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Inexpensive Wireless Microcontroller for Internet Connectivity of Chemical Devices

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Abstract

This paper presents a system for remote monitoring of turbidity data that can detect light intensity and temperature using a microcontroller and the Internet of Things. It comprises a light dependent resistor and infrared temperature sensor interfaced with an ESP-12E microcontroller, a programmable data acquisition platform which together enable remote real-time monitoring of turbidity data applicable to chemical education. This system will allow educators and students to guide and monitor chemical experiments in real-time through a web browser. Changes in turbidity and signal processing associated with light dependent resistor are stored locally on the microcontroller and transmitted wirelessly via a WiFi-based solution to a cloud-based server. The light intensity signals are visualized locally through an organic light-emitting diode and subsequently published to a sensor streaming cloud-based server. A web-based signal processing MATLAB program plots the signals available as real-time streams to authorized subscribers over standard browsers.

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Introduction

Chemical education in laboratories is usually carried out with commercial instrumentation. However, scientific instruments can be expensive relative to open-source custom built hardware,¹ and associated software packages are usually licensed and therefore not customizable.² This provides an opportunity for fabrication and control of laboratory hardware using common microelectronics,^{3,4} such as the Arduino microcontrollers.^{5,6}

The benefit of microcontrollers to students of chemistry has been reported before,^{4,7-12} along with a study that suggests technical instrument learning combined with guided inquiry increases students problem solving skills.¹³

Students typically interact with instruments in the laboratory, and although commercial instrumentation can be operated remotely,¹⁴ microcontrollers used in chemistry do not usually include wireless technology.¹⁵ An interesting example of wired technology is an automatic titrator connected to the Internet, however this method requires an additional auxiliary server to overcome microcontroller performance limitations.¹⁶

The Internet of Things (IoT) is a group of physical devices with electronics, sensors, actuators, programs, and network connectivity that connect and exchange data.¹⁷⁻²⁰ Therefore, by including wireless technology with open-source hardware, students and educators have greater access to data for analysis.

Herein, this technology report demonstrates the remarkably inexpensive ESP-12E CP2102 microcontroller (ESP-12E) for wireless transfer of turbidity data for IoT applications. The hardware uses a light dependent resistor (LDR) to sense the turbidity change of a model reaction - the rate of precipitation of sulfur using sodium thiosulfate and hydrochloric acid.²¹ Wireless chemical data transfer, programmable hardware controlled measurement, storage and acquisition is the key advantage of this microcontroller.

Hardware

The components include an ESP-12E for control and Wi-Fi connectivity, and organic light-emitting diode (OLED) for visualization, Figure 1. The ESP-12E is programmed with C/C++ language within the Arduino integrated development environment (IDE). The code used to program the ESP-12E is explained in detail in section 3 of the Supporting Information. The ESP-12E has a clock speed of 80 MHz and flash memory of 4 MB.²² As a point of reference, the commonly used Arduino Mega^{4,16,23-25} has a clock speed and memory of 16 MHz and 128 kB respectively,²⁶ showing the ESP-12E is significantly more powerful while remaining cost effective. Price comparisons of five wireless microcontrollers is available in section 1 of the Supporting Information.

For acquisition of turbidity data, an infrared (IR) thermometer and a cadmium-sulfide LDR are connected to the ESP-12E. Pin definitions and circuitry is provided as Supporting Information section 1. During use, the ESP-12E is powered via a micro USB cable connected to an AC adapter. A bill of materials (20.36 USD) is available in section 1 of the Supporting Information.

IoT platform

ThingSpeak (Mathworks) is a free IoT platform that allows data to be sent and received. Its website interface provides graphical visualizations of data posted to it, as well as MATLAB integration for more advanced analysis. For these reasons, ThingSpeak is particularly useful for prototyping and proof of concept IoT systems that require analytics. The ESP-12E sends data to ThingSpeak via a Wi-Fi Internet connection.

