International Journal of Computing Sciences Research (ISSN print: 2546-0552; ISSN online: 2546-115X)
Vol. 7, pp. 1887-1904
doi: 10.25147/ijcsr.2017.001.1.148
https://stepacademic.net

Short Paper*

Development and Testing of Lab in a Box: A Portable and Low-cost Electronics Trainer Kit intended for Computer Engineering Students

Louille Glen A. Benatiro
Department of Computer Engineering, University of San Carlos, Philippines
glenbenatiro@gmail.com
ORCID ID: 0000-0002-7250-1694
(corresponding author)

Luis Gerardo S. Cañete
Department of Computer Engineering, University of San Carlos, Philippines
lscanete@usc.edu.ph
ORCID ID: 0000-0003-3574-0976

Date received: January 29, 2023
Date received in revised form: February 13, 2023; March 26, 2023; March 30, 2023
Date accepted: March 30, 2023

Recommended citation:

> Benatiro, L. G. & Cañete, L. G. (2023). Development and Initial Testing of Lab in a Box: A Portable and Low-cost Electronics Trainer Kit Intended for Computer Engineering Students. *International Journal of Computing Sciences Research*, *7*, 1887-1904. https://doi.org/10.25147/ijcsr.2017.001.1.148

Special Issue on International Research Conference on Computer Engineering and Technology Education 2023 (IRCCETE 2023). Guest Associate Editors:* **Dr. Nelson C. Rodelas, PCpE (*Computer Engineering Department, College of Engineering, University of the East-Caloocan City; nelson.rodelas@ue.edu.ph*) and **Engr. Ana Antoniette C. Illahi**, PCpE (*Asst. Professor & Vice Chair, Department of Computer and Electronics Engineering, Gokongwei College of Engineering, De La Salle University, Taft Ave., Manila; ana.illahi@dlsu.edu.ph*).

Abstract

Purpose – The COVID-19 pandemic brought about the temporary physical closure of educational institutions globally, ushering in the shift to remote learning setups. This highlighted challenges with courses that require practical, hands-on instruction, such as with Electronics laboratory courses. In response, the researcher has proposed the development and testing of Lab in a Box, aimed to a portable and low-cost Electronics trainer kit powered by a Raspberry Pi Zero single-board computer. The device will enable students to perform hands-on Electronics laboratory activities and experiments in a remote or hybrid learning setup. Device development is ongoing as of writing. The completed device will feature Electronics laboratory equipment functionalities contained in a compact, portable case. A complementary software application to control the device, named LABSoft, is also in development. Initial real-world testing will be conducted with Computer Engineering students taking up introductory Electronics laboratory courses at the University of San Carlos, Philippines. Numerous issues were encountered during development, particularly regarding LABSoft's initial frame rate performance running on the single-core Raspberry Pi Zero. In this paper, a few optimizations, along with the current development progress, are discussed.

Method – The data block size of each data transfer using direct memory access (DMA), which is used to continually sample, copy, and store data for the oscilloscope functionality, was timestamped and profiled to determine the optimal block size. The initial graphical user interface toolkit that was used in LABSoft, which was GTK+, was switched to FLTK.

Results – The use of the determined optimal DMA data block size of 2,000 samples per block, along with the switch to a different graphical user interface toolkit, allowed LABSoft to reach its target frame rate of 25 frames per second, a considerable improvement from the initial 2 to 3 frames per second performance.

Conclusion – The optimizations performed were successful in that it greatly improved the frame rate performance of LABSoft. The single-core Raspberry Pi Zero still proves to be a capable platform for the requirements of the Lab in a Box device.

Recommendations – Further performance evaluations during the development of Lab in a Box are recommended to ensure that the Raspberry Pi Zero is still performant despite the added features and functionalities. In addition, other DMA data block size values can be investigated and tested to compare against the determined optimal size of 2,000 samples per block.

Practical Implications – The successful development of Lab in a Box will provide students with a portable and affordable Electronics test and measuring device, which will allow them to perform hands-on Electronics class experiments or projects outside of a classroom or laboratory setting.

Keywords – Raspberry Pi, Lab in a Box, Electronics, Electronics Trainer, Remote Learning

INTRODUCTION

The COVID-19 pandemic has profoundly affected humankind on a scale never before witnessed. As the World Health Organization (WHO) declared the then novel coronavirus as a pandemic on March 11, 2020 (Balkhair, 2020), lockdowns and social distancing measures were swiftly enforced to suppress the spread of the virus. This caused numerous industries globally to curtail activities, with the education industry one of the hardest hit areas. Educational institutions physically closed temporarily, and shifted to "emergency remote learning" measures, virtually all of which were conducted online (Farnell et al., 2021; Crawford et al., 2020).

This foundational shift to remote learning presented a plethora of challenges (Talib, Bettayeb, & Omer, 2021). One particular pedagogical challenge encountered was on how to effectively teach disciplines that require hands-on aspects, or access to laboratories or workshops. For instance, Electronics is a course traditionally conducted in a classroom or laboratory setting. Students perform hands-on activities and experiments to teach them practical skills. Electronics laboratory tools and equipment are also provided. With the remote learning setup, students are deprived of this in-person laboratory environment (Tadesse & Muluye, 2020) and need alternatives to bridge this crucial practical instructional gap.

In the absence of the traditional face-to-face setup, instructors and educational institutions have relied on various mediums in attempts to deliver the practical aspects of the Electronics laboratory course (Singh et al., 2020; Evstatiev & Hristova, 2020; Ciolacu et al, 2021; Morais, 2020; Sotelo et al., 2022; de Almeida et al., 2022).

