TCP) to deliver data between the HTTP client and the HTTP server. It is the most widely used and available protocol. Almost all computing devices with a TCP/IP stack have it. It uses a request and response model, which is currently the most common message exchange protocol. HTTP uses a text format, not a binary format, which allows for lengthy headers and messages. The text format is readable by human beings. Therefore, it is easy to troubleshoot (Boyd et al., 2014).

Wi-Fi:

Wi-Fi (Wireless Fidelity) is the most popular IoT communication protocol for wireless local area networks (WLAN) which utilizes the IEEE 802.11 standard through 2.4 GHz UHF and 5GHz ISM frequencies. The device which is connected to the Wi-Fi gets access to the internet if the devices are within the range of about 20 – 40 meters from the source. The data rate is up to 600 Mbps maximum, depending on the channel frequency used and the number of antennas. The Raspberry Pi is one of the most popularly used boards for IoT applications using Wi-Fi (Parekh, 2017).

ZigBee:

ZigBee (Choy et al., 2010) is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection and other short-range, low-powered device. It is a low-cost device which is used as the main communication link between the gateway and sensor network to transfer data from one end to another wirelessly within the range, the maximum transmission range is possible between 10 and 75 meters (Tørresen, Renton and Jensenius, 2010). ZigBee networks are extendable with the use of routers and allow many nodes to interconnect with each other for building a wider area network (Zakeri et al., 2018).

ZigBee protocol stack consists of four layers shown in figure 4 (Gill et al., 2009), where the Physical layer and MAC layer are defined in the IEEE 802.15.4 standard and the Network layer and Application layer are defined in the ZigBee specification.

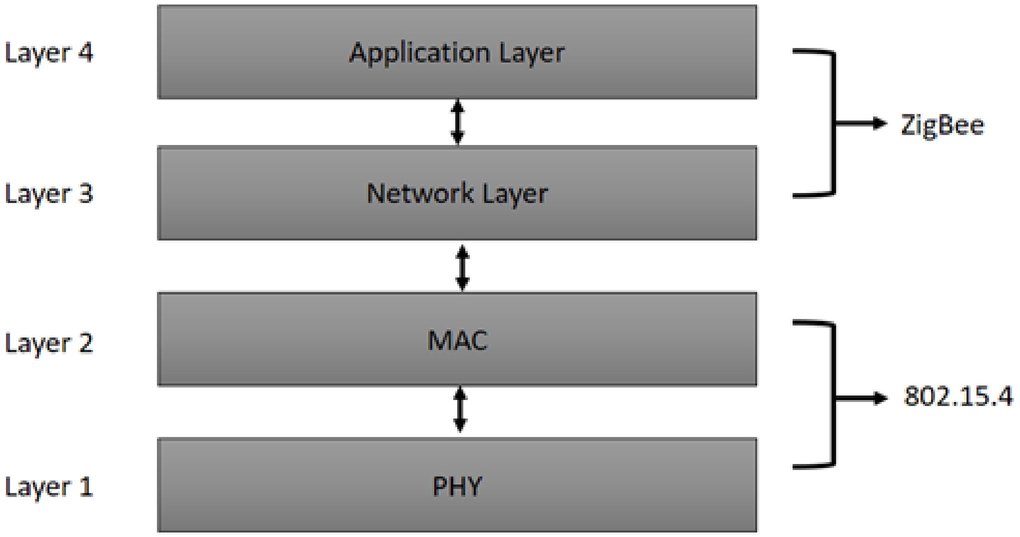


Figure 4: ZigBee protocol stack

Physical Layer (PHY):

This layer modulates the transmitting signal and demodulates receiving signal. It consists of 3 frequency bands at 2.4GHz, 915MHz and 868MHz. At 2.4GHz there are a total of sixteen different channels available and the maximum data rate is 250 Kbps for 915MHz there are ten channels and standard support a maximum data rate of 40 kbps, while at 868 MHz there is only one channel, and this can support data transfer at up to 20 kbps (Tørresen, Renton and Jensenius, 2010) (Farahani, 2008).

Media Access Control Layer (MAC):

It defines the basic packet and frame structures. The IEEE 802.15.4 specification defines four basic frame structures that can be used for receiver tests to ensure that the ZigBee receivers can respond appropriately to the generated commands. The specification has incorporated a variety of features to ensure exceedingly reliable operation. These include a quality assessment, receiver energy detection and clear channel assessment (Farahani, 2008) (Zakeri et al., 2018).

Network and Security Layer:

This layer is for network-related operations such as network setup, end device connections and disconnection to network, routing, device configurations etc. ZigBee uses a hierarchy of keys to manage security. There are three types of keys: Master, Network, and Link. The keys are distributed from a ZigBee "Trust Centre". Link Keys are for unicast communication while Network Keys are for broadcast communication. The Master Key initially shares secrets between two devices performing the key establishment procedure to generate the Link Keys. Link Keys are used to secure unicast messages between two devices at the Application Layer (Farahani, 2008).

Application Layer:

This layer is responsible for decoding and execution of commands in a ZigBee network (Farahani, 2008). It controls of payload in the frames received or to be transmitted. This layer enables the services necessary for ZigBee device objects and application objects to interface with the network layers for data managing services. This layer is responsible for matching two devices according to their services and needs. The frame format used in the application layer (Tesan, 2012) consists of the following fields.

- Frame Format; Single/Multi, broadcast frame header,
- Application command class,
- Application command,
- Command parameter1-to-X

2.3.2.Industrial Internet of Things or Industry 4.0

The Industrial Internet of Things (IIOT), is presented as a revolution that is changing the face of industry in every insightful manner (Karmakar et al., 2019). There is a huge chance, that the Industrial Internet of Things

(IIOT) or Industry 4.0 will replace simple and repetitive jobs such as production assembly, administration, quality control, and planning. The term Industry 4.0 means the "Fourth Industrial Revolution"; The First Industrial Revolution was made when mechanized steam and water-powered engines were introduced. The Second Industrial Revolution was made when Electrical power was used for mass production assembly lines. The Third Industrial Revolution was when the Automated production of computers, IT systems and Robotics were extensively used in the market (Bassi, Sep. 2017: 1-6). The fourth industrial revolution was first proposed in Germany as Industry 4.0 in the year 2011 and an Industrial Internet concept in the United States. There are several definitions, one of which is defined below,

> *"The industrial internet is an internet of things, machines, computers and people enabling intelligent industrial operations using advanced data analytics for transformational business outcomes, and it is redefining the landscape for business and individuals alike" (Boyes et al., 2018).*

As mentioned in (Qin et al., 2021) IIOT generally consist of four layers which are the device layer, network layer, service layer, and content layer. Data generated will be collected on the device layer, the collected data will be transferred to the network layer, the service layer is used to analyse the data and finally, a content layer is used to present the analysed data.

2.4. Cloud Computing

Organizations are moving to the cloud in record numbers, with an estimated 45% of IT spending shifting will shift from traditional solutions to the cloud by 2024 (ForgeRock, 2021).

According to **Emergen Research**: The cloud segment accounted for the largest revenue share in 2021. Cloud computing allows companies to store and analyse data quickly and in real-time, allowing them to get the most out of their data. Companies do not have to deploy a lot of hardware or configure and manage networks and infrastructure when they use cloud computing. Cloud computing also allows companies to scale up their infrastructure based on their requirements without having to invest in additional hardware or infrastructure.

Cloud adoption is unstoppable. Tasked with delivering new digital initiatives ahead of the competition, business and IT leaders are under pressure to take advantage of the speed, flexibility, and cost savings the cloud promises. Gartner estimates that "Seventy per cent of enterprise workloads will be in the cloud by 2024, yet three out of four organizations do not have a fit-for-purpose cloud strategy" (Gartner, 2021). To succeed with the cloud implementation, one address the top trends driving the future of the cloud.

Cloud computing provides several computing resources such as storage, database, servers, artificial intelligence (AI), networking etc. The cloud service eliminates the need for on-premise servers or IT hardware resources by making the services available over the internet. The importance of Cloud Computing is classified into three categorised as mentioned below,

Efficiency: The concept of accessing data from anywhere through the internet has enhanced the efficiency of the workforce. The services are billed as per a pay-as-you-go model. The Cloud Service Provides (CSP) deploy the best disaster recovery (DR) and backup plans to give the deploying enterprise added assurance (Srivastava and Khan, 2018).

Flexibility: There are several options for cloud storage according to the organisation's needs. The user can choose between cloud storage. The services have become very flexible and can be altered according to a company's business needs. The stored files can be shared in real-time from any part of the world (Srivastava and Khan, 2018).

Strategic Edge: The cloud computing platform offers smooth and agile services, running on automation. This usually increases the efficiency of employees, as the employees do not have to maintain the servers (Srivastava and Khan, 2018).

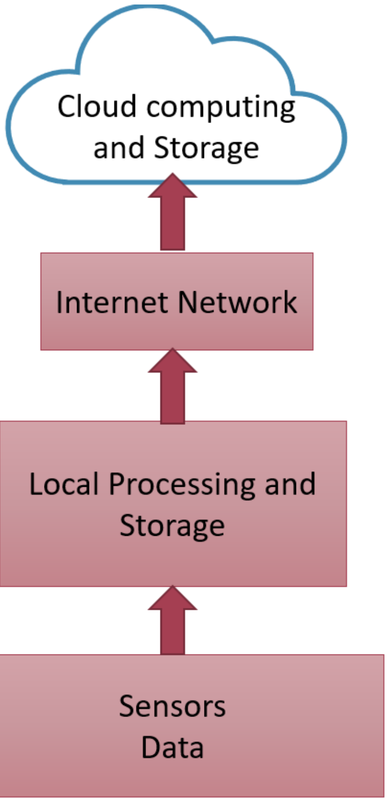


Figure 5: Data flow from the sensor to cloud storage.

Cloud computing has three kinds of services, which are SaaS, PaaS, and IaaS. SaaS; Software as a service is a collection of software available on the cloud. It can be accessed by the end users based on the subscriptions. It works on demand; end users can access the service through this service delivery model directly over the network. PaaS; Platform as a service is a collection of runtime environments such as software and development tools hosted on the provider’s servers. IaaS; Infrastructure as a service is a collection of servers, storage, and networks. In this model, resources like network, storage, virtualised servers, and routers are consumed by a user through a virtual desktop which is provided by CSP (Cloud Service Provides) (Birje et al., 2017).

There are four main cloud deployment models, which are public cloud, private cloud, hybrid cloud, and community cloud. A public cloud is a cloud platform which is under the control of a third-party provider. This cloud model is available for public use by the pay-per-use concept. In this, the customers only pay for the resources they are using. The private cloud is under the ownership of a single organization. It is mainly for the specific use of the organization. Its architecture is different from that of the public cloud. A hybrid cloud comprises two or more different cloud models. The community cloud is more or less like a public cloud but it is for a specific community of cloud users (Birje et al., 2017).

ThingSpeak:

In this thesis, ThingSpeak Web Server is used to monitor and store the data in real-time. ThingSpeak is an IoT analytics platform service that allows users to aggregate, visualise, and analyse live data streams in the Cloud platform. It allows users to send data from any device, create instant visualisation of live data and send alerts. ThingSpeak enables, sensors to send data to the cloud and store it in either a private or a public channel. On the ThingSpeak web service, data visualisation and analysis are conducted using MATLAB (MathWorks, 2022).

A channel is created using Channel Configurations to send and retrieve data to and from the channel. Using the REST API calls such as GET, POST, PUT and DELETE, to create a channel and update its feed, update an existing channel, clear a channel feed, and delete a channel. The MQTT publish method is used to update the channel feed and MQTT subscribe method is used to receive messages whenever a channel is updated. MQTT is used to send data quickly with minimum power consumption and when the device connectivity is intermittent or has limited bandwidth. MQTT receives immediate updates of data posted to a channel without polling the server for new messages (Hunkeler, Truong and Stanford-Clark, 2008).

2.5. Wireless Sensor Network

Sensors play an important part in the automation of any application by measuring and processing the collected data for detecting changes in physical things. Whenever there is a change in any physical condition for which a sensor is made, it produces a measurable response. There are different types of sensors that can range from very simple to complex.

The classification of sensors can be based on their specifications, their conversion method, type of material used, its sensing physical phenomenon, properties that they measure, and the application field.

In an IoT-based smart application, sensors play a key role in the automation of the application by making it smarter to respond without any human intervention. Wireless sensor communications play a key role in the emerging Internet of Things digital ecosystem. As the industry now gets ready to roll out the second generation of IoT devices or is directed to fully standardize the protocol suite of wireless sensor networks, and assure full IP connectivity with devices. The protocols CoAP and MQTT are possible candidates for a highly functional application layer for the Internet of Things in terms of reliable transmissions and adherence to the less verbose attributes of wireless sensor networks where sleep cycles are utilized to keep the overall power utilization of end nodes low (Roger, 2015).

2.6. Fuzzy Logic

Fuzzy logic is a kind of logic where the truth values of parameters may be any real numbers having a range between zero and one. The fuzzy logic is different from that of Boolean logic where the values are either 0 or 1 exactly. Fuzzy logic is a control and flexible system methodology for solving different kinds of problems (Klir and Yuan, 1995).

Fuzzy logic has numerous applications in several fields. The design of fuzzy logic is very simple and robust, the fuzzy logic comprises,

- Fuzzification
- Inference Engine
- Defuzzification.

Fuzzification:

Fuzzification is the process of converting a crisp input value to a fuzzy value that is performed by the use of the information in the knowledge base. Gaussian, triangular, and trapezoidal are the most commonly used membership functions in the fuzzification process. These types of MFs can easily be implemented by embedded controllers. The MFs are defined mathematically with several parameters. To fine-tune the performance of an FLC, these parameters, or the shape of the MFs, can be adapted (Kayacan and Khanesar, 2015).

Inference Engine:

The procedure through which fuzzy logic map a given input to output using some formulas is called fuzzy inference. The rule base in this inference step uses the rule firing strength for the fuzzy logical implication of the output variables. The mapping can be used for making a decision. The rule base implies the output variable. ‘IF’ & ‘AND’ functions are used to set the rules. The fuzzy inference process includes fuzzification using the membership function of crisp values, the operator of fuzzy logic, and IF-THEN rules (Kayacan and Khanesar, 2015).

Defuzzification:

It is the process of obtaining a single number from the output of the aggregated fuzzy set. It is used to transfer fuzzy inference results into a crisp output. In other words, defuzzification is realized by a decision-making algorithm that selects the best crisp value based on a fuzzy set. There are several forms of defuzzification methods, the most commonly used defuzzification method is the Centre of Area method (COA). Which is also known as the Centroid method (Correa, 2001) (Kayacan and Khanesar, 2015).

This method returns a precise value depending on the fuzzy sets’ center of gravity. The overall area of the membership function distribution used to describe the combined control action is divided into several sub-areas (such as triangle, trapezoidal, etc.). The area center of gravity, or centroid, of each sub-region, is calculated. Then the sum of all these sub-areas is used to determine the defuzzified value for a discrete fuzzy set. If the inputs are changed into the fuzzy inference system, then the logical statements are affected which changes the degree of membership in the output sets and changes the centroid location resulting in different output values (Klir and Yuan, 1995).

2.7. Review of Previous Works and Observation

(Choy et al., 2010). Developed a distributed control architecture for electroplating applications. They proposed a decentralized (distributed) approach to address the limitations in an electroplating line control system by applying a hybrid wired and wireless distributed architecture by using ARM-based controllers for rectifier control, temperature control, and hoist control. In this paper, they built an HMI device using CAN wired network to connect to the gateway, allowing operators to control and configure the electroplating line system and a data management system for recording essential production and system performance. They used ZigBee wireless network to facilitate the system diagnosis. The paper also proposed a condition monitoring configuration for the distributed control network.

(Kumar, Pande and Verma, 2015). Investigated the influences of several electro position parameters for Nickel Titanium oxide plating. They conducted a simple lab-scale experiment to deposit a Titanium oxide coating on a Nickel electrode by using a Watts bath. Their experiment found that pH, Current density, Temperature, Time, Metal Ions, Concentration Bath, and Agitation are important factors in the Electrodeposition process. The paper concludes that by controlling these factors the optimum condition for the plating solution will be achieved which improves the plating quality and reduces the production cost.

(Priya, Eswari and Akilakumari, 2015) present an Industrial WSN in IoT Environment Interface with Smart Sensor Using ARM. This system is to develop a sensor interface device that is essential for sensor data collection of industrial Wireless Sensor Networks i.e., WSN in an Internet of Things (IoT) environment. In the proposed system ARM is adopted as the core controller at the time of interfacing for industrial WSN in IoT atmosphere so that it will scan information in parallel and in real-time with high speed on multiple completely different device information and for this Intelligent device interface specification is adopted. Different Sensors are used to provide the values of Temperature, Vibration, and Gas present in the industrial environment, so that critical situations can be avoided and preventive measures are successfully implemented. The result of the system gives the value of Temperature 67.4c. If Vibration and Gas sensor is either Low or Medium, it means Low indicates that there is no gas and vibration, and then Medium indicates there is a Gas and Vibration present

(Garg and Ansari, 2019) In this paper, the authors have proposed the method to automate home appliances using ARDUINO and REST architecture. In this paper, they have used RESTful web server over SOAP-based web server, since it does not have any official standard and it is highly maintainable, scalable and lightweight (Ferreira, Dias Canedo and de Sousa, 2013). It is mentioned in the paper that RESTful web server is mostly used to create API for web-based servers and is the best way to combine HTTP and web servers, and it creates URL to each resource which makes it easy for the client to use these URL sets to get what is required. According to the result they have obtained it is proven that the use of ARDUINO UNO and REST architecture is beneficial as compared to other available resources in the field of IoT.

(Gaikwad, Chincholikar and Kharde, 2015) Provided an overview of IoT and technologies used in IoT. In this paper, they have reviewed several smart and standard technologies like ZigBee, Radio frequency identification, WSN (Wireless Sensor Network) and actuators etc. to develop IoT-based monitoring and remote operating system. In the survey, it is stated that (Prakash and Hiwale, 2016), proposed a new method to design a reconfigurable smart sensor interface for industrial WSN in an IoT environment, in which is Complex Programmable Logic Device (CPLD) is adopted as the core controller which provides reading data in parallel and in real time with high speed on multiple different sensor data. In their system, they have used IEEE1451.2 intelligent sensor interface specification standard to collect sensor data intelligently. From the result, it is known that they have achieved good effects in practical applications by monitoring water in an IoT environment in real-time. (Tiwari and Kazi, 2015) present “Autonomic Smart Sensor Interface for Industrial in IoT Environment”. This paper provides the new method i.e., the design of a functional smart sensor interface for industrial WSN in an IoT environment with a Field Programmable Gate Array device (FPGA) as a core controller. The FPGA read data in parallel and in real time with high speed on multiple different sensor data and the standard of IEEE1451.4 intelligent sensor interface specification is adopted in their design.

