Design and development of an IoT learning system for health-related applications

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***Abstract*— This paper provides relevant outcomes regarding the design and development of an IoT learning system, aimed to stimulate learning by doing while offering IoT deployment in medical science and related practices toward health monitoring and diagnostics. The system is conceptualized as a through-hole module integration board that enables data acquisition regarding body temperature, heart rate, and the saturation of oxygen in the blood, accompanied by psychrometric parameters of the environment in which the measurement is performed. The paper provides an overview in terms of favoring the development of digital technologies curriculums due to the importance and influences it might have on future experts. Last but not least, technical specifications, schematics, and overall system appearance are enclosed in detail. Finally, possible applications in process engineering and thermo-energetics are discussed as well.**

Keywords—IoT, health, medical application, sensors, learning

I. INTRODUCTION

The number of physical computing devices being used in educational institutions has increased recently [1], while the development of STEM (Science, Technology, Engineering, and Mathematics) education gained significant growth in the popularity of physical computing and robotics devices in learning [2]. Therefore, the introduction and development of digital technologies curriculums (DTCs) can boost both creativity and engagement in the learning process. On the other hand, as the Internet of Things (IoT) rapidly became the most important agenda on a global scale [3], influencing practically every sector, and driving the implementation and development of Industry 4.0, the field of education recognized the importance and influence it might have on future experts. A variety of hardware (HW) training kits evolved from the need to ensure that the process of learning is conducted in an easier, more practical, and most importantly more interesting and engaging manner. Therefore, an Arduino-based training kit that provides an active learning environment for learning the operation of six logic gates was proposed [4]. Similarly, the design, development and application of a digital trainer circuit prototyping system aimed to perform basic Boolean functions was introduced [5]. Also, another study elaborates development of an electric circuit trainer kit to determine the effectiveness of electric circuit learning media using the ADDIE model [6]. A low cost educational robotics kit based on the Arduino UNO platform is suggested to be applied in secondary schools [7]. In addition, the PortBuffer, a student constructed digital trainer for circuit prototyping system that replicates some of the functions available from commercial digital trainers was developed [8].

Some of them were focused on developing IoT systems for training purposes to advance STEM education, outline bottlenecks, and propose activities to raise awareness of teachers and offer students practical activities [9], provide an overview of existing education solutions for IoT with improvements proposal [10], or suggest development of IoT trainer that can be used in industrial practical work related to the industrial 4.0 evolution [11].

Others, on the other hand took the step forward by developing systems with online learning elements [12]–[14].

A Web-based system for training electric circuit analysis focuses on symbolic analysis techniques and tracks and coaches students through their reasoning path was proposed [12]. Furthermore, as the IoT and Big data analytics in eLearning come with both, challenges and opportunities to educational institutions and students, stimulate study focused to provide an impact of IoT & Big data analytics in the area of E-learning and study on different E-learning approaches [13].

Also, there is a study that aimed to determine the material needed for students in the Basic Practice of Electronic Control Systems (BPECS) in the automotive field, by designing the BPECS Training Kit. This was covered with the practical results of the development, eligibility of the kit, as well as user responses to the development results.

Finally, this paper provides an overview of several existing education solutions for IoT and proposes improvements. It analyzes current conditions, compares educational products, describes the architecture of our own platform, and reviews methods and technical instruments used to design software and hardware appliances.

II. Proposed IoT Learning System

The proposed IoT learning system could be recognized as a through-hole module integration board, aimed to enable learners with practical HW assembly experience before firmware development. Therefore, learners familiarize themselves with each component, its purpose, and functionality, that is, in a logical sequence, they build a system that will finally be unified by firmware development. The main functionalities learners can develop during the practical training are as follows:

- To measure atmospheric pressure, dry bulb temperature, and relative humidity,
- To measure conduction-based body temperature,
- To measure heart rate and the saturation of oxygen in the blood,
- To initiate/terminate measurement via a touch sensor,
- To establish RGB LED indication signaling,
- To correlate measurements and time units,
- To establish a data acquisition and storage system of time series data locally,
- To print the desired data on display,
- To transfer data via Wi-Fi network, and
- To link the developed system with the Blynk platform.

