

# IIoT Framework for SME level Injection Molding Industry in the Context of Industry 4.0

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## ABSTRACT

The Internet of Things (IoT) is a hype topic for nearly a decade now. Broadly growing, millions of devices get direct access to the Internet provides plenty of applications such as smart homes or mobile health management. This trend can also be found in the industry where IoT components hardened for these environments are introduced, called Industrial IoT (IIoT) devices which can be either sensors or actors, as well as mobile equipment such as smartphones, tablets, and smart glasses. Consequently, mobile communication becomes universal in smart factories. IIoT devices provide massive data on temperature, pressure, machine states, etc. But still, most of the SME level industries in the Asian region are new to these technological advancements. They still operate their facilities with conventional setups without absorbing the new opportunities which are presented by IIoT.

In the plastic injection molding industry, process parameters perform a significant role in the quality of the output product. During the manufacturing process, these process parameters have to deal with various factors such as quality and type of materials, requirement tolerance levels of the output product, Environmental conditions like temperature and humidity, etc. Injection molding has been a challenging process for many SME level manufacturers to produce products while meeting the quality requirements at the lowest cost. Most of them are unable to reach the global market in the injection molding industry due to the non-availability of the proper methods to determine the process parameters for injection molding. During production, quality characteristics may differ due to drifting or shifting of processing conditions caused by machine wear, environmental change, or operator fatigue. By determining the optimal process parameter settings productivity and quality will increase while reducing the cost of production.

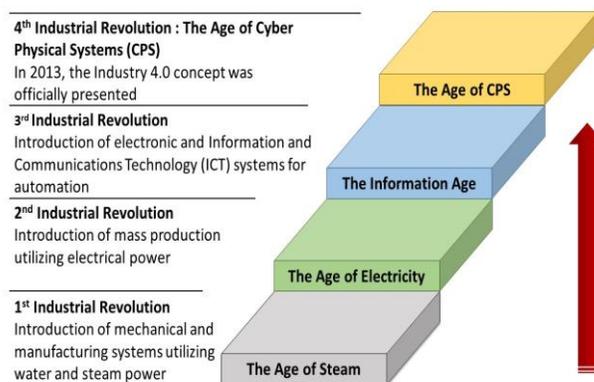
In this paper, we suggest an Industrial IIoT framework that can develop for small- and medium-sized enterprises (SMEs) level industries to optimize their production facility. With the presented framework SME level industries can start to inherit IIoT devices into their production floor to manage and monitor production parameters in real-time while improving the quality of the production.

**Keywords**— Industry 4.0, Internet of Things (IoT), Industrial IIoT, IIoT for SMEs

## I. INTRODUCTION

From the first industrial revolution, the industry was stepped into a new technological advancement during every industrial revolution. From steam power systems in Industry 1.0 to cyber-physical systems in Industry 4.0. [1]. The phenomenon of Industry 4.0 was first mentioned in 2011 in Germany as a proposal for the development of a new concept of German economic policy based on high-tech strategies [2].

The first industrial revolution was mostly driven by water and steam power and it was inherited into production plants by the end of the 18th century. At the beginning of the 20th-century second industrial revolution was begun with creating industries that are based on large manpower and electrically powered machinery. And the 3rd industrial revolution came into the picture in the 1970s and introduced automation, electronics, and internet technology to the industries [3] [4]. The evolution of industrial revolutions is shown in Figure 1.



**Figure 1:** The evolution of the industrial revolutions

Industry 4.0 is more focused on converting the process map into a flexible, dynamic, and precise production while integrating new technologies and procedures [5]. The Industry 4.0 paradigm promotes the connection of physical items such as sensors, devices, and enterprise assets, both to each other and the Internet [6] [7]. This concept enables cloud-based resources for the

production process and introduces online industrial management capabilities. The integrated manufacturing process consists of 3D printing, robotic automation, and artificial intelligence (AI). Also, intelligent manufacturing systems consist of the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Augmented Reality [8].

The most significant elements of the Industry 4.0 concept are the ability of computer systems or software to exchange and make benefit from information and connectivity [4]. It is necessary to establish a continuous flow of information between the devices and components, Machine-To-Machine communication (M2M), and vertically and horizontally integrated manufacturing systems to obtain the above concepts. In this context machines, production and factories can connect to the internet and communicate with each other through Industrial IoT. This process is mostly executed through wireless communication methods [9]. As M2M communication, Human-To-Machine communication is still playing a vital role in the industry as some production tasks are too unstructured to be fully automatized [10].

