INTERACTIVE LABORATORY LEARNING FACILITY FOR INTEGRATED INTELLIGENT AUTOMATION SYSTEMS

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***Abstract*—Extensive adaptation of intelligent automation systems for industrial applications can be observed in the modern era. Nevertheless, best results can be obtained only when all these contemporary automation technologies are incorporatedtogether. Hence, it is essential to have a broad understanding about the integration of all these smart automation systems for future developments and expansions in industrial applications. Thus, the authors have developed a novel laboratory learning facility for teaching students about Integrated Intelligent Automation Systems as a prototype of a chocolate manufacturing factory. In this setup, several modern day technologies such as controllers, Android applications, Internet of Things (IoT), Cloud Services and Artificial Neural Networks (ANN) are utilized together for handling the customer orders for chocolates. In this learning facility, several tasks based on these automation technologies are assigned for students to be completed with in an allocated time . The effectiveness of this laboratory Learning Facility is tested through a survey of several questions presented as a questionnaire at the end of practical sessions. The analyzed responses from students justify the effectiveness of this learning platform in terms of achieving the learning objectives.**

***Index Terms*—Laboratory learning facility, automation, PLC controllers, android application, IoT & cloud service, ANN**

I. INTRODUCTION

In the last few decades with the rapid development of technologies, industries which involve manufacturing, construction, material handling and transportation have adopted automated facilities. Utilization of automated facilities helps in many ways compared with the conventional labor force oriented methods used before the Industry 4.0 era. For example, the efficiency of processes are enhanced with the adaptation of automated facilities. Thus, labor force required for fulfilling a task is diminished which ultimately results in long term cost reduction [1]. Moreover, production and fulfillment of tasks in bulk quantities can also be observed with automated facilities. Furthermore, automating the industries will pave the way for boosting customer satisfaction as well.

Automation of industrial processes is based on several pillars such as controllers, microcontrollers, Android appli- cations, IoT, Cloud Services and ANN. These technologies have their own merits and demerits. Thus, if it is possible to utilize the combination of some or all the technologies, the performance of automated facilities can be enhanced. Hence, having a thorough understanding about the integration and synchronization of all these technologies will help for developing enhanced automated facilities in future.

There have been several attempts to implement laboratory learning facilities to demonstrate the utilization of previously mentioned technologies in prototype level. In [2], a smart crop harvesting robot as a laboratory prototype is developed as a solution for the lack of labor force in agricultural fields. It is mainly controlled by a Programmable Logic Controller (PLC) based control unit. Its robustness is highlighted as it can be used in numerous automated industries with minimum modifications. The authors of [3] have developed an interactive learning platform for PLCs which is used as a teaching tool about PLCs, microcontrollers such as Arduino, sensors, actuators and web applications as well. It is designed for sorting objects based on their color, weight and the object type (i.e. whether metal or non-metal) in which it is manufactured. The user can give his preferences for color, weight, object type and the required number of objects through a web interface which can be accessed remotely as well. This platform is used as a learning facility about different types of controllers, sensors and actuators. However, this learning facility does not have the facility of demand prediction so that the manufacturers can be ready for future customer requirements. Another object sorting laboratory prototype for teaching about PLCs is developed in [4]. Here the objects which are moved on a conveyor belt system, are sorted according to a specified height. One of the significant deficiency in this work is that only a limited number of controllers, sensors and actuators have been used so that a broad area of knowledge about different technologies cannot be studied by the students.

In the literature, there are some work done for teaching the use of Android applications for industrial processes. A remote laboratory management platform based on Mobile Learning (M-Learning) for delivering online education is developed in [5]. The authors have developed an Android application for teaching Proportional-Integral-Derivative(PID) control based industrial applications as a remotely accessible and controllable facility. Nevertheless, the authors have not used a Cloud service technology for enhancing the remote experiment applications in which the authors have suggested it as a future work. In [6], an Android application for reading analog variables for data monitoring purposes is implemented. This learning facility is specifically designed for conducting electrical engineering laboratory sessions which utilizes Bluetooth communication for controlling hardware components. A mobile application for teaching computer vision concepts for image processing is developed in [7]. The developed application is quite robust and helps in teaching the concepts of computer vision for image processing in a more simple and dynamic manner. The students are allowed to engage in hardware and software based practical sessions and eventually their satisfaction level is also evaluated. The results justify the effectiveness of the developed mobile application for the teaching scheme.