Current manufacturing environment

3.1. Introduction and History of the Plant

The research work was carried out in an electroplating (**Leonardt LTD**) industry that is a specialist in precision presswork and subcontract finishing. Leonardt LTD was **established** in **1856** in the West Midlands, by Diedrich Leonardt to manufacture dip pens. Diedrich Leonardt expanded their business in 1863 and 1867, as D Leonardt & Co. where they developed large export market in South America and Eastern Europe, and produced pens for the King of Italy. The manufactured pens were considered to be of high quality and included their famous patent ballpoint pens, such as the "Automatic Wonder Pen", a new type of fountain pen introduced in 1871. Despite most manufacturers of nibs established in Birmingham having since closed their factories, Leonardt & Co. is one of the few companies that have remained in the industry since its founding, although the company ceased to produce pens, they continue to produce dip and fountain nibs. The company is specialized in finishing of metal components, manufacturing products such as corners for stationery such as leather goods, photograph albums, menu covers, pattern and carpet books, binders and portfolios.

The company works with both ferrous and non-ferrous metals in high and low volumes. Leonardt has an Electroplating facility for Barrel and Rack plating. Barrel plating finishes include nickel, copper, brass, gold, silver, tin cobalt, electroless nickel, black oxide, white bronze and a range of specialised antique finishes. Decorative rack plating is also offered in nickel, gold and chrome.

Figure 6: Nickel plating tanks (Captured at Leonardt Ltd).

The production line in a typical electroplating process plant comprises numerous tanks, including pre- and post-treatments, rinsing, and plating baths. Therefore, the manufacturing of electroplating material needs numerous process stages and chemical processes. Because of the complexity of manufacturing and the process used in the production line, the automation level in chemical production lines is traditionally low and the real-time monitoring and control of process solutions along the line are very difficult for manual monitoring and control by operators. In such cases some delays in response to process changes are inevitable, and this is particularly the case when the operator responsible for monitoring and control is in doubt or the correct instructions are not available to the operator, he/she needs to consult with and seek a decision from the upper-level control manager. As a result, the change that may happen in solution conditions may lead to undesired quality in products, hence the unsuitability of the batch being produced for meeting the customer order.

To achieve high product quality in an Electroplating process plant, continuous, careful maintenance of the optimum condition of the process solution in the electroplating process tanks is necessary. The parameters such as current density, temperature, agitation system, bath pH, the conductivity of water used and plating time play important role in determining the quality of the plating product and the productivity of the plating process plant (Kumar, Pande and Verma, 2015).

The research work is mainly concentrated on the electroplating of nickel. The electroplating of nickel is a semi-automated process, where hoist movement is automated and can be switched to manual mode. At present only the pH level is digitally monitored by an operator every 10 minutes, whereas the parameters such as the temperature of the plating solution, the conductivity of the water used for plating, the density of the solution, ion concentration, an electric current passed through a solution, and the level of the solution is manually monitored and controlled by an operator.

Operation Sequence, Process, Duration and Chemicals used at the present manufacturing process plant,

Table 2: List of Nickel-plating process and its variable parameters monitored on the shop floor.

Stages	Process	Duration	Parameters monitored
1	Hot Soak	10 min	Temp: 60°C
2	Hot Soak 1st Rinse	10 min	Conductivity: 0.01
3	Hot Soak 2nd Rinse	10 min	Conductivity: 0.01
4	Acid Soak	5 min	Temp: 65°C
5	Acid Rinse	30 Sec	
6	Nickel Plating Tank	1 hr 10 Min	Temp: 45°C to 60°C pH: 3 to 4 Conductivity: 0.01
7	Nickel Drag Out 1	2 min	None
8	Nickel Drag out 2	1 min	None
9	Nickel 1nd Rinse	1 min	None
10	Nickel 2st Rinse	1 min	None
11	Alcan De-Rust	1 min	None
12	Alcan Rinse	2 min	None
13	Rinse	1 min	None
14	Final Rinse	1 min	None

The over all Nickel plating process takes about 1 hour 55 minutes and 30 seconds including all the processes.

The current situation at the shop floor:

- For plating Nickel on Steel or Brass, the load must be passed through 14 different process.
- The pH is monitored and controlled manually for every 30 minutes. The data which was collected during this period is shown in figure 7. The data was collected in a CSV file format.

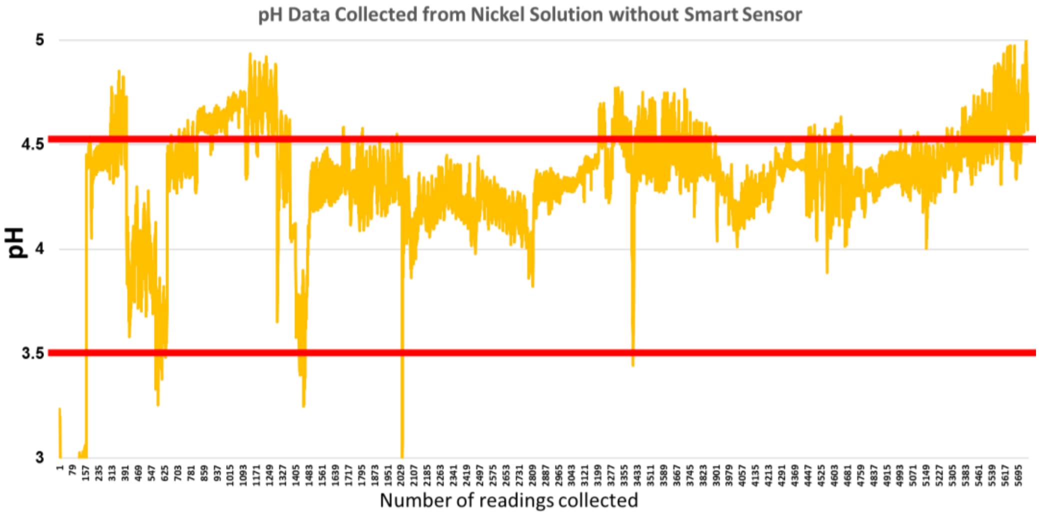


Figure 7: pH data collected from nickel solution tank before installing smart pH control system.

- The temperature of the solution is monitored and controlled manually for every 30 minutes. The data collected during this period is shown in the figure 8, showing the deviation from the expected limit of 50°C to 65°C, highlited in the blue box below, resulting in either the amount of the rework required or the excess use of raw material respectively.

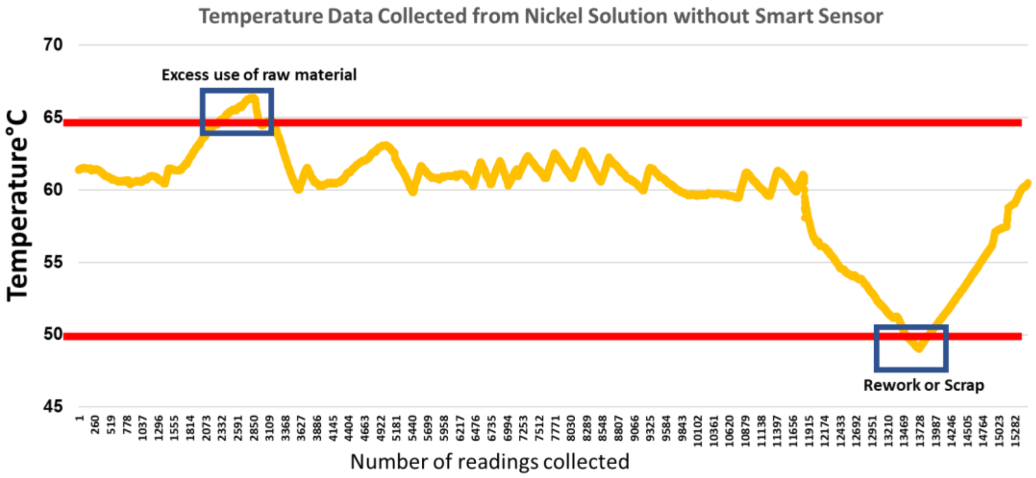


Figure 8: Temperature data collected from nickel solution tank before installing smart Temperature control system.

- Once a year Nickel plating solution will be sent to an external laboratory to check the chemical parameters of the solution and to identify the chemical which needs to be added.

3.2. Challenges / Problems in Electroplating process plant

The electroplating process is semi-automated, a typical electroplating line consists of multiple hoists for carrying the plating barrels and various process control equipment for process conditioning of variable parameters such as equipment for temperature control, pH control, control of conductivity of the water used for the plating process, solution level control, and chemical conditioning equipment for regulating chemical bath concentration (Venkateshaiah, Zakeri and Iliev, 2019).

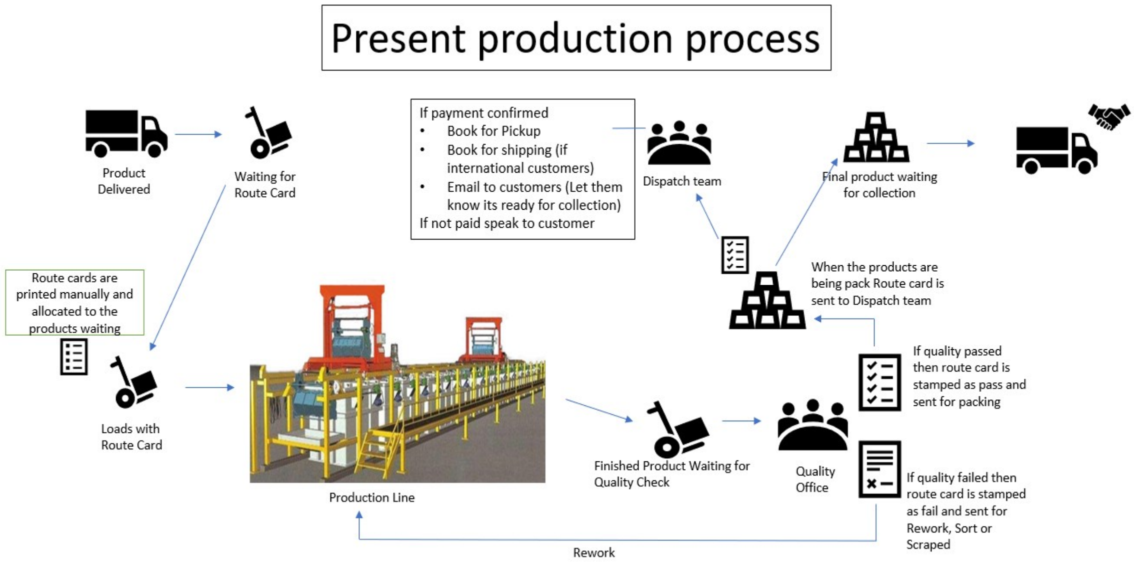


Figure 9: Present Production Process.

The current electroplating lines are centrally controlled by using PLC (Programmable Logic Controller) as the main system controller. The PLCs are mainly used for the hoist control system of the electroplating line, as the hoist is moving along a fixed rail, special flat-form multi-cord cables are used to provide control signals and power to the hoist. The flat-form cable is designed to be used in conveying and hoisting equipment and is for connecting moving machine components. These cables are highly flexible and designed to be subjected to heavy and frequent bending. However, it is expensive and heavy (Choy et al., 2010). A simple hoist configuration needs at least five flat-form cables per hoist for connecting the power source, various control pushbuttons for manual mode control, proximity sensors for the hoist positioning, acceleration and deceleration sensors vertical positioning sensors for the lifting mechanism, and protective limiting switches.

According to (Choy et al., 2010) the various sensory input signals and the actuator output signals are directly connected to the PLC via cables. Due to the high cable cost and the fluctuating copper price, the engineer will tend to keep the number of signal wires for connecting the control equipment to a minimum for fulfilling the basic control and monitoring function only. However, the limited feedback information will restrict the feasibility to implement more advanced monitoring and diagnosis functions for the system.

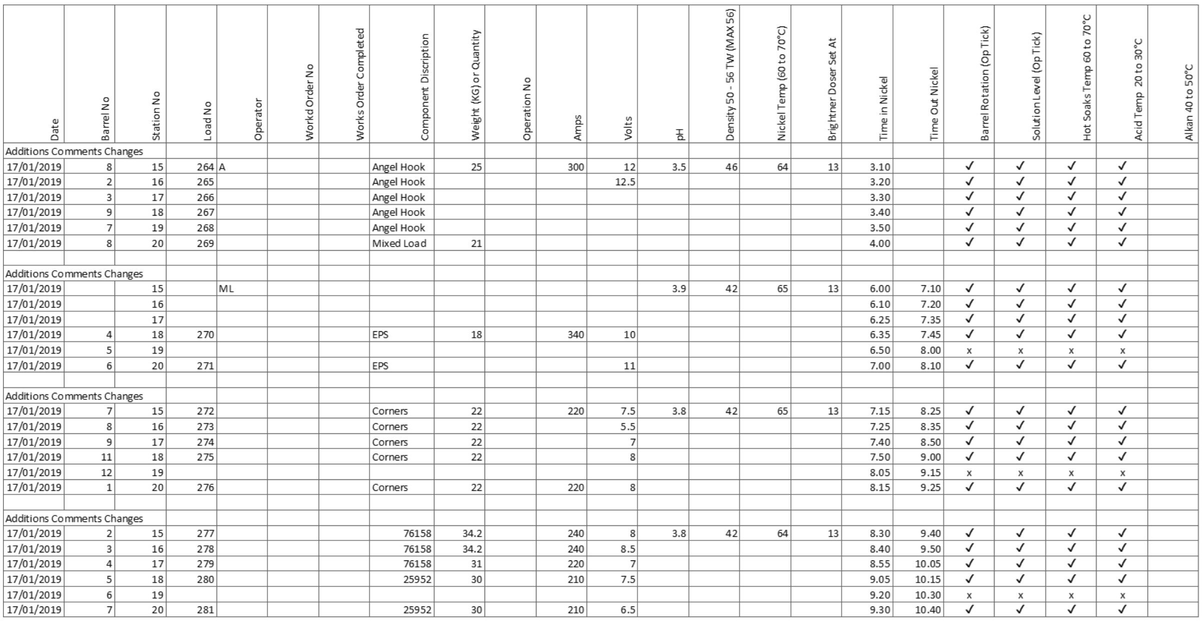
Under this circumstance, it is difficult to include any additional flat-form cable for accommodating extra feedback signals for monitoring and diagnosing the working condition of the hoist and variables parameters of the plating solution. As such, the system maintenance engineers can only adopt the time-based maintenance scheme to reduce production downtime. However, many failures that occurred in the electroplating process are not necessarily related to the ageing effect of the equipment or the utilization rate of the machine. Therefore, the time-based maintenance scheme can only prevent part of the failures but not all, and a significant number of failures may occur during operation. Worst of all, it leads to a significant delay in revealing such faults, and the failure that occurs during production operation may cause a huge loss in terms of wastage of productivity, energy and raw materials (Correa, 2001). Thus, there is a great demand for a sophisticated condition-monitoring feature in the plating line systems so that it can signal an early warning and minimize equipment downtime. However, with the ever-increasing complexity of the electroplating processes, the size or length of the plating line also increases. Therefore, it would be very costly to add many sensors to the system under the current centralised control architecture (Persechini and Jota, 2013) for conducting system monitoring and diagnosis.

At present only the pH of the plating solution is monitored and controlled but the rinse tank is not monitored for pH level, this might result in quality issues. In the rinse tank for a wide range of plating operations, extreme pH values can result in a product that is undesirably spotty or uneven in finish, colour, or texture. Hence, the rinse tanks must also be monitored for pH levels

Quality control:

The data at the shop floor level are collected manually on a data sheet and it is used for quality maintenance purposes. The sample of data collected at the shop floor level is shown in Figure 10. The data from the electroplating process line should be collected for every 10 minutes. It consists of plating Date, Barrel number, Station number, Load number, Operator, Load weight, Nickle solution temperature, pH, Amper, Volts, Density, Brightener dose, Solution level, Hot soak temperature and Acid tank temperature.

The quality is checked for each part and the reason for the quality issue and the main source (Example: Which of the plated batch number has the problem) are noted and are sent for re-work/Scrap. But the main source of rejection such as low temperature, low pH, Contamination of solution, less current supply, high conductivity, change in a chemical solution, low Nickel Content, less solution level etc. is not mentioned. Quality departments do not investigate the main reason behind rejection. The supervisor is not fully aware of the main reason for bad quality. Instead, the supervisor does the re-work on the pure assumption, which might lead to more rejection or Scrap. At present 1 out of every 10 loads is being rejected. The parameter readings which are noted manually are tracked to find the reason for rejection and are altered for rework, assuming that is the reason for bad quality. As shown in Figure 10 the parameter readings are not collected every 10 minutes instead it is collected for every 1 hour, that is because the operator is busy loading and unloading the product. At present, the problems on the shop floor are not reported on time. Mostly due to the scrap or rework the material is used at more than the expected rate.



Date	Barrel No	Station No	Load No	Operator	Workd Order No	Works Order Completed	Component Discription	Weight (KG) or Quantity	Operation No	Amps	Volts	pH	Density 50 - 56 TW (MAX 56)	Nickel Temp (60 to 70°C)	Brightner Doser Set At	Time in Nickel	Time Out Nickel	Barrel Rotation (Op Tick)	Solution Level (Op Tick)	Hot Soaks Temp 60 to 70°C	Acid Temp 20 to 30°C	Alkan 40 to 50°C
Additions Comments Changes																						
17/01/2019	8	15	264	A			Angel Hook	25		300	12	3.5	46	64	13	3.10		✓	✓	✓	✓	
17/01/2019	2	16	265				Angel Hook				12.5					3.20		✓	✓	✓	✓	
17/01/2019	3	17	266				Angel Hook									3.30		✓	✓	✓	✓	
17/01/2019	9	18	267				Angel Hook									3.40		✓	✓	✓	✓	
17/01/2019	7	19	268				Angel Hook									3.50		✓	✓	✓	✓	
17/01/2019	8	20	269				Mixed Load	21								4.00		✓	✓	✓	✓	
Additions Comments Changes																						
17/01/2019		15		ML								3.9	42	65	13	6.00	7.10	✓	✓	✓	✓	
17/01/2019		16														6.10	7.20	✓	✓	✓	✓	
17/01/2019		17														6.25	7.35	✓	✓	✓	✓	
17/01/2019	4	18	270				EPS	18		340	10					6.35	7.45	✓	✓	✓	✓	
17/01/2019	5	19														6.50	8.00	x	x	x	x	
17/01/2019	6	20	271				EPS				11					7.00	8.10	✓	✓	✓	✓	
Additions Comments Changes																						
17/01/2019	7	15	272				Corners	22		220	7.5	3.8	42	65	13	7.15	8.25	✓	✓	✓	✓	
17/01/2019	8	16	273				Corners	22			5.5					7.25	8.35	✓	✓	✓	✓	
17/01/2019	9	17	274				Corners	22			7					7.40	8.50	✓	✓	✓	✓	
17/01/2019	11	18	275				Corners	22			8					7.50	9.00	✓	✓	✓	✓	
17/01/2019	12	19														8.05	9.15	x	x	x	x	
17/01/2019	1	20	276				Corners	22		220	8					8.15	9.25	✓	✓	✓	✓	
Additions Comments Changes																						
17/01/2019	2	15	277				76158	34.2		240	8	3.8	42	64	13	8.30	9.40	✓	✓	✓	✓	
17/01/2019	3	16	278				76158	34.2		240	8.5					8.40	9.50	✓	✓	✓	✓	
17/01/2019	4	17	279				76158	31		220	7					8.55	10.05	✓	✓	✓	✓	
17/01/2019	5	18	280				25952	30		210	7.5					9.05	10.15	✓	✓	✓	✓	
17/01/2019	6	19														9.20	10.30	x	x	x	x	
17/01/2019	7	20	281				25952	30		210	6.5					9.30	10.40	✓	✓	✓	✓	

Figure 10: Present method of data collection from the shop floor.