Collaborative robots are an uprising technology that is very popular among researchers. These robots aimed to change the way of execution of complex unstructured tasks that are completely handled by human workers. Before introducing collaborative robots all these tasks were operated as fully manual operations [11]. A large number of research efforts are going around the world regarding collaborative robotics and the ways to optimize production efficiency.

This paper is structured as follows. In Section II, we offer an overview of the IoT and Industrial IoT. In Section III, we discuss Injection molding and in Section IV we present a discussion about related researches. In the next section, we discuss an IoT framework for the SME level injection molding industries. We finally conclude this paper with an outlook on future research directions in Section VI and including an acknowledgment in Section VII.

## II. INTERNET OF THINGS

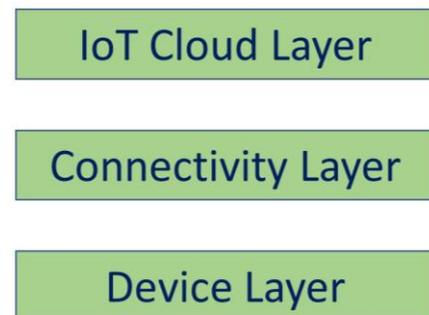
The term Internet of Things (IoT) is now more and more widely used. There is no common definition or understanding today of what the IoT embraces. The origins regarding the term date back more than 15 years and have been attributed to the work of the Auto-ID Labs at the Massachusetts Institute of Technology (MIT) on networked radio-frequency identification (RFID) infrastructures [12]. IoT is a new concept that is very quickly inheriting into the grounds of modern wireless telecommunications [13].

The most significant effect of IoT in point of view is the introduction of domestic fields in the subject,

supported living, health, industrial, social, agriculture, and transportation. Home automation also rises in acquiring a few instances of possible application scenarios and achieved new model will be useful for the role of the IoT in the near future [14].

Similarly, from another perspective for business users, the most obvious result will be the advancements of communication and connectivity in between devices incorporated, in such as industrial automation and logistic, business management also for smart transportation of assets and goods [15]. McKinsey global institute announced by 2025 internet endpoint will touch every physical thing around, furniture, cars, personal device and more, it's highlight future will be arisen by combined the technology with the interactive of human environment and extension distribution of the internet of things. "Smart" objects will perform the main roles of the IoT vision in the future [16] [17].

From the viewpoint of technology, the implementation of a product that is interconnected typically requires the incorporation of multiple software and hardware components in a multilayer stack of IoT technologies. A typical technology in an IoT stack is usually formed with three main layers. starting from the thing or device layer, the connectivity layer, and the IoT cloud layer [18] as shown in Figure 2.



**Figure 2:** The 3-layer architecture of the Internet of Things

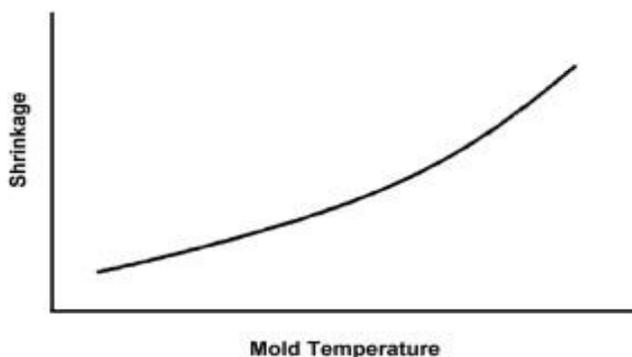
At the connectivity layer, communication protocols such as MQTT enable the communication between the individual thing and the cloud. Device communication and management software is used at the IoT cloud layer, to communicate with, equipment, and manage the connected things while an application platform enables the development and execution of IoT applications. At the device layer, IoT-specific hardware, such as additional sensors, actuators, or processors can be added to existing hardware components, and to control and operate the functionality of the physical thing installed software can be adjusted or newly integrated [19] [20].

Furthermore, analytics and data management software is applied to store, process, and analyze the data generated by the connected things, and process management software helps to define, execute and monitor processes across people, systems, and things [21]. Sequentially, the IoT application software organizes the intercommunication of people, systems, and things for a given purpose. Besides, cutting across all layers, software components manage identity and security aspects, as well as the integration with business systems, such as ERP or CRM, and with external information sources [22] [23].