The concepts of IoT and Cloud Services are used for developing smart teaching and learning facilities in certain research work. These laboratory facilities have proved to be quite effective in enhancing the knowledge about Industry 4.0 concepts such as IoT as well as barriers for knowledge sharing like time and space limitations [8]–[10]. In [10], anovel IoT based work for economic management modules based experiments teaching mode is presented. The authors have conducted a survey for assessing the effectiveness of lessons and experiments carried out with the developed IoT based teaching platform. The analyzed results show that the students prefer this novel method compared with the traditional classroom based teaching method. An IoT based language teaching platform for students is discussed in [11]. In this work, IoT technology is used for reducing the burden of teaching staff in terms of keeping records of completed tasks by each student and thus helping the teachers to focus mainly on delivering the course content in a friendly environment. Moreover, with this facility, the teachers can continuously monitor the level of participation and progress of each student. Apart from these, there are certain work in the literature which have discussed novel teaching-learning facilities that utilize IoT and ANN concepts [12]–[14].

When considering the existing work implemented for enhancing the knowledge of microcontrollers, Android applications, IoT, Cloud Services and ANN applications, most of them have used either one or few technologies together. Hence, there is still missing a proper laboratory learning platform which is capable of teaching and familiarizing the students with applications that are based on the integration and synchronization of all these technologies. In this work, the authorshave developed a novel laboratory learning facility which incorporates all these technologies. Moreover, this platform is currently being used for conducting laboratory practical sessions for final year electrical engineering undergraduates. The authors evaluated the effectiveness of this learning platform by conducting a survey with several questions. The analyzed results justify the effectiveness of the implemented laboratory learning Facility.

The main contributions of this work can be listed as follows;

- Developed a learning facility for teaching the integration and synchronization of modern day smart technologies such as PLCs, microcontrollers, Android applications, IoT & Cloud Services and ANN rather than using those technologies individually as in the literature.
- In the existing literature, most of the work have either focused only for hardware or software related practicals. Nevertheless, this learning facility can be used for conducting practicals for both hardware and software aspects of Industry 4.0 automation systems.
- Developed a prototype of a chocolate manufacturing facility in which its concepts can be adopted for real world Industry 4.0 applications.

The paper is organized as follows. Section II presents an overview of the laboratory learning facility and the oper- ation algorithm of it. A comprehensive illustration of the subsystems of this learning facility is given in Section III. Section IV summarizes the main objectives of this learning facility while Section V details the questionnaire responses and their analyzed results. Eventually, a conclusion with possible developments suggested for this laboratory learning facility is given in Section VI.

II. Architecture of Laboratory Learning Facility

In this section, a comprehensive illustration about the overall learning facility including its hardware and software applications are presented. Moreover, the operation algorithm of the laboratory learning platform is also demonstrated.

A. Overview of Laboratory Learning Facility

The laboratory learning facility is constructed as a platform for familiarizing students on how different systems such as PLC, IoT, Android application, Cloud Services and ANN are integrated and synchronized to perform a single task. Furthermore, this will demonstrate how the intelligent decision making can be incorporated for an industrial application. The hardware model used is a prototype of a chocolate packaging factory which is used as the industrial application for this learning facility. The reason behind this selection is that, it is one of the highly automated industrial application that requires mass scale production and thus efficient production handling methods are needed. Hence, this is one of the ideal industrial application that can be adopted to demonstrate and make the students familiarize with integrated automated systems.

The PLC used is the LOGO! 24RCE which is user friendly controller capable of handling heavy duty equipment. The ladder programs used for controlling the function of PLC are composed by “LOGO! SOFT COMFORT” software tool. These ladder programs can be easily uploaded to the PLC using an Ethernet cable.

