ChemDuino and PLX-DAQ Integration for Affordable Temperature Data Acquisition: Health and School Laboratory Monitoring System

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Abstract

In this article, a simple application of real-time data acquisition and temperature monitoring using ChemDuino and Parallax Data Acquisition tool (PLX-DAQ) in Microsoft Excel is presented. ChemDuino is a general practice of using the software and hardware of Arduino in chemistry or general science. This setup provides benefits not only to assist users in the laboratory during thermochemistry experiments, but also to help the medical personnel to obtain progressive body temperature data in the sick bay, especially during post-pandemic situations. The setup and codes were developed using A.D.D.I.E. method and applied as a part of the health monitoring system via online video conferencing platforms, giving a promising potential for the setup. The simple version is composed of Arduino Uno R3, LCD I2C 16x2, breadboard, temperature sensor DS18B20, and wires. It had a total cost under $20. The inexpensive construction can be used as an alternative temperature-monitoring tool. The same setup was successfully utilized in two different environments in the laboratory to determine the enthalpy change of dissolution (ΔH) for NaOH in water and at the sick bay to monitor a patient's body temperature, demonstrating the strong connection with STEM Education.

Introduction

The increasing demand driven by the industrial revolution 4.0 has led to extensive use of robotics and microcontrollers in engineering and general science [1]. Playing a significant role in bridging the analog and digital worlds across various fields, Data Acquisition Systems (DAQ) enable automation, real-time measurements, monitoring, and control systems for a broad audience [2]. Among the popular microcontrollers, Arduino stands out for its affordability and user-friendliness, finding applications in robotics and environmental science [3]. This popularity has given rise to the term "ChemDuino," combining "Chemistry" and "Arduino" [4].

In the realm of environmental science, Arduino boards have been employed as a control system in bioreactors for biochar production, CO_2 sensors for plants, and data acquisition devices for online laboratory experiments [5]. Furthermore, The uses of Arduino boards have made a significant impact on health monitoring systems, facilitating remote health monitoring through the Internet of Things (IoT), real-time healthcare for elderly patients and children, and engineering aspects of biomedical instrumentation [6-7].

Despite the heavy involvement of physics, computer science, electrical, and coding skills in implementing Arduino boards, their applications extend beyond these disciplines. The variables of interest in both the chemistry laboratory and the health system are overlapped. One of the main connections in the measurements is temperature data. Body temperature is an important clinical parameter. During the post-pandemic era, measuring body temperature is crucial, especially in early detection of the infection by fever [8]. However, the threshold for fever depends on the age of the patient and other conditions [9]. In this study, we develop codes and setup to be utilized in a thermochemistry experiment in laboratory and temperature observation in sick bay by using Parallax Data Acquisition tool (PLX-DAQ) and common online video conferencing platforms for monitoring. The aim is to develop an alternative pocket-sized device that is flexible in both environments at an affordable price.

Method

A.D.D.I.E. method (Analysis, Design, Development, Implementation, and Evaluation) was used in this study. The research and development steps in A.D.D.I.E. were straightforward and easy to evaluate [10]. The analysis was conducted to know and describe the overall needs of the users. In the laboratory, the users are educators and students. While in the sick bay, the users are the medical personnel and patients. In this step, interviews were aimed to identify the requirements and create the overall system block diagram. The system block diagram is shown in Figure 1. The block diagram showed a rough illustration of the setup and allowed us to build the system workflow. This was carried to the next step of the process.In this step, we made lists of the materials with the quantity for the setup. We used Arduino Uno R3 Atmega328P DIP, DS18B20 sensor, breadboard, Arduino USB Port, LCD I2C 16x2, pin wires, 10k resistor, and a computer. For the software, we used Arduino IDE, Parallax Data Acquisition tool (PLX-DAQ) in Microsoft Excel, and online video conferencing platforms for monitoring, e.g. Zoom, Gmeet, or YouTube Live Streaming. The Parallax Data Acquisition (PLX-DAQ) is a software add-in for Microsoft Excel, enabling easy spreadsheet analysis of data collected in the field. It supports multiple sensors for laboratory analysis and real-time monitoring. An accurate illustration of the setup is shown in Figure 2. It shows the electronic schematic and the wire connection.

