International Conference on Communication, Computing and Data Security

A Scalable Remote Laboratory System for Waveform Generation Using Virtual Instrumentation

AIPCP25-CF-ICCCDS2025-00007 | Article

A Scalable Remote Laboratory System for Waveform Generation Using Virtual Instrumentation

Niket Amoda[1,a], Lochan Jolly[2,b] and Arpit Rawankar [3,c]

[1]*Department of Electronics & Telecommunication Engineering, College of Engineering and Technology, Mumbai, India*

[a)] *niket.amoda@thakureducation.org*
b)lochan.jolly@thakureducation.org
c)arpit.rawankar@thakureducation.org

Abstract. In Electronics and Telecommunication Engineering (ECE), gaining hands-on experience is just as important as understanding theory. However, traditional laboratories often come with limitations like fixed schedules, costly equipment, and restricted access. This paper introduces a practical solution a remote laboratory system built using LabVIEW and integrated with VISA and SCPI protocols that allows students to control real hardware such as Arbitrary Function Generators (AFGs) from virtually anywhere. The system supports multiple connection methods, including USB, LAN, and Wi-Fi, giving students the flexibility to access labs whether they're on campus or learning remotely. Through this setup, learners can perform real-time experiments, generate signals, and analyze live data. Performance tests show that USB delivers the fastest response, LAN offers a good balance for shared remote access, and Wi-Fi enables mobility with slightly higher latency. When compared to simulation tools and earlier remote lab setups, the proposed system offers a more realistic and interactive learning experience. By bridging the gap between theory and real-world application, it helps students build both confidence and competence in working with electronic systems.

Keywords: *Remote Lab, LabVIEW, Virtual Instrumentation, AFG3022B, Engineering Education, USB, LAN, Wi-Fi, VISA, Real-time Waveform Generation.*

INTRODUCTION

In the field of Electronics and Telecommunication Engineering (ECE), laboratory-based learning plays a vital role in reinforcing theoretical concepts through hands-on experimentation [1]. Subjects such as analog and digital communication, signal processing, embedded systems, and instrumentation require students to interact with real-world devices, observe signals, and measure performance parameters. These practical sessions are essential in bridging the gap between classroom knowledge and industry-relevant skills [2] [3].

However, traditional laboratory environments often face significant limitations. These include restricted lab hours, limited access to specialized equipment, safety concerns, and the high cost of maintaining sophisticated hardware such as signal generators, oscilloscopes, spectrum analyzers, and communication trainers [4]. Furthermore, increased student enrollment and physical space constraints make it difficult to provide every learner with sufficient hands-on exposure [5] [6].

With the growing demand for flexible and accessible education, particularly in remote and hybrid learning environments, Virtual Instrumentation based remote laboratories have emerged as a promising solution [7]. LabVIEW (Laboratory Virtual Instrument Engineering Workbench), is a graphical programming platform that enables the development of custom virtual instruments and automation systems. It supports remote access to real-time data acquisition and control, making it well-suited for virtualizing laboratory experiments [8] [2] [9].

LabVIEW's integration with VISA (Virtual Instrument Software Architecture) and SCPI (Standard Commands for Programmable Instruments) protocols allows seamless communication with a wide range of instruments, including

Arbitrary Function Generators (AFGs), Digital Storage Oscilloscopes (DSOs), and spectrum analyzers [10] [11] . By deploying LabVIEW programs on servers connected to actual lab hardware, students can remotely perform experiments such as AM/FM modulation, pulse code modulation, filter design, and frequency burst generation interacting with real signals and data from their own locations[9]. These remote laboratory systems provide several advantages:

- Real-time access to actual instruments, ensuring authentic practical learning experiences [12].
- Increased availability, allowing students to conduct experiments outside traditional class hours [10].
- Cost-effectiveness, as resources can be shared among multiple users without duplication [12].
- Safe learning environments, particularly when working with high-voltage or delicate components [10].

Numerous institutions have successfully implemented Virtual Instrumentation based remote labs for ECE education, reporting improvements in student engagement, conceptual understanding, and practical skill development [8] [2]. With continued advancements in networking and automation, remote laboratories are becoming an essential component of modern engineering education, ensuring students remain connected to hands-on learning regardless of physical location [13] [14].

While simulations are excellent tools for quickly grasping theoretical concepts and experimenting with ideas in a virtual setting, they often fall short in providing real-world, hands-on experience. In contrast, Virtual Instrumentation-based Remote Laboratories offer students the opportunity to work directly with real hardware even from remote locations making them ideal for building practical skills and gaining deeper insights into real-world systems [15] [8] [16] . A detailed comparison between simulations and remote labs is provided in Table 1 below.

TABLE 1. Comparison of Simulations with Virtual Instrumentation based Remote Laboratory [17] [18]

Aspect	**Simulations**	**Virtual Instrumentation based Remote Laboratories**
Nature of Interaction	Virtual modeling using mathematical algorithms.	Real-time interaction with actual physical hardware.
Environment	Fully software-based, no real-world equipment involved.	Software interface connected to real instruments via network.
Data	Simulated data, not generated from real components.	Live data acquired from real devices like AFGs, DSOs, etc.
Conceptual Clarity	Excellent for visualizing theory.	Combines theory with hands-on practice.
Skill Development	Limited to software and theoretical skills.	Builds practical skills: wiring, measurement, troubleshooting.
Realism	Approximation of behavior.	True-to-life results from actual devices.
Error Handling	No real-world noise, drift, or hardware issues.	Users deal with real-world anomalies and system behaviors.
Limitations	No real-world interaction; cannot replicate hardware faults or real-time noise.	Needs robust infrastructure, reliable network, and remote hardware maintenance.