A microcontroller is used in this laboratory learning facility to function as an IoT device. Here, NodeMCU is the utilized microcontroller which is facilitated with in-built Internet access and the NodeMCU is programmed with “C Language”. The provision of an IoT facility along with the android application (as discussed in section III) facilitate in two main aspects namely (i) gathering real time data for demand prediction of customers and (ii) working of the production lines accordingly. The intelligent system in this setup has the capacity to gather and analyze data and communicate with other systems as a machine with an embedded, Internet-connected computer that includes the capacity to learn from experience and the ability to adapt according to the current data. The cloud is integrated

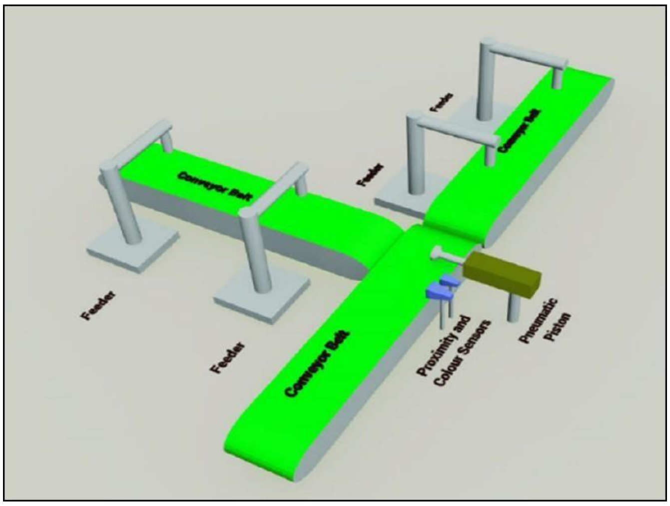

Fig. 1. Orientation of Hardware Setup as a CAD drawing

to the system using the cloud hosted database called "Firebase" which is a free service provided by Google. This service is a back end platform where the data is stored and synchronized in real time to every connected client. Authentication, hosting, cloud storage and real time database are some of the services provided by the Firebase. Among them, real time database is used for this practical setup. Furthermore, machine learning is used as an application of Artificial Intelligence (AI) that provides the systems the ability to self learn and improve from experience without being explicitly programmed. The implementation of this intelligent aspect is done by training a neural network to predict the demand of the productions. For this purpose, the data of the past production is needed. Thus, the freely accessible US Candy Productions data were used as the historical production data to develop the neural network model [15]. Here, it is assumed that the demand for US Candy is same as for the demand for chocolates. Then the ANN model is trained using 2/3rd of the total data (train data set) and the model is tuned using the rest of the data (test data set). Hence, the model output will predict the demand of the production of the factory according to present demand.

Initiation of the functioning of the laboratory learning facility is based on customer requests placed using the Android application developed. The customer is required to provide his registration details such as name, mobile number, residential address and the order preferences. When the order is placed, the input data is stored in the real time database in the "Google Firebase". NodeMCU has the access to the data stored in the database. As the next step, the production lines are manually started, and an empty container is placed in the main line (see Fig. 1 which gives the orientation of the hardware setup of the laboratory facility as a Computer Aided Design (CAD) drawing). According to the feedback of the proximity sensors placed near the feeders, the PLC stops the relevant production line and sends a signal to the NodeMCU. Then, the NodeMCU communicates the value from the database. The overall hardware and software synchronization of the learning facility is shown in Fig. 2. The operation algorithm of the laboratory learning facility is presented in a more detailed manner at the end of this section. A simple Android application is created

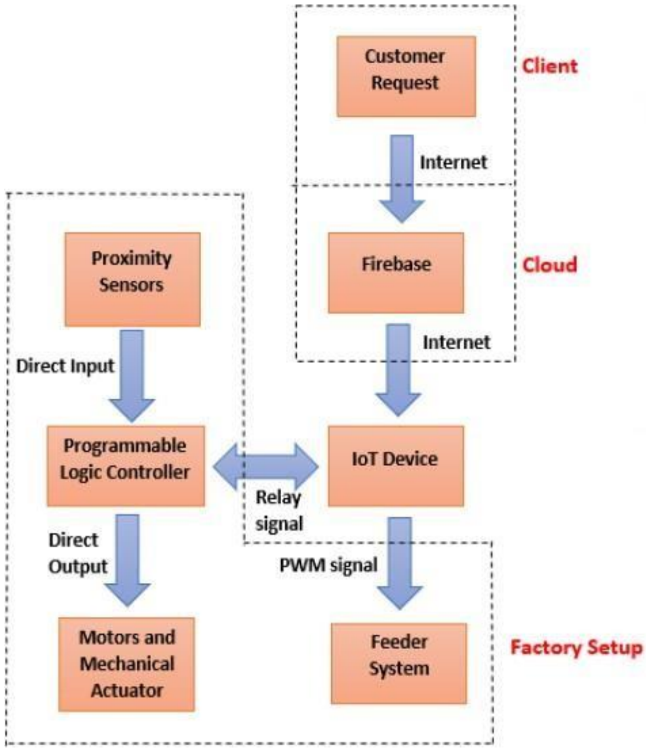

Fig. 2. Overview of Systems Integration

and used for customer order placements. This application is added to Google Play Store which can be easily downloaded.