These mediums can be considered non-traditional implementations of laboratory instruction and can be generally classified into three Categories (Faulconer & Gruss, 2018; de-Menéndez et al., 2019):

1.) Online, which is the use of simulation software such as MATLAB, LTSpice, PSpice, and Proteus
2.) Remote, which is the use of the internet and software to access actual equipment located on-site at laboratories and return their responses in real-time
3.) Distance, which is the use of portable Electronics trainers or learning kits to allow students to work on hands-on experiments or activities outside a classroom or laboratory setting

With the abrupt shift to remote learning, these NTIs are now pushed as replacements of traditional face-to-face instruction. Despite the advantages of NTIs, such as low operating, maintenance, and student costs, on demand availability, multiple access opportunities, and growth potential (Faulconer & Gruss, 2018; de-Menéndez, Guevara, & Morales-Menendez, 2019), there also exist crucial issues with their use.

It is apparent that hands-on aspects are unachievable through the sole use of simulation software. The learner fails to experience tangible results and tactile feedback. There is also a lack of access to laboratory tools and equipment that are indispensable in learning the subject matter. Simulations are best used in conjunction with hands-on approaches (Taher & Khan, 2015; Ma & Nickerson, 2006), resonating with the established theory of learning by doing (Gourmaj, Naddami, Fahli, & Nehari, 2017).

Remote implementations, meanwhile, are costly to develop and maintain. These are still actual laboratories housing equipment that are augmented with additional apparatuses and software to enable remote laboratory functionalities. These could be considered unrealistic and can be thought of as simulation laboratories by students (de-Menéndez, Guevara, & Morales-Menendez, 2019). Commercial remote laboratory offerings may also not be available for all platforms or devices (Orduna, et al., 2012), and concerns still arise regarding remote laboratories insufficiently developing students' experimental skills (de la Torre, Sánchez, & Dormido, 2016).

Lastly, for distance implementations, commercial Electronics trainers or learning kits are typically used. These provide a set of Electronics laboratory equipment features, such as an oscilloscope, multimeter, function generator, and logic analyzer, in a compact and portable package. However, these may be inaccessible or uneconomical to students given their high costs. For instance, the Analog Discovery 2, which is a compact PC-based multifunction device, has a market price of USD 399 (PHP 22,626.30). Going one model tier up, the Analog Discovery Studio, which is advertised as a fully functional portable electronics laboratory, has a market price of USD 699 (PHP 39,633.30). Affordability of these devices may be an issue, especially in middle to lower income countries like the Philippines, where the annual median household income is PHP 203,000 (USD 3,580.25), or around PHP 16,900 (USD 298.06) monthly (Philippine Statistics Authority, 2018). As another benchmark, the introductory Electronics laboratory course of the Computer Engineering program of the University of San Carlos, Philippines, totals PHP 7,545.44 (USD 133.08) (2017 figure).

In response, the researcher has proposed the development of Lab in a Box, aimed to be a portable and low-cost Electronics trainer kit, powered by a Raspberry Pi Zero single board computer. The device will feature Electronics laboratory equipment functionalities, namely an oscilloscope, multimeter, function generator, logic analyzer, power supply, and a circuit checker tool. It will also include a complementary software application, named LABSoft, to allow users to control the device.

Lab in a Box intends to aid in the practical instruction of Electronics laboratory courses in a remote or hybrid learning setup, allowing students to perform hands-on activities outside a classroom or laboratory setting. Initial real-world testing is planned to be conducted with Computer Engineering students from the University of San Carlos, Philippines, who will be taking up introductory Electronics laboratory courses.

Lab in a Box is currently in development. Numerous issues were encountered, particularly with regards to its initial performance running on the Raspberry Pi Zero. In this paper, a few optimizations to the complementary software application LABSoft are discussed, along with the current progress in the overall device development.

LITERATURE REVIEW

Lamo et al. (2022) presented a case study of a remote learning-delivered Computer Technology course at the International University of La Rioja, Spain. Online synchronous lecture sessions were held, along with tutorial sessions and forums to accommodate student questions or concerns. Students can accomplish practical activities through the simulation software Autodesk TinkerCad, or by using microcontrollers such as an Arduino. The researcher assessed four parameters from students: access to synchronous class sessions, participation in sending project proposals, marks from works, and a satisfaction survey. Results showed that students have increased their grades and have done more complex work than in previous courses. They have also evaluated the course experience positively and showed satisfaction with the results of their work. The researcher concluded that the students have satisfactorily integrated the knowledge they acquired.

Shoufan (2021) presented a pedagogical framework for active remote learning that was used to design their Embedded Systems course offering at Khalifa University, Abu Dhabi, United Arab Emirates. The instructional design's core aspect was the replacement of lectures with learning activities and hands-on experiments. Numerous technologies were utilized, namely the Moodle and Blackboard learning management systems, Youtube for hosting instructional and feedback videos, and a hardware kit that was sent to students. The kit consisted of an Arduino UNO microcontroller and a variety of electronic components that allowed the students to perform hands-on activities and a term project remotely. Results showed promising student engagement and positive perceptions of the course design.

Monzo et al. (2020) presented their inhouse- developed hardware platform named Lab@Home. This was made for the instruction of practical concepts in the remote learning-delivered Telecommunication Engineering program at the Open University of Catalonia, Spain. Lab@Home provides laboratory equipment functionalities, such as an oscilloscope, function generator, and power supply. The device must be connected to a computer with an installed complementary software to control the device. The device, along with an assortment of discrete electronic components, are sent to the students at the beginning of the semester. The researcher has compared Lab@Home with commercial Electronics trainer kits and determined that it was the best option, as it meets all the requirements in terms of affordability (at only USD 65), but with comparable features, specifications, and portability. Surveys from students showed positive reception of the device, noting that it had facilitated understanding of the concepts by means of practical experimentation, though they wished for it to have more complex functionalities.