Paper reporting is not enough for shop floor data collection systems, since it is a less efficient and more time-consuming process. It creates less visibility within the production process. The data collected is stored for 6 months before being discarded. The decisions made are based on the date information, in an emergency, it is much more time-consuming to have someone track down the information on the shop floor. There is no quick response to the changes or for any unexpected problems occurring on the shop floor. At times the process of gathering data takes more effort than the benefits are worth. By the time the data gets back to the shop floor, it is historical and less valuable which leads to problems and inefficiencies in the supply chain (Planet Run, 2021).

3.3. Conclusion

A company's ability to manage and use the knowledge about shop-floor and production processes will increasingly exert an influence on its competitiveness and capacity for innovation. The exploitation of appropriate IT systems in manufacturing is essential. Depending on their degree of maturity, such systems support the management of knowledge and complexity throughout value chains.

The project is based on the construction of Distributed Control System (DCS). The advantage of the system is reducing process time, reducing labour costs, controlling, and monitoring the real-time condition. The research aims to develop a real-time graphical user interface monitoring and network system for industrial automation. DCS is a system of controllers linked by a data network, as a single system, it has safety features, redundancy, and even diagnostics built into its controller philosophy to be more robust with less downtime.

Provision for identification of corrective measures regarding materials or manufacturing process. To improve its manufacturing processes by making them safer. It is necessary to upgrade the existing traditional wired infrastructure to a wireless solution to protect vital factory equipment from chemical corrosion. Thus, they required a reliable data acquisition device with wireless connection stability and multiple sensor combination support

Distributed control system

4.1. Introduction

To cope with unprecedented changes in manufacturing requirements, manufacturing paradigms have gradually progressed from a centralized hierarchical control architecture to loosely-coupled heterarchical control architecture known as the Distributed Control System (DCS) (Lee, Harrison and West, 2005). The DCS is a system of sensors, controllers and computers that are distributed throughout a plant for unique purposes such as data acquisition, process control, production control and management (Adhane and Kim, 2017: 83-91). The industrial control system which was traditionally managed by a large and expensive centralised control unit, typically a Programmable Logic Controller (PLC), has been distributed into sub-tasks handled by smaller controllers i.e., actuators and sensors so that they can communicate without a central controller.

The system has a hierarchical structure. Each hierarchy level in the system represents a control level, performing the particular functions and tasks involved in that level. At a lower level, the system represents the shop floor sensor level, and the structure includes several nodes named sensor nodes, actuators nodes and the shop floor operator station node to virtually mimic the existing manual operator’s functions and tasks. The level above the shop floor sensor level represents the process control level. The process controller level is linked to the shop floor nodes using wired/wireless communication technology, through which the process controller receives information from the shop floor nodes about the status of the plant operations and the process variables. The information will be displayed at the process controller level for observation by the supervisor. The level also addresses the scrap prevention issue. The level above the process control is the production control level (Adhane and Kim, 2017: 83-91). The production control level receives information from the process control level and the data received is used for the control of product quality, product traceability, data storage, scheduling and loading. The higher level in the hierarchical structure is the management control level. The management control level receives information from the supervisor which helps the management with decision making, goal setting and customer scheduling.

This section presents the architecture and components of a novel DCS for the automated process monitoring and control system.

4.2. Contribution

The following contributions are covered in this Chapter

1. A novel Distributed Control System for the electroplating process monitoring and control system is presented.
2. It is shown that the monitoring system provides an accurate estimate of the process state in terms of process parameters, data storage, product quality and traceability for scrap control, customer scheduling and loading.
3. It is shown that the traditional manual data gathering process takes more effort than the benefits are worth. This means that the operator must carry the data in hand and should meet with the supervisor or management to make the decision. By the time the data gets back to the shop floor, it is historical and less valuable which leads to problems and inefficiencies in the supply chain. Real-time data visibility enables paperless reports and spreadsheets.
4. It is shown that the management has direct access to process control level information, in this way indirectly oversees the shop floor and monitors the status of the process variables from anywhere at any time, enabling the management to provide real-time responses to process changes and disturbances. Hence, ensuring integrated management and control of product quality and production schedule.

4.3. DCS architecture for an Electroplating process plant

Figure 11 illustrates the architecture and components of the distributed control system designed for the real-time monitoring and control of the process and the control of production and quality in an electroplating plant. The system is designed to facilitate constant monitoring and real-time control of the plating process at each stage of the process in the plant. The Smart tank station is built with a Raspberry Pi single-board computer attached with sensors and actuators at the shop floor level, called the temperature node, pH node, Conductivity node, and level sensor node to perform the monitoring and control of the solution which is currently being carried out manually by the operators. The Raspberry Pi microcontroller is connected to the internet with its onboard Wi-Fi module and is enabled as the network gateway or router to transfer sensory data from the smart tank station to the ThingSpeak Cloud database.

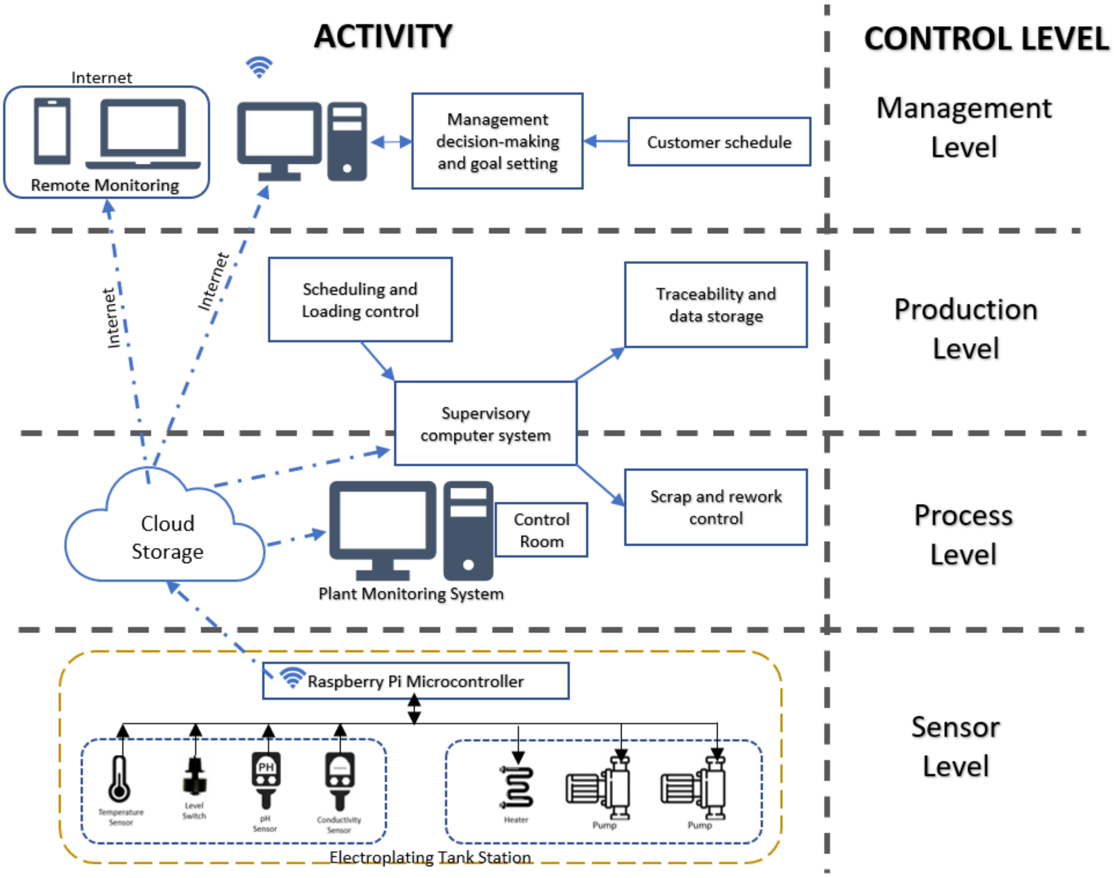


Figure 11: Distributed control system (DCS) Architecture.

Sensor Level: The developed smart tank station at the sensor level consists of sensors and actuators to collect real-time data from the shop floor to gain visibility within the shop floor operations and to control the variable parameters in the process plant. These IoT-enabled used sensors and actuators are programmed to control the variable parameters and the data collected will be stored in the ThingSpeak cloud database. The sensory data collected is immediately available to everyone in the company to have access to the most recent and accurate data set.

Process Control Level: The process controller receives information from the shop floor nodes on the status of the plant operations and the process variables. The production visibility enables the supervisor to obtain instance advice on quality and products that don’t meet required specifications. It helps the supervisor quickly recognize and amend such issues. Real-time visibility gives higher output, improved quality and the removal of scrap and waste to the manufacturers (Correa, 2001). The shop floor monitoring is essential to check on the equipment health and operations on the shop floor to monitor 24/7 and detect anomalies without involving human effort. Taking control of shop-floor activities is essential to achieve maximum production efficiency, optimize production, cut costs and increase profits.

Production Control Level: The production control level does not directly control the process but is concerned with monitoring production and monitoring targets. The production control focuses on the scheduling and loading of the finished products by tracking the status of the product and by utilising the real-time shop floor data available from the process control level. Furthermore, with their real-time visualization and transfer of data captured from the process and work in progress (still-in-production process items), the smart tank stations on the line can form a transparent network providing management with real-time notifications and greater visibility across the plant enabling management to respond quickly and make more accurate control decisions.

Management Control Level: Management Control Systems (MCS) as defined by Anthony (Langfield-Smith, 1997) is the process by which managers ensure that resources are obtained and used effectively and efficiently in the accomplishment of the organization’s objectives. MCS provides useful information for managers to do their duties.

The management control level gathers all the information in real-time from each level to evaluate the production line’s performance and the status of the processor variables. Now the management level can oversee the shop floor data from anywhere at any time, which enables the management to provide real-time responses to process changes and disturbances. Hence, ensuring integrated management and control of product quality and production schedule.

4.4. Conclusion

The smart tank station at the shop floor level constantly obtains data from the sensors and activates the actuators if the parameters deviate from a set point.

This information will be displayed in real-time at the process controller level for observation by the supervisor and simultaneously will be sent, along with any other required reports, to the management control level using cloud technology.

The supervisor or quality management level or management level can monitor the real-time data streams by logging into the private/public channel of the ThingSpeak cloud services. The ThingSpeak Cloud database allows operators to monitor and control the electroplating line system in real-time and records essential production and system performance data.

The management control level then, through cloud computing (Birje et al., 2017) has direct access to process control level information, in this way indirectly oversees the shop floor and monitors the status of the process variables from anywhere at any time, enabling the management to provide real-time responses to process changes and disturbances hence, ensuring integrated management and control of product quality and production schedule.

The main purpose of this work is to use emerging automation and communications technology to develop smart tanks that can autonomously monitor and control the process solution along the electroplating production line to maintain optimum solution conditions needed to achieve the desired quality in the electroplating product despite various disturbances resulting from constant changes in bath loading.

Designed architecture / proposed system

5.1. Introduction

Electroplating of nickel is an important process for many industries such as automotive, aerospace, electronics, medical, textiles, etc. Because it provides superior ductility, corrosion resistance, and hardness. The electroplating production line consists of several Bath (tanks), a working station that performs a certain stage of processing. The process is semi-automated and requires real-time monitoring and control of the process line. One of the biggest issues faced by the electroplating industry is manual operations, it is very difficult for the operators to maintain desired parameters, and control and monitor the process line in real-time. Therefore, a new kind of control strategy is needed (Venkateshaiah, Zakeri and Iliev, 2019).

In this chapter, an IoT-based smart tank station and smart hoist control system are presented as a new control strategy to control variable electroplating solution parameters and the hoist movement. The control systems are based on IoT and cloud computing technologies. The built prototype is tested for its accuracy, durability and efficiency.

The product quality in the electroplating process plant is determined by the condition and composition of the chemical solutions used in process tanks. Hence, the maintenance of the optimum condition of the electroplating process solution is vital to the achievement of desired product quality.

5.2. Contribution:

The following contributions are covered in this Chapter:

1. Electroplating tank parameters such as Temperature, pH, Conductivity and level of the solution are monitored and controlled in real-time to maintain the plating quality of the solution and to reduce defective deposition.
2. The sensors are calibrated and tested in an extreme environment for durability and tolerance.
3. Sensors and actuators are programmed to eliminate human intervention and enhance the safety of the operators.
4. Complete automation will avoid the barrel being left in the plating tank for a longer duration/less duration resulting in obtaining the required thickness of the metal deposition on the product (part) which avoids any inspection rejection or rework.
5. The smart hoist control system will provide a real-time update about the hoist which will help management and supervisor to track

the product which is in the tank and knows the equipment status and durability.

6. A computerised hoist provides real-time information about the sensors which are located to stop the hoist at the right position to avoid any accidents, the information collected by the sensor is used to maintain safety within the production line environment.
7. The agitation control system is monitored and controlled in real-time to provide sufficient mixing of the metal salt for the plating solution.

5.3. Smart Electroplating Production line:

This system constricts Raspberry Pi 3 Model B (RPi), the Temperature sensor, pH sensor, Conductivity sensor, level sensor, IR Sensor, and a relay system to control the actuators. The DS18B20 temperature sensor is connected to the pins (3v3, GPIO-4 and Ground), level sensor is connected to the pins (3v3, Ground, CH0 of MCP3002 chip; where the MCP3002 chip is connected to GPIO 11, 8, 10 and Ground), pH and conductivity circuit is interfaced to the Tentacle Shield which is Raspberry Pi HAT, which uses GPIO-2 and GPIO-3 pins as the Serial Data Line and Serial Clock Line for the use by the I2C protocol. The IR sensor is connected to pins (3v3, Ground, GPIO 24). The DC motor is connected to the pin relay module. The relay module is connected to the pins (GPIO

18, 11, 12, 5 Volts and Ground). One pin of the actuator is connected to the relay and another pin is connected to the ground pin of the power supply (12V).

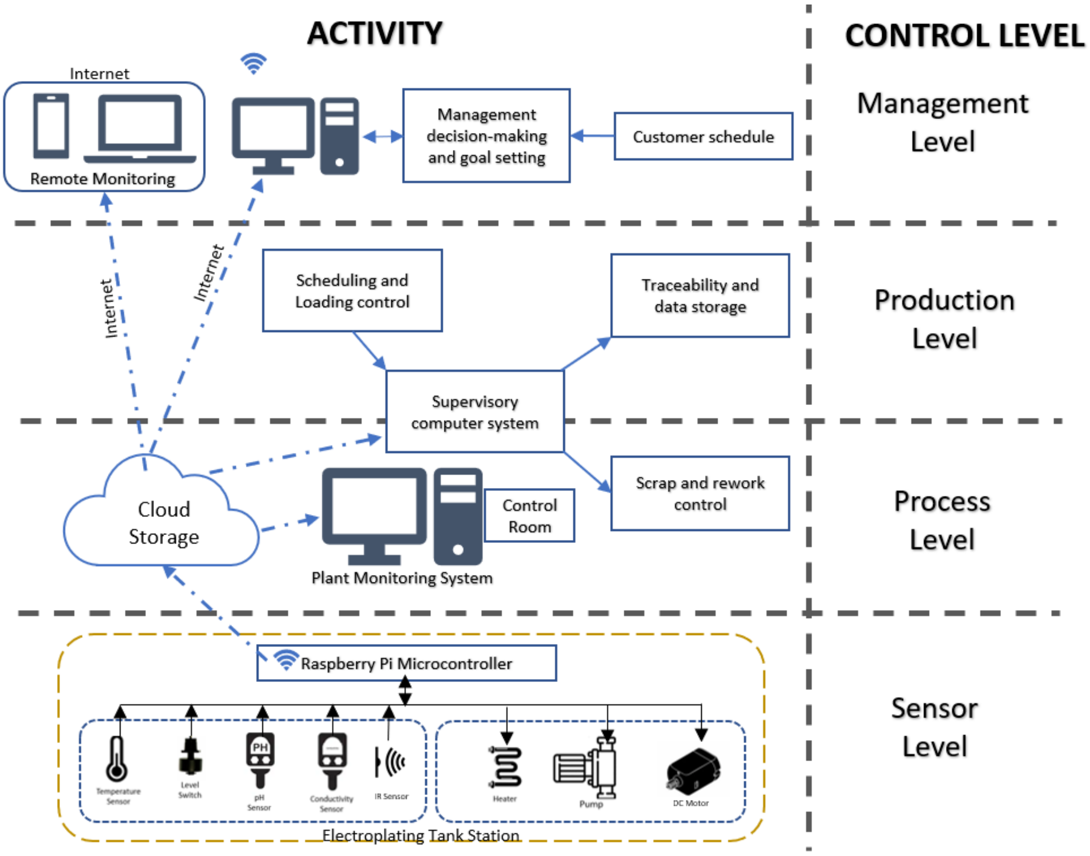


Figure 12: Overall System architecture.

Wi-Fi (IEEE 802.11 N) is used as a transceiver for data communication between sensor node database, internet and cloud services. A sensor node is an independent node capable of connecting to the ThingSpeak Cloud service with the help of a router/IoT gateway. The intended model stands distinct from traditional manual/semi-automatic systems as certain data processing is carried out on the cloud server. The main reason for including the cloud services is for execution of data management, data-centric aggregation, decision making and data analytics services for the data from the sensor nodes.

Figure 12 describes the overall system architecture of the designed system for the sensor and actuator node. A sensor node is built with a Raspberry Pi single board computer, a network gateway or router through which the node is connected to the ThingSpeak cloud database. The data from the cloud database can be accessed using any mobile device or any other portable IP-enabled handheld devices. The supervisor or quality management level or management level can monitor the real-time data streams by logging into the private/public channel of the ThingSpeak cloud services. The admin can automate certain timely decision-making methods from initiating the reaction process.

5.3.1. Smart Temperature monitoring and control system

Temperature plays a critical role during the plating process; a slight temperature change can cause a major difference. There are four types of temperature sensors in the market; Thermocouples, RTDs (resistance temperature detectors), Thermistors, and semiconductor-based integrated circuits (IC). The temperature sensor is immersed in a chemical solution which is acidic with high temperature, if the temperature sensor is made of any of the metal which can be plated, this will result in damage to the sensor. Hence, not all temperature sensors can be used in the plating solution, the temperature sensor gets corroded or weaken, resulting in a false temperature reading. Resulting in less durability and reliability of a temperature sensor in a plating environment. To avoid such consequences DS18B20 Temperature sensor made of stainless steel is used to prevent the sensor from being plated in the solution since stainless steel cannot be plated directly (Tassin et al., 1996). In this experiment, Standard Nickel on Steel Plating process is considered and the sensor is calibrated for the considered plating range. If the tip of the sensor is located at the bottom of the tank, the sensor cannot sense the rising heat. Hence, the sensor must be in the top 30% of the process solution.