The hardware setup consists of several sub systems such as conveyor belts system, mechanical actuator system and ball feeder system. In addition to that, there is a PLC & IoT control panel and a student interactive area which facilitate the students to engage in automated related laboratory tasks.

The conveyor belt system is comprised of three conveyor belts to represent the production lines in a factory which are named as Main line, Production line-1 (conveyor belt 1) and Production line-2 (conveyor belt 2). All these conveyor belts are controlled by the PLC. Furthermore, there is a mechanically controlled actuator at the junction of the main belt and the production line belts. The feeder system has four feeders (two for each belt) to feed the balls. Different varieties of the chocolates are represented by balls with four different colors and they are filled in the four feeders. The feeders work according to the servo mechanism. There are five Photo electric proximity sensors that are placed near the feeders. The laboratory learning facility operator is requested to place a tray and an order for system activation. A comprehensive illustration of all these sub systems are detailed in the next section.

B. *Operation Algorithm*

The operation algorithm of the laboratory learning facility is discussed in this subsection. Whenever a customer order is placed using Arduino application and received to the Firebase cloud, it is communicated to NodeMCU microcontroller of the laboratory learning facility. Then, NodeMCU communicates it to the PLC main control system. Thus, the PLC activates the

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Step 1) Initialize

Step 2) If Customer request received:
          Start Forward Main Belt
        Else:
          Go back to initialization (in Step 1)
Step 3) If Production order has been placed for Line 1:
          Start Forward Line 1 Belt
          Stop at feeder
          Fill required order

          If the order from Line 1 completed:
                If production order has been placed also for Line 2:
                  Start Reverse Line 1 Belt
                Else:
                  Start Forward Line 1 Belt

          Else:
                Fill required order (in Step 3)

        Else:
          Start Forward Line 2 Belt
          Push the tray when it reaches the mechanical arm
          Stop at feeder
          Fill required order


          If the order from Line 2 completed:
                Start Forward Line 2 Belt
          Else:
                Fill required order (in Step 3)

Step 4) Stop
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Fig. 3. Operation Algorithm of Laboratory Learning Facility

main conveyor belt and the placed tray is transferred to the junction of three belts where the mechanical actuator arm is located. If the customer request needs to be prepared by the contribution of both production lines, the Production line-1 starts first, then the tray moves to the conveyor belt 1 and gets filled as required per order. For the filling process, tray is stopped at each feeder. After that, Production line-1 is run reverse and transfer the tray to the junction again. Then, Production Line-2 is switched ON and the tray is transferred to each feeder in the Production line-2. Each time when the tray needs to change its production line, mechanical actuator arm is activated. If there is no requirement to be fulfilled from Production Line-1, the tray gets diverted to Production Line-2 directly without any further action. After the production of each order, the operator is able to collect the tray at the end of Production Line-2. This overall operation algorithm is presented in Fig. 3. for further understanding.

III. Construction of Laboratory Learning Facility

The implementation of the laboratory learning facility is developed as a combination of several hardware subsystems such as (Control panel, Ball feeder system & Production line system) and software subsystems such as (IoT system with the Android application). In hardware implementation, three production lines, four ball feeders and a mechanical actuator are used to control and guide the moving direction of objects. Hardware controlling, signaling and supply of power are given through Control panel. IoT system mainly contributes

