Development of Web Based Real Time Remote Laboratory for Teaching and Learning

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Abstract. A concept has been developed that utilizes the internet to conduct live laboratory exercises under remote condition. The idea about remote laboratory is based on Human-Computer Interaction (HCI) philosophy, controlling system and communication. The integration of these three components plays an important role in making the facility accessible and operational online. In order to realize this concept, an open-source development tool called Node-RED which links the user and the remote facility via a web interface platform has been adopted. Node-RED is a programming tool for connecting hardware, Application Programming Interface (API) and online services in various ways. The node-red dashboard allows users to carry out remote experiments. This strategy would also allow users to leverage internet resources to implement laboratory exercise by eliminating relevant time and space limitation problems. An experimental setup was created to demonstrate the above-mentioned remote laboratory model. Various types of sensors and actuators were used to replace physical interaction between the end-user and the laboratory deployment. A microcontroller was employed to process and relay the data between the host computer and the equipment. It was shown that the communication between the web and remote infrastructure was successfully established and the facility was able to be accessed and operated via the web-based interface using internet protocol. This endeavor serves as an important milestone towards realizing internet-based education particularly in science, technology and engineering streams which primarily involves physical laboratory exercise.

Keywords: Remote laboratory, distant learning, E-Learning, master-slave system, human-computer interface
1. Introduction
The classical practice of conducting an experiment in the laboratory has been changing radically by the advanced utilization of computers, electronic devices and the internet. This has given birth to a new concept of laboratory practice called "remote lab". Remote laboratory conceptual layout and educational approaches are designed to suit specific hardware and software [1]. By implementing the concept, learners are able to experience live experiments using dedicated tools from the website along with the internet connection [2].

As the facility is operated under the internet platform, it can be utilized from all over the world. It enables users to perform distant laboratories that can provide around-the-clock active accessibility via web system [3]. In the fields of engineering and science in particular, where practical laboratory experiments are crucial to improve and complete lessons in the classroom, the implementation of this concept would serve as a new paradigm in the knowledge transfer process [4]. Institutions can overcome financial obligations as well as increasing more learning opportunities [5]. Moreover, remote browser-accessible laboratories concept bear close resemblance to online learning mainly due to the fact that learners are not required to be placed with a specific piece of laboratory equipment [6]. Following this system, distant user can set predefined parameters as their requirements in the user-friendly interface and enable to view in graphical format [7]. Users are able to operate real experimental setup to do various aspects of exercises without space and time constraints since communications and all kinds of interactions between users and systems will be transmitted via web services [8] [9]. This concept is also suitable for class and training operations that encourage interactive involvement on top of the typical instructional approaches [10].

2. Methodology
2.1. Hardware Infrastructure
A simple science-based experiment has been chosen for demonstrating the above remote lab concept. The activity deals with creating and observing the color spectrum spread by a prism subjected to an artificial light source. The traditional way of carrying out this study requires the user to place a prism, light source and display screen at the appropriate angle and distance to allow the light to be refracted and fall on the screen as separate individual colors. To make it possible for the user to conduct this experiment without physical contact with the components, an experimental set-up was built, incorporating modules and functions to allow the system to be operated under remote conditions as shown in figure 1. In addition, a single degree of freedom (SOF) Internet Protocol (IP) camera was deployed to enable the user to view the facility at different angles such that the user would have the feeling of being present in the lab.

![Figure 1. System configuration layout for remote laboratory](image_url)
The system is built based on four important hardware modules namely server, microcontroller, sensor and actuator as well as the camera. The list of hardware for the current setup is given in Table 1.

| Module               | Instrument                                      |
|----------------------|-------------------------------------------------|
| Server               | Raspberry Pi                                    |
| Microcontroller      | Arduino UNO                                     |
| Sensor and actuator  | Temperature and relative humidity sensors,      |
|                      | Stepper motors and DC motors                    |
| Camera               | TP-Link IP camera model 250                     |

2.2. Specific Web System
An open-source tool, Node-RED was adopted to develop the web system. Node-RED is a software development tool for connecting equipment, APIs and internet services in convenient and interactive ways. It offers a browser-based editor (Figure 2) that makes it simple to connect different modules together using a broad variety of nodes in the palette that can be deployed in a single click at run time.