Fritzing was used to provide an accurate representation of the wiring in the setup. Fritzing is an open-source application to build, design, and make electronic prototypes, including Arduino [11]. Fritzing is an open-source software application designed to facilitate the creation of electronic prototypes, particularly those involving Arduino-based projects. It provides a user-friendly platform for users to design and document their electronic circuits. The primary focus of Fritzing is on ease of use and accessibility, making it an excellent tool for both beginners and experienced individuals in the field of electronics.

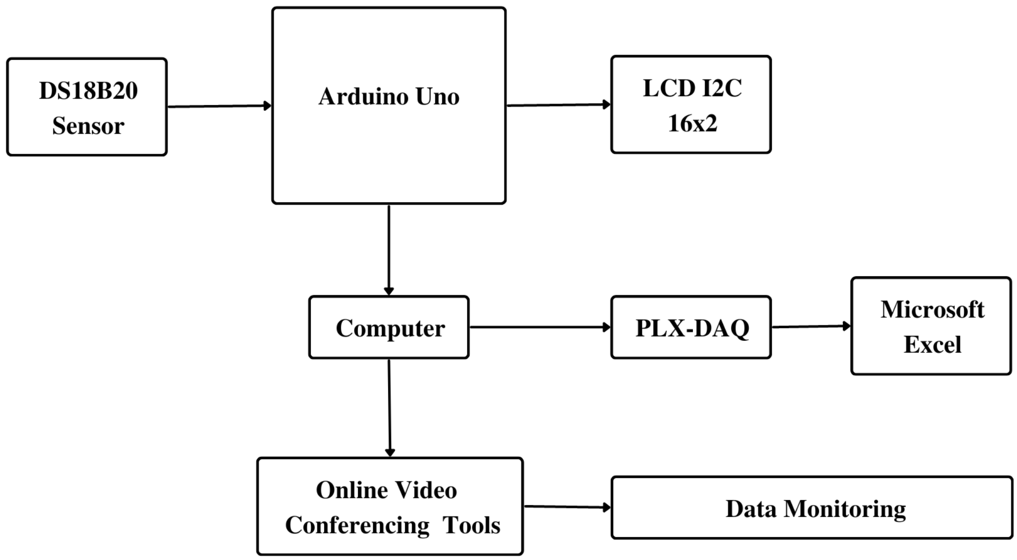

Fig. 1. Overall System Block Diagram

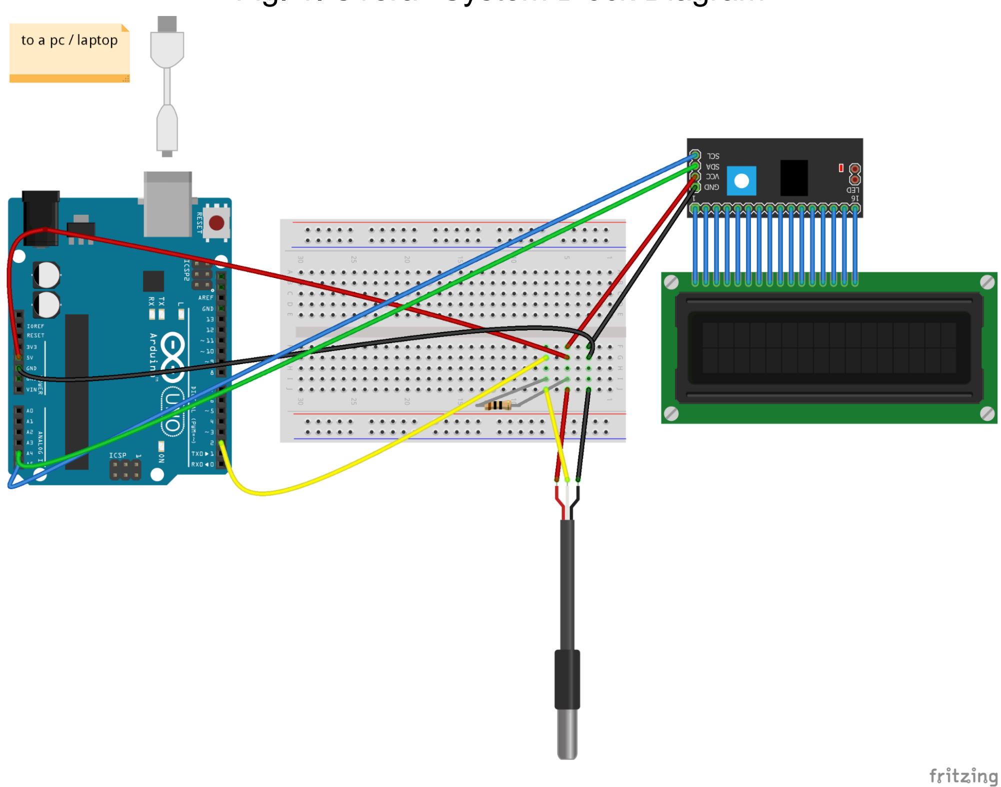

Fig. 2. Electronic circuit diagram of ChemDuino using Fritzing

We developed the electronic circuit and codes collaboratively with Arduino experts and senior educators. Then, we assembled the parts according to the Fritzing sketch from the previous step. The schematic design of networks is provided in Figure 3. Two Arduino setups with the same codes were used in the laboratory and sick bay. The temperature data were collected real-time and visualized in Microsoft Excel in the form of a thermogram, a plot of time on the x-axis versus temperature on the y-axis. The graph was then shared to other devices via wifi connection. Real-time monitoring by screen sharing can be established with any video conferencing platform. This would allow remote monitoring purposes.