Having this in mind, learners could develop an application of IoT in medical science and related practices and provide monitoring and diagnostics related to the abovementioned parameters.

A. IoT system components

To ensure stated functionalities, an integration PCB was developed. The schematic connection of selected modules is shown in Fig. 1. For IoT application design purposes, a development board, based on the ESP32 development kit which offers a powerful platform was selected.

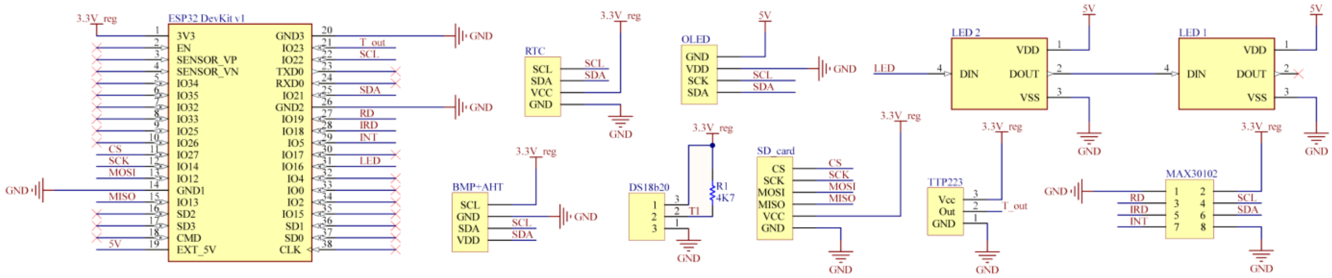

Fig. 1. Schematic representation of the developed IoT learning system

A wide range of data regarding the user's environment and the user itself is provided by several sensors and measurements, including information on heart rate, oxygen saturation, air pressure, dry bulb temperature, and relative humidity. Applications for this data range from environmental sensing to health monitoring and beyond. Fig. 2 shows the appearance of the developed integration board of the IoT system, without (left) and with attendant module-based components (right).

Fig. 2. IoT learning system integration board without(left) and with module-based components (right)

The IoT system PCB is made of FR4-standard 7G 130-140C material in 2 layers, with a 1.6 mm overall thickness (Fig.3), and a surface area of 100 mm^2.

It is equipped with BMP280, AHT20, and MAX30102 heart rate sensor with SpO_2 measurement.

The BMP280 sensor is a barometric pressure sensor, based on piezo-resistive technology that precisely measures temperature and atmospheric pressure. With resolutions of 0.01 hPa and 0.01°C, respectively, it provides measurement ranges of -40°C to +85°C for temperature and 300 to 1100 hPa for pressure [15].

The AHT20 sensor measures both, relative humidity and dry bulb temperature, and use a capacitive polymer sensor to obtain highly precise values. It can measure temperature between -40°C and +85°C with a resolution of 0.01°C and relative humidity from 0 and 100% with a resolution of 0.04% [16].

The heart rate and the saturation of oxygen in the blood (SpO_2) levels are determined by combining the MAX30102 heart rate sensor with SpO_2 measuring using red and infrared light. With an accuracy of 1 BPM, it can measure heart rate up to 165 BPM with excellent sensitivity and low battery usage. It employs a non-invasive technique to gauge the amount of SpO_2 by observing how well the blood vessels in the fingertip absorb red and infrared light [17].