The temperature sensors and heaters are placed inside each of the plating baths at locations where the temperature is vital for the plating process. The temperature sensor calibration results are given in Appendix 1a.

Temperature Sensor Specification:

After testing several sensors in the plating solution, DS18B20 a digital thermometer is used to collect the temperature data from the plating tank. It is a one-wire interface digital integrated circuit which is made of stainless steel. The operating range of the sensor is -55°C to +125°C, with ±0.5°C accuracy over the range of -10°C to +85°C (Maxim Integrated, 2019). The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. In addition, the DS18B20 can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply.

Table 3: Temperature Sensor Specification.

Temperature Sensor DS18B20	***Specification***
Measures Temperature	-55°C to +125°C
Considered Range	+40°C to +65°C
Accuracy	±0.5°C (-10°C to +85°C)
Power Supply Range	3.0V to 5.5V

Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1-Wire bus. Thus, it is simple to use one microprocessor to control many DS18B20s distributed over a large area. A total of 4 temperature sensor was connected to a single Raspberry Pi pin to check the accuracy and reliability of the system.

Steps followed to the interface temperature sensor to the Raspberry Pi microcontroller:

The following instructions are used to connect the temperature sensor to the RPi microcontroller to collect temperature data from the sensor in process tanks on the shop floor and to display that data at the operator station for the shop floor operator's monitoring and corrective actions if needed.

Step 1: Connect DS18B20 Sensor to Raspberry Pi Microcontroller as shown in Figure 13.

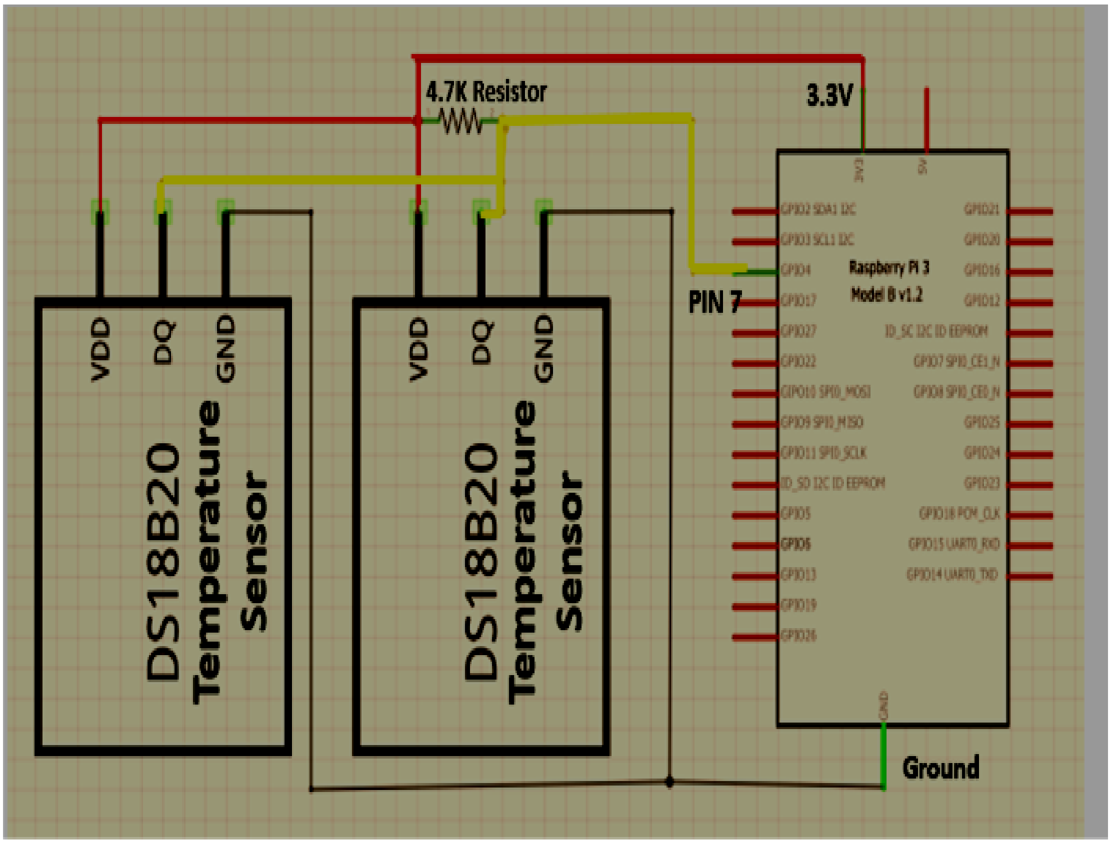


Figure 13: Circuit Diagram for interfacing Temperature sensor to the Raspberry Pi.

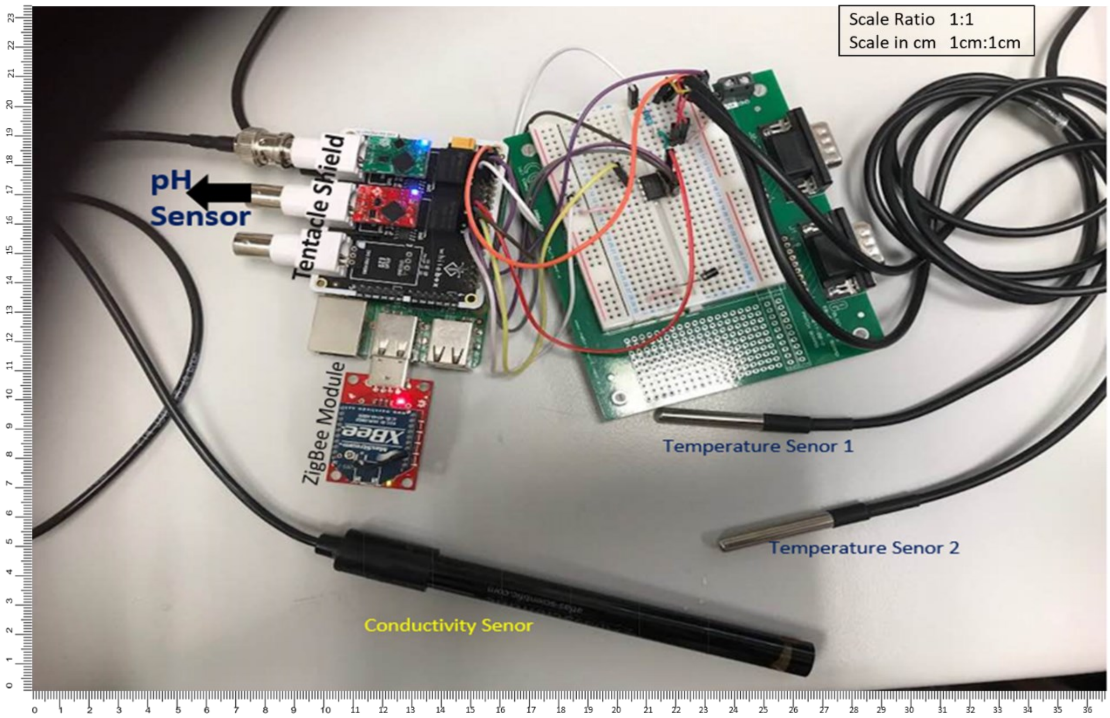


Figure 14: Sensor connections.

- First connect the 3v3 pin from the Pi up to the positive rail & a ground pin to the ground rail on the breadboard.
- Now place the DS18B20 sensor onto the breadboard.
- Place a 4.7k resistor between the positive lead and the output lead of the sensor.
- Place a wire from the positive lead to the positive 3v3 rail.
- Place a wire from the output lead back to pin #4 (Pin #7 if using physical numbering) of the Raspberry Pi.
- Place a wire from the ground lead to the ground rail.

Step 2: Once done the circuit should look similar to the diagram below.

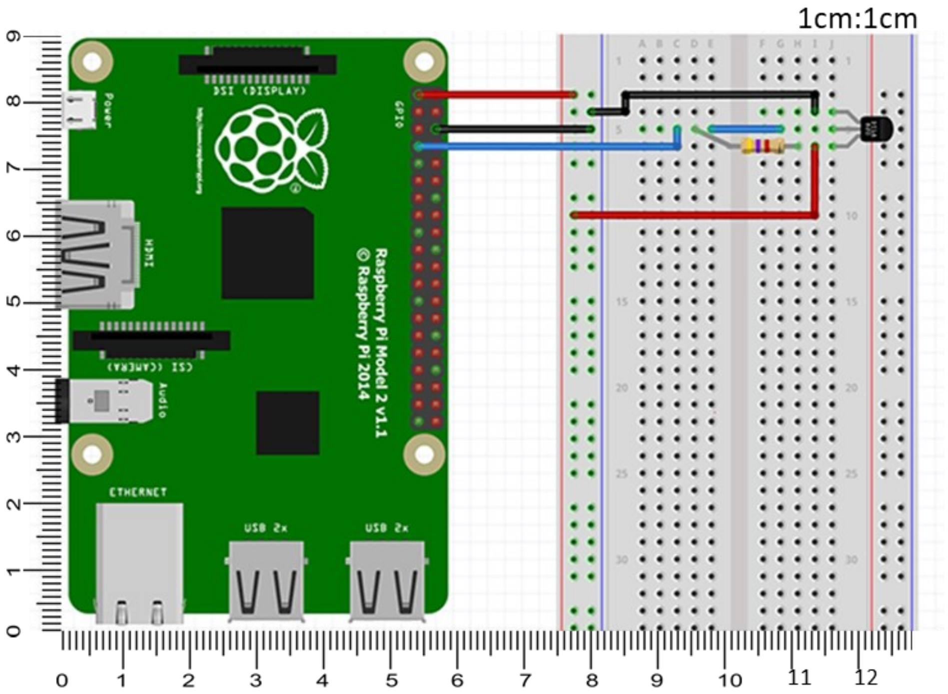


Figure 15: Temperature sensor breadboard connection to Raspberry Pi.

Step 3: Instructions to write the python code for the temperature Sensor,

The code for setting up the temperature sensor is a little more complex than the circuit itself. This is just because of the way the data that comes from the sensor need to be handled.

Before making the Python script ready, the raspberry pi was set up by adding libraries and One Wire support. To do this the following steps were carried out,

a. To add support, the boot config file was edited, this was done by running the following command:

- `sudo nano /boot/config.txt`

b. At the bottom of config file, the following script line was added.

- `dtoverlay = w1 − gpio`

c. Raspberry pi was rebooted to ensure all the security patches are working correctly.

- `sudo reboot`

d. Once the Raspberry Pi was booted back up, the `modprobe` command was executed to load the correct modules.

- `sudo modprobe w1 − gpio`

- `sudo modprobe w1 − therm`

e. Now change into the devices directory and use ls to see the folder/files in this directory.

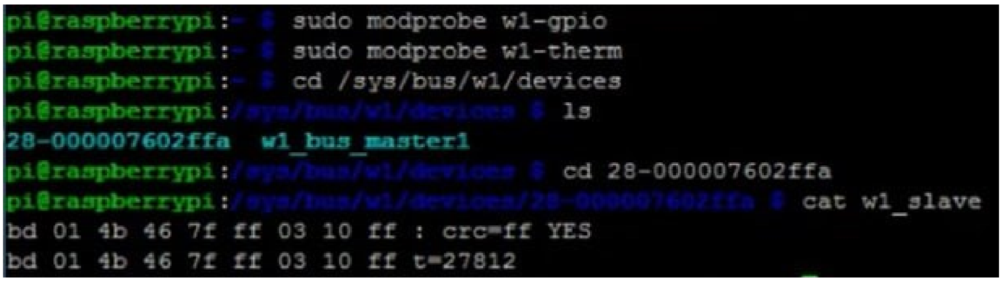
- `cd /sys/bus/w1/devices`

- `ls`

f. Run the following command, change the numbering after cd to what has appeared in your directory by using the ls command. (If you have multiple sensors there will be more than one directory)

- $cd\ 28-000007602ffa$
- $cat\ w1\_slave$

g. This should output data but as you will notice it is not very user friendly. The first line should have a YES or NO at the end of it. If it is YES, then a second line with the temperature should appear.



```
pi@raspberrypi:~ $ sudo modprobe w1-gpio
pi@raspberrypi:~ $ sudo modprobe w1-therm
pi@raspberrypi:~ $ cd /sys/bus/w1/devices
pi@raspberrypi:/sys/bus/w1/devices $ ls
28-000007602ffa  w1_bus_master1
pi@raspberrypi:/sys/bus/w1/devices $ cd 28-000007602ffa
pi@raspberrypi:/sys/bus/w1/devices/28-000007602ffa $ cat w1_slave
bd 01 4b 46 7f ff 03 10 ff : crc=ff YES
bd 01 4b 46 7f ff 03 10 ff t=27812
```

The Python code to control and monitor the Temperature of the Electroplating solution:

The first step is to import the libraries, the RPi GPIO pins are imported to assign the input and output pins. The time library controls how often the sensor data is collected and the delay between the actuator operation. The "*httplib*" and "*urllib*" handle the HTTP request and response directly. The 'sys' is used to access system-specific parameters and functions. The serial encapsulates the access to the serial port. The 16-digit API key is used to read and write to a ThingSpeak channel. GPIO pin are assigned to the actuators and sensors. DS18B20 communicates over a 1-wire bus and it does not require the GPIO pin to be defined. The GPIO pins are set as Input and Output as required.

The program is given in the link attached below.

https://github.com/navnami/RPi_Script/blob/main/Temperature.txt

5.3.2. Smart pH monitoring and control system

The pH value (Rico, 2019) is an important determining factor in an electroplating process, pH is a temperature dependant. As temperature increases, the measured pH of any solution will decrease, meaning it will become more "Acidic". The pH level is maintained by dosing the required chemical in the plating tank. The pH sensors consist of a pH-sensitive element that provides a temperature signal to the analyser. Using a specially formulated pH-sensitive glass in contact with the liquid solution being monitored, the pH electrode develops a voltage potential that is dependent on the pH of the solution. The reference electrode is designed to maintain a constant voltage potential and serves to complete the pH measuring circuit within the solution by providing a known reference potential for the pH electrode. The difference in the voltage potentials of the pH and reference electrodes provides a millivolt signal that depends linearly on the pH of the solution. It is important to remember that the pH electrode, a reference electrode, and a temperature meter are not measuring pH directly, but are interpreting a voltage that generally — but not exactly — mirrors change in the pH value. Because the variations in the voltage do not vary exactly proportionally to changes across the full pH scale, meters need to be periodically recalibrated to assure the overall accuracy and repeatability of electrometric pH testing.

The IoT-based pH circuit is programmed to measure and control the pH level of the solution. The Cloud-based communication system is set up to collect and store data in real-time on a ThingSpeak web service software.

pH sensor Specification:

The Atlas Scientific pH circuit is used to collect the pH level of the solution.

Table 4: pH Sensor Specification.

pH Sensor	Specification
Range	0.01 – 14.000
Accuracy	0.02 +/– 0.002
Response time	1 reading per sec
Data protocol	UART & I2C
Default I2C address	99 (0x63)
Operating voltage	3.3V – 5V

Tentacle Shield is used to interfacing pH sensors to the Raspberry Pi board. It is a fast and easy way to read multiple sensors from a Raspberry Pi. The Tentacle T3 eliminates the need for wiring, multiplexing and electrical isolation. It comes with a Raspberry Pi HAT form factor; it can be simply plugged into the raspberry pi. It is compatible with all the EZO devices made by Atlas Scientific. The EZO^{TM} pH Circuit and EZO^{TM} Conductivity Circuit are connected to the Raspberry Pi as shown in the figure below,

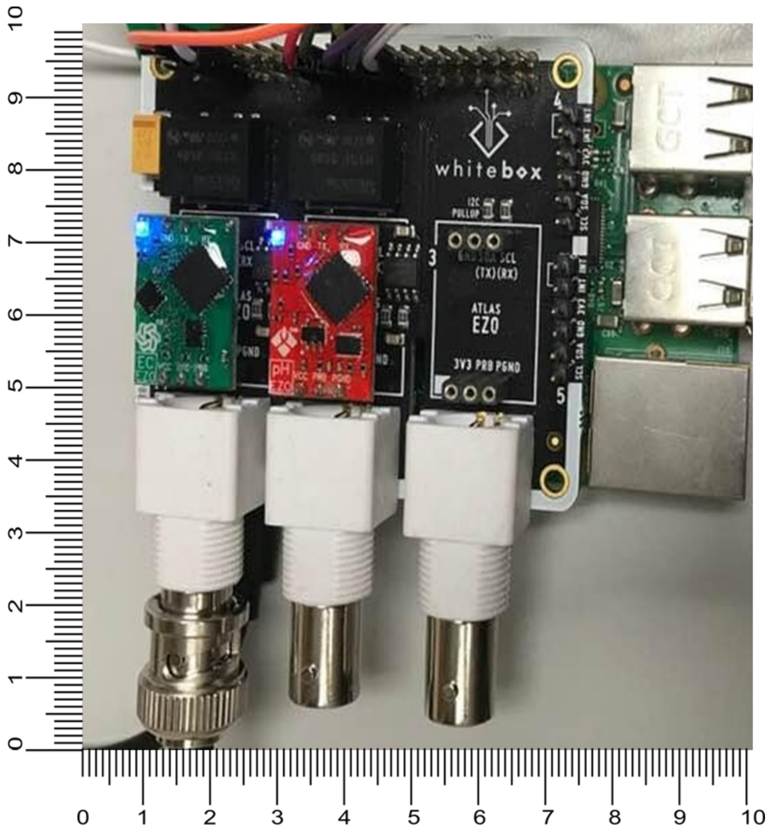


Figure 16: The EZO^{TM} pH Circuit and EZO^{TM} Conductivity Circuit.

The pH circuit was calibrated by following the steps provided by Atlas Scientific LLC. The steps to interface pH sensor with raspberry pi microcontroller are given in section 4.3.3.2.

The Python code to control and monitor the pH of the Electroplating solution:

Atlas Scientific provides the python code; the code is used to interface the pH Circuit. I started by importing the required python modules. RPi GPIO is imported to assign the input and output pins. The time library controls how often the sensor data is collected and the delay between the actuator operation. The “$httplib$” and “$urllib$” handle the HTTP request and response directly. The serial encapsulates the access for the serial port. “$Import\ io$” is used to create file streams, “$import\ string$” helps to read strings and import “$fcntl$” is used to access I2C parameters. The 16-digit API key is used to read and write to a ThingSpeak channel. To assign GPIO pin to the actuators and sensors, EZOTM pH circuit is interfaced to the Tentacle Shield which is RPi HAT, it uses GPIO-2 and GPIO-3 pins as the Serial Data Line and Serial Clock Line for the use by the I2C protocol. The GPIO pins are set as Input and Output as required. The Atlas Scientific I2C class code is used to interface with the pH circuit.