### III. INJECTION MOLDING

Injection molding is the most widely used industrial method for the production of plastic parts. A wide range of products is produced using injection molding, which ranges considerably in scale, complexity, and use. The injection molding process entails the use of an injection molding unit, a raw plastic material, and a mold. The plastic is heated in the injection molding machine and then injected into the mold where it cools and solidifies to the final component. The reason is that success in this industry obviously depends on reliability, speed, accuracy, providing suitable services, and having superior technology, and those who fail to meet these expectations would naturally lose their place in the market [24] [25].

In plastic injection molding, the mold cooling process plays a vital role. It is directly involved with the efficiency of the machine and also with the quality of the product [26]. As the temperature of the mold is adjusted upwards the molded part cools more slowly and the cycle time has to increase to allow the same degree of cooling before the part is ejected. More slow cooling helps to relax stress and to shrink amorphous and semi crystalline molded plastic components as shown in Figure 3. Slower cooling promotes a higher degree of crystallization in semi-crystalline parts, which leads to higher shrinkage if all other variables remain constant [27].



**Figure 3:** The relationship between mold temperature and shrinkage

### IV. PRIOR APPROACHES

Reference	Year	Description/ Findings
[28]	2017	This article introduces the architecture and functional framework of an IoT-based energy management system (EMS) and builds an index system for evaluating the operational level of industrial energy-intensive equipment.
[29]	2017	This study provided an account of the latest developments in the application of IoT to various supply chain processes and areas of supply chain management.
[30]	2017	This study proposes a framework for the structural characteristics of a smart factory that can derive the local or global optimal solution for the injection molding system and accumulate know-how, which can be used to anticipate future abnormal symptoms.
[31]	2018	A concept for flexible smart manufacturing using the technologies of network services and 5G and requirements and use cases are introduced which allow for performance measurements of the 5GTANGO system and SDN.
[32]	2018	This research proposes to bridge the gap between overseeing AI methodologies that are common and lower-level process AI that will play an important role in IIoT.
[33]	2018	This study proposed an intelligent manufacturing system (IMS) composed of three subsystems: intelligent parameter optimization system of PIM process, database management system, and real-time monitoring and control system.
[33]	2018	This research presented a good use of Smartphone technology by providing safety and secure traveling to the traveler using a wrong path alert mechanism.

[34]	2018	This study proposed a system framework to optimize the process parameters of the injection molding system.
[35]	2018	A novel methodology developed for quantitative modeling of robustness management in SIIoT.
[36]	2019	This research applied a simulation-based optimization method to cloud-based data analytics.
[37]	2019	This study presented an overall architecture of injection molding machine cloud service (IMMCS) configuration and its components.
[38]	2019	This study aimed to analyze the loads from the injection molding process on sensor-supported electronics. The loads were determined both on the printed circuit board (PCB) substrate and the 28 assembled electronic components.
[39]	2019	The Product, Process, Resource, Energy (PPRE) data model for retrieving data from several databases was proposed to store data related to the energy efficiency of the dyeing process.
[40]	2019	This research investigated the indexability of IoT data utilizing metric and Ptolemaic indexing approaches
[41]	2020	This study describes the initiatives for the improvement of the quality, estimation of the manufacturing costs, customer requirements, and optimization of the process should be best understood by the manufacturing industries to obtain the maximum benefits.

normal scenario in the industrial environment. In most of the SME level plastic injection molding plants are neglecting this effect and continue their production with a constant temperature chilled water supply for their molds. The fluctuation of the surrounding environment temperature and the mold temperature throughout a day is shown in Figure 4.

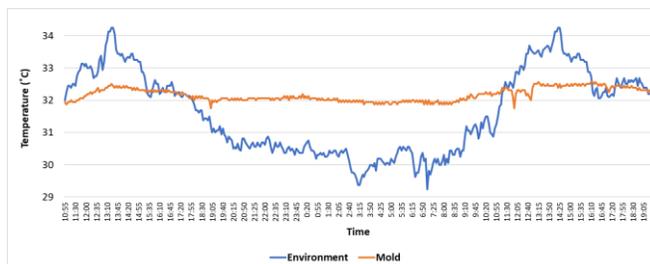


Figure 4: Temperature fluctuation of mold and environment

Figure 4 describes the real scenario of temperature fluctuation inside of a typical factory. The heat transferring rate and direction between the mold and the environment is changing with time because the environmental temperature is fluctuating throughout the day. Change of the heat transferring direction is shown in Figure 5.