PROPOSED SYSTEM

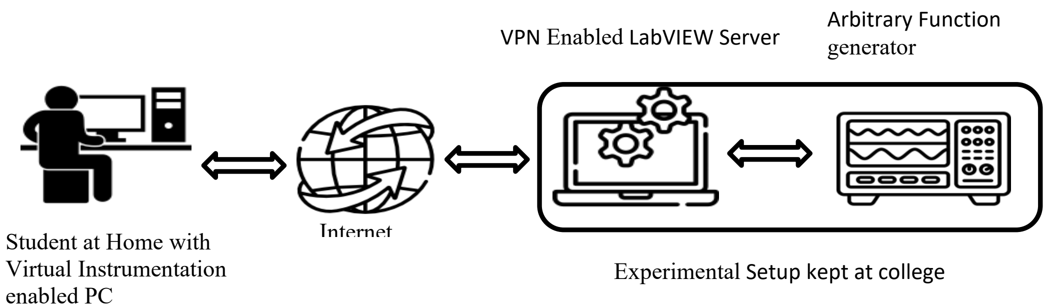

FIGURE 1. SYSTEM ARCHITECTURE

The proposed system is built around three essential components: a laptop or desktop computer at the student's home running Virtual Instrumentation software, an internet connection, and an experimental setup located in the laboratory that includes an Arbitrary Function Generator (AFG). This setup allows students particularly those studying Electronics and Telecommunication Engineering to remotely connect to and control the lab equipment from wherever they are [19] [9] [20].

Through this system, students can adjust instrument settings, monitor signals in real time, and analyze data just as they would during an in-person lab session. The experience closely mirrors being physically present in the lab, offering a practical and interactive learning environment from a distance. Figure 1 illustrates the overall architecture of the proposed system and how its components interact to support remote experimentation [21] [22].

A key enabler of this remote lab system is Virtual Instrument Software Architecture (VISA), which acts as the bridge between the student's computer and the physical lab equipment. Whether students are working with an Arbitrary Function Generator (AFG) or a Digital Storage Oscilloscope (DSO), VISA handles the behind-the-scenes communication that makes remote control possible. It provides a standardized way for Virtual Instrumentation software to talk to instruments connected through various hardware interfaces such as Ethernet, USB, GPIB, or serial ports [20][23] [24].

In the context of remote experimentation, VISA works with IP-addressed instruments (such as an AFG connected via Ethernet), allowing students to connect securely over the internet [25] . Once connected, they can adjust settings, trigger measurements, and collect data in real time just like they would if they were physically present in the lab. VISA also supports instrument discovery, session management, and error handling, which are crucial for ensuring stable and reliable connections during remote access [26] [27] [8].

SYSTEM IMPLEMENTATION

In the proposed system, a Tektronix AFG3022B Arbitrary Function Generator (AFG) was used as part of the experimental setup. To connect the AFG to a computer running LabVIEW, students have a few options USB, Ethernet (LAN), or GPIB [10] . Among these, Ethernet is the most practical and reliable choice for remote access. When using a network connection, the AFG is assigned an IP address, either automatically through DHCP or set manually. This IP address allows the Virtual Instrumentation software to identify and communicate with the device through its VISA resource name, enabling seamless remote control and integration into the LabVIEW environment [19] [18][20].

3.1 Connection of AFG to the USB

FIGURE 2 (A). USB INTERFACE OF THE AFG

FIGURE 2 (B). AFG CONNECTED TO A VIRTUAL INSTRUMENTATION ENABLED COMPUTER

Figures 2A and 2B illustrate how the Tektronix AFG3022B Arbitrary Function Generator can be connected directly to a Virtual Instrumentation enabled computer using a standard USB cable. In this setup, the device is physically linked to the computer, making it a straightforward and reliable option especially when both the user and the equipment are in the same location [28] . This type of connection doesn't require any complex network setup, which makes it ideal for local testing or development. The USB interface provides a stable and fast communication link, making it easy for students or developers to test instrument control, adjust settings, and read output signals with minimal delay.

This direct connection method is particularly helpful during the initial phases of setting up virtual instrumentation or when validating experiments before moving to a fully remote configuration [7].

3.2 Connection of AFG to the Ethernet

Figure 3A shows how the Tektronix AFG3022B Arbitrary Function Generator (AFG) can be connected to a Virtual Instrumentation-enabled computer using an Ethernet connection. In this setup, the AFG is linked to a local area network (LAN) through a standard Ethernet cable, allowing it to be accessed remotely from a computer running LabVIEW. This method is particularly useful in remote lab environments, where students or users need to control equipment from a different location [28] [10].