The program is given in the link attached below.

https://github.com/navnami/RPi_Script/blob/main/pH.txt

5.3.3. Smart Conductivity monitoring and control system

Conductivity is one of the most popular measurements used along with an analysis of the Total Dissolved Solids (TDS). The electrical conductivity of water is directly related to the concentration of dissolved ionized solids in the water. Ions from the dissolved solids in water create the ability for that water to conduct an electrical current, which can be measured using a conventional conductivity meter.

When correlated with laboratory TDS measurements, electrical conductivity provides an approximate value for the TDS concentration, usually within ten per cent accuracy. Conductivity is the reciprocal (inverse) of electrical resistivity and has the SI units of siemens per metre (Sm-1). Measuring conductivity can provide a guide to the contamination of water. The higher the purity of water, the lower its conductivity.

The conductivity meter measures the electrical conductivity of the ions in a solution. To do this, it applies an electrical field between two electrodes and measures the electrical resistance of the solution. To prevent changes occurring in the substances, or the deposit of a layer on the electrodes', etc., alternating current is used. The units of measurement which are normally used are S/cm.

The measurement of conductivity is important in the electroplating industry, it is the capacity a solution has for conducting an electrical current (IC Controls, 2017) (Parra et al., 2015). Conductivity is a measurement of the total concentration of ions in a solution for the determination of impurities in the solution.

Conductivity sensor specification:

The Atlas Scientific Conductivity circuit is used to collect the conductivity readings from the water supplied to the plating process, it measures the ability of the water to conduct an electrical current.

Table 5: Conductivity Sensor Specification

	Conductivity Sensor	***Specification***
1	Range	0.07 to 500,000+ μS/cm
2	Accuracy	±-2%
3	Response time	1 reading per sec
4	Data protocol	UART & I2C
5	Default I2C address	100 (0x64)
6	Operating voltage	3.3V – 5V

Steps followed to interfacing pH and Conductivity sensor with raspberry pi:

Step 1: The I2C interface on the RPi is enabled. This is done by entering the following at the command prompt to start the configuration tool

$$sudo\ raspi-config$$

Step 2: From the raspberry configuration list, option 9 is selected and in the Advanced Options > option A7 – I2C is selected. After this, option "Yes" is selected for all the questions and the raspberry pi was rebooted using the command below to ensure all the security patches are working correctly

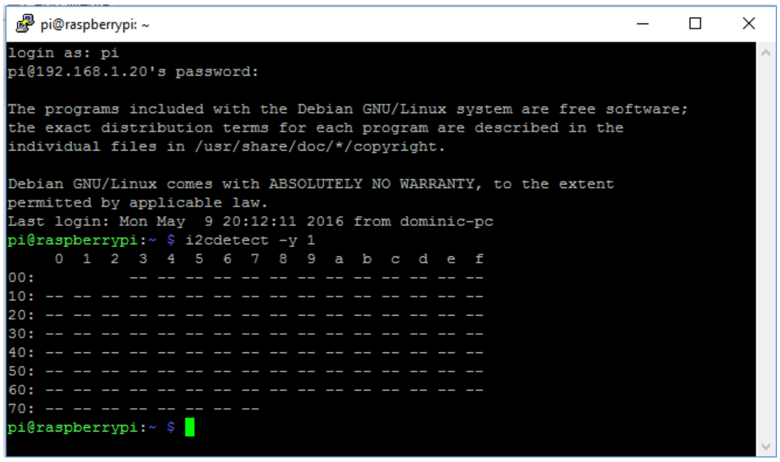
```
sudo reboot
```

Note: The GPIO pins 2&3 on the RPi have now been configured as the Serial Data Line (SDA) and Serial Clock Line (SCL) for use by the I2C protocol.

Step 3: After the reboot the following commands are entered on the command prompt

```
sudo apt − get update
sudo apt − get install i2c − tools
i2cdetect − y 1
```

The following result was obtained without the sensor attached.



```
login as: pi
pi@192.168.1.20's password:

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Mon May  9 20:12:11 2016 from dominic-pc
pi@raspberrypi:~ $ i2cdetect -y 1
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
70: -- -- -- -- -- -- -- --
pi@raspberrypi:~ $
```

Step 4: After setting up the I2C module the EC sensors are connected. The following materials are used to set up the conductivity and pH sensors with Raspberry Pi.

- Raspberry Pi
- Atlas Scientific Electrical Conductivity sensor kit
- Atlas Scientific TEN-T3 Whitebox Labs Tentacle T3

Figure 17: Atlas Scientific TEN-T3 Whitebox, pH sensor and a Conductivity sensor.

Step 5: The EC circuit must be in the correct mode when delivered the EC circuit will be in UART (serial) mode, the EC circuit has to be manually switched from UART mode to I2C mode. When this is done the EC circuit will have its I2C address set to 100 (0x64 Hexadecimal). To do this the following actions for pH and conductivity circuits are carried out:

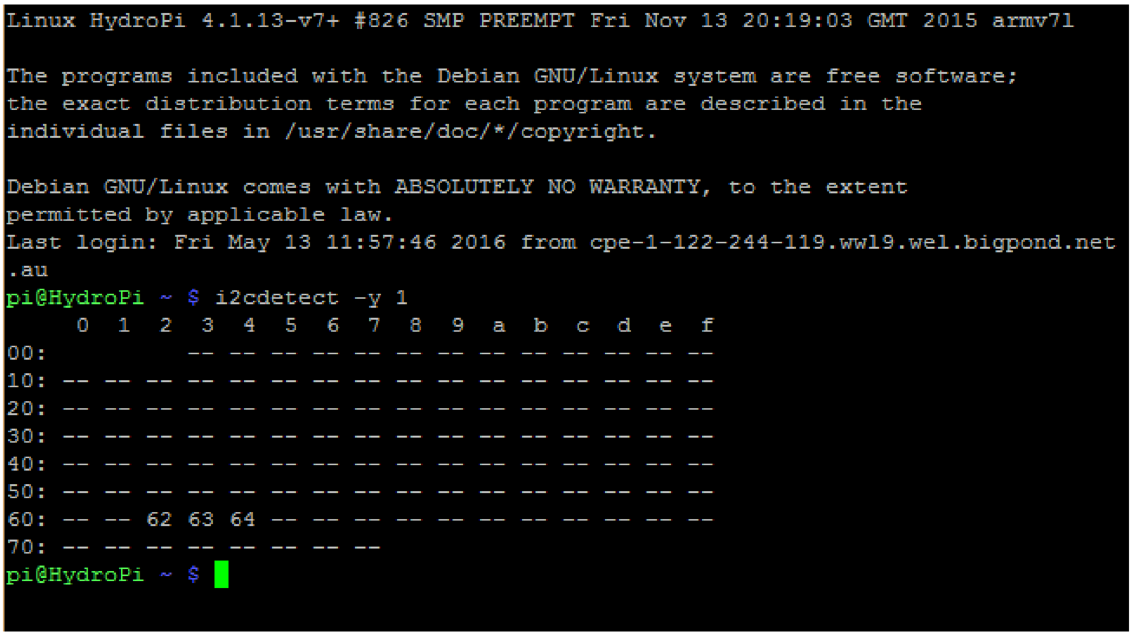
- The device was cut off from the power
- The jumper wires going from TX and RX to the RPi are disconnected
- The PRB pin to the TX pin is shorted
- 5 volts power is supplied to the device
- The colour of the LED changed from Green to Blue
- The connection from the probe pin to the TX pin is removed

Step 6: TEN-T3 Whitebox Labs (Tentacle T3) is mounted on RPi. The pH and Conductivity circuit are connected to the RPi as shown in the figure.

Step 7: By entering the following command a quick test was run to prove that the sensors are set up correctly,

$$i2cdetect\ -y\ 1$$

The following response appeared, if not then check connections, ensure the light on the EC circuit is blue and reboot RPi.



```
Linux HydroPi 4.1.13-v7+ #826 SMP PREEMPT Fri Nov 13 20:19:03 GMT 2015 armv7l

The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Fri May 13 11:57:46 2016 from cpe-1-122-244-119.wwl9.wel.bigpond.net
.au
pi@HydroPi ~ $ i2cdetect -y 1
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
60: -- -- 62 63 64 -- -- -- -- -- -- -- -- -- -- --
70: -- -- -- -- -- -- -- --
pi@HydroPi ~ $
```

The Python code to control and monitor the Conductivity of the water used for the Electroplating process:

Atlas Scientific provides the python code; the code is used to interface the Conductivity Circuit. I started by importing the required python modules. RPi GPIO is imported to assign the input and output pins. The time library controls how often the sensor data is collected and the delay between the actuator operation. The "*httplib*" and "*urllib*" handle the HTTP request and response directly. The serial encapsulates the access for the serial port. "*Import io*" is used to create file streams, "*import string*" helps to read strings and import "*fcntl*" is used to access I2C parameters. The 16-digit API key is used to read and write to a ThingSpeak channel. To assign GPIO pin to the actuators and sensors, EZO™ Conductivity circuit is interfaced to the Tentacle Shield which is RPi HAT, it uses GPIO-2 and

GPIO-3 pins as the Serial Data Line and Serial Clock Line for the use by the I2C protocol. The GPIO pins are set as Input and Output as required. The Atlas Scientific I2C class code is used to interface with the Conductivity circuit.

The program is given in the link attached below.

https://github.com/navnami/RPi_Script/blob/main/Conductivity.txt

5.3.4. Smart Level monitoring and control system

When the barrel is moved from one tank to another it alters the level of the solution, if the level of the solution is not maintained, the load immersed in the tank might not be completely covered with the solution, resulting in uneven plating. The plating solution level must be maintained to a required level to keep the barrel completely immersed in the plating solution. Water Level Depth Detection Sensor is used to build the prototype.

The Level switch must be located above the highest liquid level, once the sensor is submerged in the solution the pump will be turned off. The sensor must be clear of parts or apparatus moving in and out of the tank. When the electroplating tank solution level is low and if the heater is turned ON there is a high chance of fire, hence the level of the solution must be monitored and controlled throughout the plating process.

Level Sensor Specification:

This water level sensor module has a series of parallel exposed traces to measure droplets/water volume to determine the water level. Very Easy to monitor water level as the output to analogue signal is directly proportional to the water level.

Table 6: Level Sensor Specification.

	Conductivity Sensor	***Specification***
1	Detection Area	40mm x 16 mm
2	Sensor type	Analog
3	Working current	<20mA
4	Operating voltage	3V – 5V

The Python code to control and monitor the Level of the Electroplating process tank is given in the link below.

https://github.com/navnami/RPi_Script/blob/main/Level.txt

5.3.5. DC Motor control for Agitation and Hoist Control

Hoist automation controlled by a pre-defined production sequence is capable of transferring products between workstations. Multiple hoists are used in the production line. The hoist can pick up and put down products to the workstation. Because of its chemical nature, processing starts when the hoist plunge item into the bath as a result of putting it down. Processing stops when the hoist picks an item out of the bath. The IR sensor is used to know the status of the hoist once the barrel is put down the IR sensor indicated that the barrel has been dropped into the tank. This triggers the DC motor and starts the agitation process for the nickel solution. Multiple IR sensors located in the production line update the status of the hoist and the barrel location.

Hoists can move independently, therefore schedule must not let the hoists collide. Hoists have specified collision zone, within the axis of their movement. The routing algorithm must control the position of the hoists, so they never come closer than the specified collision zone. The operator can track the position of the hoist and can avoid any accidents which can occur. The hoist is scheduled and programmed in as a closed loop system, so no human intervention is allowed, this avoids any accidents in the chemical environment. The whole control device of the system is a small Raspberry Pi. This computing system is used to automate hoist just with a card-size computing system or a microchip and the industrial environment data can be viewed or monitored from IoT.

DC Motor and IR Sensor Specification:

An infrared sensor (IR sensor) is a radiation-sensitive optoelectronic component with spectral sensitivity in the infrared wavelength range of

780 nm to 50 µm. A DC motor is an electrical machine that converts electrical energy into mechanical energy. In a DC motor, the input electrical energy is the direct current which is transformed into the mechanical rotation.

Circuit connection for IR sensor and DC Motor with Raspberry Pi:

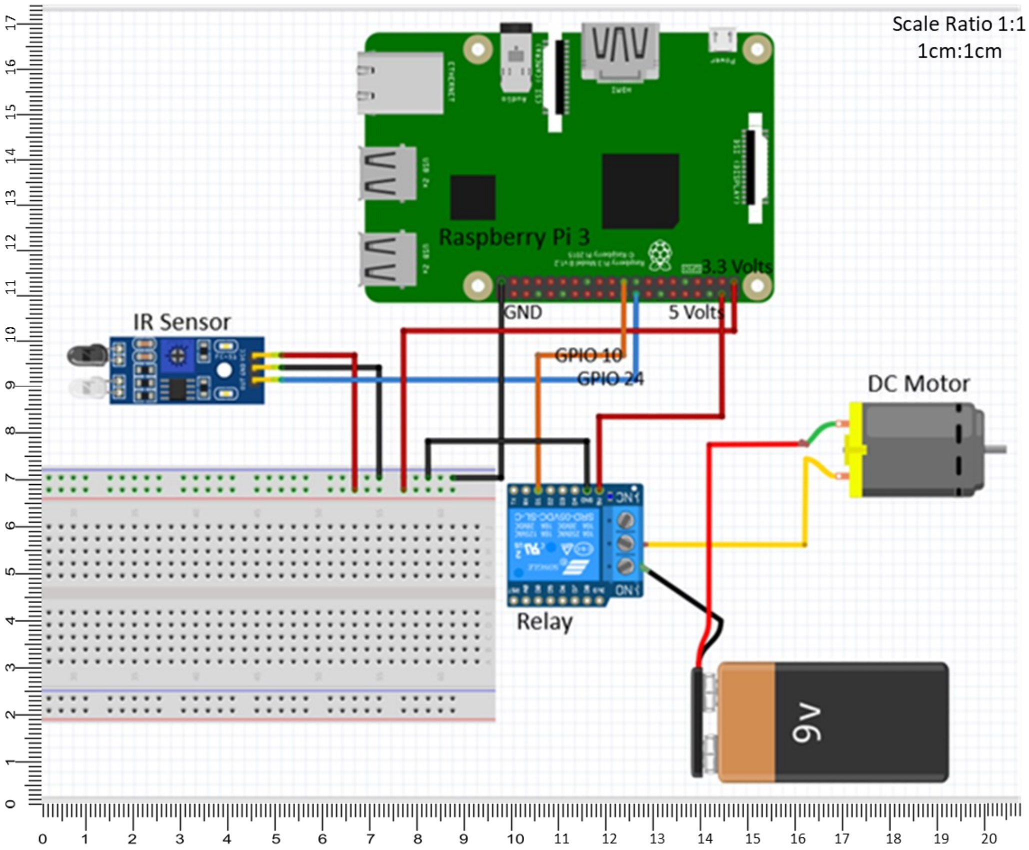


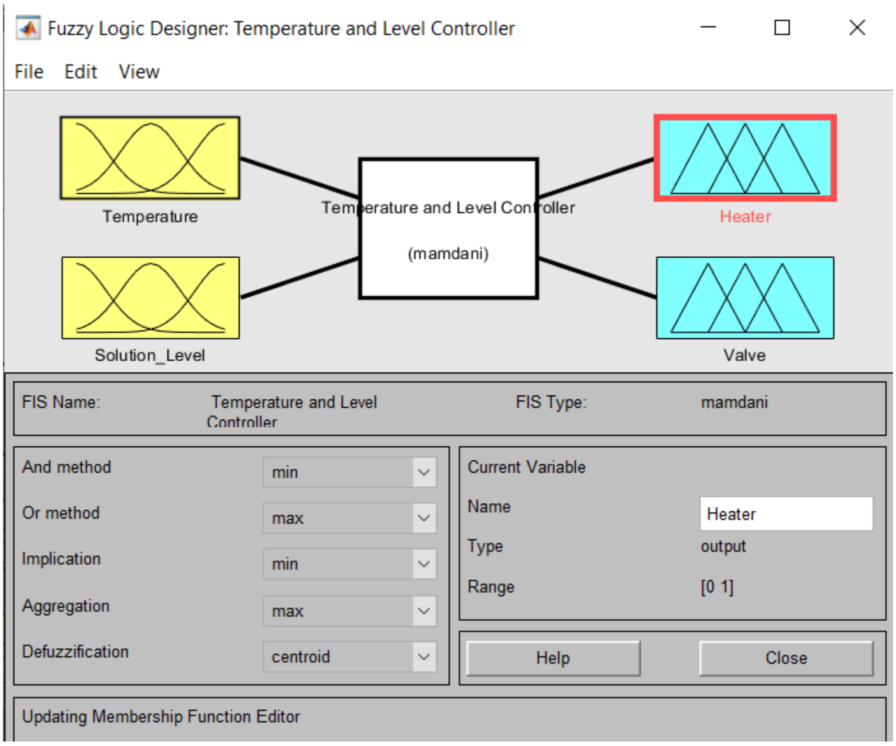
Figure 18: Circuit connection for Dc Motor and IR Sensor

The Python code to control and monitor the Agitation and Hoist system of the Electroplating Production line is given the link below.

https://github.com/navnami/RPi_Script/blob/main/Level.txt

5.4. Fuzzy Logic Implementation

In this section, the Fuzzy Logic (Bonato, Mrak and Badurina, 2015) implementation to control the Temperature and Level of the solution in an Electroplating Process tank is explained. The Temperature and Solution Level values are fed to the fuzzy logic module. The fuzzy logic gets the temperature and solution level as crisp values whereas the fuzzification converts these temperature and solution level values to fuzzy values by using fuzzy membership functions. The fuzzy rules are deployed on these fuzzy values, and the output of these rules is assigned to defuzzification and converted again to crisp output (Zühtüogullari, Saritas and Allahverdi, 2009).



FIS Name: Temperature and Level Controller

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

Current Variable

Name: Heater

Type: output

Range: [0 1]

Updating Membership Function Editor

Figure 19: Fuzzy Logic Designer for Temperature and Level Control.