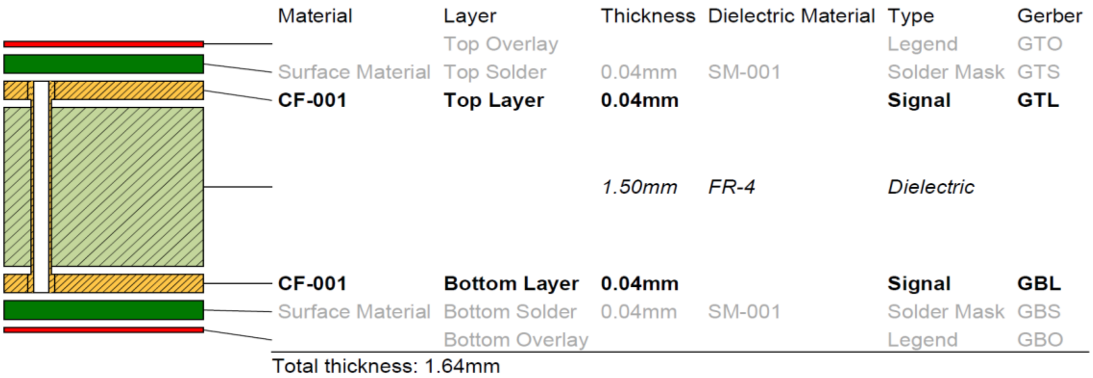

Fig. 3. IoT system PCB Layer Stack Lege

To measure body temperature a DS18B20 digital temperature probe was proposed due to its direct-to-digital functionality. Besides its unique 1-Wire interface, the sensor resolution is user-configurable to 9, 10, 11, or 12 bits, corresponding to increments of 0.5°C, 0.25°C, 0.125°C, and 0.0625°C, respectively [18]. This probe is attachable to the board via a 3-pin JST XH connector.

To maintain accurate timekeeping, the RTC DS3231 module, a highly precise real-time clock that uses a temperature-compensated crystal oscillator was proposed. It operates on a wide range of supply voltages and gives time and date information in binary-coded decimal (BCD) format [19].

To ensure a graphical representation of the sensor and other relevant data an OLED display unit, based on SSD1306 with self-illumination capability, 0.96" diagonal, and a high resolution of 128 $*$ 64 pixels, as well as viewing angle greater than 160 degrees, was selected [20].

Various signaling functions are ensured by 2 RGB addressable LEDs. WS2812B is an intelligent control LED light source that the control circuit and RGB chips are integrated into a package of 5050 components [21].

To enable data logging functionality in the local MicroSD card module was applied [22].

An OLED display, RGB addressable LED, SD card port, and RTC DS3231 module are all provided on the development board in addition to its sensor features. While the SD card port provides for data logging and storage, the OLED display and RGB LED can be used to display data and status information in a practical, easy-to-read manner.

A simple capacitive touch sensor is foreseen on the board to provide the ability to initiate a variety of operations or functionalities within an application. Users can simply interface with the board and associated software by gentle finger touch [23].

The development board uses the Blynk platform to show information and visualizations based on the principle given in Fig. 4. Using the assistance of a drag-and-drop interface, users of the well-liked and user-friendly IoT platform Blynk can develop their user interfaces for their applications [24], [25].

This platform makes it simple to view data in real-time and gives consumers remote access to their applications for management and monitoring.