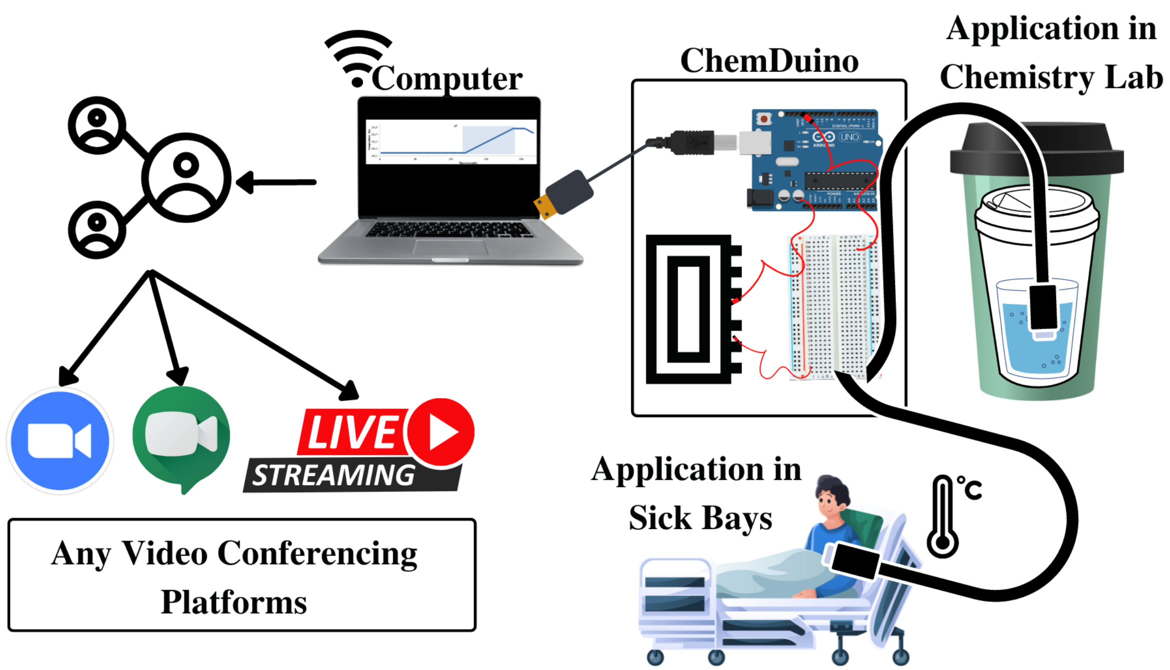

Fig. 3. Schematic Design of Networks

The codes were developed based on the network simplicity in Figure 3. The system workflow was developed as simply as possible, so that the novices can easily troubleshoot the setup.
The following codes are the Arduino program source codes for the system workflow:

```
void setup(void)
{
  Serial.begin(9600);
  Serial.println("ChemDuino is ready");
  sensors.begin();
  lcd.init();
  lcd.backlight();
  lcd.setCursor(0,0);
  lcd.print("Sickbay");
  lcd.setCursor(0,1);
  lcd.print("Ready");
```

```
  delay(3000);
  lcd.clear();
}

void loop(void)
{
  delay (500);
  Serial.print("Requesting temperatures...");
  sensors.setResolution(12);
  sensors.requestTemperatures();
  Serial.println("DONE");
  float tempC = sensors.getTempCByIndex(0);
  if (tempC != DEVICE_DISCONNECTED_C)
  {
    Serial.print("Solution Temperature: ");
    Serial.println(tempC);
    lcd.setCursor(0,0);
    lcd.print("Temperature:");
    lcd.setCursor(0,1);
    lcd.print(tempC);
    lcd.print((char)223);
    lcd.print("C");
    lcd.print(" | ");
    lcd.print(DallasTemperature::toFahrenheit(tempC));
    lcd.print(" F");
  }
  else
  {
    Serial.println("Error: Could not read temperature data");
  }
    {
  Serial.print(",");
  Serial.println("LABEL,Date,Time,Temperature");
  Serial.print("DATA,DATE,TIME,");
  Serial.print(sensors.getTempCByIndex(0));
  Serial.print(",");
}}
```

The Arduino code is available as an attachment [12]. The setup was tested in the laboratory by users to determine the enthalpy change of dissolution (ΔH) for NaOH in water. It was also tested to measure the body temperature of patients in the sick bay under the supervision of medical personnel. The measurement was repeated several times on different days over two weeks. We collected the comments and inputs from users to evaluate the setup and measurements. Then, we made the follow-up adjustment.

Results and Discussion

In the interviews, educators have provided key information related with the need of an alternative tool to measure temperature and enthalpy change of reactions based on automation directly into a computer. The results must be able to be shared real-time to other devices, allowing collaboration among educators. In this case, Arduino UNO WiFi Rev2 with ESP8266 integrated Wi-Fi module can be a solution. However, this version of Arduino is far more expensive compared to Arduino Uno R3. Based on the need analysis, we can simply use screen sharing features from common online video conferencing platforms to support the activity in the laboratory. This simple monitoring method has been proven effective. In this study, we monitored the results from PLX-DAQ remotely.

In the sick bay, the medical personnel wanted to minimize any physical contact with patients. In the interviews, there was a need to have an alternative tool with certain criteria, e.g., low-cost, easy setup, and able to measure body temperature of patients over a certain period. The aim was to measure and record the patient's body temperature continuously. A PC or laptop must be involved in the measurements, allowing a possible connection to a projector in an off-line environment. From the collection of needs, we developed the system block diagram in Figure 1. The data displays were coming from the graph in Microsoft Excel and the LCD I2C, providing an alternative if one of the display systems did not work. The Celsius and Fahrenheit scale were used in the codes. Those are established temperature scales and used throughout most of the world.