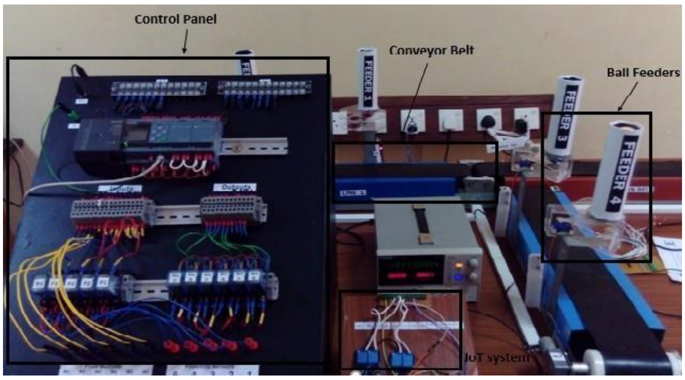

Fig. 4. Hardware Setup of Laboratory Learning Facility

to build up the connection between hardware system and Android application through cloud computing. Creation of a user interface that consists of tutorials to be followed when using the laboratory learning facility is developed using Visual Basic software. Also, the ladder programming, NodeMCU programming and Google Firebase connection establishment are done as a part of programming. Implemented overall hardware setup is shown in Fig. 4.

A detailed illustration about the main subsystems of this laboratory learning facility is given below.

A. Control Panel

In this laboratory learning facility, the control panel consists of a PLC and its expansion modules, power supply module, terminal blocks, relays, push buttons (ON, OFF and emergency) and several indicators. The upper part of the control panel is dedicated for the LOGO! 24RCE CPU and expansion modules. The students will be able to engage in laboratory practical sessions by establishing proper connections using the wiring diagram specified in the laboratory sheets. Moreover, they will be able study about wiring of sensors & their controlling using relay modules from this hardware related practical. The student interactive area including the control panel of the laboratory learning facility is shown in Fig. 5.

B. Production Line System

As mentioned before, the production line system is comprised of three conveyor belts as Main line, Production line-1 and Production line-2. There is a 24V DC motor dedicated for each belt as the actuator. The relays on the panel board can be used to set each of these motors to forward or reverse. The controlling of the production line system is done according to the commands and signals of LOGO! 24RCE PLC. Each production line has two feeders and there are five proximity switches for the purpose of positioning of the tray during the operation. These 24V NPN type photoelectric proximity sensors are used for positioning the container when it comes under a feeder.

C. Ball Feeder System

Four feeders are used in this laboratory learning facility. These feeders are used to fill the tray according to the customer requirement. A NodeMCU is used as the controller for the feeder system. NodeMCU receives the feeder activation signals from LOGO! 24RCE PLC, and receives the information

