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Remote laboratory: using Internet-of-Things (IoT) for E-learning

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***Abstract* – In order to equip engineering E-learners with realistic hands-on laboratory experience, remote access to an operating lab may be provided. Such an access can be implemented using live video streaming from a physical lab coupled with IoT telemetry and telecontrol.**

The progress of an ongoing remote laboratory project is presented. Three different video streaming solutions were compared side-by-side, the back end electronic architecture was fully developed and the most notable observations are now reported.

Keywords – remote laboratory, E-learning, Internet-of-Things, engineering education, low cost live video streaming.

I. INTRODUCTION

The relentless increase in human knowledge, together with the steady advances in technology, call for continuous improvements in the provision of higher education, especially in engineering, in order to make the best use of resources and keep the learners engaged with up-to-date educational activities. Modern online technologies provide, *i.a.*, rapid and inexpensive access to a range of useful learning resources such as vendor technical documentation and application notes, topical tutorials, forum discussions, educational videos and even complete massive open online courses (MOOC). E-learning aims to use the latest technological developments for reducing educational costs and widening participation. In the spirit of this goal, we have worked to combine the Internet-of-Things (IoT) and live video streaming technologies to create the 'presence effect' of an electronics engineering lab over the Internet.

It is important to differentiate between a virtual (i.e. simulated) and a remote (i.e. physical) laboratory environment. The former requires the development of one-off virtual reality or simulation software. Distribution and maintenance costs are negligible, but the development itself can be very costly if it is to feel realistic and engage the learners. By contrast, a remote lab gives online access to actual physical instruments and/or actuators and thus requires session scheduling and some maintenance. Some educational projects try to combine the two abovementioned approaches. One notable example is the India-wide Virtual Lab project [1], which, being mostly virtual, does include some provisions for 'remotely triggering an experiment in an actual lab'.

Wikipedia hosts a list of past and ongoing remote lab projects [2], although some of them no longer have an online presence. For example, the website for the Labshare project, which received AUD 3.8 million from the Australian government over 2009-2011 [3], is no longer being updated. We assume that the project could not continue because it was not possible to find long-term financing for its maintenance after the initial funding was used up.

Some of the present authors have been involved in the remote laboratory access project [4] that was accessed from national and international locations on numerous occasions and demonstrated at an IEEE profile conference [5]. It was dedicated to measuring the volt-ampere characteristics of a semiconductor diode. It was developed using an IP camera, which provided a live video stream, and an embedded web server to control the diode's voltage. Despite being a successful feasibility study, this project identified some serious usability shortcomings. These included:

- uneven natural lighting resulted in noticeable shadows and differences in image quality, depending on the time of the day [5, fig.4];
- it was impossible to host the setup at the university site because the corporate firewall for security reasons was configured to block all the external access attempts;
- the need to use two separate browsers (one for viewing the video stream and the other for control of the test rig) was inconvenient and resulted in noticeable lags between the diode's voltage changes and video response to these;
- national access was relatively smooth, but the international connections were smooth for twenty or so seconds, after which the learners' browsers needed to be restarted.

These issues were solvable in principle. For example, the last three could be addressed by employing a dedicated server with a video capture capability outside of the university's network. However, they could not be resolved within the remote laboratory's targeted budget.

This remote laboratory access project was restarted last year at Sheffield Hallam University, after the increased availability of single board computers (SBCs) such as Raspberry Pi and its competitors could provide decent computing, networking and video capture capabilities at low cost. Teaching enhancement funding was used to procure suitable hardware for the project. Undergraduate students of computer systems engineering were tasked to set up and test several alternatives for live video streaming as part of their second year project module. At this stage we aimed to develop the back end IoT electronic architecture and compare different ways of streaming live video. This paper presents a snapshot of our development results and findings to date.

II. Why the Volt-Ampere Characteristic of a Semiconductor Diode?

The laboratory experiment, accessed remotely, must satisfy various criteria in order to be genuinely useful to the learners. First, it should fit well into the universally-accepted curriculum of a relevant course. Second, it should use common industry-standard equipment to achieve the presence effect. Third, it should have a limited number of sensors and actuators that can be easily controlled and/or read by the back end electronics. This list can be expanded by adding various cost (development, maintenance, running), pedagogical, safety and other requirements. We selected measurement of the volt-ampere characteristic of a semiconductor diode for the following educational reasons:

- this is likely the first semiconductor device that electrical and electronics students encounter in their studies;
- measurements require two digital multimeters, which only a few learners have access to for conducting such an experiment on their own;
- there are many types of semiconductor diodes which have significant differences in their characteristics (Si and Ge based power and small signal standard diodes; Schottky, Zener, tunnel and Gunn diodes to name a few, some of which are difficult to source at low cost).

There are also some economic reasons:

- the setup requires only two standard multimeters and a regulated variable voltage power supply;
- automation enables keeping the diode's current within safe limits, eliminating the possibility of blowing it up during experimentation or by connecting it incorrectly, thus lowering maintenance costs and keeping the learner safe.