In the Design phase, the system workflow in Figure 3 needed to be supported with a suitable sensor. Several sensors were compared in Table I. The comparison also involved the price ($) of the sensors. Thermocouple is a reliable industrial sensor with a wide temperature range. However, to measure body temperature and solution, this is not suitable. LM 35 is a good candidate. It is low-cost and has the right temperature range. However, most of the LM 35 sensors are sold without the wires, just the pinhead. In order to measure the temperature of solutions, the sensor must be made waterproof. Users are required to solder and cover the wires with plastic cables or shrinkable sleeves and epoxy resin [13]. In this study, the sensor has to be waterproof and easy to use. The suitable sensor for the setup is DS18B20. It is economical, readily available in the market with long wires attached, and has the temperature range for both uses in the chemistry laboratory, sick bay, and air temperature measurement [14].

TABLE I. The lists of different temperature sensors

Sensor	Comparison		
	Temperature Range	Price ($)	Reference
Thermocouple	-50 to 700 ± 1^{O}C	20-45	Datasheet [15]
DS18B20	-55 to 120 ± 0.5^{O}C	1-2	Datasheet [16]
LM 35	-50 to 155 ± 0.5^{O}C	1-2	Texas instruments [17]

The device was tested to monitor the increasing temperature from the dissolution process of NaOH in water. This was a common calorimetric method to determine the enthalpy change of dissolution (ΔH) [18]. Thermochemistry experiments require stringent control of the system and environment parameters. The tip of the sensor needed to be fully immersed in the solution, in order to achieve a stable temperature measurement. In Microsoft Excel, the data field was directly converted into a scatter plot, a thermogram. Real-time data acquisition using PLX-DAQ is presented in Table II. There were around 30 users testing ChemDuino in a thermochemistry laboratory experiment. The users were asked to assemble and disassemble the ChemDuino. They found out that the VCC, DQ, and GND jacketed cables of DS18B20 were easily dislodged from the breadboard. The evaluation was to solder the cables. The soldering process took less than 10 minutes, allowing the molten tin to solidify on the surface of the wires.

TABLE II. Data acquisition from PLX-DAQ in a real-time thermochemistry experiment

Date	Data Acquisition		
	Time	Temperature (°C)	Feedback
18/11/2022	09:36:27	31.87	Requesting temperatures...DONE
18/11/2022	09:36:28	31.87	Requesting temperatures...DONE
18/11/2022	09:36:29	32.00	Requesting temperatures...DONE
18/11/2022	09:36:37	33.44	Requesting temperatures...DONE
18/11/2022	09:36:38	33.44	Requesting temperatures...DONE
18/11/2022	09:36:39	33.44	Requesting temperatures...DONE
18/11/2022	09:36:40	33.38	Requesting temperatures...DONE
18/11/2022	09:36:41	33.31	Requesting temperatures...DONE
18/11/2022	09:36:42	33.31	Requesting temperatures...DONE

The temperature data in Microsoft Excel was then converted into enthalpy change of dissolution (ΔH). For each experiment, 0.500 grams of analytical grade NaOH (Merck) and 100.0 cm^3 of distilled water were used. Layers of paper cups with a lid were prepared as the insulating container. Thermochemistry formula was used to calculate the enthalpy change of dissolution (ΔH) of NaOH in water, where m_{water} is mass of water, c_{water} the specific heat of water ($4.18 J.K^{-1}.g^{-1}$), and ΔT is the temperature rise [18-19].

TABLE III. Laboratory experiment results

Parameters	Experiments, N = 30	
	Using an analogue thermometer	ChemDuino with DS18B20
Average Values, kJ mol^{-1} (± estimated standard deviation)	−38.6 ± 5.0	−44.7 ± 4.3
[a]Difference, %	8.10	6.43
[b]Error, %	10.23	3.95
Notes: [a]the percentage difference with the instructor value (−42.0 kJ mol^{-1}) [13], [b] the percentage error from the theoretical value of enthalpy change of dissolution (ΔH) of NaOH in water (−43.0 kJ mol^{-1}) [18-19]		

The experiments were conducted using analogue alcohol thermometer and DS18B20 temperature sensor. The experiment results were compared and presented in Table III. From 30 times repetition (N) of thermochemistry experiments, the average enthalpy change of dissolution (ΔH) for NaOH in water using DS18B20 provides smaller estimated standard deviation, reflecting the data are less spread out. In that comparison, a calorimeter with an analogue thermometer gave a relatively higher estimated standard deviation. The percentage differences in Table III were calculated from the instructor value (−42.0 kJ mol^{-1}) of another similar experiment with paper cup calorimetry [12]. The reference theoretical value of enthalpy change of dissolution (ΔH) of NaOH in water is −43.0 kJ mol^{-1} [18-19]. This value was used to measure the percentage errors for both experiments. These results have demonstrated the usability of the ChemDuino in the laboratory.