METHODOLOGY

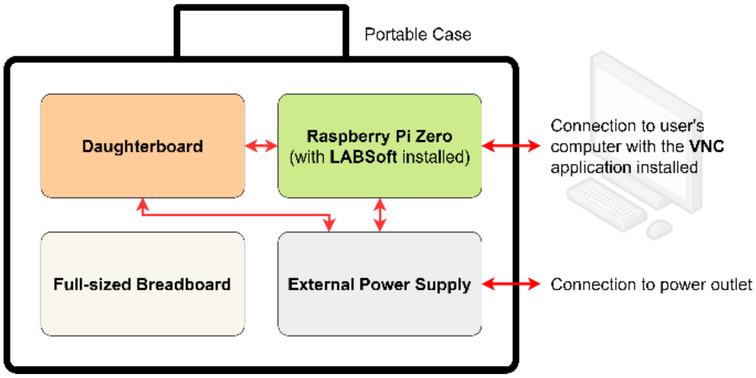


Figure 1. Lab in a Box Simplified Block Diagram Overview

System Overview

The development of Lab in a Box is ongoing as of writing. Figure 1 shows a simplified block diagram overview of the device. Once finished, the complete device package will comprise of a Raspberry Pi Zero single-board computer, a daughterboard, a full-sized breadboard, and an external power supply, all enclosed in an A4-sized case for compactness and portability. A complementary software application, named LABSoft, is included for user control.

The device features a set of Electronics laboratory equipment functionalities, namely an oscilloscope, multimeter, function generator, logic analyzer, power supply, and a circuit checker tool. These are embodied as hardware modules, which are fabricated on the daughterboard. This daughterboard interfaces with the Raspberry Pi Zero through its General-Purpose Input/Output (GPIO) pins.

Lab in a Box is aimed mainly at students and is designed with ease of setup in mind. To use the device, users need to:

1. Connect the Raspberry Pi Zero to a computer using a USB cable with a micro-B end,
2. Install the VNC software application on the computer,
3. Open a VNC instance on the computer and connect to the Raspberry Pi Zero, and

4. Run the preinstalled LABSoft on the Raspberry Pi Zero's desktop environment

VNC is a graphical desktop-sharing protocol that allows remote access and control of another computer. The wired VNC through USB connection only requires a single USB cable as tunneling is provided for the VNC, Ethernet, and USB protocols. The USB power provided by the connection also powers the Raspberry Pi Zero. This design choice frees the Raspberry Pi Zero from requiring separate connections for display and I/O devices, which would only add complexity and reduce device portability. User control and information display are therefore done through the computer, running a VNC instance.

Software

The development of LABSoft, a complementary software application to the Lab in a Box, is ongoing as of writing.

LABSoft contains a tabbed user interface, with each tab page dedicated to a specific device functionality. Input UI elements, such as drop-down lists and editable text fields, are used to control parameters such as the voltage per division setting of the oscilloscope, or the output frequency of the function generator. Meanwhile, output UI elements, such as text fields, a typical oscilloscope graph display, and an *n*-channel logic analyzer display, are used to show relevant information or data samples.

To obtain greater performance out of the single-core Raspberry Pi Zero, Lab in a Box is heavily reliant on Direct Memory Access (DMA). This is a feature that allows subsystems, usually a specialized DMA controller, to access main system memory and perform memory to I/O (or vice versa) data transfer independent of the CPU. As the operation of the oscilloscope and logic analyzer functionalities may be heavy on input bandwidth and may consume significant CPU cycles, DMA is utilized to perform sampling and storage of data samples. This frees up CPU computational power for other tasks, like processing of data and updating of the user interface.

LABSoft is developed using the C++ programming language and the Fast Light Toolkit (FLTK) graphical user interface (GUI) toolkit. Actual software development and compilation is done on a Raspberry Pi 3B+ to leverage its faster performance and similar hardware architecture to the Raspberry Pi Zero.

To implement its functions, LABSoft accesses and manipulates the hardware peripheral registers on the BCM2835 system-on-a-chip of the Raspberry Pi Zero. These hardware peripherals are the SPI, DMA, GPIO, clock, and Pulse-Width Modulation (PWM) peripheral. This necessitated the researcher to develop a software library. This library manages the memory accesses to the hardware peripheral registers, and exposes them for easy manipulation in code. LABSoft has been designed to run on top of this library.

Hardware Progress

As of writing, the design and development of the circuit schematics and printed circuit board (PCB) layouts of the oscilloscope, function generator, power supply, and circuit checker modules, have been finished. The PCBs of these modules have been fabricated, which are shown in Figures 2, 3, 4, and 5. They are currently being unit tested. The design and development of the multimeter modules have been deferred as there were multiple issues encountered.