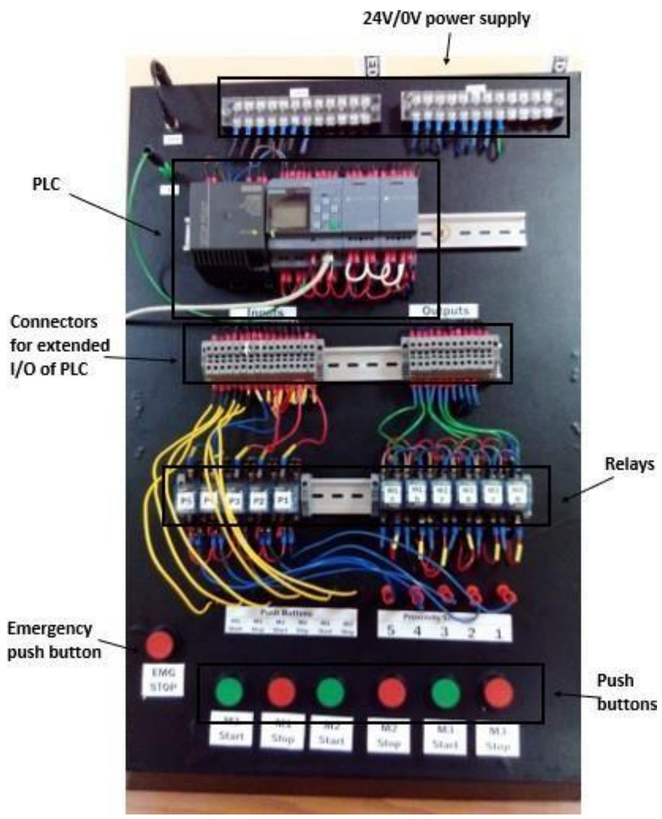

Fig. 5. Control Panel of the Laboratory Learning Facility

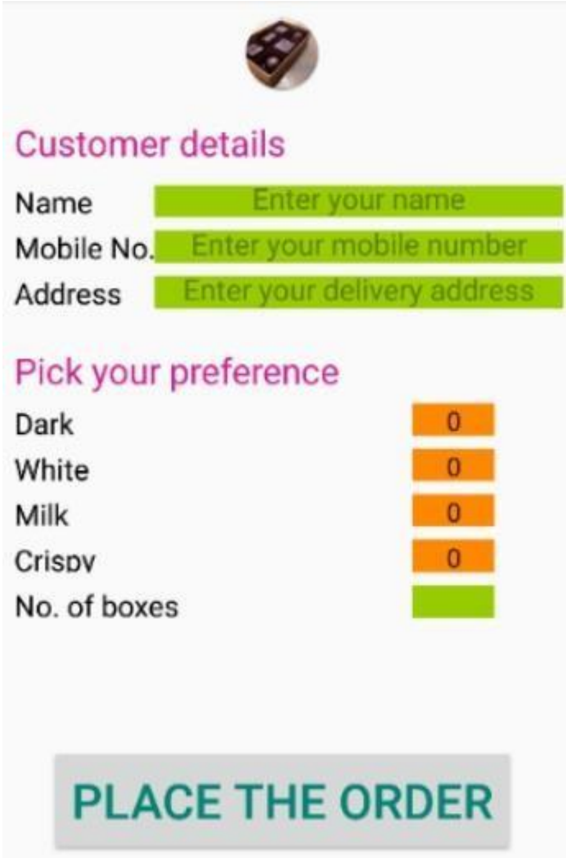

Fig. 6. Mobile Application for Customer Orders

about the number of required balls from Google Firebase cloud platform. When the feeding is completed, a signal is sent by the microcontroller for the PLC to indicate the feeding is finished. A servo motor is used as the actuator for each feeder. After positioning the tray using the proximity sensor, the feederstarts its operation.

D. Android Application

In this laboratory learning facility, one of the main objectives is to enhance the knowledge of students about Indus- try 4.0. Hence, a system to control the setup with IoT is also included in the laboratory learning facility. For that, a NodeMCU unit and Google Firebase cloud service is used to upload the real time data to get the user requests using an Android application. This is developed as a front-end application to build the relationship of real time data, hardware setup and cloud service. The Android application developed for obtaining the user demand and preferences is given in Fig. 6.

E. Demand Prediction by ANN

Machine learning is a tool for using ANN which is widely used in modern industrial automation tasks. A demand prediction facility for this laboratory learning facility is added by ANN to get a next day demand prediction based on the historical data collected from the Android application. Jupyter notebook is used as an open source web applica- tion which allows to create and share documents containing live programmes. Python programming language is used for developing the code. Using Keras library and Long Short Term Memory (LSTM) method, a model for the prediction is trained. For this, the freely accessible US Candy Productions data were used as the historical production data [15]. This feature of the laboratory learning facility helps the student to understand about future industry automation systems that will be developed with ANN. A sample demand prediction obtained for this automated task is shown in Fig. 7.

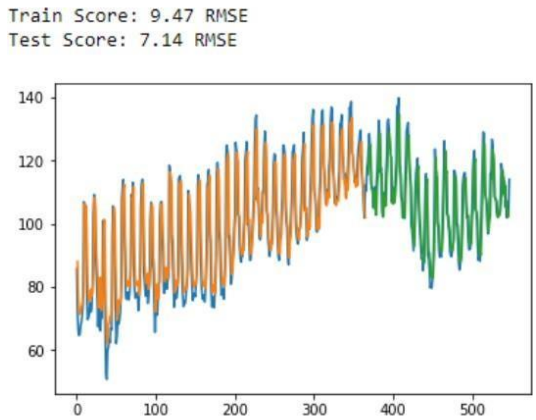

Fig. 7. Sample Demand Prediction

IV. Teaching & Learning Scheme

Interactive teaching and learning sessions were conducted using the laboratory facility. The laboratory sheets for practical were prepared for achieving the following learning outcomes while focusing on enhancing the knowledge of automated systems;

- Familiarize the learners with hardware & software configurations, wiring and establishing connections between sensors & controllers and the operation of PLC & IoT devices.
- Evaluate and design integrated systems in industrial automation with cloud communication.
- Use the concepts of Industry 4.0 in automation systems.
- Enhance the knowledge of ANN based concepts in industrial automation.

