Transformation to a smart factory using NodeMCU with Blynk platform

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ABSTRACT

Incorporating internet of things (IoT) in industrial systems prompted the development of industrial internet of things (IIoT) systems, which in turn enable the automation of intelligent devices to gather, analyze, and transmit data from industrial systems in real-time. This paper develops a low-cost and smart industrial remote monitoring and control system based on NodeMCU microcontrollers and Blynk server platform. It is deployed to remotely monitor manufacturer's environment and industrial equipment and control them autonomously. Also, it protects the manufacturer's employees from fire catastrophe by warning them using a buzzer and notification. The system comprises two main parts, sensing and actuation. The sensing part consists of three subsystems that measure temperature and humidity, water flow, and flame. The actuation part consists of a water pump, light, and fan. A powerful user interface is developed based on the Blynk platform. The proposed system controls the water pump by sensing water flow autonomously. In addition, based on a fire detected, a protection system is implemented to shut down the electricity from load in case of fire event occurs. Several testing scenarios were carried on to check the response of the system, and the result shows successful implementation of the proposal to handle different situations.

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1. INTRODUCTION

Today smart factories have opened the road for a new industrial transformation known as industry 4.0. By adopting the industry 4.0 standard, industrial machines can interact with each other and automatically operated with little or no human intervention to enable real-time production [1], [2]. The main objective of an IIoT system is to assure the efficacy of industrial systems operations, improve productivity, and enhance the control of industrial systems [3].

Ramalingam *et al*. [4] implemented an internet of things (IoT) based system for detecting harmful gases and reporting air pollutions in a plant. Using sensors and a Raspberry Pi microcontroller, their proposed system was also used to analyze environment such as temperature, humidity, and the released gases during production. Mohod and Deshmukh. [5] adopted an IoT system that utilizes general packet radio service (GPRS) technology to offer high quality, low cost, and secure connection in all coverage regions without requiring a significant amount of hardware equipment for global system for mobile communications (GSM) operators for monitoring and controlling a manufacturer. Several researches are conducted in different fields related to industrial monitoring and control systems. Janhavi *et al*. [6] developed a system based on Arduino microcontroller to monitor and regulate water flow in a pipe. Omran *et al*. [7] implemented a safe and energy-efficient smart house based on Wi-Fi that allows local and remote monitoring of home devices by a mobile phone and a computer. Karuppusamy [8] proposed a technique to remotely monitor and control electrical devices utilizing the Blynk platform and a sensor close to the electrical device to transmit the device's state through a wireless connection. In addition, author used a smartphone to control multiple electronic devices such as lights and the plugs of several heavy electrical appliances. Kishore *et al*. [9] presented a smart house automation system that monitors temperature and humidity through a sensor module and controls devices. In addition, a security system was developed using a PIR sensor to detect human movement. They used Arduino Uno and the ESP8266 microcontrollers, which make their proposed system cost-effective and portable. Kumar [10] developed a smartphone application to control and monitor water flow in house pipes through a graphical user interface that is connected to the internet.

Zhang *et al*. [11] presented a gateway architecture as a solution to the issue of industrial equipment's communication difficulties using the cloud. Hrehova *et al*. [12] adopted an IoT strategy to allow manufacturers to analyze product data generated by devices in real time and so keep track on the quality of the manufacturing process. Chang and Martin [13] proposed a real-world application using smart sensors to measure the oven temperature for a manufacturing company. Mansour *et al*. [14] proposed a system to monitor machines in a facility producing wet tissue papers. IoT is used to monitor and control the operation of all production machines. Mancheno and Gamboa [15] proposed an IIoT gateway to gather data from industrial devices via conventional digital or analog inputs and outputs. Their prototype allows bidirectional connection with a distant station through the serial communications protocol Modbus and the RS-485 interface. The solution is based on an ethernet module-equipped Arduino Uno board. This board implements the essential functionality to establish communication and enable data management using the MQTT protocol at higher tiers. Using Node-RED, an alternative monitoring interface was also constructed. Diaz-Choque *et al*. [16] designed and implemented a temperature transducer consisting of a MAX6675 converter module and an Arduino Nano microcontroller. The goal of their implementation was to illustrate the viability of integrating a programmable logic controller and the Arduino as an option to automating a concentric tube heat exchanger for monitoring and data collecting using a supervision, control, and data acquisition system. Salunkhe *et al*. [17] presented energy meter monitoring with ESP 32 microcontroller and cloud platform. A hardware configuration is designed for data retrieval utilizing an RS 485 communication-interfaced smart meter to reduce power loss and save money on annual energy usage. Yadav *et al*. [18] established an IoT-based industrial monitoring system with intelligent sensors to monitor the status from anywhere on the earth using the Blynk app.