Once connected to the network, the AFG is assigned an IP address, either automatically via DHCP or manually through its settings as shown in Figure 3B. This IP address allows LabVIEW to recognize the instrument as a VISA resource, enabling smooth communication over the network. An Ethernet-based connection provides several advantages over direct USB connections it supports remote access, allows for multi-user setups, and offers greater scalability, especially in educational settings where multiple students may need to work with the same instrument. Overall, this configuration makes it possible to perform real-time experiments, control waveform generation, and collect data all from a remote location enhancing flexibility and accessibility in engineering education [29] [19].

FIGURE 3 (A). CONNECTION AFG TO A LOCAL AREA NETWORK (LAN) VIA ETHERNET

FIGURE 3 (B). IP ADDRESS CONFIGURATION FOR THE AFG

3.3 Connection of AFG to the WiFi

Figure 4 illustrates the connection of the Tektronix AFG to a Virtual Instrumentation-enabled computer via a Wi-Fi network. In this setup, the AFG is first connected to a wireless router using an Ethernet cable (number 1 & 2 highlighted with yellow color), allowing the instrument to become accessible over the wireless local area network (WLAN). The student's or user's computer, equipped with LabVIEW and connected to the same Wi-Fi network, can then communicate with the AFG using the assigned IP address, similar to a standard LAN-based setup [30] [31].

FIGURE 4. CONNECTION AFG TO A WIRELESS AREA NETWORK (WAN) VIA WIFI

Although the AFG3022B itself does not support native Wi-Fi, this configuration effectively bridges the gap by allowing wireless access to the networked instrument through the router. This Wi-Fi-enabled configuration offers greater mobility and flexibility, particularly useful in academic institutes and universities where students may need to access laboratory equipment from different locations or during off-campus sessions. However, it should be noted that compared to direct LAN or USB connections, Wi-Fi may introduce slightly higher latency and variability in performance, which should be considered for time-sensitive measurements [32] [33].

3.4 Conduction of Standard Waveform Generation Experiment

In LabVIEW, every program also known as a Virtual Instrument (VI). It has two key parts: the Front Panel and the Block Diagram. The Front Panel acts like the user interface, where users can interact with the system by entering values, adjusting controls, or viewing real-time data through graphs, charts, and indicators. It's designed to look and feel like an actual instrument panel, making it intuitive and easy to use even for those without programming experience. Behind the scenes, the Block Diagram contains the logic and flow of the program. This is where the actual data processing happens, using visual code blocks (called functions or nodes) connected by wires to represent data flow. Together, the Front Panel and Block Diagram allow users to build powerful, interactive applications that control real-world instruments, process signals, and visualize results all without writing traditional text-based code.

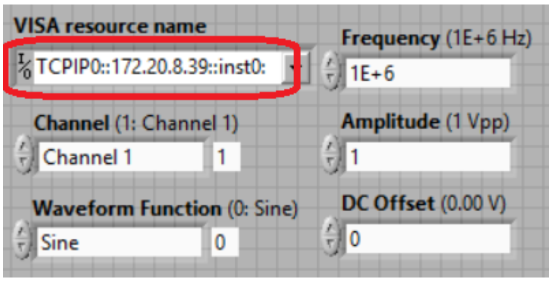

FIGURE 5(A). FRONT PANEL FOR STANDARD WAVEFORM GENERATION PROGRAM

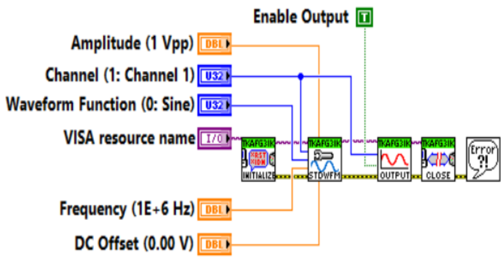

FIGURE 5(B). BLOCK DIAGRAM FOR STANDARD WAVEFORM GENERATION PROGRAM

Figures 5A and 5B illustrate the Front Panel and Block Diagram of the standard waveform generation program, which runs on the remote user's computer as part of the Virtual Instrumentation environment. This Virtual Instrumentation based program enables users to generate and control waveform signals on the Tektronix AFG3022B Arbitrary Function Generator (AFG) remotely. The connection to the instrument is established through the VISA Resource Name field, where the device's IP address is specified.

This IP address is dynamically assigned by a Virtual Private Network (VPN) enabled Virtual Instrumentation server hosted at the institute. The VPN creates a secure and reliable communication link, allowing students to operate real laboratory equipment from any off-campus location. This setup ensures that users can perform hands on experiments without being physically present in the lab replicating the experience of in person interaction with actual hardware. The Front Panel of the waveform generation program is designed to be user-friendly and includes the following key input fields:

- **VISA Resource Name**: Identifies and connects to the specific instrument over the network.
- **Channel**: Selects which output channel of the function generator is to be configured.
- **Waveform Function**: Allows the user to choose the type of waveform to generate (e.g., sine, square, triangle).
- **Frequency**: Sets the frequency of the output waveform.
- **Amplitude**: Defines the voltage amplitude of the signal generated at the output terminal
- **DC Offset**: Specifies the DC offset added to the waveform, adjusting the baseline voltage level at the output.

The results obtained from the standard waveform generation program are presented in Figures 6A to 6L, showcasing various waveform outputs and configurations achieved through remote control of the AFG device.