The C code uploaded to the ESP-12E program memory is explained in detail in section 3 of the Supporting Information along with an example of MATLAB integration. Briefly, data from the LDR and IR sensor input on the ESP-12E is continuously stored in memory and periodically uploaded in bulk to a ThingSpeak channel via the Internet. Details of

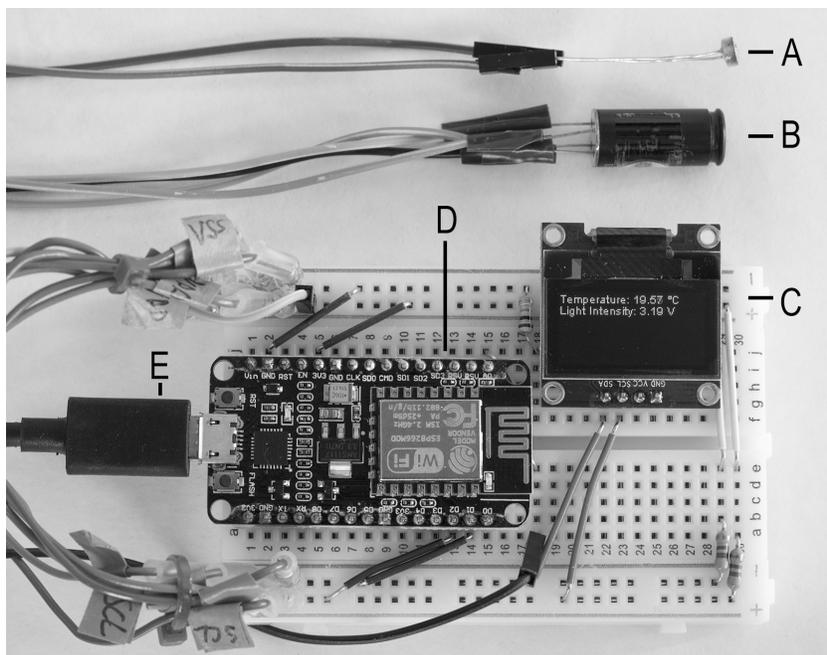


Figure 1: Photograph of hardware where A, B, C, D and E correspond to LDR, IR thermometer, OLED, ESP-12E and micro USB power cable respectively

how to setup a ThingSpeak channel is provided in section 3 of the Supporting Information. ThingSpeak is limited to an upload every 15s. Because data acquisition more often than once every 15s is desired, the bulk upload approach overcomes this limitation.

Application of ESP-12E to Chemical Experiment

Data acquisition and upload to the IoT platform using the ESP-12E is performed in a simple experiment to qualitatively investigate the effect of temperature on reaction rate between sodium thiosulfate and hydrochloric acid (Supporting Information section 2). This reaction has previously been used for experimentation and discussion related to chemical research^{27,28} and chemical education.^{29,30} It is useful to introduce students to basic collision theory, and on successful completion, provides students with a dataset accessible on the Internet. Light intensity is measured using the LDR and changes when sodium thiosulfate produces colloidal sulfur according to the reaction,³⁰



Commercial colorimeters or calibrated light sensors have increased sensitivity and accuracy compared to LDRs,^{31,32} and at a higher cost, although for qualitative measurement the LDR can adequately detect variations in light intensity³¹ without amplification of the signal necessary.

The LDR and a $10\text{ k}\Omega$ resistor are connected in series and the output voltage across the LDR is determined according to the resistive divider rule between two resistors (Supporting Information section 1). As a result, the output voltage varies in the range 0 -3.3 V. The output of the circuit is connected to the analog-to-digital converter (ADC) of the ESP-12E (pin A0) and is used to measure the output voltage of the LDR sensor, it is assumed that any change in light intensity is proportional to this output voltage.^{33,34} The ESP-12E has a 10-bit ADC; therefore $2^{10} = 1024$ quantization levels with a sensitivity of $3.3\text{ V}/1024 = 0.0032\text{ V}$ in the sensor voltage output.

The IR thermometer is used to record temperature. Both light and temperature data is sampled at an interval of 500 ms, filtering is applied to the LDR data (Supporting Information section 3), and both temperature and light data is periodically uploaded to the ThingSpeak channel. The plotted graph shows temperature ($^{\circ}\text{C}$) against $1/\text{Time}$, s^{-1} , Figure 2. This plot yields more qualitative information than a classical human eye colour change approach. The rate of change can be measured from the graph slope or the time taken for a change to occur. The result provides useful information for increasing students conceptual understanding of reaction rates.