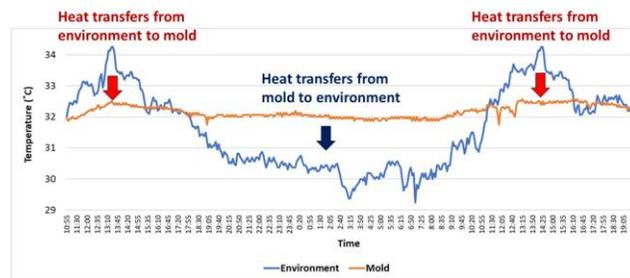


Figure 5: Fluctuation of the direction of heat transfer between mold and environment

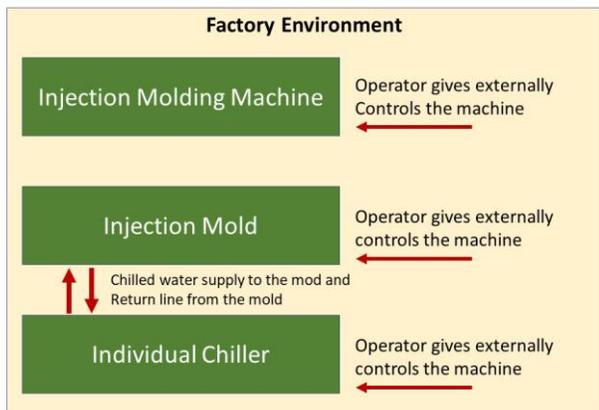
The proposed IIoT framework is capable of creating the infrastructure facilities which need to address the mold cooling rate fluctuation with the changes in environmental temperature. By deploying the proposed system temperature of the chilled water can be controlled to maintain a constant heat transfer rate from the mold to provide even cooling for the injected part without affecting the cycle time.

## V. DEVELOPED IIoT FRAMEWORK FOR A SME LEVEL CONVENTIONAL INDUSTRIAL INJECTION MOLDING SETUP

Most of the IIoT applications developed for the injection molding machines were not addressed the mold temperature controlling as it is one of the most important parts of the injection molding process. The industrial environment's temperature is fluctuating in a sinusoidal pattern with time and this effect is more powerful than the

A scenario for the development of the IIoT framework for an injection mold and a machine has been developed at the Department of Mechanical and Manufacturing Engineering of the University of Ruhun and Atlas Axillia Company Private Limited. In the process, we planned to convert a conventional cold runner injection mold into an IoT enabled tool.

In a typical injection molding set up, Three main components can be identified as the injection molding machine, injection mold, and individual chiller. Mold is mounted on the injection molding machine and the individual chiller is used to supply chilled water for the cooling process of the mold. Material injection and clamping are the only connections between the injection machine and the mold. On the other side, a chiller is connected with the mold to remove heat from the mold plates to ensure the solidifying process of the plastic item inside cavities. The temperature of the chilled water supply from the chiller and flow rate is maintained constantly throughout the total production time. This standalone component setup is shown in Figure 6.



**Figure 6:** Stansalone arrangement of the Injection Mold Machine setup

The injection molding machine and Chiller were fully automated machines and they don't require human intervention during their operation. Injection mold was a cold runner three plate mold which had 24 cavities and it requires human intervention for removing ejected items and runners. All these 03 pieces of equipment were working independently without communicating with each other. This setup is the same as the traditional scenario of standalone automated machines introduced by Industry 3.0.

This prototype model was planned to develop by using a microcomputer, Human Machine Interface (HMI), and a Programmable Logic Controller (PLC). The microcomputer was used to extract data from the system and feed them into the cloud. An HMI was assigned to

fulfill the execution process to receive data from the cloud and execute them through a PLC. Three software were used in this framework including Mosquito Broker [42], Node-RED [43], and InfluxData Consent Manager (InfluxDB) [44]. Inputs of the system are shown in Table 1 and the outputs of the system are shown in Table 2.