III. What Are the Objectives of the Present Developoment?

We plan to develop and deploy a remote access solution for an existing undergraduate lab experiment: measurement of a diode's volt-ampere characteristic. The students will be encouraged to use the online version or asked to use both and describe their user experiences. The learners' feedback will be collected and analysed in order to enhance the hardware/software/firmware provisions and lab sheets. Most of the developments are to be conducted as part of the academic assignments for various project modules.

IV. Low Cost Options for Streaming Live Video and Outcomes of Their Trials

We originally anticipated that using a Raspberry Pi-like SBC, which is built around a complete system-on-chip integrated circuit to reduce costs, would be the only feasible option for the project. Raspberry Pi seems to be better supported than its alternatives, and the latest Raspberry Pi 3 is the most capable SBC of the RPi family at present. However, a recently-launched Intel Compute Stick (a complete small factor PC with an HDMI output) [6] made an unexpected contender to most ARM-based SBCs, and its inexpensive alternative MeeGoPad T07 [7] was bought as an alternative to RPi. It was used on Windows 10 to explore non-Linux options for the project. Affordable video capture options at present include:

- IP cameras (complete video streaming solution which only requires a network connection to operate; built-in protocols allow bypassing simple Internet firewalls, which is a security concern but could simplify access for this project; highest cost; was used in the previous development);
- web cameras (connected via USB to a host computer which should feature a streaming video web server; moderate cost; could be used for both computing platforms);
- cameras which connect directly to the dedicated SBC pins (the lowest cost if available; only the RPi has this option available).

Out of the five usable SBC/video capture combinations, the following three were explored by separate groups of students (fig. 1):

- Raspberry Pi + IP camera;
- Raspberry Pi + RPi camera;
- MeeGoPad T07 + web camera.

The students' trials resulted in the following findings. All the groups managed to enable video streaming over the same LAN. A wired LAN connection was found to be much better than the WiFi one, even for the MeeGoPad that was connected to a wired LAN via an additional USB-to-Ethernet bridge. (It should be noted that the same connection is internally used in RPi as well.) The MeeGoPad demonstrated the best performance in terms of image quality and responsiveness. Access to the firewalled streaming video server via a virtual private network was found to be cumbersome, and too many access rights had to be given to an occasional user. When NGINX and Apache web servers were compared against the RPi with the RPi camera, the former demonstrated much better performance. Custom web pages, developed to display the video stream with some user controls (Fig.1), required combined use of HTML, CSS and JavaScript.

V. The Back End Electronic Architecture

The architecture was devised to address the following principal requirements:

- parts to be used must be mass-produced, inexpensive, easily obtainable and swappable;
- they must conform to relevant safety standards, operate unattended and have either low power

consumption or be capable of operation in low power mode to save on running costs;

- the number of custom devices should be kept to a minimum.

The setup is to be powered from a standard laptop-like power supply. These are inexpensive, can safely be plugged into the mains for a long time, and waste little power in stand-by mode. Laptop power supplies output a fixed-value, fixed-polarity voltage of around 20V. To extend the applicable voltage range and enable its smooth control from negative to positive values without noticeable cross-over distortion, a boost converter with fixed output voltage will power two high-voltage operating amplifiers (opamps). Such converters are available from many manufacturers, provide reasonable conversion efficiencies and keep their set output voltages reasonably stable across a range of temperatures.

The output voltage of the first opamp, used as the voltage follower, is fixed at the mid-point of its supply voltage by connecting its non-inverting input to a resistive potential divider, which halves the power supply voltage to create the virtual ground. The second opamp, used as an inverting amplifier with a suitable gain, has its non-inverting input connected to the output of the first opamp, and its non-inverting input connected to the variable voltage source, which is controlled over the Internet. The diode in question is to be connected between the opamps' outputs (bridge configuration), and the voltage across it will always be equal to the remotely set voltage times the second opamp gain, irrespective of any supply voltage fluctuations. Dual channel high-voltage opamp KA334 with built-in thermal shutdown was selected for added assurance of safe unattended operation. The complete custom electronic circuit requires fewer than 10 electronic components in total.

The previous development used a single hardwired diode, which limited application of the setup to a single experiment per learner. For this project, an additional board will be used to select one diode out of the available set either at random (assessment mode) or by user selection (exploration mode). A standard multi-channel electromechanical relay board is to be used for this purpose. The diodes will be connected to the relay board using a dummy board with screw terminals to enable quick replacement of the tested parts, which may include other non-linear two-terminal components such as resettable fuses or voltage surge protectors. If an RPi with its exposed pins is used as the web server, a standard Pi HAT input/output board can control the relay board, and a standard Pi HAT DAC board can control the voltage applied to the diode. If a MeeGoPad is used as the server, there will be a need for an additional microcontroller board connected to it via USB. An Arduino-compatible board with an additional DAC shield seems adequate for this task.