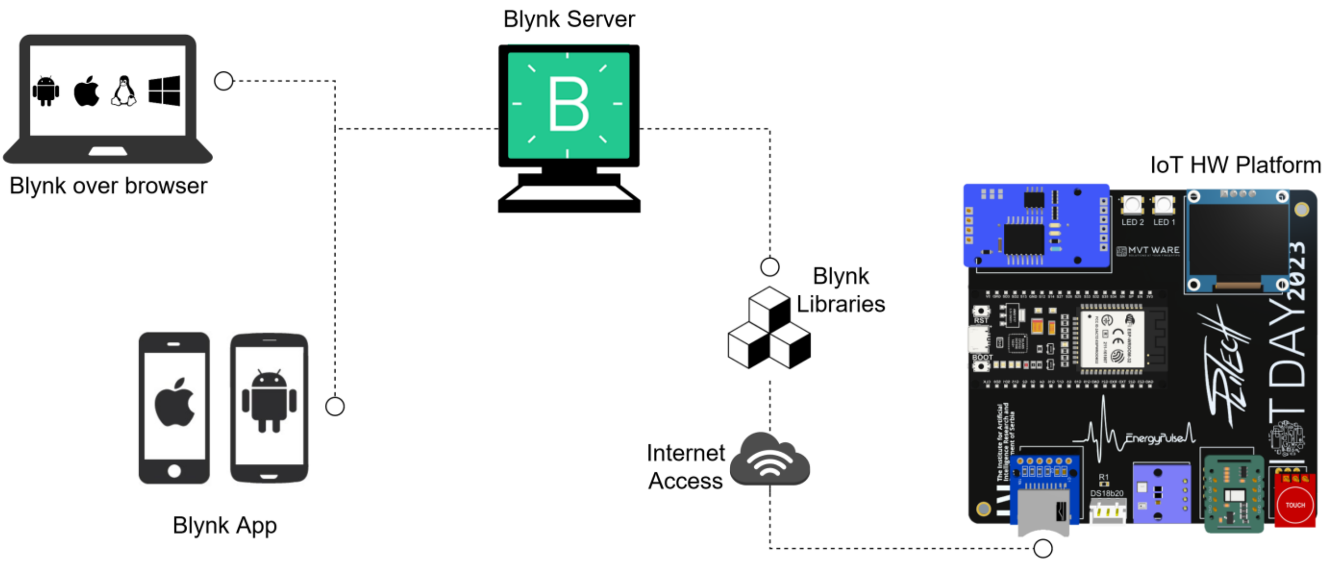

Fig. 4. The functional diagram of the Blynk platform integration

III. Discussion

The proposed development board based on the ESP32 microcontroller provides, all in all, a flexible and strong platform for creating IoT applications. Thus, is a great option for a variety of applications, from environmental monitoring to health tracking and beyond, thanks to its array of sensors, display, input features, and compatibility with the Blynk platform. The further learning process may develop toward anomaly detection using Edge Impulse and machine learning, Tensorflow micro speech recognition with the external microphone, deploying Grafana or other telemetry service software, and much more.

However, another interesting learning activity for application in thermo-energetics and process engineering area could be established. Since the proposed system provides information regarding dry bulb temperature, relative humidity, and atmospheric pressure over time, by deploying PsychroLib [26], a library of functions that enables the calculation of psychrometric properties of moist and dry air, a variety of additional thermodynamic properties could be determined in real-time. The estimation of these properties is critical in several engineering and scientific applications such as heating, ventilation, air conditioning (HVAC), meteorology, environmental engineering, etc.

The library is available for Python, C, C#, Fortran, JavaScript, Microsoft Excel Visual Basic for Applications (VBA), works in both, metric and imperial systems of units, and the functions are based on ASHRAE Handbook - Fundamentals formulae.

IV. Conclusion

On its way to progress, Industry 4.0 brought many opportunities, as well as challenges for promising early-stage professionals. To overcome these, a solid foundation in the field could be provided from various sources nowadays, while educational institutions still play a major role in ensuring the opportunity to become acquainted with the issues and ability to solve diverse tasks in the area of interest. In the modern world, problem-solving requires various HW/SW tools, which are often expensive, and not easy to access, while simultaneously requiring constant improvements due to rapid technology advances.

Unquestionably, traditional learning approaches significantly contributed to current economic and technological development, while at this point, integration of Industry 4.0 concepts, led by IoT, rapidly becomes a major priority for academic institutions to provide innovative and more engaging curricula.

In this paper, the IoT learning system was proposed to create a novel, low-cost learning opportunity, and enrich the current state of the field. The system is designed to be simple, illustrative, easy to modify, interesting, and appealing for learners to work with, as it combines elements of electronics, energy, medicine, control, computer science, and communication, thus creating the entire mechatronics spectrum.

Motivation for the development of such a solution is driven by the necessity to ensure a more stimulating, practical, and hands-on experience, in which the modular nature of the system itself allows further experimentation in future learning activities. In addition, a positive affective learning outcome could be expected for both, experienced and inexperienced practitioners, as such a learning approach boosts a high degree of relevance conceptualization, interaction, and confidence. Repetitive providing of the proposed learning approach, can stimulate creativity among learners and encourage them to start creating their modules, systems, platforms, etc.

The ever-increasing number of smart devices on the market presents a challenging environment for both, knowledge- providers and receivers, in which identified issues should be addressed in a way that opens up new possibilities for continuous development.

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