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An Inexpensive, Open-Source USB Arduino Data Acquisition Device for Chemical Instrumentation

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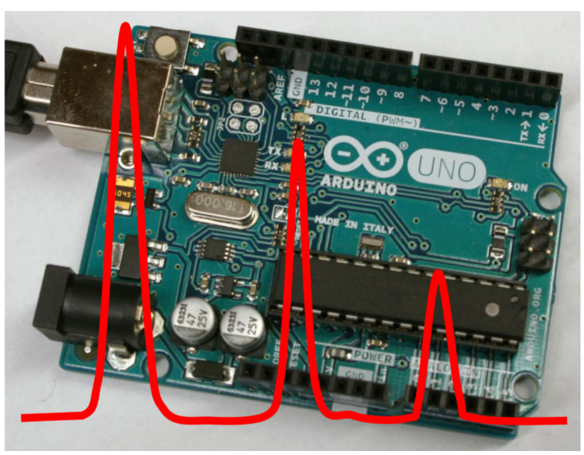
Abstract

Many research and teaching labs rely on USB data acquisition devices to collect voltage signals from instrumentation. However, these devices can be cost-prohibitive (especially when large numbers are needed for teaching labs) and require software to be developed for operation. In this article, we describe the development and use of an open-source USB data acquisition device (with 16-bit acquisition resolution) built using simple electronic components and an Arduino Uno that costs under $50. Additionally, open-source software written in Python is included so that data can be acquired using nearly any PC or Mac computer with a simple USB connection. Use of the device was demonstrated for a sophomore-level analytical experiment using GC and a CE-UV separation on an instrument used for research purposes.

GRAPHICAL ABSTRACT



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ASSOCIATED CONTENT

Supporting Information

The Supporting Information contains a copy of the described Python software, instructions on its use and how to download other Python dependencies, a wiring diagram and parts list to put together the described device, and a comparison to commercially available USB data acquisition devices.

Keywords

Second-Year Undergraduate; Graduate Education/Research; Analytical Chemistry; Laboratory Instruction; Computer-Based Learning; Instrumental Methods; Laboratory Computing/Interfacing; Laboratory Equipment/Apparatus

INTRODUCTION

Open-source microelectronics have become increasingly useful in the field of analytical chemistry due to their low cost and integrated development interfaces.[1] In the research lab, microcontroller boards (such as the Arduino Uno) can be coupled to both in-house[2] and portable[3] instrumentation for user control, data acquisition, and analysis. In undergraduate teaching laboratories, these devices enable students to gain hands-on experience with building and programming the instrumentation being used in class projects.[4, 5] Examples of Arduino-based instrumentation used for laboratory experiments include a photometer[6], automated burets[7, 8] and a PCR thermocycler.[4] During classroom demonstrations, Arduinos have been used to couple sensors such as pH meters or thermometers to either large LCD displays[9] or real-time data graphs that can be displayed on a digital projector.[10] In this technology report, we describe an in-house developed Arduino-based circuit for electronic data acquisition. While data acquisition schemes using Arduinos have been reported for other instruments[11–13], this setup utilizes open-source software, written in Python, to enable easy, low-cost data acquisition compatible with any PC or Mac. By providing all of the necessary software and hardware instructions here, this device can be a useful alternative for USB-driven data acquisition devices that require more expensive software packages.[14, 15]

HOW IT WORKS

The device utilizes an Arduino Uno and 16-bit analog-to-digital converter (ADC) (ADS1115, Adafruit Industries, New York, NY) for control and data acquisition (Figure 1). The ADC, which enables higher resolution data acquisition than is possible with an Arduino Uno alone, is mounted on a solderless breadboard and connected to the microcontroller via jumper cables (full circuit diagrams for setup are provided in the Supporting Information). Though not shown here, an electronics enclosure can be used to protect the device from laboratory spills if needed. During use, the Arduino is connected to a standard USB-port on any laptop or desktop computer to supply power (up to 5V at ~500 mA) and enable data acquisition. The entire cost of the setup shown in Figure 1 is under $50, which is one-half to one-third the cost of widely-used, commercially available USB data acquisition devices. Details on parts and vendors for the device described here, as well as a table of direct comparisons with five commercial USB devices, are included in the Supporting Information.

The open-source software used to control this device was developed in Python. A Python-based toolset for instrument control using Arduinos called *Instrumentino* was previously described[16], but we have used a different set of routines to simplify the user interface for USB data acquisition. On the instrument front panel (see Supporting Information), users are able to select the serial port for data transfer to the connected computer, the analog input channel for data acquisition, the data acquisition rate, the file time length, and the file path/

name. The data are output as a tab-delimited text file and can easily be re-plotted and analyzed in any spreadsheet or graphing program. Although data acquisition rates up to 860 Hz are possible with the ADC breakout board, the maximum rate was limited to 500 Hz in the software to ensure stable data acquisition over time. This rate is lower than that achievable by many commercial USB data acquisition setups, but is sufficient for most classroom[17] and laboratory experiments[18] (excluding the use of ultrafast techniques[19, 20] and oversampling filters[21]). A key advantage of the open-source software is that it can be installed on nearly any PC or Mac computer (including student laptops, if so desired) without a software license, which can be a costly addition to data acquisition setups depending on the program.