The main contribution of this research is the development of an IoT-based monitoring and control system that is used to transfer a traditional customized plant into a contemporary plant. The proposed system is designed and implemented using the NodeMCU-ESP8266 control boards. The proposal is divided into three phases: monitoring the water flow in a pipe and accordingly control the water pump; monitoring the factory's temperature and humidity; and finally, introducing a fire system with alarm and notification. The overall system is connected to the internet and a powerful user interface is developed using Blynk server platform to enable the transmission of user commands and system status to the user's smartphone. The goal is to design an industrial remote monitoring and control system that lowers human efforts and costs and protects employee proposed architecture of the monitoring and control system.

2. METHOD

Remote monitoring and control are a combination of hardware and software to monitor the events and changes in the factory and control all devices remotely from anywhere in the world [19]. Based on industry 4.0 reference models [20], [21], an architecture for the industrial IoT (IIoT) environments is proposed in this paper. The proposed architecture includes four layers, sensing and actuation, network, cloud server, and application, as shown in Figure 1. The main purpose of the sensing and actuation layer is to collect data and react smartly in a timely manner. This layer includes various input devices (sensors) and output devices (actuators) as depicted in reference [22]. The network layer provides the connection between the sensing and actuation, and service layers [23]. This layer includes Wi-Fi in addition to a microcontroller that serves as the system's brain. The server layer collects and processes data in real-time [24], and the final application layer is the user interface, which displays the data obtained from other three layers.

The proposed system in this paper is divided into three parts, as shown in Figure 2. Table 1 depicts the necessary hardware and software components used to implement the proposed customized system. The first subsystem is to control the operation of a water pump by remotely monitoring a water flow sensor. The pump is manually controlled through the Blynk app interface and Google voice assistant. The second subsystem encapsulates temperature and humidity sensor that is used to measure temperature and humidity inside the factory and accordingly controls a fan in automated way. The third subsystem is the fire alarming system, which detects fire using a flame sensor and invoke a buzzer and send messages to alarm and notify operators. Figure 3 presents a schematic diagram showing the connection of the overall proposed system.

