Developing a self-organised Smart Tank Station for Electroplating Process Plant

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Abstract— **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 in products. Parameters such as current density, temperature, agitation system, bath pH, bath concentration and plating time are known to have important role in determining the quality of the plating products and the productivity of the plating process plant. This paper presents the works being carried out by the authors in developing smart sensors and smart actuators for measurement and control of values of these parameters, and use of these smart devices for transforming the process tanks into smart tank stations to enable the tanks to monitor the condition of process solution along the line and maintain the desired process solution condition for achieving specific quality in plating products. The paper explains the ways the smart devices installed in or used around the tank stations and the use of ThingSpeak in developing smart tank stations.**

Keywords- IoT, Cloud Service, ThingSpeak, and Electroplating

I. INTRODUCTION

Achieving the product quality in an Electroplating [22] process plant requires continuous, careful maintenance of optimum condition of the process solution in the electroplating process tanks. According to [1] parameters such as current density, temperature, agitation system, bath pH, bath concentration and plating time play important role in determining quality of the plating product and the productivity of plating process plant. The production line in a typical electroplating process plant comprises numerous tanks and process stages and operations. The real time monitoring and control of process solution along the line is very difficult for manual monitoring and control by operators. Previous work of the authors [2] concentrated on developing a real time monitoring and control system for an electroplating process plant, enabled achievement of real time measurement and control of the values of some of the identified parameters of the solution in the tank in order to maintain desired condition in solution for achieving desired quality in the product. This paper presents further works being carried out by the authors on developing smart sensors [2,8] and the smart actuators [2,17] and their installations in, or attachment to the tank station transforming the tanks into the smart tank stations, each capable of monitoring and controlling own solution condition and maintaining the optimum of the solution in the tank. An optimized smart tank station allows operators tasks to be executed with high reliability with minimum to none requirements for manual intervention. It also facilitates automatic tracking of workflow and scheduling and optimization of energy consumption inherent in the tank station leading to increase yield, uptime, and quality, as well as reducing cost and waste. 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.

The plating electroplating process solution is controlled by keeping the bath (solution) parameters constant and assuming there will be a constant reaction rate [1,17]. But in practice, due to constant change in bath loading, there will be disturbances in the parameters, hence it is necessary to monitor and control solution parameters in real-time. 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 condition needed to the achieve desired quality in the electroplating product despites various disturbance resulting from constant changes in bath loading.

II. ELECTROPLATING MANUFACTURING AS AN EMMERGING ADAPTABLE MANUFACTURING TECHNIQUE FOR SURFACE ENGINEERING

There is a demand for adaptable manufacturing processes in metal processing industry for a wide range of applications. One of the most important application is the metal surface engineering which determines product functionality. There are few different techniques being used such as physical vapor deposition [25], laser technology [24,21], thermal spray and electroplating process [23,27], the latter is one of the most effective one. Metallic coatings production involves electrochemical reactions at the electrode/electrolyte interface, with deposition of ions from the solution to the electrodic surface with the electron transfer. Electroplating gained interest starting in 1840, in Birmingham, England [26]. This led to the establishment of Birmingham as the industrial center for electroplating. Electroplating technology has been rediscovered after the Second World War with the discovery of semiconductors and the growth of the electronics industry, esspecially in metallization of printed wiring boards. In 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 [22].

III. Overall System Architecture:

In this work, sensor nodes are designed using Raspberry Pi [15] as processing unit; where DS18B20 Temperature Sensor, pH [1,3] and Conductivity Sensor [1,4,27] are connected to Rapberry Pi, Optical Level Sensor is connected to Arduino, and actuators are controlled via relay switch. Wi-Fi (IEEE 802.11 N) is used as 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 [8,18] Cloud service [5,7,8] with the help of router/IoT gateway. The intended model stands distinct from traditional manual/semi-automatic system as certain data processing are 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.

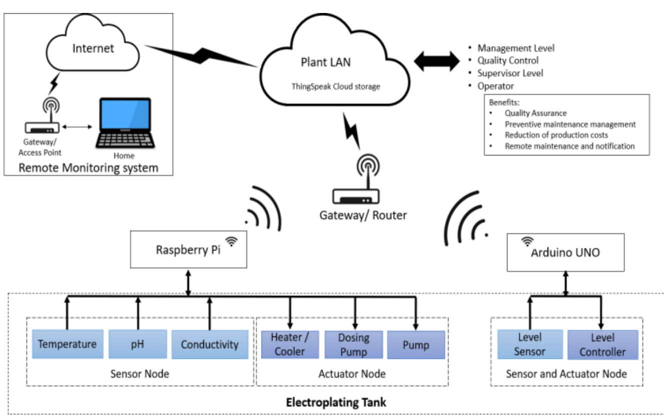


Fig. 1. Overall System Architecture.