Figure 2. Node-RED web-based editor

Further, this software can also be used to incorporate JavaScript functions for flows of bits and configuring nodes to accomplish signal communication from the web environment to the controller as shown in Figure 3.

Figure 3. Node-RED JavaScript
The backend programming will be translated into a user-friendly dashboard shown in Figure 4 which allows effective user-hardware interface. After deploying all flows and nodes successfully, all control interfaces such as switches, buttons and toggle-buttons would appear in the dashboard during compilation. Thus, the user would only be interacting via the dashboard from a web browser to take control over modules in the laboratory.

![Node-RED dashboard](image)

**Figure 4.** Node-RED dashboard

### 2.3. User Access Functionality

In order to establish a secure laboratory operation, an access system has to be developed which allows authorized users to control the facility. In the present work, a web-based access module has been developed which prompts the user to register and specify the access details prior to being allowed to communicate with the system. To systematically enable this access functionality, a system called ‘client-host’ swap mode was introduced. An authentication method was formed within the system to ensure the safety of the server-side from malicious threats. This is accomplished by denying connectivity protocol from unauthorized users. At the heart of the process, two accounts under administrator and user profiles will be launched as the user enters the website. The administrator has the full right to take control over the user profiles. The user can only be granted access upon verification by the admin. Further, under the current access protocol design, the admin has the option to delete user access requests as shown in Figure 5. This would give the admin more control on monitoring the laboratory condition by tracking the user’s history.

![Admin Panel](image)

**Figure 5.** Admin Panel
To gain access to the remote facility, users must first apply via the registration site as shown in Figure 6. Upon completing the form on the web page which includes specifying their id and password, the users will be directed to a second window layer that prompts them to insert their log in details (Figure 7). All this information will be channeled to the admin portal for verification and approval before they are granted secure access to the facility.

**Figure 6. User Registration panel**

![User Registration panel](image)

**Figure 7. User Login Page**

![User Login Page](image)

3. Result and Discussion

The complete layout of the overall system encompassing the hardware tools and the communicative interface is illustrated in Figure 8. In detail, the microcontroller is responsible for transmitting output signals to operate the actuation devices as well as receiving information from the sensor modules to be displayed in the web interface. Users send a specific command to interact with the facility by pressing buttons or switches from the Node-RED interface. As the microcontroller used in the current project is a serial device that communicates via a USB serial connection, the Serial IN and OUT nodes are used within the software to synchronize the data packet going in and out from the controller. This phase is critical since any missing information during this data communication would be detrimental to the execution of each task. Upon
successful recognition between the software and hardware pins, the triggering signal will be securely transmitted via the Raspberry PI server for performing the command respectively. Modules like motors connected to the controller will move following specific signals. On the other hand, a specific IP address is released by the access point for the IP camera to view the facility online. The flow of communication between the facility and the user is given in Figure 9.

**Figure 8.** Setup for light spectrum

**Figure 9.** Communication flow between the user and lab facility

In addition, to enable more freedom for the user to view the facility and pinpoint the location of interest during an experiment, a motor has been mounted on the camera which enables 180degree rotation covering the entire lab infrastructure as Shown in Figure 10. The user would benefit from getting more realistic vision mobility that resembles the user presence in the lab.
4. Conclusion
An innovative framework for remote laboratory based on open source development tools has been developed. The main feature of the system is that, it can be accessed by the user from a browser-based system hosted in a special computer that is connected to various hardware modules within the experimental setup to perform laboratory exercises remotely. The framework was developed using open source web based software called “Node-RED” which serves to connect the user and the remote facility under web platform. This tool operates by relaying the command from the user towards the server and controller which translates into a sequence of signals to operate the sensors and actuators to accomplish remote interaction. In addition, a dashboard is provided by Node-RED as a web-interface to establish communication between the client and the hardware. An experimental set-up was established to demonstrate the concept. It was shown that the facility was successfully operated remotely using the above interface from a web browser. In brief, the project established the sustainability of converting the current manual laboratory facility into a remote system that enables the user to conduct experiments under a remote management protocol using internet communication technology.

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