**Table 1:** Inputs of the system

Sensing Characteristic	Input Signal
Environment Temperature	MAX6675 K type temperature probe [45]
Mold Cavity Plate Temperature	MAX6675 K type temperature probe
Chilled water inlet temperature	MAX6675 K type temperature probe
Completion of Mold Close	From Injection molding machine control unit
Injection mold machine running condition	From Injection molding machine control unit

**Table 2:** Outputs of the system

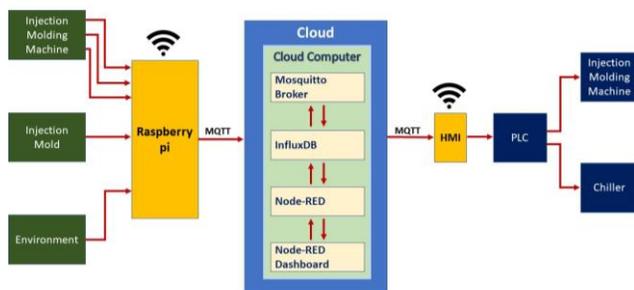
Action	Output
Production count	Node-RED Dashboard, InfluxDB, and HMI (Haiwell HMI C7S-W) [46]
Machine running status	Node-RED Dashboard and HMI (Haiwell HMI C7S-W)
Mold temperature	Node-RED Dashboard, InfluxDB, and HMI (Haiwell HMI C7S-W)
Environmental Temperature	Node-RED Dashboard, InfluxDB, and HMI (Haiwell HMI C7S-W)
Chilled water inlet temperature	Node-RED Dashboard and InfluxDB
Injection Machine Stop function	PLC (Haiwell T16S2T) [47]
Chiller set temperature variation	PLC (Haiwell T16S2T)
Chiller Start/ Stop function	PLC (Haiwell T16S2T)

In this set-up, we planned to deploy 03 temperature sensors and 02 digital signal inputs as the inputs for the system for the initial stage. Raspberry pi module was proposed to handle the input side of this

framework and through a 4G LTE enabled WiFi connection, it was connected with the cloud. Input data were transferred using Message Queuing Telemetry Transport (MQTT) publish-subscribe network protocol and Eclipse Mosquitto broker to the cloud.

Both Amazon Web Services (AWS) Cloud Compute Service and Google Cloud Console services were compatible with the proposed framework. After configuring the cloud computer, Mosquitto Broker, Node-RED and influxDB software need to be installed. Then the connection between the raspberry pi module and cloud computer can establish using Mosquitto Broker. And the received data can process using the Node-RED software and store in a table using InfluxDB time-series database. Also, all the real-time data can be displayed by using the Node-RED dashboard.

For the execution side, we decided to use a PLC by considering its robustness for the harsh environments due to the machine environment and the difference between the types of devices which is going to do the execution part. We defined 03 main actions in the Node-RED program and those commands transfer using MQTT publish-subscribe network protocol. Those signals receive by the HMI on the execution side through a 4G LTE WiFi router and transfer to the PLC. Transferred signals will execute once they transfer from the HMI. Besides this HMI offers a graphical interface for real-time data and manual over-ride commands for the operators to take control of the system at any time. This feature provides the reliability for withstanding this kind of a system in a dynamic industrial environment. The proposed IoT framework is shown in Figure 7.



**Figure 7:** Architecture of the proposed IoT network

Plant owners and higher management team can access the real-time data of the equipment by accessing the Node-RED dashboards and InfluxDB from anywhere in the world. Higher management can take accurate decisions and apply modifications to the production floor with real-time data. And the reduction in the clerical staff and paperwork will boost the smoothness of the operations and transparency of the organization. This framework is

enabling this feature for SME level industries at a reasonable cost using this reliable IoT framework.

## VI. CONCLUSION

This article described the significance of the Internet of Things and Services and their importance for SME level industries to withstand in future industrial environments. It illustrated that Industry 4.0 has already been started and will affect our life and the future business model expressly. SME level industries can step into a new level by Integrating IoT fundamentals into their production process. And it will be essential for every industry in the near future because no one will survive stand-alone without connecting with the new technological advancements. It demonstrated the importance of Industry 4.0 and new opportunities within an application that is realized for an industrial injection molding machine with minimal expertise knowledge and investment. The future works concentrate on the realization of a distributed remote application based on software agents and research on the significance of controlling mold temperature concerning the environmental temperature and propose a best controlling method (Fuzzy or PID).

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