Fig. 1. describes the overall architecture of the designed system for sensor and actuator node. A sensor node is built with Raspberry Pi single board computer, a network gateway or router through which node is connected to Thingspeak cloud database. The data from the cloud database can be accessed using any mobile devices or any other portable IP enabled hand-held devices. The supervisor or quality management level or management level can monitor the real time data streams by logging to the private/public channel of the ThingSpeak cloud services. The admin can automate certain timely decision-making methods from initiating reaction process.

IV. Design and Implementation of the System for Real Time Analysis of IOT Data Streams:

The designed system consists of Raspberry Pi and Arduino Microcontroller to monitor Temperature, pH, conductivity and level of the solution. Actuators are controlled via Relay switch to optimize the solution parameters. Temperature, pH and Conductivity sensor are connected to Raspberry Pi and level sensor comes through Arduino to measure the variables of electroplating process solution. The information obtained from RPi is displayed in real time for control and supervisor level. Data stored on cloud are retrieved for analysis they will be supplied to the analytic module where analytic module compares 3 days operation for visualization of sensors, so the variation or difference can be seen. Later, the analytic module will be directed to actuation module which visualizes to supervisor mode upon threshold triggering relevant actions. With the designed system i.e. shop floor monitoring system; an actionable, real-time shop floor data is utilized anytime, anywhere, by anyone who is authorized to use the ThingSpeak application to drive up quality, boost performance and improve bottom line.

The measured variables are used to detect the condition of the solution in the electroplating process tank. The sensors are connected to a microcontroller-based measuring node, which process and analysis the data. In this design ThingSpeak cloud storage system is used to transfer data from shop floor to management level for visual display. The shop floor sensor and actuator node present the readings of the sensors and controls solution parameters. The sensors are shown to work within their intended accuracy ranges. The result demonstrates that the system is capable of reading parameters and can successfully process, transmit and display the readings.

With the capability offered by IoT for connectivity and communication between devices, smart devices are designed and developed to regulate themselves without requiring human intervention.

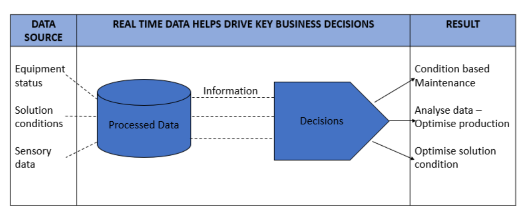


Fig. 2. Data Flow cause.

A. *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) [15,18]. 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, initially conceived of for education, it has become a mass product[15].

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

Biggest advantage of using Raspberry Pi is,

- pH and Conductivity circuit is connected to the Tentacle T3 Shield, it eliminates the need for wiring, multiplexing and electrical isolation. Because it comes in a Raspberry Pi HAT form factor, it can be simply plugged into Raspberry Pi.
- Multiple DS18B20 Temperature Sensor can be connect to a single RPi GPIO pin to gather sensor data from different Temperature Sensors.
- Arduino UNO can be downloaded to Raspberry Pi Linux which extends Input/output capability, allowing Arduino to be controlled via Raspberry Pi.

B. *Temperature Sensor*

Temperature plays a critical role during plating process, a slight change in temperature can cause a major difference. During plating temperature sensor is immersed in a chemical solution 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, durability and reliability of a temperature sensor in a plating environment is less. To avoid such consequences DS18B20 Temperature sensor made of stainless steel is used to prevents the sensor being plated in the solution, since stainless steel cannot be plated directly [1,21]. A total of 4 temperature sensor was connected to a single Raspberry Pi pin to check the accuracy and reliability of the system. In this experiment Standard Nickel on Steel Plating process is considered and the Sensor is calibrated for the considered plating range.

Table 1. Temperature Sensor Specification.

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

The temperature sensor comes with 100cm length, but the sensor cable was extended for the required length. Hence, the sensor was re-calibrated, and the calibration result is given in Table 2.