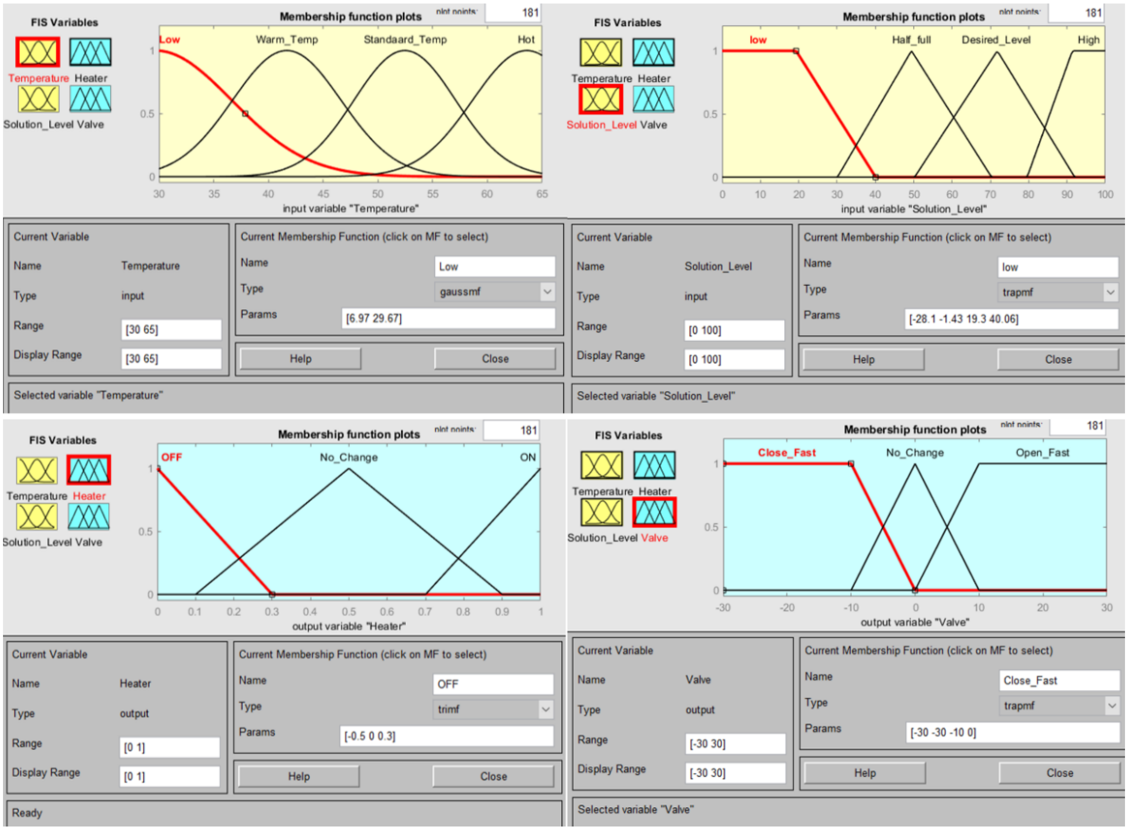
The controller is designed by using MATLAB software to control the Temperature and Level of the Electroplating tank solution. Mamdani fuzzy model has fuzzy rules consisting of antecedent and consequent predicts.

The ***Membership functions*** consist of 2 variables; Electroplating Solution Level and Temperature which are controlled by the Heater and Valve. The range of Temperature and Solution Level is set in the Membership functions editor.

- ***For temperature***, the parameters are defined as Low Temp, Warm Temp, Standard Temp, and Hot.

- ***For Solution Level***, the parameters are defined as Low, Half Full, Desired Level, and High.
- Gaussian type is used for Temperature Plot.
- Triangular and Trapezoidal types are used for Solution Level Plot.
- Fuzzification works on the input variables.

Fuzzification:



Current Variable
Name: Temperature
Type: input
Range: [30 65]
Display Range: [30 65]

Current Membership Function (click on MF to select)
Name: Low
Type: gaussmf
Params: [6.97 29.67]

Selected variable "Temperature"

Current Variable
Name: Solution_Level
Type: input
Range: [0 100]
Display Range: [0 100]

Current Membership Function (click on MF to select)
Name: low
Type: trapmf
Params: [-28.1 -1.43 19.3 40.06]

Selected variable "Solution_Level"

Current Variable
Name: Heater
Type: output
Range: [0 1]
Display Range: [0 1]

Current Membership Function (click on MF to select)
Name: OFF
Type: trimf
Params: [-0.5 0 0.3]

Ready

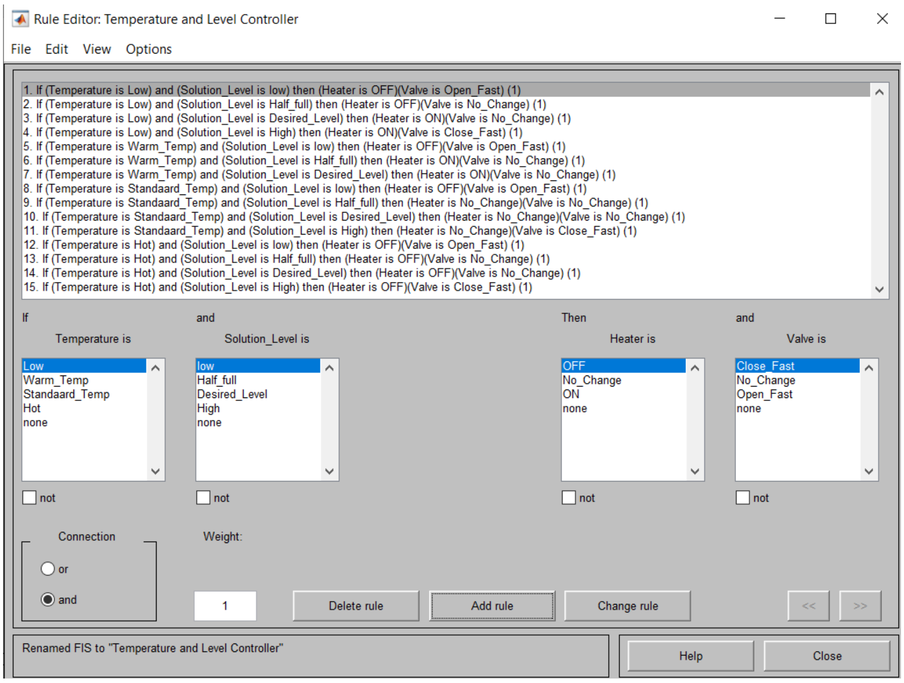
Current Variable
Name: Valve
Type: output
Range: [-30 30]
Display Range: [-30 30]

Current Membership Function (click on MF to select)
Name: Close_Fast
Type: trapmf
Params: [-30 -30 -10 0]

Selected variable "Valve"

Figure 20: Fuzzification by defining membership functions for input and output variables.

Inference engine:



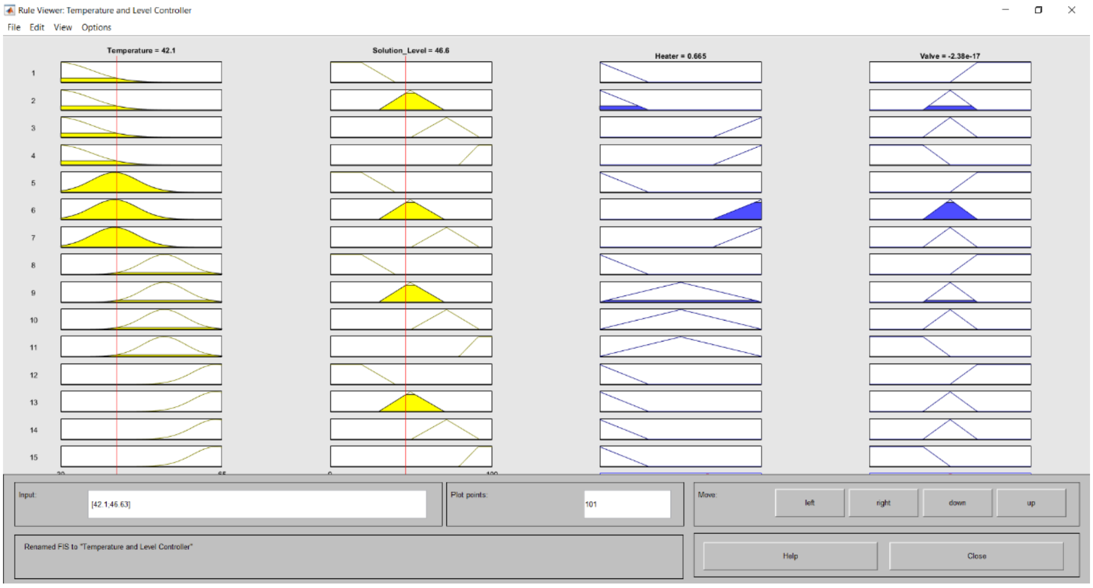
1. If (Temperature is Low) and (Solution_Level is low) then (Heater is OFF)(Valve is Open_Fast) (1)
2. If (Temperature is Low) and (Solution_Level is Half_full) then (Heater is OFF)(Valve is No_Change) (1)
3. If (Temperature is Low) and (Solution_Level is Desired_Level) then (Heater is ON)(Valve is No_Change) (1)
4. If (Temperature is Low) and (Solution_Level is High) then (Heater is ON)(Valve is Close_Fast) (1)
5. If (Temperature is Warm_Temp) and (Solution_Level is low) then (Heater is OFF)(Valve is Open_Fast) (1)
6. If (Temperature is Warm_Temp) and (Solution_Level is Half_full) then (Heater is ON)(Valve is No_Change) (1)
7. If (Temperature is Warm_Temp) and (Solution_Level is Desired_Level) then (Heater is ON)(Valve is No_Change) (1)
8. If (Temperature is Standaard_Temp) and (Solution_Level is low) then (Heater is OFF)(Valve is Open_Fast) (1)
9. If (Temperature is Standaard_Temp) and (Solution_Level is Half_full) then (Heater is No_Change)(Valve is No_Change) (1)
10. If (Temperature is Standaard_Temp) and (Solution_Level is Desired_Level) then (Heater is No_Change)(Valve is No_Change) (1)
11. If (Temperature is Standaard_Temp) and (Solution_Level is High) then (Heater is No_Change)(Valve is Close_Fast) (1)
12. If (Temperature is Hot) and (Solution_Level is low) then (Heater is OFF)(Valve is Open_Fast) (1)
13. If (Temperature is Hot) and (Solution_Level is Half_full) then (Heater is OFF)(Valve is No_Change) (1)
14. If (Temperature is Hot) and (Solution_Level is Desired_Level) then (Heater is OFF)(Valve is No_Change) (1)
15. If (Temperature is Hot) and (Solution_Level is High) then (Heater is OFF)(Valve is Close_Fast) (1)

Weight: 1

Renamed FIS to "Temperature and Level Controller"

Figure 21: Inference engine of Temperature and Level sensor.

Defuzzification:



Temperature = 42.1

Solution_Level = 46.6

Heater = 0.665

Valve = -2.38e-17

Input: [42.1,46.63]

Plot points: 101

Renamed FIS to "Temperature and Level Controller"

Figure 22: Defuzzification of Temperature and Level sensor.

3D Graph surface viewer:

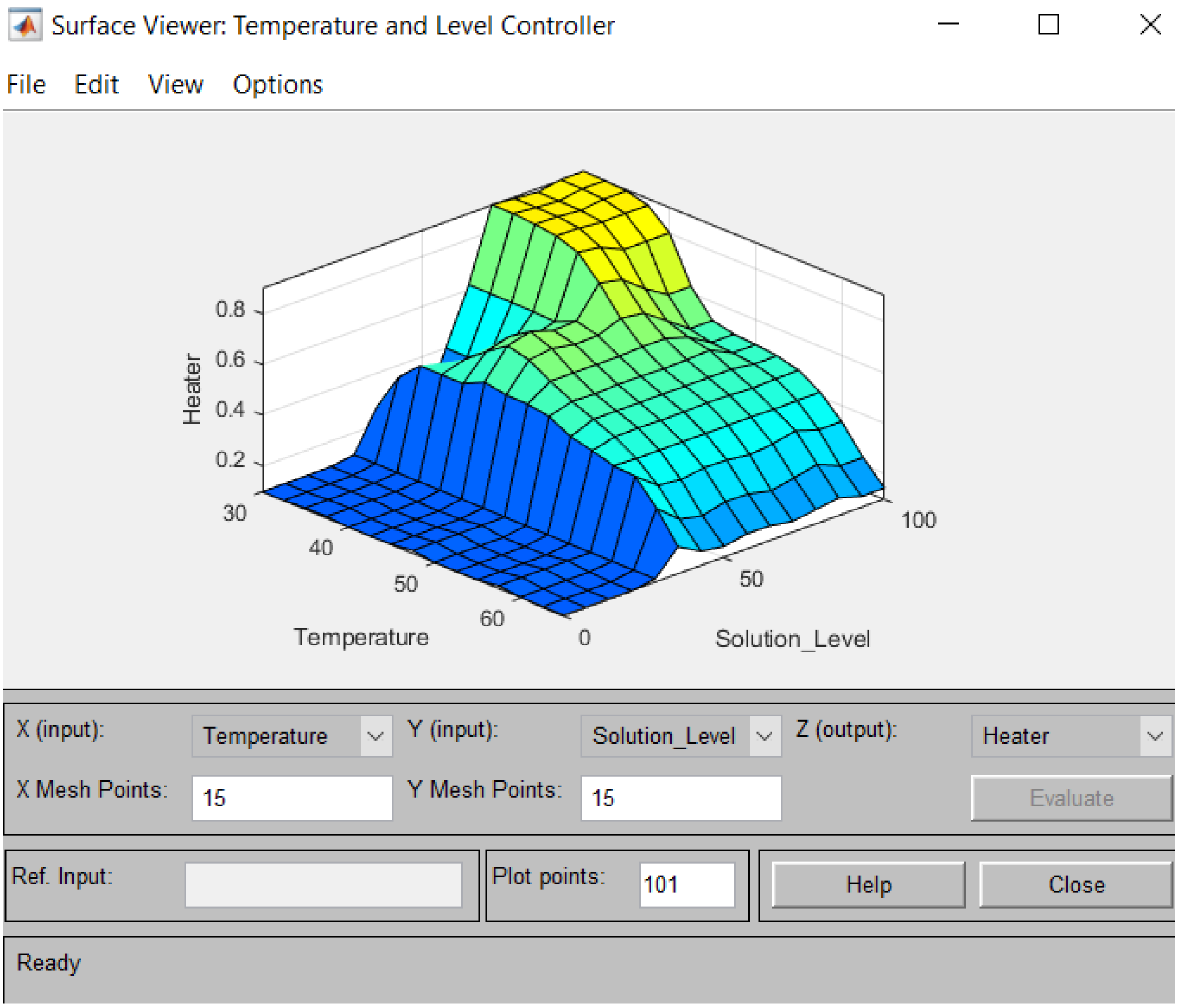


Figure 23: 3D Graph surface viewer for Temperature and Level sensor.

5.5. Conclusion

In this chapter, a novel monitoring and control of an electroplating process line using a smart tank station and smart agitation system are presented. The methodology is based on IoT and cloud computing technology. In addition, the Fuzzy logic technique is used to control actuators using Mamdani Fuzzy mechanism. The ZigBee technology is also implemented to understand the working principle and the advantages of the low-power wireless local area network (WLAN).

The real-time monitoring and control of all vital variables of the process solution are maintained and the condition of the solution is optimised for achieving desired quality in electroplating products. The smart sensors and actuators have enabled the process tanks to be transformed into a smart tank station capable of self-organizing the condition of their process solutions along the production line. In addition to this, a DC motor is programmed to monitor and control the hoist movement and to maintain the agitation of the solution as required by the product.

As a result, management can now use IoT links facilitated in the system to oversee the task of the process controller and intervene in real-time to ensure the management of production and quality to meet customers' requirements and reduce waste.

Data Collection

6.1. Introduction

ZigBee IoT network protocol and Wi-Fi IoT network protocols are used to collect the shop floor sensor data. ZigBee is a mesh network which is designed specifically for the control and sensor network based on the IEEE standards for low-power wireless personal area networks (WPANs) that cover a large area. ZigBee technology is used to transfer data from the show floor level to the supervisory control level. The instruction to implement ZigBee technology and the result obtained is given in section 6.2. Wi-Fi is a technology for wireless local area networking with devices based on IEEE 802.11 standards. The Wi-Fi is enabled on a Raspberry Pi device to connect to the internet and the data collected from the sensors are transferred to the ThingSpeak web-based cloud platform using the MQTT and REST API to publish the sensor data on the ThingSpeak Channel.

6.2. Implementation of ZigBee technology

The ZigBee technology (The medium-range IOT Network Protocol) is implemented and tested to transmit temperature data collected from the process tank at the shop floor level to the supervisory station at the process control level. The ZigBee device that is connected to the sensor node is configured as a ZigBee coordinator to establish the network and to store information like security keys. The ZigBee device that is connected to a raspberry pi microcontroller at the process control/ supervisory level is configured as a router, which acts as an intermediate node as shown in Figure 24.

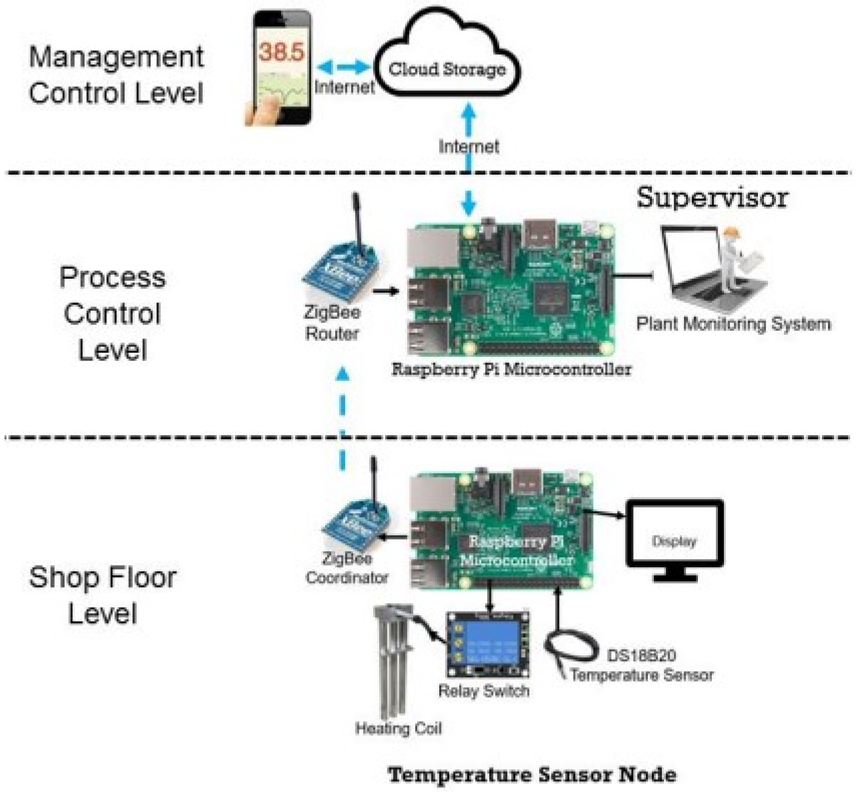


Figure 24: Various control levels of designed architecture.

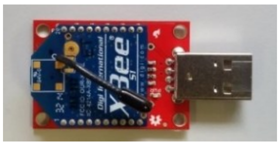
The data from the ZigBee coordinator to a router will be sent as a message. The message consists of the header and payload. The header contains the source address and the message ID. The payload contains the data to be carried inside the message.

Steps followed to interface the ZigBee device with the Raspberry Pi:

The ZigBee devices must be configured with the same PAN ID to form networks (star, mesh network etc). The configuration is done using Digi's configuration software, X-CTU (Bansal, 2017).