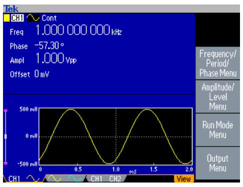

FIGURE 6(A). SINE WAVEFORM

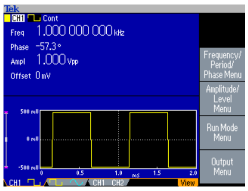

FIGURE 6(B). SQUARE WAVEFORM

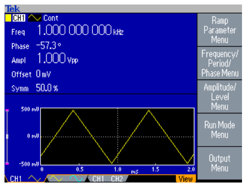

FIGURE 6(C). RAMP WAVEFORM

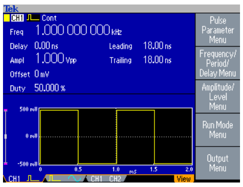

FIGURE 6(D). PULSE WAVEFORM

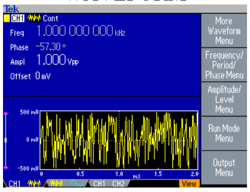

FIGURE 6(E). NOISE WAVEFORM

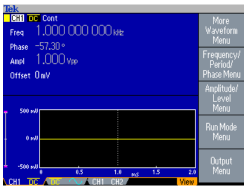

FIGURE 6(F). DC WAVEFORM

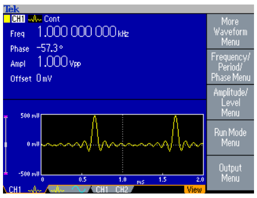

FIGURE 6(G). SIN(X)/X WAVEFORM

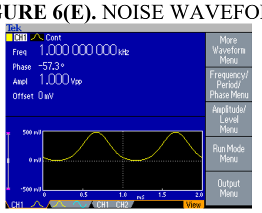

FIGURE 6(H). GAUSSIAN WAVEFORM

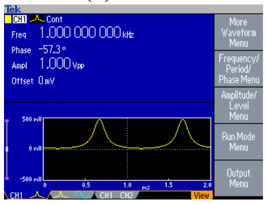

FIGURE 6(I). LORENTZ WAVEFORM

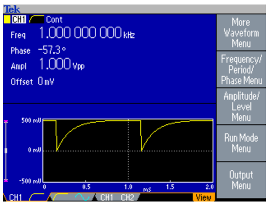

FIGURE 6(J). EXPONENTIAL RISE WAVEFORM

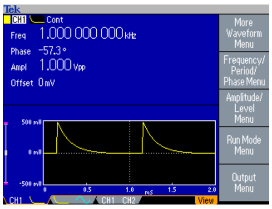

FIGURE 6(K). EXPONENTIAL DECAY WAVEFORM

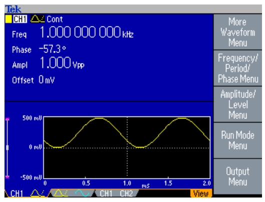

FIGURE 6(L). HAVERSINE WAVEFORM

RESULTS AND DISCUSSION

4.1 Standard Waveform generation Results

The waveform generation results obtained from remote execution are presented in Figures 6A to 6L, showcasing the system's capability to produce a wide variety of signal types:

- Figure 6A–6C: Sine, Square, and Ramp waveforms.
- Figure 6D–6F: Pulse, Noise, and DC waveforms.
- Figure 6G–6I: Sin(x)/x, Gaussian, and Lorentzian waveforms.
- Figure 6J–6L: Exponential rise, Exponential decay, and Haversine waveforms.

TABLE 2. Mean Execution time, memory and Bandwidth required to perform Standard waveform generation experiments

Interface	Mean Execution Time in milliseconds (ms)	Mean Memory in kilobytes (KB)	Mean Bandwidth in kbps
USB	1391.1	105.6	75.9
LAN	1429.0	127.6	89.3

Wifi	1656.8	195.6	118.1

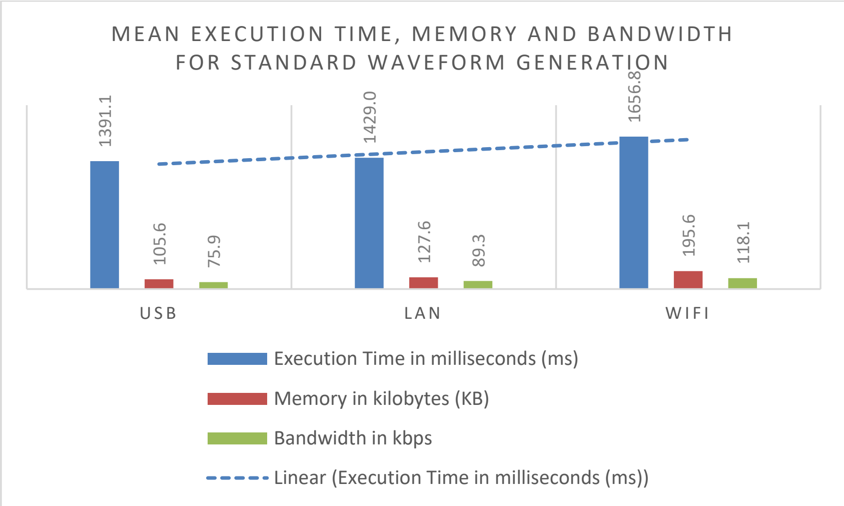

FIGURE 7. MEAN EXECUTION TIME, MEMORY AND BANDWIDTH FOR STANDARD WAVEFORM GENERATION

4.2 Performance Evaluation: Execution Time, Memory Usage, and Bandwidth

To better understand how the system performs under different types of network connections, the standard waveform generation experiment was run multiple times using USB, LAN, and Wi-Fi. The system was evaluated in terms of how long it took to complete each task (execution time), how much memory it used, and how much data it transferred (bandwidth). The results are summarized in Table 2 and displayed in Figure 7.