TABLE 2. DS18B20 Temperature Sensor 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

C. *pH of the solution*

The pH value [1] 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’.

$$pH = -\log 10[H+] \qquad \text{Eq. (1)}$$

Equation (1), is to calculate the pH of the solution; where, ‘p’ is the shorthand version for the mathematical term ‘–log10’ (negative log to the base 10). The ‘H’ refers to the Hydrogen Ion, [H+] standing for the ‘concentration of Hydrogen ions’. The greater the hydrogen ion concentration [H+], the lower the pH [20].

The Atlas Scientific pH circuit is used to collect the pH level of the solution. The Range of pH for electroplating depends on the type of metal being plated.

- In this experiment a pH range of 3.8 to 5 is considered
- Considered pH range is for plating standard nickel on steel
- Temperature maintained for this process is 55°C to 65°C

TABLE 3. pH Sensor Specification [3]

	pH Sensor	**Specification**
1	Range	0.001 to 14.000
2	Accuracy	+/– 0.002
3	Response time	1 reading per sec
4	Data protocol	UART & I2C
5	Default I2C address	99 (0x63)
6	Operating voltage	3.3V to 5V

pH circuit is programmed to measure and control the pH level of the solution and to store the data collected on the cloud storage system using ThingSpeak software.

D. *Conductivity Sensor*

The measurement of conductivity is important in electroplating industry, it is the capacity a solution has for conducting an electrical current [1,16,19]. Conductivity is a measurement of the total concentration of ions in a solution for the determination of impurities in the solution. Equation (2) is to calculate the conductivity of the solution,

$$\text{Conductivity of the solution} = \frac{K_{cell}}{R} * \frac{1}{1+\left(\frac{\alpha}{100}\right)*(T_{TC}-25)} \qquad \text{Eq. (2)}$$

Conductivity is the temperature compensated reading in siemens/cm

- K_{cell} = cell constant in cm^{-1}, typically in the range 0.01/cm to 50/cm
- R = measured resistance in ohm
- α = temperature compensation factor as % change per °C, typically close to 2.0
- T_{TC}= measured temperature of the sample in °C

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 4. Conductivity Sensor Specification [5]

	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 to 5V

E. Level Sensor

The plating solution level must be maintained to a required level, Optical level sensor 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.

V. COMMUNICATION SYSTEMS FOR WIRELESS CONNECTIVITY AND IOT DATA STREAMING

A. ThingSpeak

ThingSpeak [14] is an open data platform for the IoT. The Raspberry Pi device can communicate with ThingSpeak using a RESTful API (Application Programming Interface) [14], to transfer data. Data is sent and received via simple “Hypertext Transfer Protocol” (HTTP) POSTs, this communication happens through plaintext, JSON or XML. The data is then uploaded to the cloud and from there can be used for a variety of purpose, since it relates to MATLAB it provides several options to analyse the data obtained by plotting the graph. Data from RPi device will be uploaded for every 15 second, ThingSpeak can either keep the data in private or it can be made public [8,18].

In addition to this, ThingSpeak is used to analyse and act on the data collected, the data from the past 3 days can be compared and analysed to get better quality of the product. It provides an online text editor to perform data analysis and visualization using MATLAB® [18]. It can also perform actions such as running regularly scheduled MATLAB code or sending a tweet when the data passes a defined threshold.

B. Instruction to upload data to ThingSpeak Cloud storage system:

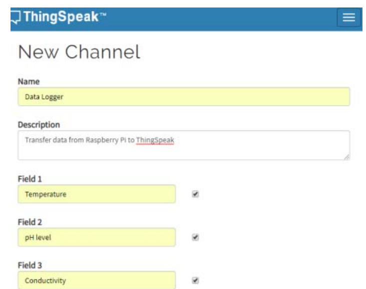
To upload sensor data collected from Raspberry Pi to ThingSpeak Cloud storage a channel must be created where the API Keys to read and write will be produced. To access ThingSpeak application site, we will need to create an account.

Following are the steps needed to complete the channel creation.

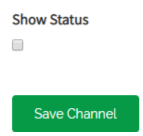
Step 1: Sign Up at ThingSpeak.

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

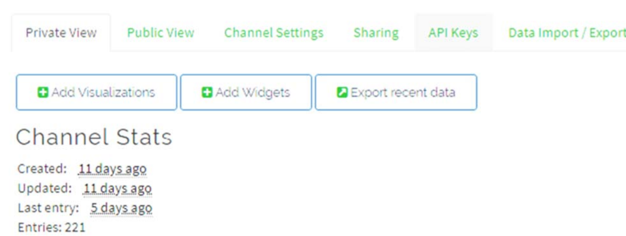
Step 3: Select the number of fields required and name it accordingly.