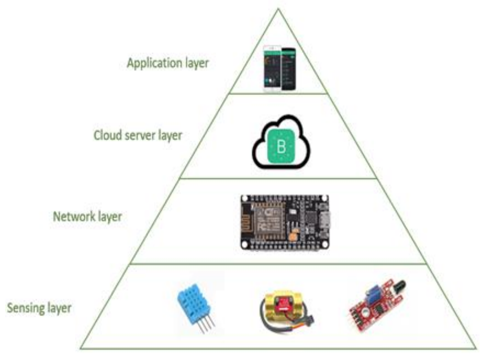

Figure 1. Proposed IIoT system layers

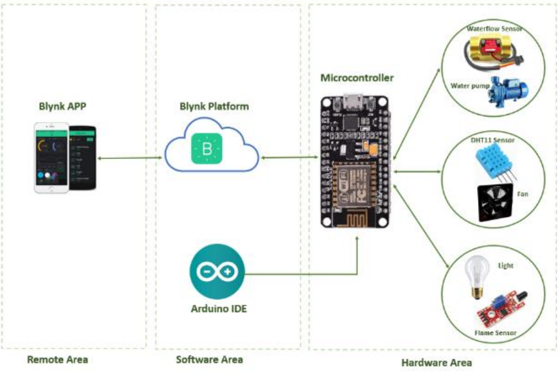

Figure 2. Basic design of the proposed monitoring and control system

Table 1. The hardware and software elements in the IoT architecture

Hardware	
	NodeMCU-ESP8266: an open-source and low-cost development board for IoT applications. One of its features is that WiFi and Bluetooth are integrated. In addition to the processor's power, its small size helps prevent space in the project [25].
	Water flow sensor: it is a sensor of the turbine type to measure the flow of water. When the water passes, several pulses come out; the water flow can be calculated by counting pulses [26].
	DHT11 sensor: it senses the environment (temperature and humidity) and transmits signals to the microcontroller; a reliable digital sensor is a low-cost, ultra-low-power, long-term stable and reliable digital sensor [27].
	Flame sensor: it senses the presence of fire or flame through the difference of light, providing an analogue output to control the alarm [28].
	Relay module: the relay module controls real-time appliances such as lighting. Essentially, it functions as a switch to activate the devices automatically when the sensors surpass a specific threshold value. Relays have three pins: normally open, normally closed, common, and coil [29].
Software tools	
	Arduino software (IDE): a program is an open-source resource whose environment consists of two fundamental components: the editor and the compiler. The editor is used to compose the essential code whilst the compiler builds and uploads the code to the Arduino module. This environment is compatible with both C and C++ [30].
B	Blynk IoT platform: a platform that allows the development of intelligent IoT devices to be easy and quick. It is suitable for controlling Arduino, Raspberry Pi, and NodeMCU. It can remotely collect, store, and display sensor data and operate actuators. The Blynk server is an open-source server based on Java. The Blynk application offers a tool for developing user interfaces over the Internet and as well as It provides data storage [31].
IFTTT	IFTTT ('If This Then That'): a web service used to create applets. Applets are nothing but a set of interrelated conditional statements that hook up the different applications. These are fired when an event occurs in the web service. [32].
Google Assistant	Google Assistant: a software program powered by artificial intelligence and provided by Google. It is used to accomplish tasks for the user based on commands.

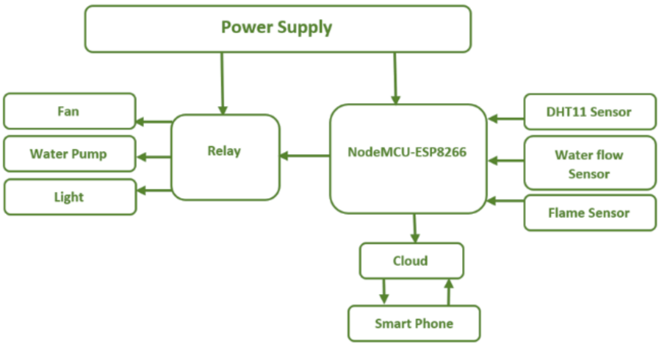

Figure 3. Schematic diagram showing the connection of the overall proposed system

3. PROPOSED SYSTEMS IMPLEMENTATION

The proposed system is implemented based on NodeMCU microcontroller. It is connected to Blynk server over the internet using username, password and authentication token. Multiple sensors are used including flame sensor, water flow sensor, DHT11 sensor. In addition, three relays are used to control three devices separately that are considered high-power demand actuation devices. Figure 4 shows the hardware circuit of the proposed system.

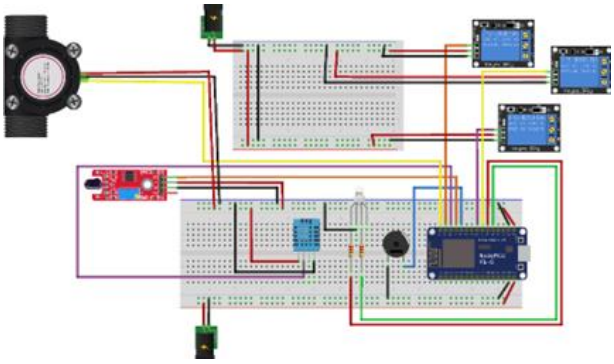

Figure 4. Hardware circuit for the proposed monitoring and control system

NodeMCU microcontroller is attached to the water flow sensor with an input port. A relay delivers energy to the water pump directly from the AC source. Each relay is connected to a digital output port of NodeMCU. The water sensor starts by sensing the water flow in the pipe, and then all sensor data is transmitted through the microcontroller to the user's smartphone and displayed using the developed user interface that is implemented in the Blynk IoT platform. The amount of flow can be continuously monitored through the user's smartphone. The user will receive a notification and email to the user's smartphone. The user may manually turn on/off the water pump via a button in the user-developed interface or via Google voice assistant. Pseudocode 1 shows the algorithm for the water flow module**.**