In the laboratory sheets, basic explanations covering the concepts of Industry 4.0 were provided. Operating principle, electrical characteristics, mounting and interfacinginformation were given to create the basic understanding of the components or subsystems. Next, simple tasks were presented to be tried out. In this way, the students were methodically guidedto follow the learning methodology of identifying the problems, analyzing the problems and propose solutions for them. Eventually, proposed solutions were applied in the laboratory learning facility. A Computer and the PLC Programming software ("LOGO! SOFT COMFORT") were provided to facilitate students to program the PLCs as per thesolutions they were going to propose. Furthermore, more complex problems were presented later as design challenges. Laboratory sheets provided basic theoretical and technical details on different components available in the laboratory learning facility. The practical tasks were based on covering three main aspects as PLC & NodeMCU interconnection, NodeMCU & Google Firebase interconnection and basic con- cepts of ANN. An evaluation method was also identified for aproper learning and teaching scheme. Firstly, the students wereadvised to complete the wiring connection in the con- trol panel by referring the wiring diagrams. The laboratory sheets provide guidance for operating PLC, "LOGO! SOFT COMFORT" software & NodeMCU configuration along with a discussion tobe submitted as a coursework task. In the theory section, step by step guidance for operating LOGO! 24RCE PLC and its software, program uploading methods in PLC, NodeMCU and Google Firebase, method of establishing connection between Google Firebase and NodeMCU were briefed. After the completion of those preliminary tasks, the students were assigned with three exercises such as;

- Establishing the communication between PLC and NodeMCU.
- Establishing the communication between Firebase and NodeMCU.
- Discussion related to intelligent aspects for factory automation.

The students were evaluated based on the completion level of tasks assigned and the courseworks prepared. The programmed codes and supporting files were submitted to the instructor in charge of the lab experiment. When the students had completed all the practical related work, as the final task, they were supposed to answer a questionnaire. This allowed

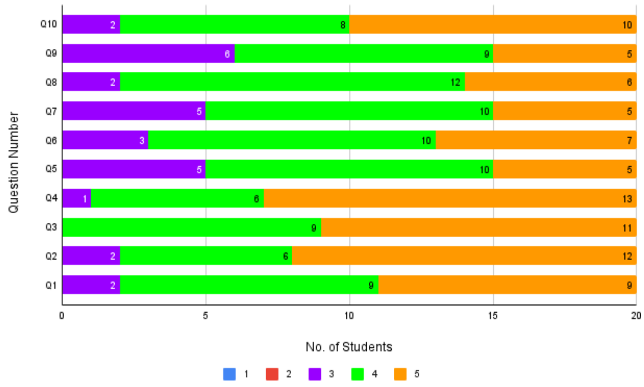

Fig. 8. Student Responses for Achievement Level of Learning Outcomes (1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Disagree)

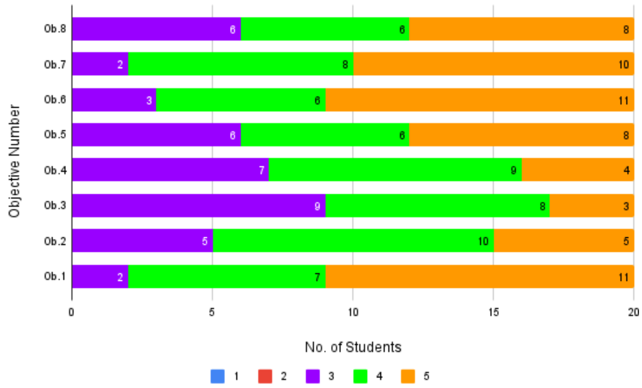

Fig. 9. Student Responses for Level of Understanding on Automation Technologies (1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Disagree)

to assess the effectiveness of these practical sessions and thus was be used as a tool for identifying future developments of the laboratory learning facility.

V. Results and Discussion

A. *Questionnaire Responses*

After practical sessions, feedback responses were collected about the learning facility from 20 students (15-male and 5-female). Based on their responses, an analysis was done to evaluate the performance of the developed laboratory learning facility. These students were Electrical Engineering undergraduates. At the end of practical sessions, all the 18 questions (10-general questions for assessing the achievement level of learning outcomes and 8-questions for assessing the level of understanding of Industry 4.0 technologies) in the questionnaire were briefed and they were allowed to provide their responses. They ranked their experience from 1 to 5 point Likert scales. The responses received for questions are shown in Fig. 8 and Fig. 9. The mode and median calculations of the responses are tabulated in Table 1 and Table 2.