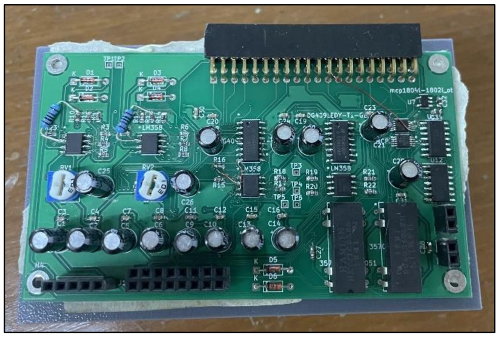


Figure 2. Oscilloscope Module

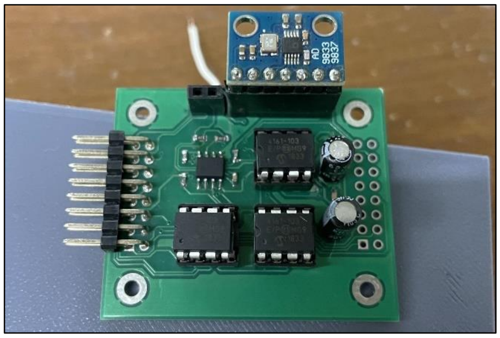


Figure 3. Function Generator Module

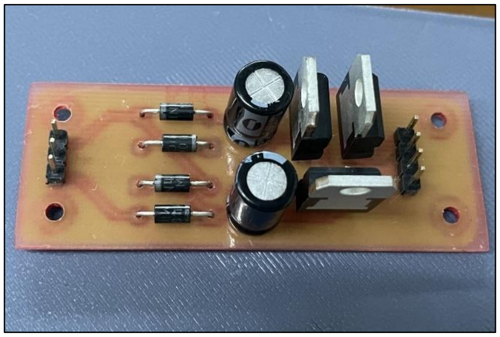


Figure 4. Power Supply Module

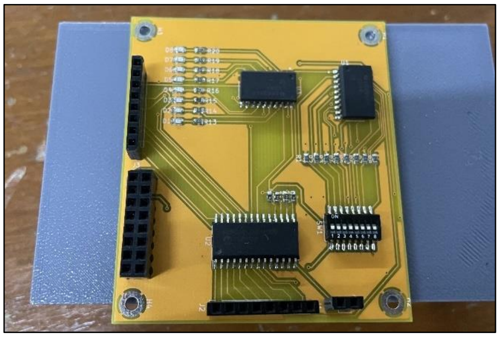


Figure 5. Circuit Checker Module

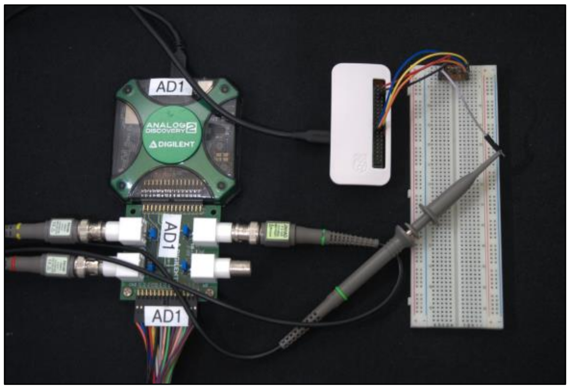


Figure 6. Simple Oscilloscope Module with an RPi Zero and an Analog Discovery 2

LABSoft Optimizations

The development of LABSoft began with a bare-bones oscilloscope module as the target initial iteration. This was paired with a Texas Instruments ADS7883 analog-to-digital converter (ADC) circuit setup, as shown on Figure 6.

DMA was implemented to manage the sampling and storage of data samples from the ADC. Actual data transfer between the ADC and the Raspberry Pi Zero was done through SPI. The DMA transfers work on a data block basis. Essentially, the DMA controller runs the SPI peripheral to sample up to *n* number of samples. Once these *n* samples are obtained, the DMA controller transfers this block of data samples to uncached memory. This *n*, the number of samples per block, was arbitrarily set to an initial value of 100.

For the GUI, GTK was initially used. GTK is a free and open-source widget toolkit for creating GUIs. The actual plotting of the graph on the oscilloscope module, however, was done using OpenGL, which is an application programming interface for rendering 2D and 3D vector graphics. This was selected as it was hoped that OpenGL would be hardware-accelerated by the graphics processing unit of the Raspberry Pi Zero.

```
Voltage: 2.264 V2.500 V / div    0.000 div
Ch2: 5.000 V     1.000 V / div    0.000 div
```

Figure 7. First Iteration of LABSoft with Oscilloscope Module

It turned out that performance of the initial iteration, shown on Figure 7, was exceptionally poor, rendering at only 2-3 frames per second. There were only two possible causes of this sluggish performance: either a problem on the DMA capture of data from the ADC, or from the rendering of the captured data on the oscilloscope display. Code profiling was necessary.

DMA capture was tested first. LABSoft was modified such that each DMA-transferred block of data would contain a timestamp when it was copied to uncached memory. This timestamp came from a 32-bit free-running clock register of the Raspberry Pi Zero for best accuracy. These blocks of data, along with their timestamps, were dumped into a comma-separated values (CSV) file for analysis. Through this, rendering of the samples on the oscilloscope display was bypassed. The DMA sample rate was set at the proposed Lab in a Box maximum of 200,000 samples per second. An oscilloscope was hooked up to the ADC's pins to verify that the chip was receiving the correct SPI signals.

Analysis of the CSV file revealed that each DMA-transferred data block mostly had a timestamp interval of around 480 microseconds, which is near the calculated 500 microseconds for a 100 samples per block size (at 200 kHz sampling rate). However, numerous random spikes in values, some reaching 8600 microseconds, were observed. Visual observations from the oscilloscope were showing expected values: SPI transfer of each sample was happening at 200 kHz.

It was hypothesized that this was due to the block size being too small. To find an optimal value, several different sizes were tested, which included 400, 800, 1600, and 3200 samples per block. Each test contained 1,000 data block samples.

Aside from the block sizes in question, it was also conjectured that the GTK GUI toolkit was just too slow for the Raspberry Pi Zero. The OpenGL rendering of the samples on the oscilloscope display was profiled in code, and results showed a rendering execution time of around 500 to 800 milliseconds. This is unacceptable, as at least 25 frames per second (FPS) was the targeted frame rate. With 25 FPS, the necessary processing to display each frame should have a total maximum execution time of only 40 milliseconds. With this, a switch was made to another GUI toolkit: Fast Light Toolkit (FLTK). FLTK is a free and open-source C++ GUI toolkit that highlights its "functionality without the bloat" and its "design to be small and modular", which would imply faster, lightweight performance.

RESULTS

Figure 8 shows the effects of the different DMA data block sizes to the percentage error of the timestamp interval values from the expected interval values. Notable observations are that 100 samples per block resulted to a wide range of error values, and 2,000 samples per block yielded a result that, although wasn't accurate, but was the most precise. This was selected as the optimal data block size as the apparent offset is more predictable and can be fixed in code. Further testing is yet to be conducted to ensure that the offset does not gravely affect the results obtained from the oscilloscope module.