Pseudocode 1. Water calculation module

```
//Initialization
DEFINE Flowsensor, input;
DEFINE Relay and LCD output;
SET Flowsensor=D4, Relay=D2
SET Frequency, WaterFlow_LPS, Total
SET Wifi_Auth, Net_Name, Net_Password
REPEAT
        BLYNK (Auth, Net_Name, Net_Password);
        DIGITAL.WRITE(Relay, High) ;//Turn Water Motor ON
        [Pulse_High, Pulse_Low] =READ(Flowsensor);
        Frequency=1000000/ (Pulse_High+ Pulse_Low);
        WaterFlow_LPS= Frequency/ (7.5*60);
        If (Frequency >=0)
                If (isinf (Frequency))
                        BLYNK.WRITE(Total, Not Flowing);
                        LCD.WRITE(Not Flowing);
                Else
                        BLYNK.EVENT(Water flows into the pipe);
                        Total += WaterFlow_LPS;
                        BLYNK.WRITE (Frequency, WaterFlow_LPS, Total);
                        LCD.WRITE(Water Flowing);
                        LCD.WRITE (Frequency, WaterFlow_LPS, Total);
                        DIGITAL.WRITE(Relay, Low) ;//Turn Water Motor OFF
                Endif
        Endif
        DELAY (1000);
End
```

The second developed subsystem involves measuring temperature and humidity inside the factory using DHT11 sensor that is connected to a NodeMCU through a dedicated input port. In addition, a relay connects the NodeMCU with the fan. The DHT11 begins by detecting the temperature and humidity. Therefore, all sensor data is delivered to the user's smartphone, and the temperature and humidity inside the factory are continuously monitored. When the temperature increases above 25 °C, the fan will be operated automatically to achieve the proper limit for the industrial environment and prevent damage to the factory's products and machinery. Pseudocode 2 below shows the temperature and humidity algorithm; if the temperature exceeds the threshold limit, the controller will send a signal to the relay to operate the fan.

Pseudocode 2. Temperature and humidity module
```
//Initialization
DEFINE DHT11 sensor, input;
DEFINE relay output;
SET DHT11 sensor=D5, relay=D1
SET Temperature_THRESHOLD=25
SET T=DHT.READTemperature(true);//for Celsius
SET H=DHT.READHumidity(true);//for Percentage
SET Wifi Auth, Net_Name, Net_Password
REPEAT
        BLYNK (Auth, Net_Name, Net_Password);
                If (T>= Temperature_THRESHOLD)
                        DIGITAL.WRITE(relay, High) ;//Turn Fan ON
                Else
                        DIGITAL.WRITE(relay, Low) ;//Turn Fan OFF
                Endif
               BLYNK.WRITE Temperature
               BLYNK.WRITE Humidity
        End
```

Finally, the third module is the fire alarming subsystem that has the flame sensor and interfaced as an input port to NodeMCU microcontroller. A buzzer is used for alarming. It is connected to a relay that is in turn connected to an output port of the NodeMCU microcontroller. In addition, a red-green-blue LED is used as an additional notification for the plant’s operators. A green color represents a normal state. When a fire occurs, the flame sensor will detect the change and the NodeMCU automatically turns on the buzzer and triggers the LED to red color. Moreover, through the Blynk platform, a notification of a fire in the factory is sent. Pseudocode 3 shows an algorithm for a fire system.

Pseudocode 3. Fire detection and alarm module
```
//Initialization
DEFINE Flamesensor, input;
DEFINE relay, Red LED, Green LED, and Buzzer output;
SET Flamesensor =D0, relay=D5, Red LED=D7, Green LED=D8, Buzzer=D2
SET Fire =DIGITAL.READ (Flamesensor);//read FLAME sensor
SET Wifi Auth, Net_Name, Net_Password
REPEAT
        BLYNK (Auth, Net_Name, Net_Password);
                If (Fire== Low)
                        DIGITAL.WRITE(Relay, High) ;//Turn Load ON
                        DIGITAL.WRITE(Buzzer, Low) ;//Turn Buzzer OFF
                                for (SET i=0; i<255; increment i)
                                ANALOG.WRITE(Green LED, i) ;//Turn Green LED ON
                                DELAY (5);
                                End for
                                for (SET i=255; i>0; decrement i)
                                ANALOG.WRITE(Green LED, i) ;//Turn Green LED OFF
                                DELAY (5);
                                End for
                Else
                DIGITAL.WRITE(Relay, Low) ;//Turn Load OFF
                        DIGITAL.WRITE(Buzzer, High) ;//Turn Buzzer ON
                                for (SET i=0; i<255; increment i)
                                ANALOG.WRITE(Red LED, i) ;//Turn Red LED ON
                                DELAY (5);
                                End for
                                for (SET i=255; i>0; decrement i)
                                ANALOG.WRITE(Red LED, i) ;//Turn Red LED OFF
                                DELAY (5);
                                End for
                        BLYNK.EVENT(There is a fire in a factory);
                Endif
               DELAY (200);
End
```