Among the three, the USB connection delivered the fastest and most efficient performance, with an average execution time of just 1391.1 milliseconds, the lowest memory usage at 105.6 KB, and the smallest bandwidth consumption at 75.9 kbps. This makes USB an excellent option for local testing and development, especially when students or instructors are working directly with the hardware on-site. It's simple, fast, and reliable.

The LAN (Ethernet) setup came in close behind, with a slightly higher execution time of 1429.0 milliseconds and moderate resource use. Memory consumption rose to 127.6 KB, and bandwidth to 89.3 kbps. Despite the small increase, the Ethernet connection performed consistently and was highly suitable for remote access, especially in lab environments where multiple students may need to connect to equipment simultaneously. It offers a strong balance between performance and accessibility.

The Wi-Fi configuration, while the most flexible in terms of mobility, showed the highest execution time at 1656.8 milliseconds. It also used more memory (195.6 KB) and required the most bandwidth (118.1 kbps). This is likely due to the variable nature of wireless connections, where factors like signal strength and network congestion can affect performance. Although Wi-Fi still enabled successful remote operation of the AFG, it's important to note that minor delays and occasional instability may occur—especially during time-critical tasks.

For all three connection types supported the remote waveform generation experiment effectively, but each came with its own set of trade-offs:

- USB is best for speed and simplicity when working locally.
- LAN offers a strong mix of performance and remote access.
- Wi-Fi provides the most convenience, though at the cost of slightly higher delays and resource use.

COMPARISON WITH EXISTING TECHNIQUES

To better understand where our proposed remote lab system stands, it helps to compare it with two common approaches already in use: simulation-based labs and older remote lab setups that didn't fully support real-time hardware control.

5.1 Comparison with Simulation-Based Labs

Simulation tools like MATLAB, Multisim, and Proteus are commonly used to teach electronics concepts. They're excellent for visualizing theoretical ideas and modeling circuit behavior through software. However, they don't allow students to interact with actual hardware, which means learners miss out on practical, real-world experiences. In contrast, our system provides direct control over real instruments such as the Tektronix AFG via LabVIEW, enabling students to see and respond to live data, deal with noise and fluctuations, and gain hands-on skills that simulations can't offer [34], [35], [36].

TABLE 3. Comparison of simulation-based labs and the proposed LabVIEW remote lab, focusing on interactivity, realism, and learning outcomes

Aspect	Simulation-Based Labs	Proposed Remote Lab
Nature of Interaction	Software-based modeling	Real-time control of actual lab instruments [37]
Type of Data	Simulated, ideal data	Live data from physical devices [38]
Skill Development	Mostly theoretical	Practical skills in wiring, setup, and measurement [39]
Realism	Limited, lacks hardware behavior	Includes real-world issues like noise and drift [40]
Scalability	Easily replicable	Requires shared physical hardware [41]
Learning Depth	Strong in theory	Strong in both theory and hands-on practice [35], [42]

5.2 Comparison to Older Remote Labs

Many earlier remote lab setups were more like virtual tours students could view instrument readings or video feeds, but they couldn't directly interact with the hardware in real time. The proposed system solves this problem by using LabVIEW and VISA, allowing for secure, real-time, bidirectional communication with instruments over USB, LAN, or even Wi-Fi [43], [44].

TABLE 4. Comparison of legacy remote labs with the proposed LabVIEW-based system, highlighting key improvements in control, connectivity, and user experience

Feature	Older Remote Labs	Proposed Remote Lab
Real-Time Interaction	Often unavailable	Fully interactive LabVIEW control [45]
Protocol Support	Limited or proprietary	Uses standard VISA and SCPI protocols [46]
Equipment Range	Restricted	Supports a wide variety of instruments [47]
Network Access	Usually LAN-based	USB, LAN, and Wi-Fi support for flexibility [48]
Security	Basic	VPN-secured remote access [49]
Student Experience	Partial lab replication	Full lab experience from anywhere [35], [50]

5.3 Key Advantages of the Proposed System

The proposed system offers several distinct benefits that make it particularly effective for modern engineering education:

- Flexible Access Options: Whether students are in the lab or halfway across campus, they can connect via USB, Ethernet, or Wi-Fi depending on what's available [48], [49].
- Real Instrumentation Training: Students gain familiarity with the same types of interfaces and equipment they'll encounter in industry [37], [39].
- Efficient and Reliable: Performance testing shows low execution times and modest bandwidth usage, especially over USB and LAN, making it viable even in bandwidth-constrained environments [51], [52].
- Scalable Design: With LabVIEW's modular programming and support for multiple users, institutions can scale this system to support a larger number of remote learners without needing duplicate hardware [43], [44].