USING THE DEVICE

To demonstrate the use of the Arduino Uno-based data acquisition device with our open-source software and compare it to commercial acquisition modes, experiments commonly found in teaching and research laboratory settings were conducted. Within our analytical teaching laboratory (a sophomore level course typically enrolling about 20 students in a 4-hour laboratory period led by a teaching assistant), one two-period experiment involves the separation and identification of alcohols by GC-TCD. In Figure 2A, chromatograms from the separation of three alcohols (air as dead-time marker, 1-propanol, 1-butanol, and 1-pentanol) on a packed GC column acquired using the existing LabJack interface and the Arduino-based device described here are compared. The chromatograms are identical, demonstrating that this open-source device is a low-cost replacement for the current data acquisition scheme used in the teaching lab. Although not implemented here, the actual building of the Arduino device could also be incorporated into a laboratory experiment that uses the device for added hands-on experience with open-source electronics.[4, 6] In our own research group, the Arduino Uno was used to acquire data directly from an Agilent 7100 CE with integrated UV detection. Here, the data acquired by the manufacturer software are the same as those obtained with the Uno and Python software for the separation of thiourea, dopamine, and serine (Figure 2B).

For many time-based experiments on home-built instrumentation where acquisition rates up to 500 Hz are sufficient, such as amperometry or chromatography, this device is an ideal option for data acquisition with 16-bit signal resolution. Commercially available devices capable of 16-bit data acquisition can exceed $300, making them potentially unsuitable for large-scale deployment in teaching settings. Many instruments are able to send a digital signal (via relay or contact closure) to trigger data acquisition. An option to detect this external trigger using a digital input on the Arduino is included in the software (Supporting Information) to enable further integration with existing instrumentation. The device described in this report enables logging of voltage signals from both commercial and home-built instrumentation into our open-source software that can be used on nearly any computer at a lower cost than many commercial alternatives. In order to further reduce costs, other parts of chemical instrumentation such as flow control[22] and detection[6, 23] can also be constructed and controlled with microcontroller devices whether for research or teaching needs. With such home-built detectors, there is a need to convert a chemical signal into a voltage that can be detected; the study of these circuits can be added to the curriculum in both undergraduate and graduate analytical courses to further student understanding of instrument design.[4, 6] If the needs for a specific experiment exceed those of the device described here, a number of other microcontrollers and programming languages can be utilized[1] and necessary circuit components can be integrated onto a single printed circuit board.[24]

CONCLUSION

In this report, we have detailed the design and use of a 16-bit data acquisition device using the Arduino Uno with open-source Python software as a tool for both teaching and research laboratories. At under $50, this device costs significantly less than comparable commercial products; it does not require access to commercial software licenses, either. For laboratory courses that require a number of acquisition setups, Arduinos are a cost-effective option, especially with the included software that can be installed on individual student computers if enough are not available in the lab. With an easy-to-construct layout using widely available parts, this USB-data acquisition setup should be ready to use in nearly any setting where a voltage-vs.-time signal needs to be collected.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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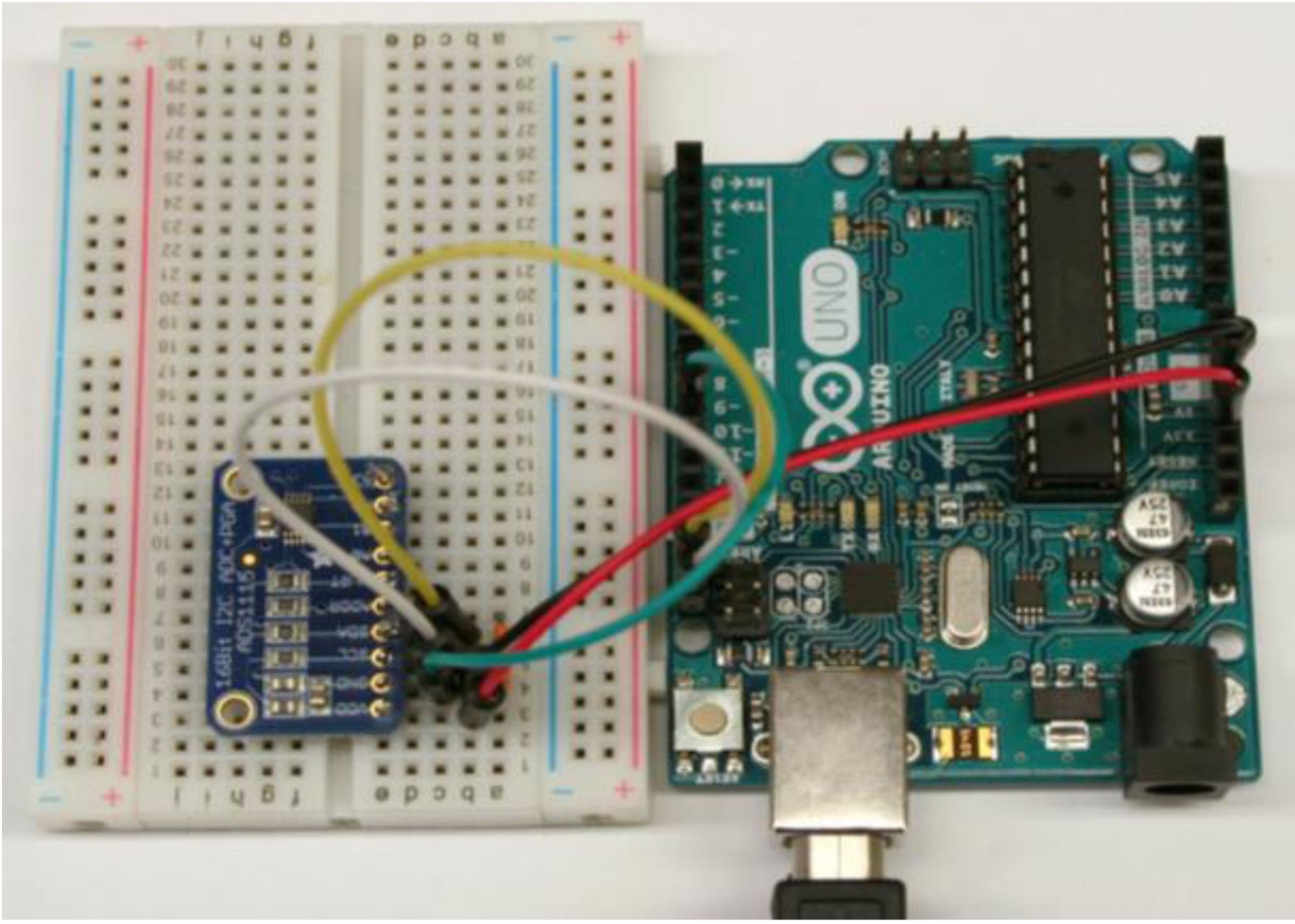