With the new DMA data block size and the switch to FLTK, the current iteration of LABSoft, shown on Figure 10, can now reach 25 frames per second in the oscilloscope module display, with frame rendering times comfortably below 40 milliseconds. Figure 9 shows the considerable per-frame rendering time between OpenGL and FLTK.

Other modules of LABSoft have also underwent continuous development. Figure 11 shows the individual tabs of the current iteration of LABSoft. This is shown running on a Raspberry Pi 3B+.

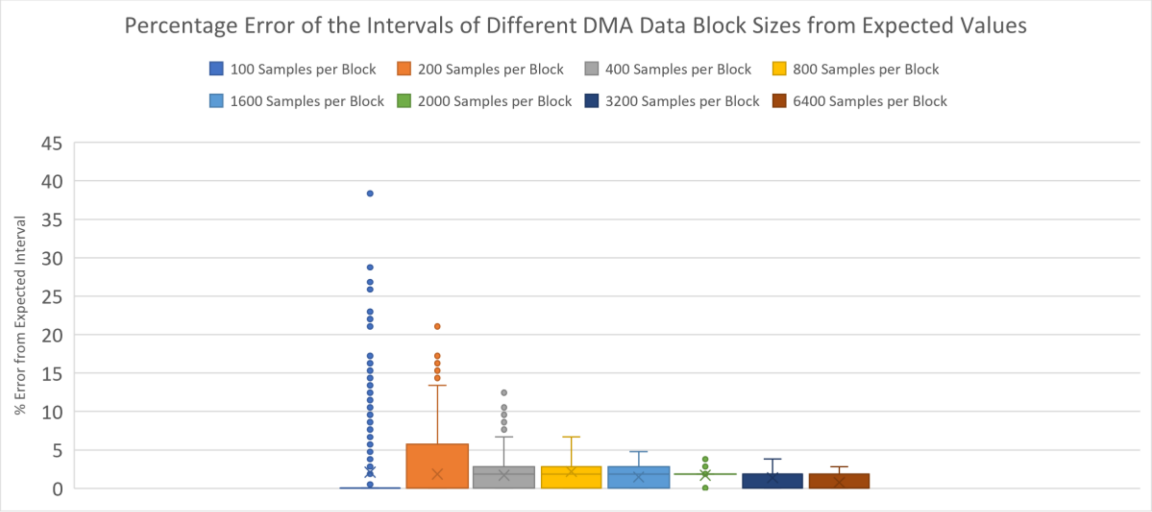


Figure 8. Percentage Error of Intervals of Different DMA Data Block Sizes

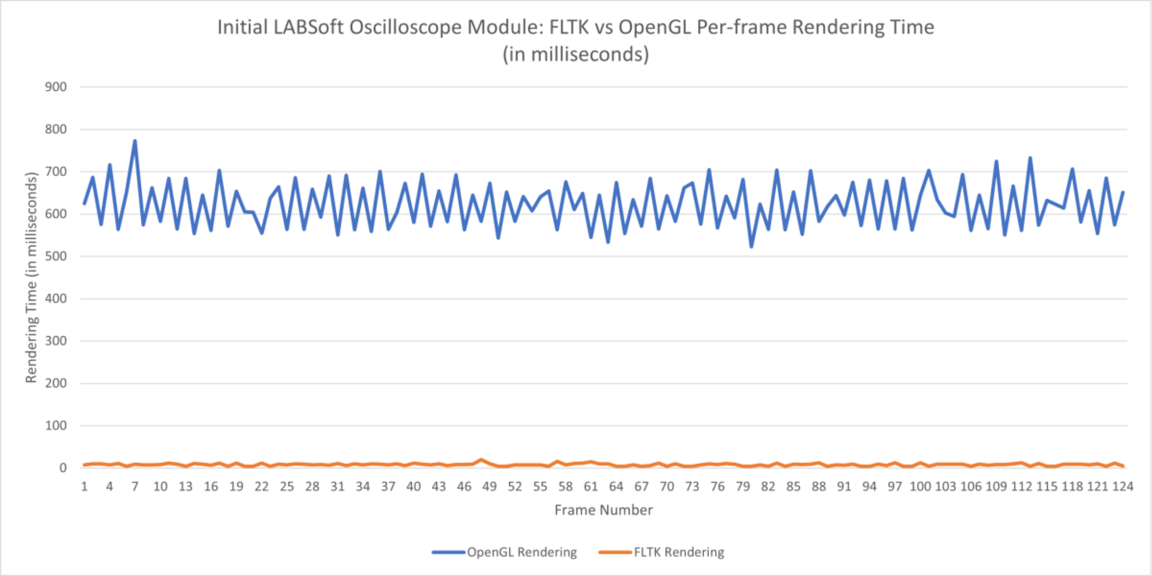


Figure 9. OpenGL vs FLTK Per-frame Rendering Time

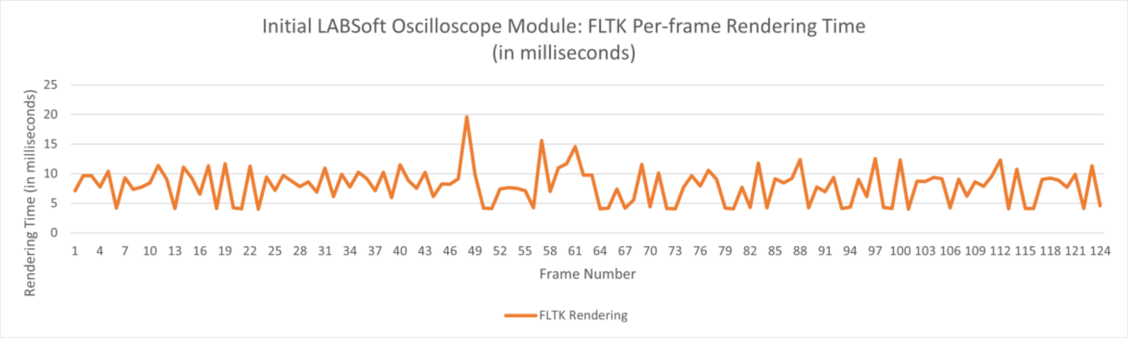
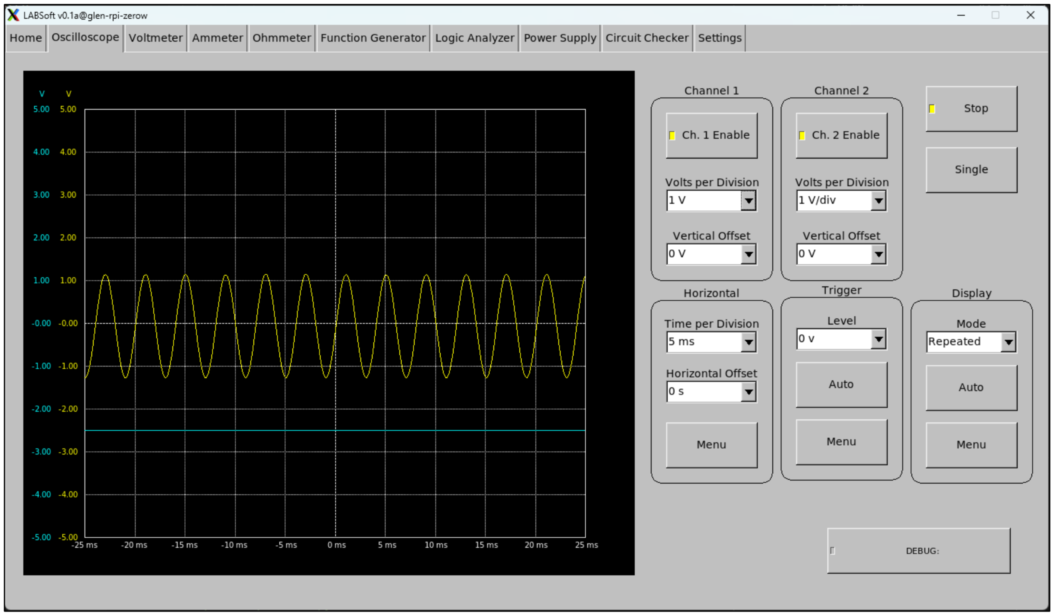
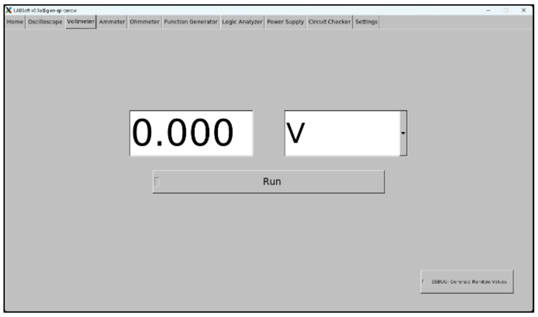


Figure 10. FLTK Per-frame Rendering Time

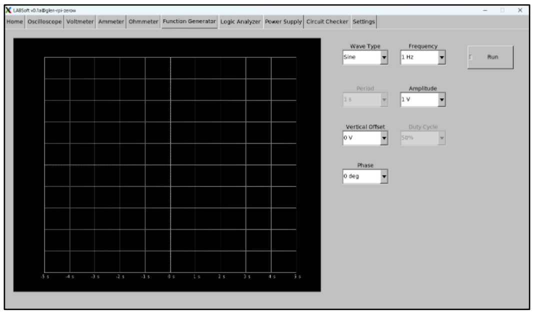


Volts per Division: 1 V
Vertical Offset: 0 V
Volts per Division: 1 V/div
Vertical Offset: 0 V
Time per Division: 5 ms
Horizontal Offset: 0 s
Level: 0 V
Mode: Repeated