Step 1: XCTU Software was downloaded on the laptop or PC to configure the XBee module.

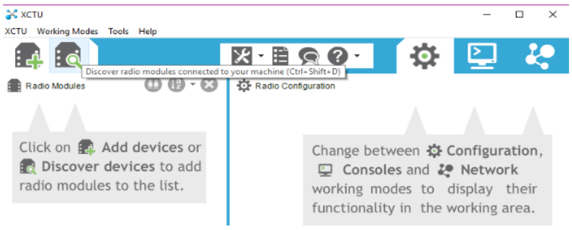
Step 2: ZigBee XBee module was placed properly on ZigBee Dongle.



Step 3: To configure ZigBee Module the dongle was connected to a laptop or PC where software is downloaded.

Step 4: One end of the Zigbee is configured as a coordinator, to transfer the data collected on the shop floor and the other end is configured as a router which receives data at the process control level.

Step 5: Using the Search option- "Discover radio modules connected".

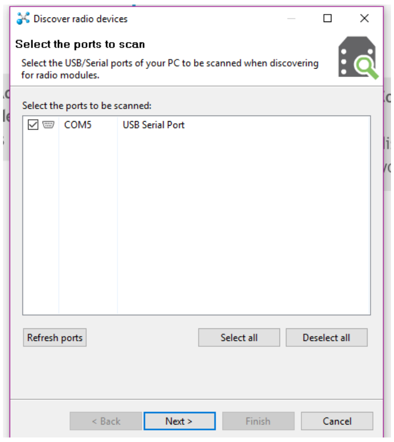


Discover radio modules connected to your machine (Ctrl+Shift+D)

Click on **Add devices** or **Discover devices** to add radio modules to the list.

Change between **Configuration**, **Consoles** and **Network** working modes to display their functionality in the working area.

Step 6: The 'COM' port was selected which appears in the window, it indicates the USB Serial Port to which ZigBee Dongle is connected and 'Next' was selected.



Select the ports to scan

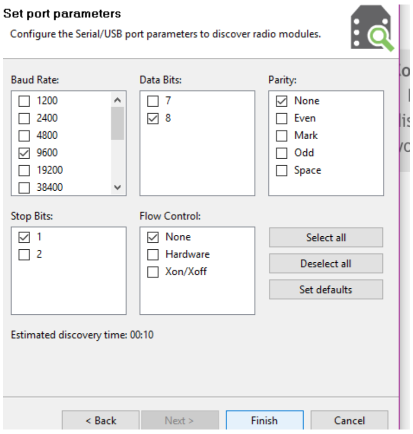
Select the USB/Serial ports of your PC to be scanned when discovering for radio modules.

Select the ports to be scanned:

☑ COM5 USB Serial Port

Step 7: Setting port parameters,

- Baud Rate: 9600
- Parity: None
- Stop bits: 1
- Flow control: None
  Clicked on 'Next'



Set port parameters

Configure the Serial/USB port parameters to discover radio modules.

Baud Rate:
- ☐ 1200
- ☐ 2400
- ☐ 4800
- ☑ 9600
- ☐ 19200
- ☐ 38400

Data Bits:
- ☐ 7
- ☑ 8

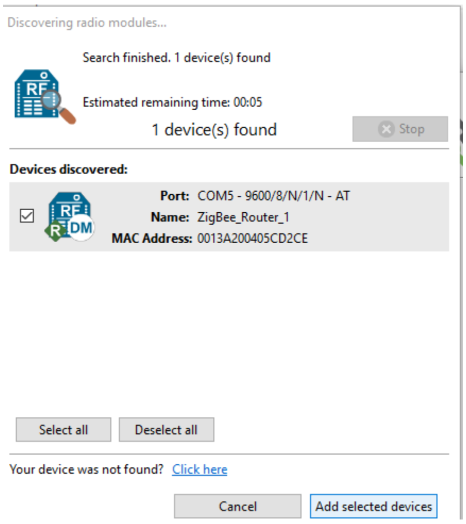
Parity:
- ☑ None
- ☐ Even
- ☐ Mark
- ☐ Odd
- ☐ Space

Stop Bits:
- ☑ 1
- ☐ 2

Flow Control:
- ☑ None
- ☐ Hardware
- ☐ Xon/Xoff

Estimated discovery time: 00:10

Step 8: The Device discovered was selected and clicked on "Add selected devices".



Discovering radio modules...

Search finished. 1 device(s) found

Estimated remaining time: 00:05

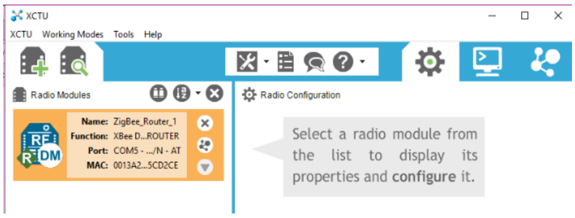
1 device(s) found

Devices discovered:

☑ **Port:** COM5 - 9600/8/N/1/N - AT
Name: ZigBee_Router_1
MAC Address: 0013A200405CD2CE

Your device was not found? Click here

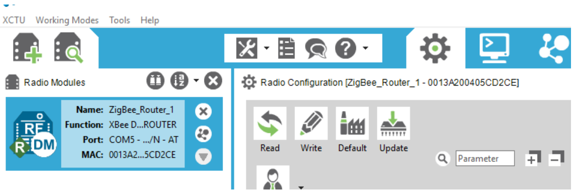
A Radio Module appeared as shown



Name: ZigBee_Router_1
Function: XBee D...ROUTER
Port: COM5 - .../N - AT
MAC: 0013A2...5CD2CE

Select a radio module from the list to display its properties and configure it.

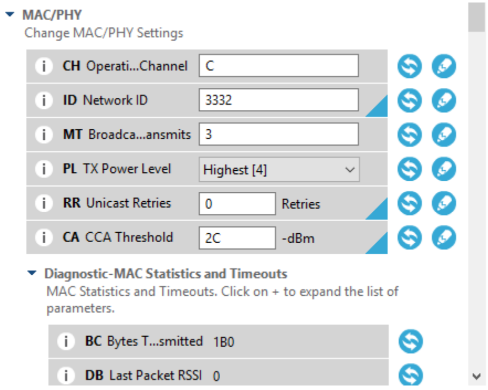
Step 9: The device to configure the Radio Module as Coordinator is selected



Radio Configuration [ZigBee_Router_1 - 0013A200405CD2CE]

Name: ZigBee_Router_1
Function: XBee D...ROUTER
Port: COM5 - .../N - AT
MAC: 0013A2...5CD2CE

Step 10: The parameters Channel (CH) and Network ID (ID) is checked



MAC/PHY
Change MAC/PHY Settings

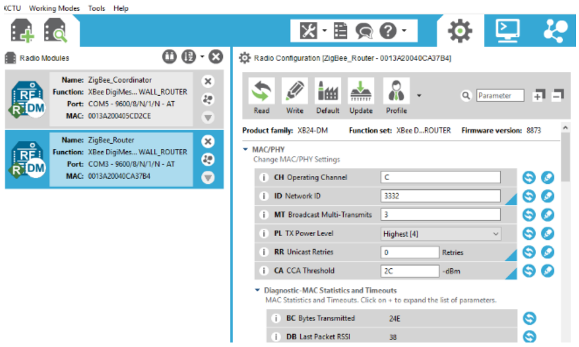
CH Operati...Channel: C
ID Network ID: 3332
MT Broadca...ansmits: 3
PL TX Power Level: Highest [4]
RR Unicast Retries: 0 Retries
CA CCA Threshold: 2C -dBm

Diagnostic-MAC Statistics and Timeouts
MAC Statistics and Timeouts. Click on + to expand the list of parameters.

BC Bytes T...smitted 1B0
DB Last Packet RSSI 0

Step 11: Step 1 to Step 9 is repeated to configure the ZigBee module as a router.

Step 12: The parameter channel and Network ID is checked. The network ID of the router must be the same as the Network ID of the coordinator.



Radio Configuration [ZigBee_Router - 0013A20040CA37B4]

Name: ZigBee_Coordinator
Function: XBee DigiMes... WALL_ROUTER
Port: COM5 - 9600/8/N/1/N - AT
MAC: 0013A200405CD2CE

Name: ZigBee_Router
Function: XBee DigiMes... WALL_ROUTER
Port: COM3 - 9600/8/N/1/N - AT
MAC: 0013A20040CA37B4

Product family: XB24-DM
Function set: XBee D...ROUTER
Firmware version: 8873

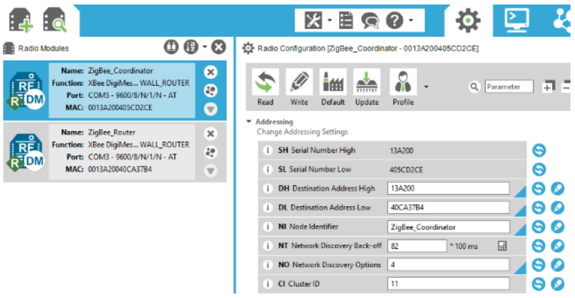
MAC/PHY
Change MAC/PHY Settings

CH Operating Channel: C
ID Network ID: 3332
MT Broadcast Multi-Transmits: 3
PL TX Power Level: Highest [4]
RR Unicast Retries: 0 Retries
CA CCA Threshold: 2C -dBm

Diagnostic-MAC Statistics and Timeouts
MAC Statistics and Timeouts. Click on + to expand the list of parameters.

BC Bytes Transmitted: 24E
DB Last Packet RSSI: 38

Step 13: The SH (Serial Number High) and SL (Serial Number Low) of the Router is noted and copied that to DH (Destination High) and DL (Destination Low) the Coordinators respectively.



Radio Configuration [ZigBee_Coordinator - 0013A200405CD2CE]

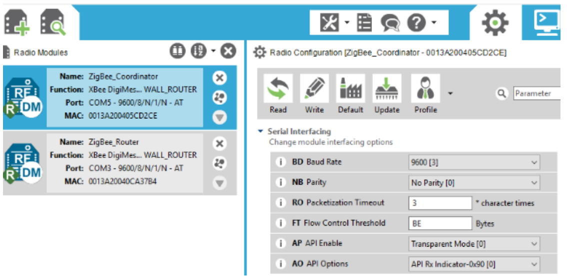
Name: ZigBee_Coordinator
Function: XBee DigiMes... WALL_ROUTER
Port: COM5 - 9600/8/N/1/N - AT
MAC: 0013A200405CD2CE

Name: ZigBee_Router
Function: XBee DigiMes... WALL_ROUTER
Port: COM3 - 9600/8/N/1/N - AT
MAC: 0013A20040CA37B4

Addressing
Change Addressing Settings

SH Serial Number High: 13A200
SL Serial Number Low: 405CD2CE
DH Destination Address High: 13A200
DL Destination Address Low: 40CA37B4
NI Node Identifier: ZigBee_Coordinator
NT Network Discovery Back-off: 82 * 100 ms
NO Network Discovery Options: 4
CI Cluster ID: 11

Step 14: Serial Interfacing of ZigBee Coordinator and Router was edited, selected "Transparent Mode [0]" in API Enable options for both coordinator and router.



Radio Configuration [ZigBee_Coordinator - 0013A200405CD2CE]

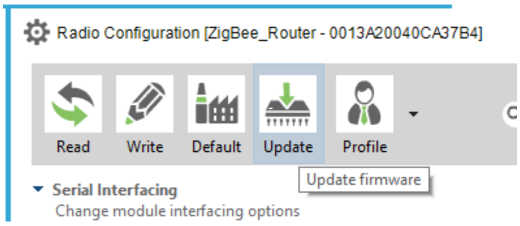
Name: ZigBee_Coordinator
Function: XBee DigiMes... WALL_ROUTER
Port: COM5 - 9600/8/N/1/N - AT
MAC: 0013A200405CD2CE

Name: ZigBee_Router
Function: XBee DigiMes... WALL_ROUTER
Port: COM3 - 9600/8/N/1/N - AT
MAC: 0013A20040CA37B4

Serial Interfacing
Change module interfacing options

BD Baud Rate: 9600 [3]
NB Parity: No Parity [0]
RO Packetization Timeout: 3 * character times
FT Flow Control Threshold: BE Bytes
AP API Enable: Transparent Mode [0]
AO API Options: API Rx Indicator-0x90 [0]

Step 15: Updated, for both router and coordinator.


Radio Configuration [ZigBee_Router - 0013A20040CA37B4]

Serial Interfacing
Change module interfacing options

Step 16: To set up ZigBee on Raspberry Pi

- The python-serial was installed by using the command below,

```
sudo apt − get install python − serial
```

- To receive data at the router from the coordinator the following code is used,

Code for Router:

```
import serial

ser = serial.Serial('/dev/ttyUSB0', 9600)

while True:

    incoming = ser.readline().strip()

    print 'Data Received'
```

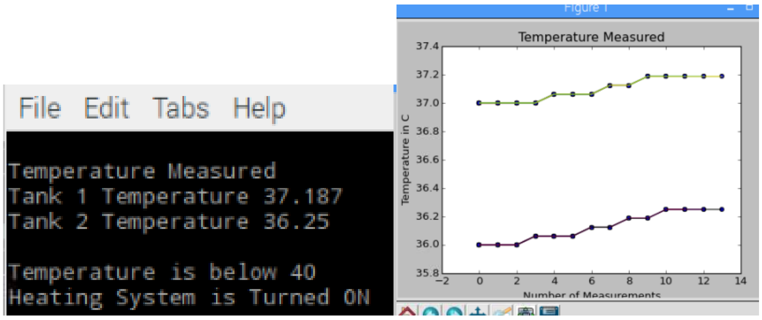
```
    print ‘%s\n’ %incoming
```

Code for Coordinator:

```
import serial

ser = serial.Serial(‘/dev/ttyUSB0’, 9600)

while True:

    ser.write(Data to be transferred)
```

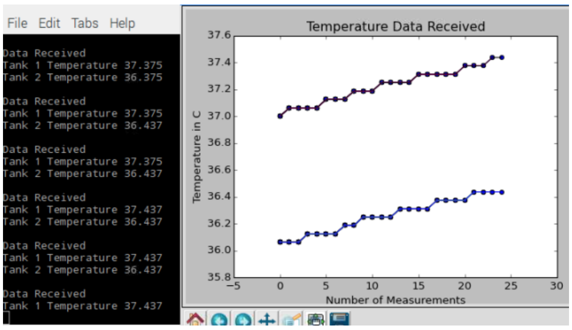
The data transferred from the coordinator is received from the XBee end device connected to the Raspberry pi IoT gateway. When the internet is provided to the Raspberry pi gateway the temperature data will be available from the cloud. The temperature readings can be monitored from any smart device, laptop, or desktop computer if the internet is provided. The following results are achieved by the system:

- Data generated from the shop floor sensor node, shown in Figure 25.
- Figure 26 represents the Temperature Data received at the Process Control Level (ZigBee Router).
- Smartphone monitoring, shown in Figure 27.



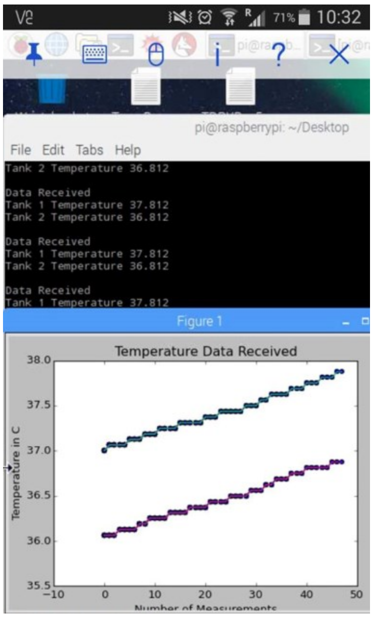
```
Temperature Measured
Tank 1 Temperature 37.187
Tank 2 Temperature 36.25

Temperature is below 40
Heating System is Turned ON
```

Figure 25: Data generated from the shop floor sensor node



```
Data Received
Tank 1 Temperature 37.375
Tank 2 Temperature 36.375

Data Received
Tank 1 Temperature 37.375
Tank 2 Temperature 36.437

Data Received
Tank 1 Temperature 37.375
Tank 2 Temperature 36.437

Data Received
Tank 1 Temperature 37.437
Tank 2 Temperature 36.437

Data Received
Tank 1 Temperature 37.437
Tank 2 Temperature 36.437

Data Received
Tank 1 Temperature 37.437
```

Figure 26: Data received at the Process Control Level



```
Tank 2 Temperature 36.812

Data Received
Tank 1 Temperature 37.812
Tank 2 Temperature 36.812

Data Received
Tank 1 Temperature 37.812
Tank 2 Temperature 36.812

Data Received
Tank 1 Temperature 37.812
```

Figure 27: Smart Phone Monitoring.

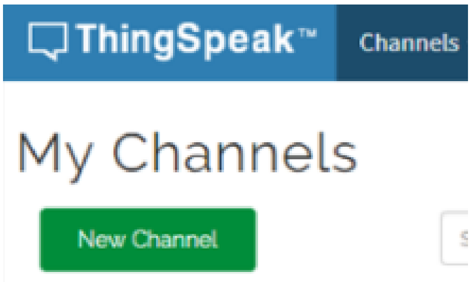
6.3. ThingSpeak Cloud storage

The Wi-Fi technology is used to transfer sensor data collected from Raspberry Pi to ThingSpeak Cloud storage. To achieve this Raspberry Pi is provided with a Wi-Fi connection, now that the Raspberry Pi is given internet the data is transferred to ThingSpeak web-based platform for cloud storage. On the ThingSpeak website, a channel must be created where the API Keys to read and write will be produced. To access the ThingSpeak application site, a ThingSpeak private network was created, to provide dynamically scalable infrastructure for application, data and file storage. Private clouds are built exclusively for a single enterprise. They aim to address concerns on data security and offer greater control.

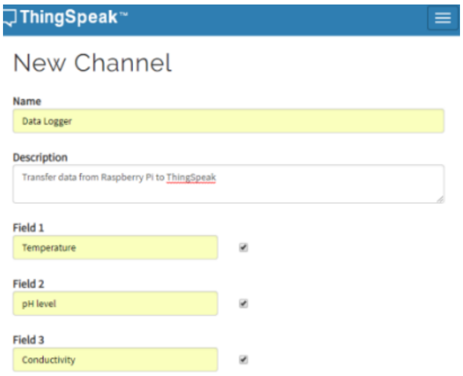
Following are the steps carried out to create the ThingSpeak channel:

Step 1: Sign Up at ThingSpeak.

Step 2: Created a channel by clicking on "New Channel".



Step 3: The number of fields were selected and name it accordingly.