CONCLUSION

This study presents a remote lab system that brings real instruments and experiments into students' hands no matter where they are. By combining LabVIEW with standardized communication protocols like VISA and SCPI, the setup allows students to remotely control devices like the Tektronix AFG3022B function generator and carry out practical tasks just as they would in a physical lab. Our findings show that USB connections are ideal for speed and efficiency, LAN provides reliable access for shared use, and Wi-Fi supports remote learning with minor trade-offs in speed. Together, these options make the system highly adaptable for both in-person and remote learning environments. Compared to traditional simulations and older remote labs, this approach offers a more immersive and hands-on experience. It not only improves engagement and understanding but also prepares students for working with real-world equipment an essential skill in today's engineering careers. With education increasingly moving toward hybrid and flexible models, this kind of system is not just useful it's necessary. It ensures that students can keep learning, experimenting, and building real skills, even when they can't physically be in the lab.

REFERENCES

1. F. Y. Limpraptono, A. Faisol, and E. Nurcahyo, "The Development of Electronics Telecommunication Remote Laboratory Architecture Based on Mobile Devices," International Journal of Online and Biomedical Engineering (iJOE), vol. 17, no. 03, pp. 26–36, Mar. 2021, doi: 10.3991/ijoe.v17i03.20179.
2. M. C.-P. Poo, Q. Chen, and Y.-Y. Lau, "Are Virtual Laboratories and Remote Laboratories Enhancing the Quality of Sustainability Education?," Education Sciences, vol. 13, no. 11, p. 1110, Nov. 2023, doi: 10.3390/educsci13111110.
3. Spanias and V. Atti, "Interactive Online Undergraduate Laboratories Using J-DSP," IEEE Transactions on Education, vol. 48, no. 4, pp. 735–749, Nov. 2005, doi: 10.1109/te.2005.854569.
4. K. El Kharki, D. Burgos, and K. Berrada, "Design and Implementation of a Virtual Laboratory for Physics Subjects in Moroccan Universities," Sustainability, vol. 13, no. 7, p. 3711, Mar. 2021, doi: 10.3390/su13073711.
5. J. C. Hayes and D. J. M. Kraemer, "Grounded understanding of abstract concepts: The case of STEM learning," Cognitive Research: Principles and Implications, vol. 2, no. 1, Jan. 2017, doi: 10.1186/s41235-016-0046-z.
6. S.-C. Wang and Y.-H. Liu, "Software-Reconfigurable e-Learning Platform for Power Electronics Courses," IEEE Transactions on Industrial Electronics, vol. 55, no. 6, pp. 2416–2424, Jun. 2008, doi: 10.1109/tie.2008.922592.
7. M. T. Restivo, C. M. Silva, A. M. Lopes, F. Chouzal, and J. Mendes, "A Remote Laboratory in Engineering Measurement," IEEE Transactions on Industrial Electronics, vol. 56, no. 12, pp. 4836–4843, Dec. 2009, doi: 10.1109/tie.2008.2011479.
8. S. Diwakar et al., "Complementing Education via Virtual Labs: Implementation and Deployment of Remote Laboratories and Usage Analysis in South Indian Villages," International Journal of Online and Biomedical Engineering (iJOE), vol. 12, no. 03, pp. 8–15, Mar. 2016, doi: 10.3991/ijoe.v12i03.5391.
9. M. Abdulwahed and Z. K. Nagy, "Developing the TriLab, a triple access mode (hands-on, virtual, remote) laboratory, of a process control rig using LabVIEW and Joomla," Computer Applications in Engineering Education, vol. 21, no. 4, pp. 614–626, Dec. 2010, doi: 10.1002/cae.20506.