Figure 11. Current LABSoft Oscilloscope Iteration Running on the Raspberry Pi Zero



0.000 V



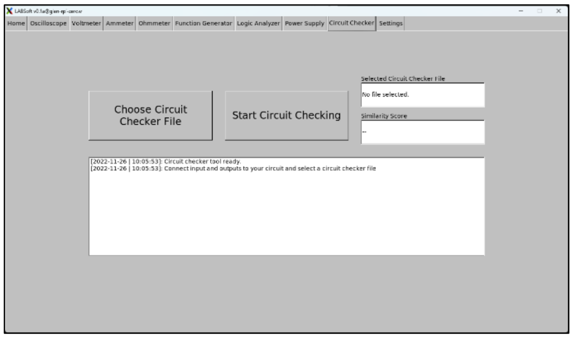
Wave Type: Sine
Frequency: 1 Hz
Amplitude: 1 V
Vertical Offset: 0 V
Phase: 0 deg

Figure 12. Voltmeter

Figure 13. Function Generator

Memory Depth: 4096
Sample Rate: 1 kHz
Time per Division: 1 ms/div
Position: 0 s
Display Mode: item

Figure 14. Logic Analyzer



Selected Circuit Checker File: No file selected.
Similarity Score: --

```
[2022-11-26 | 10:05:53]: Circuit checker tool ready.
[2022-11-26 | 10:05:53]: Connect input and outputs to your circuit and select a circuit checker file
```

Figure 15. Circuit Checker

DISCUSSION

The switch from GTK to FLTK, along with the new DMA data block size, proved to be a significant performance uplift from the unsatisfactory 2-3 frames per second of the first iteration. The Raspberry Pi Zero appears to be a capable computing platform for the computational and I/O heavy operations of the Lab in a Box, despite only having 1 CPU core. GTK+ and OpenGL appeared to be computationally heavy for the Raspberry Pi Zero to smoothly run.