Name
Data Logger

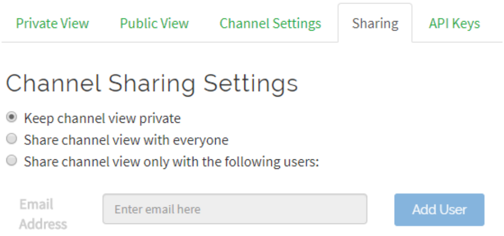
Description
Transfer data from Raspberry Pi to ThingSpeak

Field 1
Temperature ☑

Field 2
pH level ☑

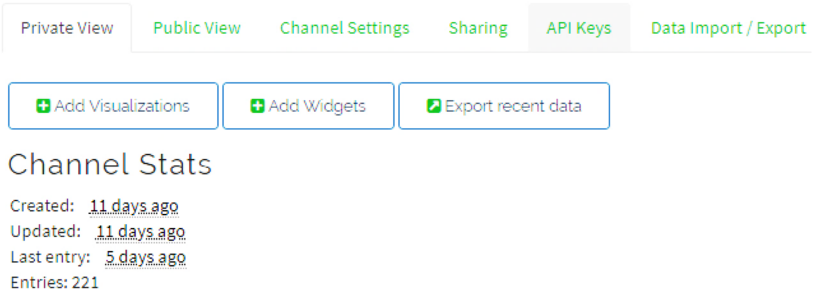
Field 3
Conductivity ☑

Step 4: The channel was made private by selecting the option 'Keep Channel view private'.



● Keep channel view private
○ Share channel view with everyone
○ Share channel view only with the following users:

Step 5: On the API tab, the "write API key" was copied and was used in the python program to send data from RPi to the ThingSpeak Channel for Cloud storage.



Channel Stats

Created: 11 days ago
Updated: 11 days ago
Last entry: 5 days ago
Entries: 221

Step 6: The data collected from the Raspberry Pi is displayed on the ThingSpeak channel as shown below. Figure 28 shows the Temperature, pH, Conductivity and Level sensor data collected from the show floor Nickle tank station. Figure 29 shows the big data collect from the sensor, the time interval for data collection can be changed according to the needs of the operation at the show floor level.

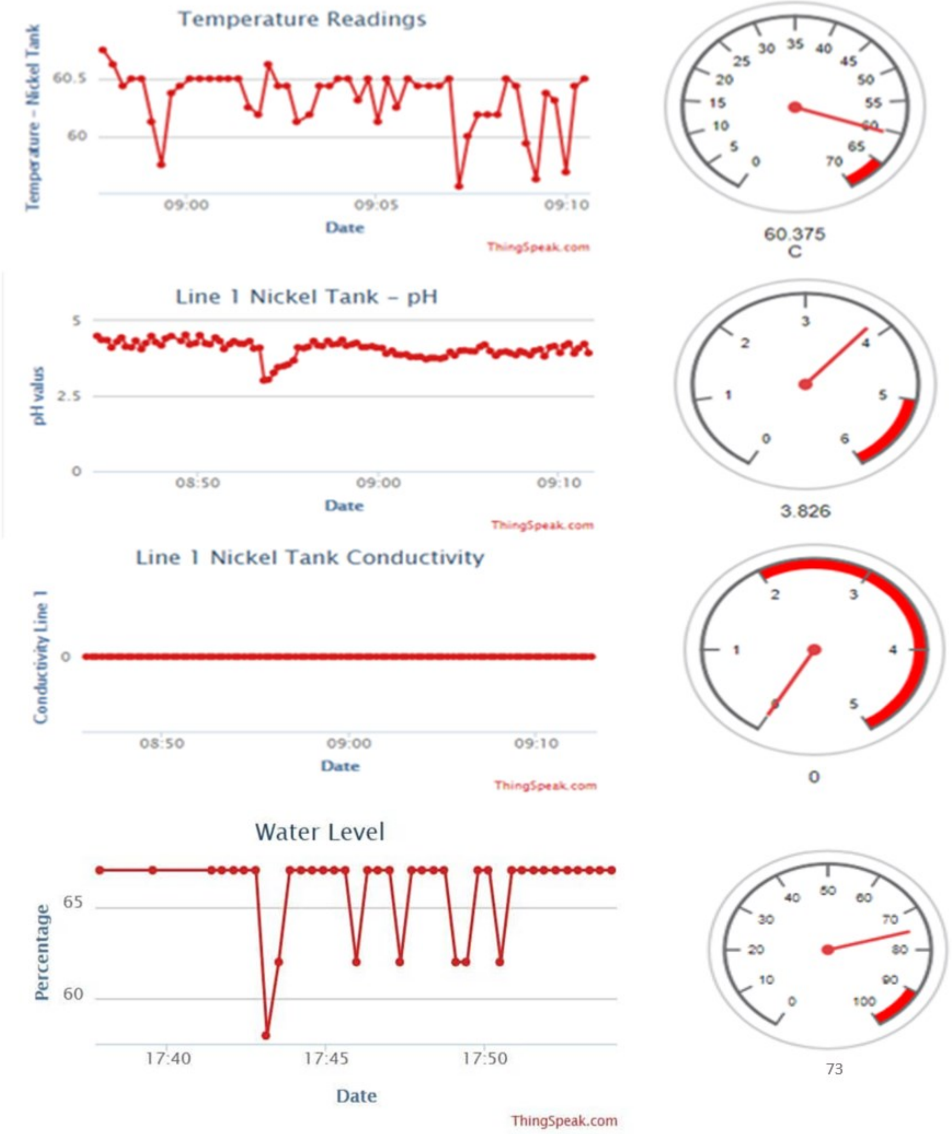


Figure 28: ThingSpeak Streaming Sensor Data.

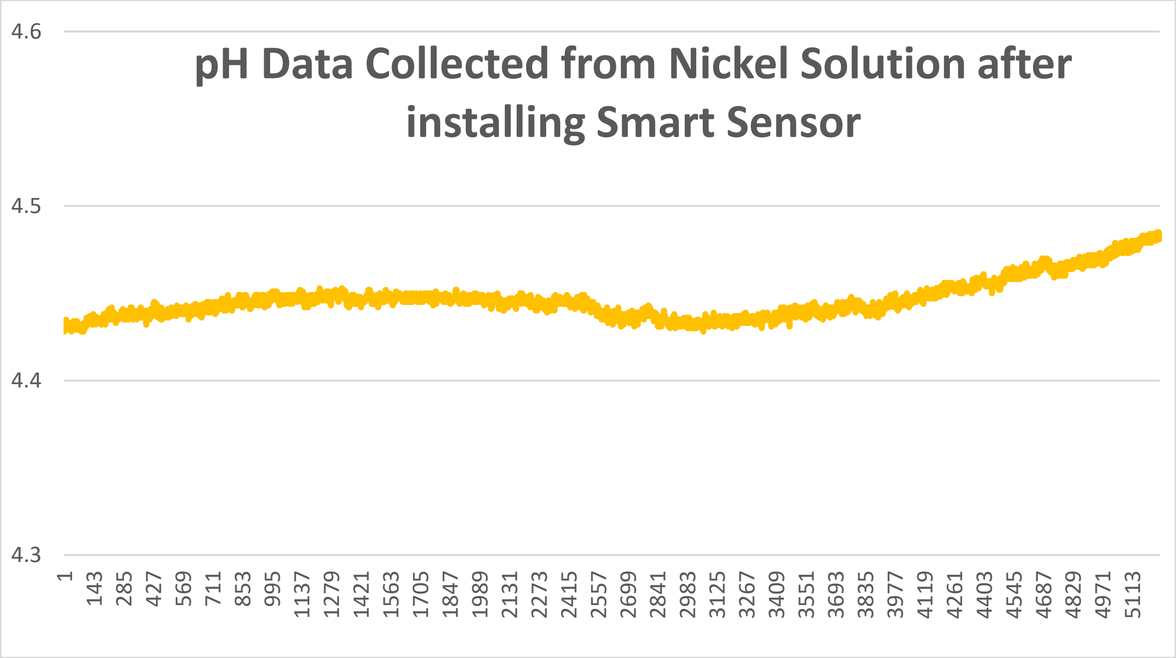
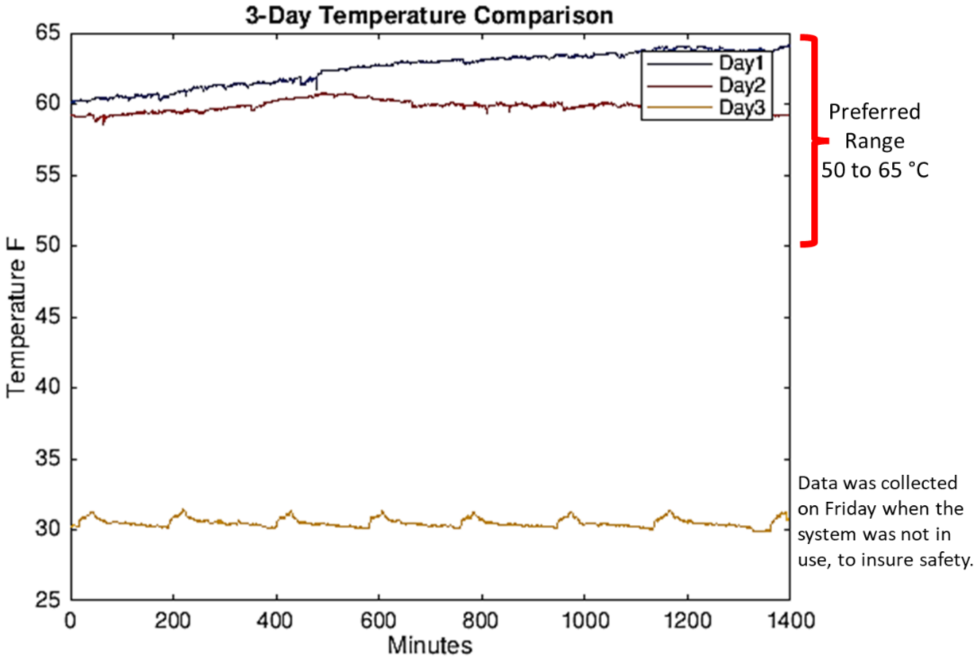


Figure 29: Big Data Produced by the pH Sensor Node.

Step 7: Using the ThingSpeak MATLAB facilities the data collected can be analysed in many ways. For example, 3 days of data collected from the sensor node can be compared and analysed the data fluctuation.



Preferred Range 50 to 65 °C

Data was collected on Friday when the system was not in use, to insure safety.

Figure 30: Shows the Comparison of 3 days of Temperature data collected from the sensor node using ThingSpeak MATLAB Code.

6.4. Cost Model

A generic cost model for the prototype developed in this study is given in Table 7 which is the estimated cost to install smart sensors and actuators at the shop floor Nickel process plant. During this research effort was made to connect most of the existing sensors and actuators of the plant at the shop floor to the microcontroller to turn them into the smart devices having the enough memory and communication facilities to hold data and transfer data to the respective operations controllers or management of the plant. The Table 7 consist of the list of devices used during this research and the cost of devices required to collect real time data for the Nickel-plating process. Both before and after inflation rates are mention below.

Table 7: Generic Cost Model

	Cost Before Inflation	Cost after inflation
Raspberry Pi Board	£280.32	£788.00
Raspberry Pi HAT	£95.96	£108.00
Temperature Sensor	£8.00	£11.75
pH circuit	£42.99	£45.99

Conductivity Circuit	£50.89	£55.89
T3 Tentacle Board	£82.84	£83.84
Heating coil	£210.95	£225.95
Relay Switch	£27.20	£39.16
Connecting Wires	£24.95	£34.95
Level Sensor	£225.36	£237.36
IR Sensor	£10.99	£17.78
DC Motor	£383.80	£384.37
ZigBee Module	£99.72	£99.72
ZigBee Dongle	£46.34	£46.34
ThingSpeak Subscription	£570.00	£570.00
Total =	£2,160.31	£2,749.10

6.5. Conclusion

The sensor node designed is developed for monitoring an electroplating tank solution quality. Obtained sensor data from each node are achieved in the corresponding local database and ThingSpeak cloud database. The cloud database is to enable visibility, traceability, remote monitoring, future retrieving and trend analysis. ThingSpeak cloud services are used for storing the data in the online cloud database mainly for running analytics services. Private and public views for the channel are configured in this cloud service.

Smart sensors and actuators for control of all vital variables at process solution are developed to maintain it at desired values. These smart devices have enabled the production line to be transformed into a smart electroplating process line which will achieve specific quality in plating products. The main parameters required to maintain quality in electroplating solution are monitored and controlled.

Conclusion and Future works

7.1. Conclusion

The maintenance of the optimum condition of the electroplating process solution is vital to the achievement of desired product quality and achievement of production schedule in the electroplating industry. However, this is a complex task requiring real-time monitoring and control of numerous tanks and process stages and operations on the production line in an electroplating plant.

Monitoring and control of the hoist system are vital. A computerised hoist provides real-time information about the sensors which are located to stop the hoist at the right position to avoid any accidents, the information collected by the sensor is used to maintain safety within the production line environment. A new computer programmable hoist will provide a real-time update about the hoist which will help management and supervisor to track the part which is in the tank and know the equipment status and durability. Complete automation will avoid the barrel being left in the plating tank for a longer duration/less duration resulting in obtaining the required thickness of the metal deposition on the product (part) which avoids any inspection rejection or rework.

A novel distributed control System (DCS) was designed and presented in this thesis for real-time monitoring and control of the process, production, and quality in an electroplating plant. The system allows for monitoring and control of process parameters at the plant level using IoT–based wireless communication technology and facilitates real-time responses to process disturbances from anywhere anytime using IoT devices and cloud computing. In addition to having autonomous monitoring and control at the shop floor level, the Management level and Supervisory level can now use the IoT link provided here to oversee the task of the process controller and intervene in real-time to ensure the management of product quality and achievement of production schedule to meet customer requirements and to reduce waste (unwanted products/scrap).

Following the programmed commands, an automated production line is a process that which raw materials enter, and finished products leave, with little or no human intervention. The fast, stable and accurate production flow contributes to the reduction of production time and cost of the manufacturing products. The use of automated production lines significantly reduces production costs and labour costs. The real-time information is shared at each control stage for the management to make the right decision.

7.2. Limitations and Future work

Although this research has been carefully conducted and followed guidelines and suggestions, it is not without limitations. Considering these limitations, its findings should be taken seriously. Overcoming these limitations would be a direction for future research. Firstly, not all parameters are monitored and controlled. Other variables such as solution density, ions concentration and current supplied to the plating solutions are not monitored and controlled. It is vital to maintain all the solution parameters to the required range. Even slight changes in any of the parameters can result in the rejection of the plated product. Future research must consider monitoring and control of the other variables' parameters.

Second, this research was carried out on Nickle plating process, it would be interesting to implement the smart sensors and actuators to monitor and control other electroplating process such as gold, silver, copper, white bronze, chrome, etc, and even the electroless plating process where temperature and pH parameters are crucial.

Third, the introduction of a barcode scanner at each stage will help the management and supervisor to understand the logistics of the product within the shop floor level. This will help the management to make a better decision while communicating with the customers regarding product delivery.

Fourth, regarding the production line control. The introduction of IoT-based manufacturing execution systems (MES) will provide manufacturers with the ability to monitor and report on machines on the shop floor, as well as manual processes through an automated software system. Shop floor production systems and ERP systems operate on a different interpretation of real-time one typical of the strategic management of the business, the other associated with the punctual execution of the process. The systems must communicate and act as a seamless whole to allow the manufacturing industry to meet the dynamic demands coming from customers, regulators, suppliers and even internal staff.

Last but not the least, the research was conducted in the U.K based Electroplating industry. It is interesting to see how other countries or other companies in the U.K are utilising the new technologies in the market to improve their production and to maintain the best quality of their products.

Appendices

Appendix 1: Temperature Sensor calibration:

A constant temperature is critical for the plating process. An experiment is conducted to check the accuracy and durability of the temperature sensor when immersed in the electroplating solution. In this experiment, a Raspberry Pi microcontroller is used to monitor the temperature of the plating solution in real-time. A pre-calibrated thermometer is used as the reference point.

Three different temperature sensors are used in this experiment,

- The DS18B20 temperature sensor is directly immersed in the plating solution.
- The DS18B20 is insulated with a PVC tube immersed in the plating solution.
- Non-contact IR Temperature sensor is located 15cm above the plating solution.

Test	Thermo meter	Sensor 1 (Direct Contact with Solution)	Sensor 2 (Insulated in PVC Tube)	Sensor 3 (Non-contact IR Sensor)	Settling time
Normal water	22.5 °C	22.125 °C	22.812 °C	20.05	125µs to 2 Min

Hot Water	63.425 °C	64.875 °C	65.687 °C	52.2	0 - 5 Min

Sensors	Error in Normal Water	Error in Hot Water	Settling time
Temperature Sensor 1 (Direct contact with Solution)	0.375 °C	-0.45 °C	30 Seconds
Temperature Sensor 2 (Insulated in PVC Tube)	-0.412 °C	-2.262 °C	3-5 Min
Temperature Sensor 3 (Non-contact IR Sensor)	0.025 °C	11.5 °C	125us

Correct Location for the temperature sensor in the process tank:

Test	Temperature Sensor 1 (Direct contact with the solution)	Temperature sensor 2 (Insulated in PVC Tube)	Temperature Sensor 3 (Non-contact IR Sensor)
Sensor reading at the bottom of the tank	63.187 °C	61.75 °C	Can only read the surface temperature
Sensor reading is located in the top 30% of the process solution	65.875 °C	64.937 °C	
Difference	-2.688 °C	-3.187 °C	

The PVC tube of 10mm inner diameter takes a while to read the accurate tank temperature, that is due to the air in the tube. If the tube is filled with water, the sensor reads the temperature quickly compared to the empty tube. But the reading is stable once the sensor is settled with the environment.

If the tip of the sensor in a process tank is located at the bottom of the tank, the sensor cannot sense the raising heat, during plating the solution is agitated hence, the sensor the solution reads equal temperature reading throughout.

Accuracy Test: readings were taken every 30 seconds for 5 minutes:

Test	Reference Temperature	IR Sensor	DS18B20 (Insulated in a PVC tube)	DS18B20 Direct contact with the solution
	72.2	63.1	70.187	71.812
	72.4	62.7	70.187	72.187
	73	61.2	70.687	72.812
	73.1	59.5	71.437	72.875
	72.9	60.2	71.625	72.562
	72.8	58.5	71.625	72.5
	72.6	58.4	71.625	72.312
	72.4	58	71.437	72.125
	72.3	56.8	72.25	72
	72.1	56.4	71.125	71.812
Standard deviation	72.58	59.48	71.2185	72.2997
Error		13.1	1.3615	0.2803

The accuracy test was run for days, the test revealed deviations of <0.35, <1.5, and >10 for, DS18B20 Direct contact with the solution, DS18B20 (Insulated in a PVC tube) and IR Sensor respectively when compared to the Reference Temperature which is measured by a precision PT100 temperature measuring instrument. All sensor types showed stable readings for 2 weeks. The high variability of IR Temperature sensor reading is due to steam.

TABLE 2 DS18B20 Temperature Sensor direct contact with solution calibration result

Test	Temperature Range	Accuracy
1	Room Temperature	±0.35°C
2	+40°C to +65°C	±0.5°C
3	Above 70°C	±0.75°C

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