In the sick bay, the usability test was conducted together with the patient. The clinical scenario was depicted in Figure 4. A thermogram from PLX-DAQ was produced and monitored. The monitoring was conducted remotely between a nurse and a physician at two different locations in Figure 4. Stable body temperatures were obtained within less than 5 minutes, as detected from a plateau on the graph (Figure 5) . The overall setup has assisted the work of medical personnel to monitor the body temperature of patients. The medical personnel were equipped with a manual booklet to use ChemDuino. The reference about normal body temperatures in different anatomical locations is presented in Table IV.

TABLE IV. Normal body temperature range based on the medical reference [21]

Age (Years)	Source of Temperature Reading	
	Ears	*Armpits*
Between 0 to 2	36.4–38 °C	34.7–37.3 °C
Between 3 to 10	36.1–37.8 °C	35.9–36.7 °C
Between 11 to 65	35.9–37.6 °C	35.2–36.9 °C
More than 65	35.8–37.5 °C	35.6–36.3 °C

The medical personnel commented that the temperature reading was faster reaching a plateau with armpits as the source of temperature reading. However, the auditory canal (ears) has also been evaluated to have a good clinical agreement in measuring the body temperature of a patient [20]. In the perspective of medical personnel, a thermogram is a body temperature time series. A person with body temperature higher than the normal can be considered having a fever. A thermogram provided patterns to be used to diagnose certain infections or diseases. Thus, it is a key clinical tool for medical personnel. A statistical approach has already been used to distinguish fever from malaria and dengue patients from a thermogram analysis [20].