On the incremental progress of hardware development, unit testing of the fabricated hardware modules is currently in progress. Each module should perform within specifications and with sufficient accuracy before being integrated into the Lab in a Box. Deviations from correct value will be corrected in this stage. On the software front, UI frontends of the modules have already been created, which are shown on Figures 11, 12, 13, 14, and 15.

There are still components of Lab in a Box that need to be designed and developed. These are the circuit front end for the logic analyzer, the A4-sized case, the external power supply, and further development of the other modules of LABSoft. Integration of Lab in a Box will commence once all components have been independently developed and tested. Tests to determine if the Raspberry Pi Zero is sufficiently performant with LABSoft will also be conducted. The aim is to be able to run LABSoft smoothly at around 30 frames per second with the Pi Zero.

As the development of the multimeter module has been deferred due to multiple issues encountered during circuit development, the researcher is considering bundling the Lab in a Box with a stand-alone multimeter for its first iteration. This can be supported by the consideration that the cost of multimeters is going down to affordable ranges, which can be confirmed by a scholarly search of online retailers within the Philippines. The researcher is also considering purchasing an off-the-shelf power supply, or a laptop charger, to serve as the device's external power supply. This might prove to be more cost-effective instead of developing and fabricating a power supply from the ground up.

Initial real-world testing of Lab in a Box will be conducted with Computer Engineering students of the USC. Specifically, students who will be taking up CPEA 2101 – Electrical Circuits. This is the first Electronics laboratory course that they will take in the program. Real-world testing will be carried out by requesting the instructors of the laboratory courses to allow selected students to use the device in a few experiments and assessments towards the end of the course. The scope of real-world testing will focus on qualitative aspects of the device as experienced by the students. This will be through an online survey. The survey will explore perceived device affordability, usefulness, functionality, effectivity, and ease of use.

CONCLUSIONS AND RECOMMENDATIONS

This paper discusses the current development progress of Lab in a Box, intended to be a portable and low-cost Electronics trainer kit, powered by a Raspberry Pi Zero single-board computer. This device is proposed a response to the challenge of conducting effective instruction of Electronics laboratory courses in a remote learning setup, which was the norm during the COVID-19 pandemic. The device will feature Electronics laboratory equipment functionalities, namely an oscilloscope, multimeter, function generator, logic analyzer, and a power supply. A circuit checker tool, a full-sized breadboard, and a complementary software application named LABSoft will also be included. The device will allow students to perform hands-on experiments, projects, or assessments outside a classroom or laboratory setting, or at the comfort of their homes.

The performance optimizations showed that the Raspberry Pi Zero, having a suggested retail price of only 5 USD, can still handle the computational demands of the Lab in a Box given that the right GUI toolkit is used. This is despite having only 1 CPU core, evidently a far slower model compared to higher tier models of the Raspberry Pi family with 4 CPU cores. As more features will be added in the progress of LABSoft development, along with future integration of the hardware, additional testing will be necessary to ensure that the Raspberry Pi Zero is still performant. Further optimizations should still be explored to make best use of the Raspberry Pi Zero, which would help to reserve computing power for future features.

IMPLICATIONS

The development of Lab in a Box will provide students with a portable and affordable Electronics test and measuring device. This will allow them to perform hands-on Electronics experiments or projects outside a classroom or laboratory setting. For a considerably low cost, the device will equip students with a capable multi-function instrument that could provide comparable features and performance of more expensive Electronics test and measuring equipment.

The benefits provided by Lab in a Box allow it to remain as a compelling educational instrument post pandemic. As the device will provide flexibility in allowing hands-on Electronics activities to be performed outside of a classroom or laboratory setting, along with the ability to confirm constructed circuits with the circuit checker tool, it could power new learning modes for Electronics laboratory courses, or enrich hybrid or remote learning setups. This could offer a paradigm shift in how the course is delivered. For instance, a fully remote Electronics laboratory course might be structured around the utilization of Lab in a Box. Class lectures can be conducted through synchronous or asynchronous online sessions, while practical aspects are taught using the device through hands-on experimentations and projects. This is all without needing students to physically attend the classroom or laboratory.

ACKNOWLEDGEMENT

The researcher would like to greatly thank Dr. Luis Gerardo S. Cañete for imparting his invaluable knowledge and assistance to the development of the Lab in a Box.

DECLARATIONS

Conflict of Interest

All authors declare that they have no conflicts of interest.

Informed Consent

The conducted research did not include any testing nor human participants, hence, this is not applicable.

Ethics Approval

The conducted research did not include any testing nor human participants, hence, this is not applicable.

REFERENCES

Balkhair, A. A. (2020, March). COVID-19 Pandemic: A New Chapter in the History of Infectious Diseases. *Oman Medical Journal, 35*, e123–e123. doi:https://doi.org/10.5001%2Fomj.2020.41

Ciolacu, M. I., Marcu, A.-E., Vladescu, M., Stoichescu, D., & Svasta, P. (2021, October). Education 4.0 Lab for Digital Innovation Units – Collaborative Learning in Time of COVID-19 Pandemic. *2021 IEEE 27th International Symposium for Design and Technology in Electronic Packaging (SIITME).* IEEE. doi:https://doi.org/10.1109/SIITME53254.2021.9663606