VI. Further Project Goals

This summer the back end architecture will be implemented and tested. At the start of the 2017/18 academic year, new project students will be tasked to integrate both the video feed and controls into one web page. If possible, we will find solutions for connecting to the remote lab from outside the corporate firewall, and road test the performance of the remote lab with the view to introducing the lab to the curriculum in the academic year of 2018/19.

VII. Conclusions

Although the project is still far from being completed, we consider the following results most useful for further development:

- the performance of the most recent Raspberry Pi 3 for live video streaming was inferior to that of the MeeGoPad with a web camera;

- live video streaming using wired LAN connections significantly outperformed those using built-in WiFi adapters;

- design of a modern responsive front end for the remote lab will necessarily require some expertise in a combined use of HTML, CSS and JavaScript;

- electronic back end architecture was fully designed and will be implemented over the summer to be used along with next year's student project activities;

- a solution for hosting the remote lab behind a corporate firewall is yet to be found.

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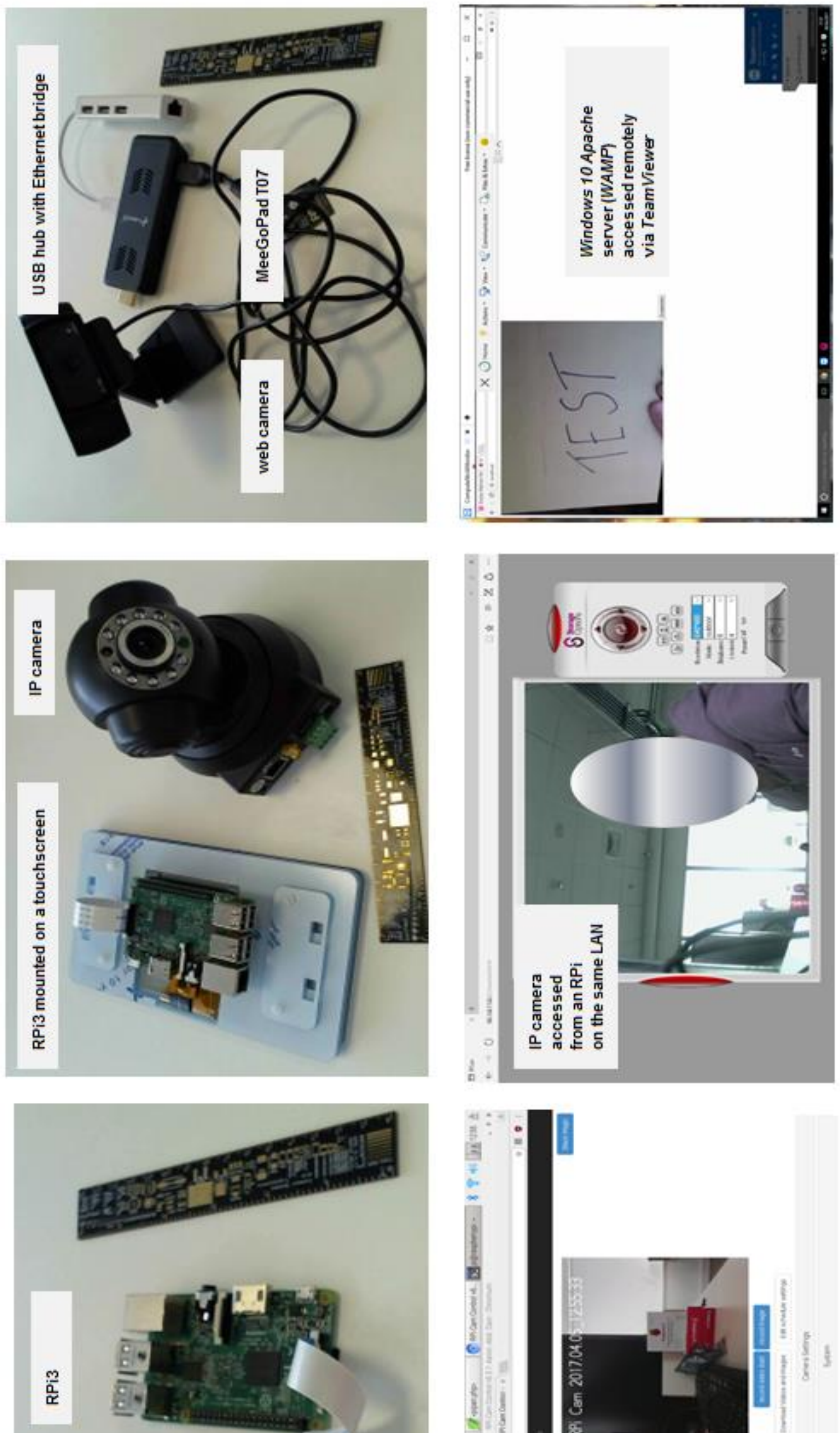

Fig.1. Hardware used by different student groups (top row) and corresponding screenshots (bottom row)