4. DESIGN OF USER INTERFACE

The graphical user interface (GUI) is designed based on the Blynk IoT platform. It provides a way over IoT technology to handle user commands and display system status, with the ability to remotely monitor sensor data, store and visualize data, and accordingly control system hardware. Among other things, it provides a comparable application programming interface (API) and GUI for all supported hardware and devices. Major components of the Blynk platform are listed below [33]: i) Blynk App that allows the development of a user interface using a drag-and-drop widget. The following widgets are utilized in this project: gauge widget for viewing real-time data, super chart widget for displaying the period of graphical data, button widget to control, labelled value widget to display the amount of water in the liter, and LCD widget to display whether there is a water or not; ii) Blynk server that is in charge of all communications between the mobile device and actuators. It is an open-source, and supports huge number of devices; and iii) Blynk libraries that enables server connectivity and handles all incoming and outgoing instructions.

5. GOOGLE VOICE ASSISTANT

In this approach, the user gives voice instructions using their smartphone's Google assistant application. However, Google assistant cannot interact directly with the Blynk platform. That is where IFTTT comes in (abbreviation of “If This Then That”, which is considered as a tool for automation to connect apps and services). It links Google assistant and the Blynk application that is necessary to provide the statement of the commands in which the user will use during the operating system while constructing the applet. IFTTT then sends these commands to the NodeMCU ESP8266 microcontroller. The Wi-Fi module directly sends user commands to a relay that is connected to the water pump. This relay module switches the gadget ON or OFF based on the user's instructions. Figure 5 shows the communication between the Google assistant application and the Blynk platform.

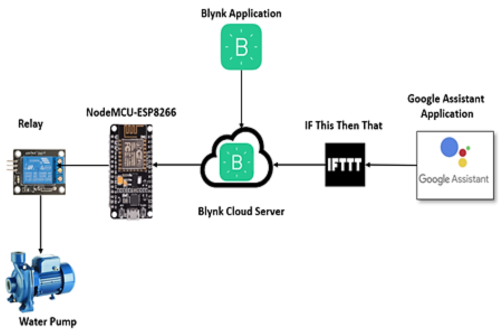

Figure 5. Communication between Google assistant and Blynk platform

6. RESULTS AND DISCUSSION

Factory’s data can be viewed on a smartphone by using the Blynk app. The graphical user interface was designed to display the temperature and humidity data from the DHT11 sensor, and the water flow data from the water flow sensor. The gauge was used to show real-time data, whilst the super chart was used to graphically depict the increase and decrease of temperature, humidity, and water. The developed GUI with a realistic result captured on a given scenario of system operation is depicted in Figure 6 below that was taken from the Blynk app.

The super chart shown in Figure has two axes, x and y. The x-axis shows the time in addition to the time range picker, allowing to choose the required periods (15 m, 30 m, 1h, 3h, …). The y-axis shows auto-scale incoming data. The height of the data is shown in percentage. Figure7 shows water flow and fire detection notifications at two other different scenario. When the water passes through the sensor of the pipes, the administrator's smartphone will receive a notification and an email to inform the operator about the presence of water. The notifications were updated once every 6 hours. Fire detection notifications will be monitored regularly every hour until the event is the figured by the administrator. Figure 8 illustrates the stages carried out for testing and detection of the fire system. In the first stage, the system appears in its normal state. After a fire was detected from the flame sensor, the second stage is activated to notify operators and promptly command the system to shut down the load. Figure 9 shows the results captured from the hardware implementation after running water flow monitoring and water pumping control subsystem.