Crawford, J. A., Butler-Henderson, K. A., Jurgen, R., & Malkawi, B. H. (2020, April). COVID-19: 20 countries' higher education intra-period digital pedagogy responses. *1, 3*. doi:https://doi.org/10.37074/jalt.2020.3.1.7

de Almeida, F. V., Hayashi, V. T., Arakaki, R., Midorikawa, E., de Mello Canovas, S., Cugnasca, P. S., & Corrêa, P. L. (2022, September). Teaching Digital Electronics during the COVID-19 Pandemic via a Remote Lab. *Sensors, 22*, 6944. doi:https://doi.org/10.3390/s22186944

de la Torre, L., Sánchez, J. P., & Dormido, S. (2016, April). What remote labs can do for you. *Physics Today, 69*, 48–53. doi:https://doi.org/10.1063/PT.3.3139

de-Menéndez, M. H., Guevara, A. V., & Morales-Menendez, R. (2019, September). Virtual reality laboratories: a review of experiences. *International Journal on Interactive Design and Manufacturing (IJIDeM), 13*, 947–966. doi:https://doi.org/10.1007/s12008-019-00558-7

Evstatiev, B. I., & Hristova, T. V. (2020, October). Adaptation of Electrical Engineering Education to the COVID-19 Situation: Method and Results. *2020 IEEE 26th International Symposium for Design and Technology in Electronic Packaging (SIITME)* (pp. 304–308). IEEE. doi:https://doi.org/10.1109/SIITME50350.2020.9292142

Farnell, T., Matijevic, A. S., & Schmidt, N. S. (2021). *The impact of COVID-19 on higher education: a review of emerging evidence.* Tech. rep., NESET, Network of Experts working on the Social dimension of Education and Training. doi:http://doi.org/10.2766/069216

Faulconer, E. K., & Gruss, A. B. (2018, May). A Review to Weigh the Pros and Cons of Online, Remote, and Distance Science Laboratory Experiences. *The International Review of Research in Open and Distributed Learning, 19*. doi:https://doi.org/10.19173/irrodl.v19i2.3386

Gourmaj, M., Naddami, A., Fahli, A., & Nehari, D. (2017, August). Teaching Power Electronics and Digital Electronics using Personal Learning Environments. From Traditional Learning to Remote Experiential Learning. *International Journal of Online Engineering (iJOE), 13*, 18. doi:https://doi.org/10.3991/ijoe.v13i08.6840

Lamo, P., Perales, M., & Fuente-Valentín, L. d.-l. (2022, February). Case of Study in Online Course of Computer Engineering during COVID-19 Pandemic. *Electronics, 11*, 578. doi:https://doi.org/10.3390/electronics11040578

Ma, J., & Nickerson, J. V. (2006, September). Hands-on, simulated, and remote laboratories. *ACM Computing Surveys, 38*, 7. doi:https://doi.org/10.1145/1132960.1132961

Monzo, C., Cobo, G., Morán, J. A., Santamaría, E., & García-Solórzano, D. (2020, January). Lab@Home: The Open University of Catalonia Hands-on Electronics Laboratory for

Online Engineering Education. *Electronics, 9*, 222. doi:https://doi.org/10.3390/electronics9020222

Morais, M. K. (2020, December). Teaching Power Electronics with the Aid of Open Source Simulation Tool eSim. *2020 IEEE Bombay Section Signature Conference (IBSSC).* IEEE. doi:https://doi.org/10.1109/IBSSC51096.2020.9332179

Orduna, P., Garcia-Zubia, J., Rodriguez-Gil, L., Irurzun, J., de-Ipina, D. L., & Gazzola, F. (2012, April). Using LabVIEW remote panel in remote laboratories: Advantages and disadvantages. *Proceedings of the 2012 IEEE Global Engineering Education Conference (EDUCON).* IEEE. doi:https://doi.org/10.1109/EDUCON.2012.6201134

Philippine Statistics Authority. (2018). *2018 Family Income and Expenditure Survey.* Philippine Statistics Authority. Philippine Statistics Authority. Retrieved from https://psa.gov.ph/sites/default/files/FIES 2018 Final Report.pdf

Shoufan, A. (2021, March). Active Distance Learning of Embedded Systems. *IEEE Access, 9*, 41104–41122. doi:https://doi.org/10.1109/ACCESS.2021.3065248

Singh, G., Mantri, A., Sharma, O., & Kaur, R. (2020, September). Virtual reality learning environment for enhancing electronics engineering laboratory experience. *Computer Applications in Engineering Education, 29*, 229–243. doi:https://doi.org/10.1002/cae.22333

Sotelo, D., Sotelo, C., Ramirez-Mendoza, R. A., López-Guajardo, E. A., Navarro-Duran, D., Niño-Juárez, E., & Vargas-Martinez, A. (2022, March). Lab-Tec@Home: A Cost-Effective Kit for Online Control Engineering Education. *Electronics, 11*, 907. doi:https://doi.org/10.3390/electronics11060907

Tadesse, S., & Muluye, W. (2020). The Impact of COVID-19 Pandemic on Education System in Developing Countries: A Review. *Open Journal of Social Sciences, 08*, 159–170. doi:https://doi.org/10.4236/jss.2020.810011

Taher, M., & Khan, A. (2015, June). Effectiveness of Simulation versus Hands-on Labs: A Case Study for Teaching an Electronics Course. *2015 ASEE Annual Conference and Exposition Proceedings.* Seattle: ASEE Conferences. doi:https://doi.org/10.18260/p.23920

Talib, M. A., Bettayeb, A. M., & Omer, R. I. (2021, March). Analytical study on the impact of technology in higher education during the age of COVID-19: Systematic literature review. *Education and Information Technologies, 26*, 6719–6746. doi:https://doi.org/10.1007/s10639-021-10507-1

Author's Biography

Louille Glen A. Benatiro
Master of Science in Computer Engineering Student, University of San Carlos
Bachelor of Science in Computer Engineering, University of San Carlos, 2020

Luis Gerardo S. Cañete, PhD
Doctor of Science and Engineering, Fukushima University, 2015
Master of Science and Technology, Fukushima University, 2012
M.Engg. Computer Engineering, University of San Carlos, 2006