Conclusion

The simple methodology laid out in this technology report provides wireless internet connectivity to open-source laboratory hardware. This affords new opportunities to exploit combinatorial strategies in a wide variety of systems for both teaching and research laboratories. A classic chemical experiment is demonstrated involving the measurement of temperature

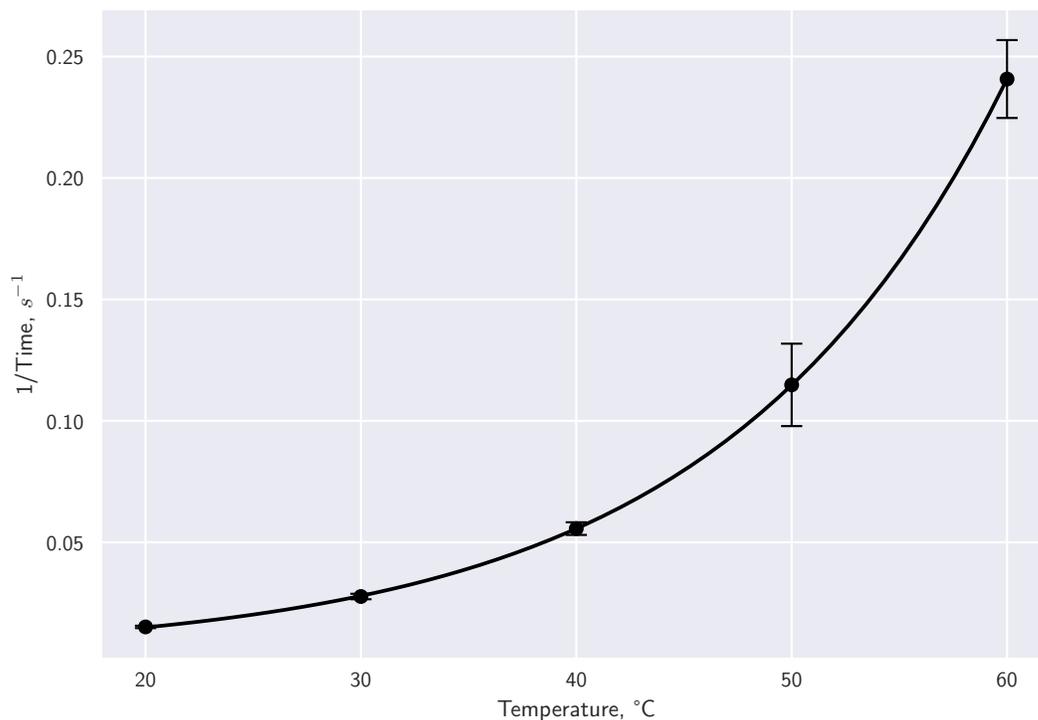


Figure 2: The effect of temperature on molecular kinetic energy is plotted as temperature against rate of sulphur formation (n=3). Exponential curve fit where $0.0025exp(-0.0758x) + 0.0035$ $R^2 = 0.9999$

and light data using a microcontroller. Turbidity data is sent over a wireless network to a cloud-based server that is then used to plot turbidity data. This new method of wireless data acquisition is inexpensive and does not require commercial software licenses. Because all data is sent to the ThingSpeak server, it is not necessary to have desktop computers in the laboratory. Details of how to program the microcontroller are provided along with the actual code used in this report. The hardware is comprised of few parts, a microcontroller, an OLED display, IR temperature sensor and LDR. Collectively this hardware handles data logging of temperature and light measurements, real-time display and uploading to the Internet. This approach can be implemented and adapted into modern microcontrolled experiments where data needs to be transmitted wirelessly in a simple, powerful, and affordable manner.

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Supporting Information Available

- ESP-12E.png: ESP-12E pin definitions
- Circuit.png: Circuit diagram
- Code listings

This material is available free of charge via the Internet at <http://pubs.acs.org/>.

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Graphical TOC Entry