Fig. 4. The usability test in the sick bay by users

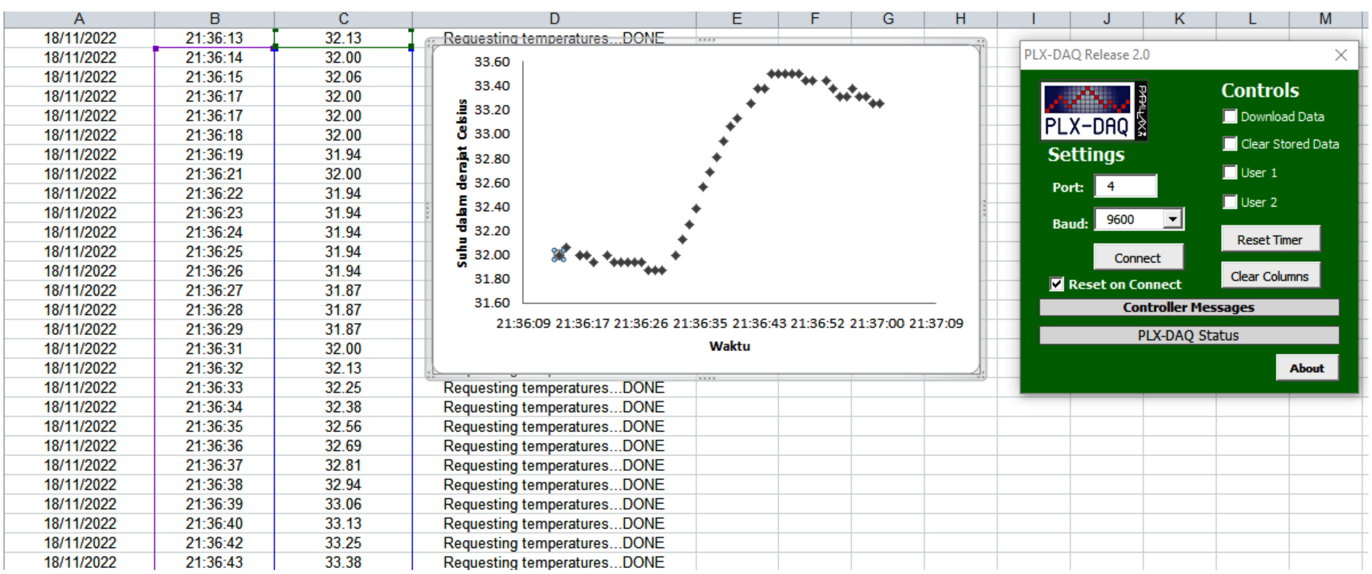

Fig. 5. Online monitoring of the thermogram produced in PLX-DAQ

Conclusions

Arduino, a leading figure in the domain of open-source electronics, has emerged as a crucial catalyst driving the progress of do-it-yourself (DIY) electronics ventures and educational endeavors. Since its establishment in 2005, Arduino has played a pivotal role in shaping the electronics landscape, presenting a versatile framework that empowers individuals, students, and professionals to delve into and innovate within the realm of physical computing. The setup and application of Arduino in Chemistry have been developed to answer the needs for real-time temperature data acquisition systems in the laboratory and sick bay. The A.D.D.I.E. method gave a systematic approach in the research and development stages to fulfill the criteria in both environments. The device provides assistance for educators and medical personnel to measure, collect, and display temperature data in the form of a thermogram. The body temperature monitoring can be useful to help medical personnel to recognize a clinical condition. The online video conferencing tool was used to share the results to other devices in real-time. PLX-DAQ has facilitated real-time data acquisition and monitoring. The overall networking system can be developed further for industrial and engineering application. Despite only measuring temperature, the usability tests showed a good agreement in the connectivity and flexibility. In the future, several functionalities might be added to assist both laboratory experiments and health monitoring systems. This will provide new possibilities in both environments for embedded measurement systems and healthcare service using Arduino boards.