Figure 1.

Photograph of the Arduino Uno, ADS1115 Analog-to-Digital Converter placed onto a circuit breadboard, and the wiring connections needed for the data acquisition device.

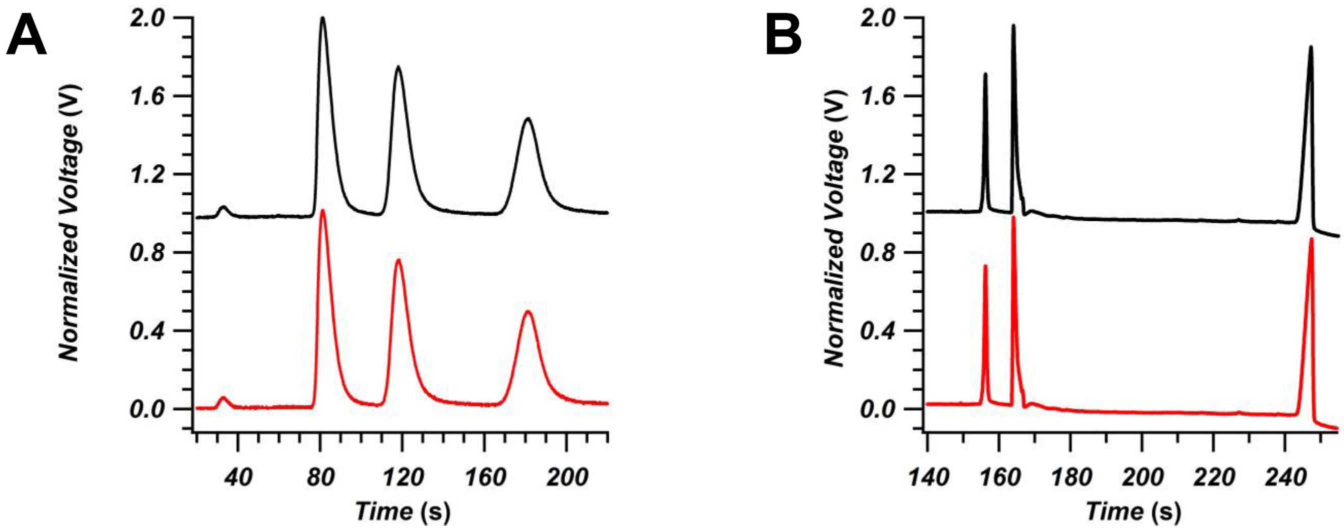

Figure 2.

Comparison of data collected (and normalized to 1 V) using pre-existing software (red traces) to the Arduino-ADS1115 device described in this paper (black traces, offset by 1 V for clarity). In (A), the separation of 1-propanol, 1-butanol, and 1-pentanol (with air as a dead-time marker) on a packed GC column for a sophomore-level analytical lab is shown. In (B), the separation of thiourea, dopamine, and serine with a commercial CE-UV research instrument is demonstrated. Full information on the separation conditions and instrumentation can be found in the Supporting Information.