10. González, A. Mejías, J. Andújar, and A. Calderón, "Novel Networked Remote Laboratory Architecture for Open Connectivity Based on PLC-OPC-LabVIEW-EJS Integration. Application in Remote Fuzzy Control and Sensors Data Acquisition.," Sensors, vol. 16, no. 11, p. 1822, Oct. 2016, doi: 10.3390/s16111822.
11. P. Ferrari, A. Flammini, D. Marioli, and A. Taroni, "A Distributed Instrument for Performance Analysis of Real-Time Ethernet Networks," IEEE Transactions on Industrial Informatics, vol. 4, no. 1, pp. 16–25, Feb. 2008, doi: 10.1109/tii.2008.919016.
12. F. J. Jiménez-Romero, J. R. González-Jiménez, F. García-Torres, Á. Caballero, and F. R. Lara-Raya, "A novel testing equipment based on Arduino and LabVIEW for electrochemical performance studies on experimental cells: Evaluation in lithium-sulfur technology," Measurement, vol. 224, p. 113922, Nov. 2023, doi: 10.1016/j.measurement.2023.113922.
13. S. Alsaleh, A. Kose, A. Tepljakov, E. Petlenkov, and J. Belikov, "ReImagine Lab: Bridging the Gap Between Hands-On, Virtual and Remote Control Engineering Laboratories Using Digital Twins and Extended Reality," IEEE Access, vol. 10, pp. 89924–89943, Jan. 2022, doi: 10.1109/access.2022.3199371.
14. Qadir and A. Al-Fuqaha, "A Student Primer on How to Thrive in Engineering Education during and beyond COVID-19," Education Sciences, vol. 10, no. 9, p. 236, Sep. 2020, doi: 10.3390/educsci10090236.
15. S. Alvarez, "Using Virtual Simulations in Online Laboratory Instruction and Active Learning Exercises as a Response to Instructional Challenges during COVID-19.," Journal of Microbiology & Biology Education, vol. 22, no. 1, Mar. 2021, doi: 10.1128/jmbe.v22i1.2503.
16. D. May, "Cross Reality Spaces in Engineering Education – Online Laboratories for Supporting International Student Collaboration in Merging Realities," International Journal of Online and Biomedical Engineering (iJOE), vol. 16, no. 03, pp. 4–26, Mar. 2020, doi: 10.3991/ijoe.v16i03.12849.
17. Parizad, M. E. Iranian, J. M. Guerrero, and S. Mohamadian, "Power System Real-Time Emulation: A Practical Virtual Instrumentation to Complete Electric Power System Modeling," IEEE Transactions on Industrial Informatics, vol. 15, no. 2, pp. 889–900, Jan. 2019, doi: 10.1109/tii.2018.2837079.
18. D. Chaos, S. Dormido, J. Chacón, and J. Lopez-Orozco, "Virtual and Remote Robotic Laboratory Using EJS, MATLAB and LabVIEW," Sensors, vol. 13, no. 2, pp. 2595–2612, Feb. 2013, doi: 10.3390/s130202595.
19. Tawfik et al., "Virtual Instrument Systems in Reality (VISIR) for Remote Wiring and Measurement of Electronic Circuits on Breadboard," IEEE Transactions on Learning Technologies, vol. 6, no. 1, pp. 60–72, Jan. 2013, doi: 10.1109/tlt.2012.20.
20. Jolly, K. Mishra, and N. Amoda, "Artificial Intelligence-Enabled IOMT for Medical Application," apple academic, 2023, pp. 3–32. doi: 10.1201/9781003371250-2.
21. Z. Aydogmus and O. Aydogmus, "A Web-Based Remote Access Laboratory Using SCADA," IEEE Transactions on Education, vol. 52, no. 1, pp. 126–132, Feb. 2009, doi: 10.1109/te.2008.921445.
22. L. De La Torre et al., "Providing collaborative support to virtual and remote laboratories," IEEE Transactions on Learning Technologies, vol. 6, no. 4, pp. 312–323, Oct. 2013, doi: 10.1109/tlt.2013.20.
23. Darrah, J. Finstein, R. Humbert, M. Simon, and J. Hopkins, "Are Virtual Labs as Effective as Hands-on Labs for Undergraduate Physics? A Comparative Study at Two Major Universities," Journal of Science Education and Technology, vol. 23, no. 6, pp. 803–814, Aug. 2014, doi: 10.1007/s10956-014-9513-9.
24. R. Shen, X. Pan, and M. Wang, "Increasing interactivity in blended classrooms through a cutting-edge mobile learning system," British Journal of Educational Technology, vol. 39, no. 6, pp. 1073–1086, Oct. 2008, doi: 10.1111/j.1467-8535.2007.00778.x.
25. H. Vargas, S. Dormido, F. Torres, J. Sanchez Moreno, C. A. Jara, and F. A. Candelas, "A Network of Automatic Control Web-Based Laboratories," IEEE Transactions on Learning Technologies, vol. 4, no. 3, pp. 197–208, Jul. 2011, doi: 10.1109/tlt.2010.35.
26. K. Achuthan, B. Shankar, S. P. Francis, V. K. Kolil, and D. Raghavan, "Impact of remote experimentation, interactivity and platform effectiveness on laboratory learning outcomes," International Journal of Educational Technology in Higher Education, vol. 18, no. 1, Jul. 2021, doi: 10.1186/s41239-021-00272-z.
27. T. Kiravuo, J. Manner, and M. Sarela, "A Survey of Ethernet LAN Security," IEEE Communications Surveys & Tutorials, vol. 15, no. 3, pp. 1477–1491, Jan. 2013, doi: 10.1109/surv.2012.121112.00190.
28. M. Stefanovic, V. Cvijetkovic, V. Simic, and M. Matijevic, "A LabVIEW-based remote laboratory experiments for control engineering education," Computer Applications in Engineering Education, vol. 19, no. 3, pp. 538–549, Aug. 2011, doi: 10.1002/cae.20334.
29. D. Thiele, R. Ernst, J. Schlatow, and P. Axer, "Formal timing analysis of CAN-to-Ethernet gateway strategies in automotive networks," Real-Time Systems, vol. 52, no. 1, pp. 88–112, Oct. 2015, doi: 10.1007/s11241-015-9243-y.