References

[1] Kondaveeti, H. K., Kumaravelu, N. K., Vanambathina, S. D., Mathe, S. E., & Vappangi, S. (2021). A systematic literature review on prototyping with Arduino: Applications, challenges, advantages, and limitations. *Computer Science Review*, *40*, 100364. https://doi.org/10.1016/j.cosrev.2021.100364

[2] Kumar, S., Kolekar, T., Patil, S., Bongale, A., Kotecha, K., Zaguia, A., & Prakash, C. (2022). A low-cost multi-sensor data acquisition system for fault detection in fused deposition modelling. *Sensors*, *22*(2), 517. https://doi.org/10.3390/s22020517

[3] Sulimro, F. L., Santoso, G. A., Josephine, A. R., & Prabowo, N. K. (2023). Arduino microcontroller boards in digital learning for science and STEM education: A bibliometric analysis (2012-2022). *Arduino Microcontroller Boards in Digital Learning for Science and STEM Education: A Bibliometric Analysis (2012-2022)*. https://doi.org/10.58445/rars.747

[4] Prabowo, N. K., Paristiowati, M., Irwanto, I., Afrizal, A., & Yusmaniar, Y. (2023, October). ChemDuino-Calorimetry to determine the enthalpy change of neutralization of an acid−base reaction: Making a familiar experiment “greener”. *In AIP Conference Proceedings* (Vol. 2958, No. 1). AIP Publishing. https://doi.org/10.1063/5.0175294

[5] Küçükağa, Y., Facchin, A., Torri, C., & Kara, S. (2022). An original Arduino-controlled anaerobic bioreactor packed with biochar as a porous filter media. *MethodsX*, *9*, 101615.https://doi.org/10.1016/j.mex.2021.101615

[6] Küçükağa, Y., Facchin, A., Kara, S., Nayır, T. Y., Scicchitano, D., Rampelli, S., ... & Torri, C. (2022). Conversion of Pyrolysis Products into Volatile Fatty Acids with a Biochar-Packed Anaerobic Bioreactor. *Industrial & Engineering Chemistry Research*, *61*(45), 16624-16634. https://doi.org/10.1021/acs.iecr.2c02810