B. *Analysis of Students' Responses*

The Cronbach's alpha was used for measuring the internal consistency of the items of questionnaire. It was 0.96 for

TABLE I
STUDENT RESPONSES FOR ACHIEVEMENT LEVEL OF LEARNING OUTCOMES

Questions		Rati gs prc vided by stude ts						
		1	2	3	4	5	Mode	Median
Activities done with the learning facility were interesting and interactive.	Q1	0	0	2	9	9	4	4
The learning facility had adequate number of tasks allocated.	Q2	0	0	2	6	12	5	5
The Lab sheet instructions was clear and easily understandable.	Q3	0	0	0	9	11	5	5
The lab session was well planned and conducted with sufficient instructions.	Q4	0	0	1	6	13	5	5
Time allocated for each session was sufficient.	Q5	0	0	5	10	5	4	4
Became familiar about the Hardware & Software configurations and operation of PLC & IoT Platform.	Q6	0	0	3	10	7	4	4
Became familiar about Integrated Systems in Factory Automation with Cloud Communication.	Q7	0	0	5	10	5	4	4
Became familiar about Intelligent systems and Internet of Things in Factory Automation(Industry 4.0).	Q8	0	0	2	12	6	4	4
Became familiar about Artificial Neural Network concepts in Factory Automation.	Q9	0	0	6	9	5	4	4
Can recommend as a good learning facility for integrated intelligent automation systems.	Q10	0	0	2	8	10	5	4.5

TABLE II
STUDENT RESPONSES FOR LEVEL ON UNDERSTANDING OF AUTOMATION TECHNOLOGIES

Understanding of Technologies	Objective Number	Ratings provided by students						
		1	2	3	4	5	Mode	Median
PLC (LOGO!) Programing	Obj.1	0	0	2	7	11	5	5
IOT devices	Obj.2	0	0	5	10	5	4	4
Usage of Cloud Services	Obj.3	0	0	9	8	3	3	4
Artificial Neural Network concepts in Factory Automation	Obj.4	0	0	7	9	4	4	4
Industry 4.0	Obj.5	0	0	6	6	8	5	4
Sensor Integration	Obj.6	0	0	3	6	11	5	5
Motor Actuator Control	Obj.7	0	0	2	8	10	5	4.5
Simulations with PLC and IOT	Obj.8	0	0	6	6	8	5	4

this experiment and since the calculated value is greater than 0.9, it can be concluded that the internal consistency of the items as excellent [3]. This confirms that the questionnaire is well acceptable for evaluating the learning outcomes. None of the

responses are negative feedback and only four feedback responses are in the "Neutral" category. All other responses are in "Agree" and "Strongly Agree" category. The mode and median for each responses are consistent with either "Agree" category or "Strongly Agree'" category. This confirms that this laboratory learning facility is quite suitable for learners and effective for providing the understanding about integrated intelligent automated systems.

VI. CONCLUSION & FUTURE WORK

This paper presents the implementation of a novel laboratory learning facility for teaching the integration of modern day smart technologies such as PLCs, microcontrollers, Android applications, IoT & Cloud Services and ANN. The specialty of this work compared to the existing work is that this utilizes the integration and synchronization of all these technologies for performing a specific industrial application rather than the usage of smart technologies individually. Here, the preparation of chocolate orders based on customer demand is used as the prototype industrial application. The customer is able to give his preferences using the Android application developed and based on his demand, the preparation of the order happens in a prototype level. For this, conveyor belts, sensors and actuators are incorporated in the laboratory learning facility. Moreover, a trained neural network is used for predicting the customer demand as an additional feature.

A systematic teaching & learning scheme was developed using the laboratory prototype and the students were assigned with several challenging tasks. They were guided and evaluated by an instructor. The authors conducted a survey for evaluating the effectiveness of this laboratory learning facility. The analyzed results justify the acceptability of this learning facility for teaching & learning the integrated intelligent automation systems.

As future work, controllers' communication protocol aspects such as Profibus communication can be used in this facility for teaching & learning cost effective field-bus communication. In addition to that, ANN can be further developed for evaluating uncertainties and as a decision supporting system for smart production. This will further enhance the knowledge of students about the integration of intelligent technologies for real world industrial applications.

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