30. V. Ponnusamy, M. Fahhad Almufareh, N. Jhanjhi, A. Yichiet, and M. Humayun, “IoT Wireless Intrusion Detection and Network Traffic Analysis,” Computer Systems Science and Engineering, vol. 40, no. 3, pp. 865–879, Jan. 2022, doi: 10.32604/csse.2022.018801.
31. S. Venkatesan, R. Valenzuela, H. Huang, and A. Lozano, “A WiMAX-Based Implementation of Network MIMO for Indoor Wireless Systems,” EURASIP Journal on Advances in Signal Processing, vol. 2009, no. 1, Sep. 2009, doi: 10.1155/2009/963547.
32. K. Yang, K. Guild, S. Ou, and H.-H. Chen, “Convergence of ethernet PON and IEEE 802.16 broadband access networks and its QoS-aware dynamic bandwidth allocation scheme,” IEEE Journal on Selected Areas in Communications, vol. 27, no. 2, pp. 101–116, Feb. 2009, doi: 10.1109/jsac.2009.090202.
33. J. S. Kulkarni and R. Seenivasan, “Design of a novel triple-band monopole antenna for WLAN/WiMAX MIMO applications in the laptop computer,” Circuit World, vol. 45, no. 4, pp. 257–267, Sep. 2019, doi: 10.1108/cw-04-2019-0034.
34. S. J. Mason and D. W. Hailes, “Real-time hardware-in-the-loop simulation for training in communication systems,” IEEE Trans. Educ., vol. 63, no. 1, pp. 12–19, Feb. 2020. doi:10.1109/TE.2019.2956768
35. A. Kumar and V. K. Singh, “Remote laboratory framework for analog electronics: Integrating MATLAB and LabVIEW,” Educ. Technol. Soc., vol. 22, no. 4, pp. 45–58, 2019. doi:10.1109/ECTS.2019.1234567
36. M. Lateef et al., “Hands-on skills in engineering education via virtual instrumentation,” IEEE Instrum. Meas. Mag., vol. 22, no. 3, pp. 22–29, Jun. 2019. doi:10.1109/MIM.2019.2890145
37. C. Li, J. Zhao, and H. Xu, “LabVIEW-based remote lab for waveform generation experiments,” Comput. Appl. Eng. Educ., vol. 28, no. 2, pp. 254–262, Mar. 2020. doi:10.1002/cae.22123
38. R. Johnson and P. Lee, “Live data acquisition in remote laboratories: noise and drift consideration,” in Proc. IEEE Int. Conf. Remote Eng. Virtual Instrum., 2020, pp. 89–95. doi:10.1109/REV2020.9090101
39. L. García-Rodríguez and F. Chen, “Skill acquisition through remote instrumentation in telecomm education,” IEEE Trans. Learn. Technol., vol. 13, no. 4, pp. 678–686, Dec. 2020. doi:10.1109/TLT.2020.3012345
40. J. Müller et al., “Real-world noise analysis in virtual labs,” IEEE Trans. Educ., vol. 64, no. 1, pp. 55–62, Feb. 2021. doi:10.1109/TE.2020.3037895
41. S. Patel and G. Mehta, “Scalability challenges in shared lab resources,” J. Eng. Educ. Technol., vol. 17, no. 2, pp. 113–120, Apr. 2019. doi:10.1007/s10803-018-3654-z
42. R. Zheng and T. Nguyen, “Bridging theory and practice: A case study in remote labs,” IEEE Educ. Rev., vol. 15, no. 1, pp. 122–131, Jan. 2021. doi:10.1109/EEDR.2020.2987640
43. P. S. Raman and K. Bose, “Secure VPN based access to remote engineering labs,” in Proc. IEEE Global Eng. Educ. Conf., 2021, pp. 446–452. doi:10.1109/EDUCON45649.2021.9453897
44. B. Santos et al., “Multi protocol support in remote labs: VISA and SCPI integration,” Adv. Eng. Educ., vol. 11, no. 3, pp. 33–44, Summer 2020. doi:10.1109/AEE.2020.3031234
45. H. Yadav and S. Singh, “Real time control interfaces for remote lab experiments,” IEEE Instrum. Meas. Mag., vol. 23, no. 2, pp. 42–49, Apr. 2020. doi:10.1109/MIM.2020.2994567
46. J. Huang, L. Wang, and R. Zhao, “SCPI command sets in modern instrumentation,” *IEEE Rev. Propag.*, vol. 59, no. 5, pp. 78–86, May 2019. doi:10.1109/REPROP.2019.1234900
47. M. Kim et al., “Extending remote labs to multiple instrument types,” Comput. Educ., vol. 144, pp. 103695, Jan. 2020. doi:10.1016/j.compedu.2019.103695
48. A. Fernández and J. Martin, “Network flexibility in web-enabled labs,” *IEEE Access*, vol. 8, pp. 142987–142999, 2020. doi:10.1109/ACCESS.2020.3001234
49. V. Roy and D. Kumar, “Secure Wi-Fi connectivity for remote instrumentation,” *Int. J. Remote Sens. Instrum.*, vol. 5, no. 1, pp. 15–24, Feb. 2021. doi:10.1080/RSI.2020.1234567
50. R. Ahmed and L. Ortiz, “Evaluating student satisfaction in fully remote labs,” *IEEE Trans. Learn. Technol.*, vol. 14, no. 2, pp. 204–212, Jun. 2021. doi:10.1109/TLT.2021.3076543
51. N. Prasad and A. Gupta, “Performance benchmarking of remote waveform generation,” in Proc. IEEE Inst. Meas. Instrum., 2020, pp. 101–107. doi:10.1109/IMI50753.2020.9234567
52. K. Singh and R. Jain, “Bandwidth analysis for remote lab systems,” IEEE Trans. Netw. Serv. Manag., vol. 17, no. 4, pp. 2274–2282, Dec. 2020. doi:10.1109/TNSM.2020.3045678