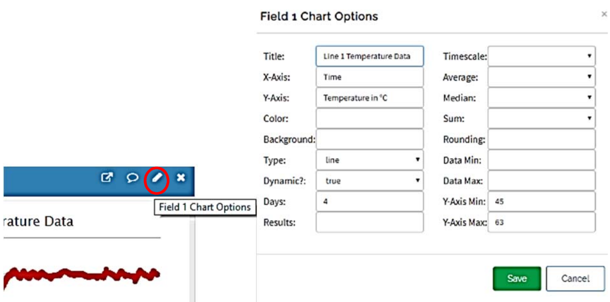
Step 4: To make the data public we must select 'Make Public' option before clicking 'Save Channel'.



Step 5: Click the API tab, here you will find your write API key to be used while sending data to the ThingSpeak Channel (copy the “write API key”, this key is used in python program to send data from RPi to ThingSpeak Cloud storage).



Step 6: To compare 3 days data collected, select on "Field Chart Options”, and specify days and other required parameters.



VI. Result and Discussion:

The sensor node designed was 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 Fig 3 shows the screen shot of local data streaming and ThingSpeak data streaming. The cloud database is for remote monitoring, future retrieving and trend analysis.

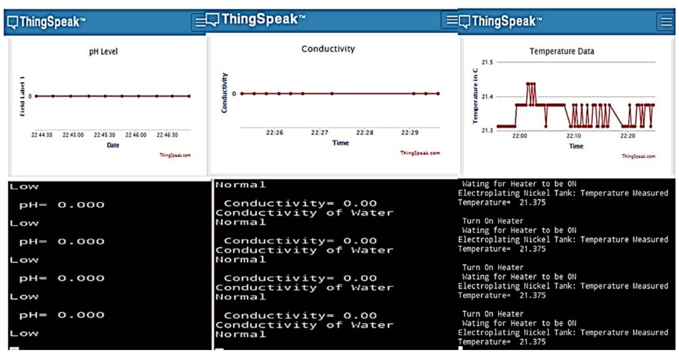


Fig. 3. ThingSpeak Streaming Sensor Data.

ThingSpeak cloud services is used for storing the data in the online cloud database mainly for running analytics services. Private and public view for the channel are configured in this cloud service. The main parameters which required to maintain quality in electroplating solution is monitored and controlled.

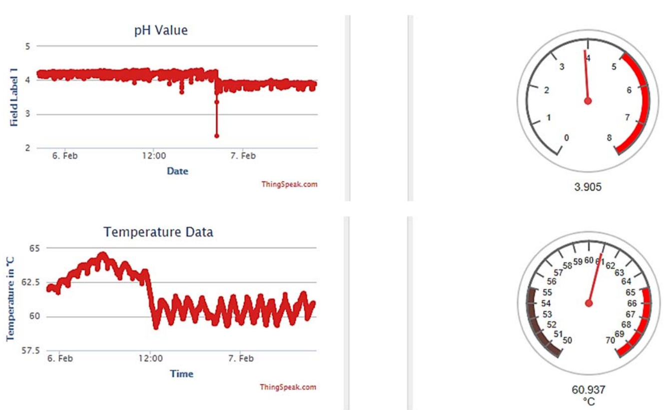


Fig.4. Big Data Produced by the Sensor Node, ThingSpeak Monitoring System.

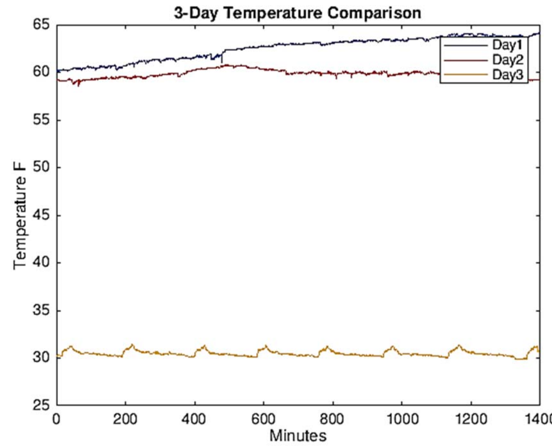


Fig. 5. Shows the Comparison of 3 days data collected from sensor node using ThingSpeak MATLAB Code.

VII. Conclusion

Smart sensors and actuators for control of all vital variables at process solution are developed in order to maintain it at desired values. These smart devices have enabled the process tank to be transformed into a smart tank station which will achieve specific quality in plating products.

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