Figure 6. Developed GUI for monitoring and control

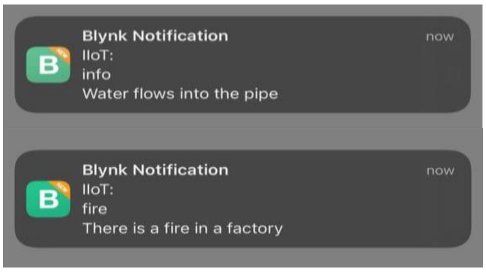

Figure 7. Water flow and fire detection notifications

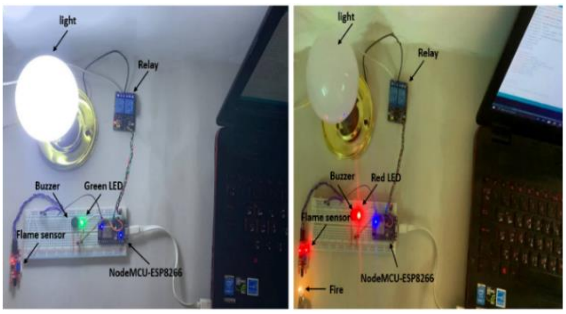

Figure 8. Testing fire detetion subsystem

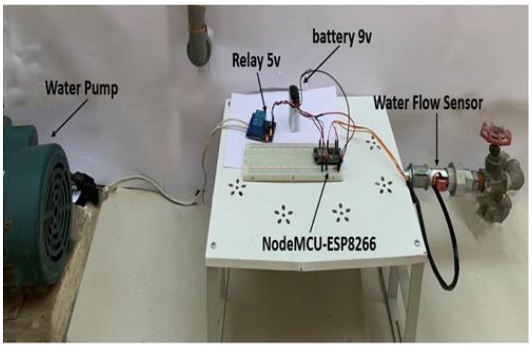

Figure 9. A scenario showing wather flow monitoring and pump control subsystem

Several operating scenarios were carried out to check for the overall proposed system effectiveness. The first experiments were conducted for each subsystem separately. This is to test operation of each subsystem individually. It was reported that the current deployed flame sensor in fire detection and notification subsystem sometimes gave inaccurate readings. This in turn lead to a small delay, less than two seconds, in triggering the alarm and notification. The issue can be addressed by replacing it with a more accurate sensor, so that the system will immediately respond by checking sensor's response if it accedes the pre-defined threshold or not. Next, experimental scenarios were considered for multiple events form the three subsystems at the same time. Experiments show the successful operation of all scenarios. However, some experiments that trigger more than one event at a time showed some delay in response but the delay in less than a second and therefore can be neglected. Thus, the proposed system can be deployed for applications that are classified as soft real-time systems. Also, the proposed system can present an effective solution for monitoring and control small-scale manufacturer. If large number of subsystems are integrated, the proposed system will be failed since it relies on single microcontroller. For this reason, the system is limited to operate successfully on small number of sensors and actuators. Nevertheless, adding more microcontrollers will allow for integrating medium- and large- scale manufacturers. However, several important factors will come out and need to be addressed to get system work as intended. Some of these factors are microcontrollers task allocation and management, synchronization, and priority mapping of events to address according to their importance.

7. CONCLUSION

This paper describes the design and implementation of the IIoT for remote monitoring and control using NodeMCU. The project aimed to develop an effective solution for industrial monitoring and control that saves time and cost while protecting employees from a fire disaster by warning them with a buzzer and notification. Three subsystems were implemented including monitoring of temperature and humidity of a manufacturer and accordingly fan control, water flow monitoring and pump control, and fire detection, notification and alarming. A powerful GUI was developed for Android smartphones based on Blynk platform with suitable display widgets. The operation of fan, pump, and LED notifier were controlled either automatically or manually via interfacing control buttons or Google voice assistant. Furthermore, the fire system was designed to turn off the electricity in the case of a fire detected and a notification and warning messages were issued for the responsible party. Future research may include the use of multiple controllers that communicate with each other to cover the transformation of a medium or large scale traditional industries into smart ones.

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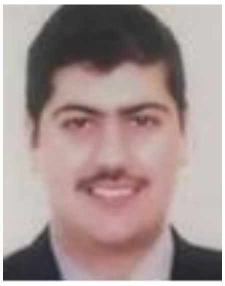

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