[7] Saha, R., Biswas, S., Sarmah, S., Karmakar, S., & Das, P. (2021). A working prototype using DS18B20 temperature sensor and arduino for health monitoring. *SN Computer Science*, *2*, 1-21. https://doi.org/10.1007/s42979-020-00434-2

[8] Odusami, M., Misra, S., Abayomi-Alli, O., Olamilekan, S., & Moses, C. (2022). An Enhanced IoT-Based Array of Sensors for Monitoring Patients' Health. In *Intelligent Internet of Things for Healthcare and Industry* (pp. 105-125). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-81473-1_5

[9] Gul, M. H., Htun, Z. M., & Inayat, A. (2021). Role of fever and ambient temperature in COVID-19. *Expert Review of Respiratory Medicine*, *15*(2), 171-173. https://doi.org/10.1080/17476348.2020.1816172

[10] Branch, R. M. (2009). *Instructional design: The ADDIE approach* (Vol. 722). New York: Springer. https://doi.org/10.1007/978-0-387-09506-6

[11] Faina, A. (2022, August). Learning Hands-On Electronics from Home: A Simulator for Fritzing. In *Climbing and Walking Robots Conference* (pp. 404-413). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-15226-9_38

[12] Norbertus Krisnu Prabowo, Gabriella Anna Santoso, Felicia Liem Sulimro, & Amanda Rae Josephine. (2023). Real-Time Temperature Data Acquisition System Using ChemDuino in Chemistry Laboratory and Sick Bay. *SPK SMAK PENABUR Kelapa Gading*. https://doi.org/10.5281/zenodo.10211941

[13] Vallejo, W., Diaz-Uribe, C., & Fajardo, C. (2020). Do-it-yourself methodology for calorimeter construction based in Arduino data acquisition device for introductory chemical laboratories. *Heliyon*, *6*(3). https://doi.org/10.1016/j.heliyon.2020.e03591

[14] Elyounsi, A., & Kalashnikov, A. N. (2021). Evaluating suitability of a DS18B20 temperature sensor for use in an accurate air temperature distribution measurement network. *Engineering Proceedings*, *10*(1), 56. https://doi.org/10.3390/ecsa-8-11277

[15] "Type K thermocouple," Tempsens. [Online]. Available: https://tempsens.com/type-k-thermocouple. [Accessed: 16-Feb-2023].

[16] "DS18B20," Programmable Resolution 1-Wire Digital Thermometer | Analog Devices, 09-Aug-2019. [Online]. Available: https://www.analog.com/en/products/ds18b20.html. [Accessed: 16-Feb-2023].

[17] "LM35," LM35 data sheet, product information and support | TI.com. [Online]. Available: https://www.ti.com/product/LM35. [Accessed: 16-Feb-2023].

[18] S. S. Zumdahl, S. A. Zumdahl, D. J. DeCoste, and G. M. Adams, Chemistry. Boston, MA: Cengage Learning, 2018.

[19] T. L. Brown, H. E. LeMay, B. E. Bursten, C. J. Murphy, and P. M. Woodward, “Chemistry: The central science,” University of Illinois Urbana-Champaign, 01-Jan-1970. [Online]. Available: https://experts.illinois.edu/en/publications/chemistry-the-central-science-4. [Accessed: 16-Feb-2023].

[20] Vargas, B., Cuesta-Frau, D., González-López, P., Fernández-Cotarelo, M. J., Vázquez-Gómez, Ó., Colás, A., & Varela, M. (2022). Discriminating bacterial infection from other causes of fever using body temperature entropy analysis. *Entropy*, *24*(4), 510. https://doi.org/10.3390/e24040510

[21] Marui, S., Misawa, A., Tanaka, Y., & Nagashima, K. (2017). Assessment of axillary temperature for the evaluation of normal body temperature of healthy young adults at rest in a thermoneutral environment. *Journal of physiological anthropology*, *36*, 1-7.https://doi.org/10.1186/s40101-017-0133-y