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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, a remote access to an operating lab should 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 various video streaming solutions were compared side-by-side, the back end electronic architecture was fully developed and most notable observations are reported.

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

I. INTRODUCTION

The relentless increase in human knowledge and steady technology advances call for continuous improvements of higher educational provisions, especially in engineering, in order to make the best use of the resources available and keep student learning engaging and up-to-date. Modern online technologies, *i.a.*, do provide rapid and inexpensive access to a range of novel useful learning resources like vendor technical documentation and application notes, topical tutorials, forum discussions, educational videos and even complete massive open online courses (MOOC). E-learning aims at using the recent technological developments for reducing the educational costs and widening participation. We work towards combining the Internet-of-Things (IoT) and live video streaming technologies for creating the "presence effect" of an electronic engineering lab over the Internet.

It is important to discriminate between virtual (i.e. simulators) and remote (i.e. physical) laboratory environments. The former require one off software development then negligible distribution and maintenance costs but the development could be very costly to feel realistic and engage the learners. In turn, the remote labs give online access to common physical instruments and/or actuators and require session scheduling and some maintenance. Some educational projects try to combine the two above mentioned approaches. Most 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], some of which no longer have any online presence though. For example, the website for the Labshare project, which received 3.8M AUD from the Australian government over 2009-2011 [3], is no longer updated. We assume that the project could not continue because it was not possible to find long term financial solution for its maintenance when the initial funding have been used up.

Some of the present authors have been involved in the remote laboratory access project [4] that was successfully accessed from national and international locations and demonstrated at an IEEE profile conference [5]. It was related to measuring volt-ampere characteristic of a semiconductor diode. It was developed using an IP camera, which provided 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, including

- uneven natural lighting resulted in notable 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 blocked all the external access attempts for security reasons;
- using two separate browsers (one for viewing and the other for control) was inconvenient and resulted in notable lags between the two;
- national access was relatively smooth but the international one was smooth for about twenty or so seconds only after which the browser needed to be restarted.

These issues, despite being solvable in principle (for example, the last three could be addressed by employing a dedicated internet server with a video capture capability outside of the university's network), could not be resolved within the targeted remote laboratory budget.

This remote laboratory access project was restarted last year at the Sheffield Hallam University as increasing availability of low cost single board computers (SBCs) like Raspberry Pi and its competitors, which provide decent computing, networking and video capture capabilities at low cost, could address the cost constraints. Teaching enhancement funding was used to procure suitable hardware for the project. Undergraduate students, studying computers systems engineering, were tasked to set up and test several alternatives for live video streaming as the 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 the snapshot of our development results and findings to date.

II. Why 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 the relevant course. Second, it should use common industry-standard equipment to achieve the presence effect. Third, it should have limited number of sensors and actuators that can be easily controlled and/or read by the back end electronics. This list can go on and on by adding various cost (development, maintenance, running), pedagogical, safety and other requirements. We selected measurement of the volt-ampere characteristic of a semiconductor diode because of the following educational reasons:

- this is likely the first semiconductor device that electrical and electronic students encounter in their studies;
- measurements require two digital multimeters that not many learners have readily available for conducting such an experiment on their own;
- there are many types of the semiconductor diodes featuring 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 these diodes are difficult to source at low cost);

and the following economic reasons:

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

III. What are the objectives of the present developoments?

We aim to develop and deploy 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 reflect on 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 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, that are built around a complete system-on-chip integrated circuit to reduce costs, would be the only viable option for the project. Raspberry Pi itself seems to be best supported compared to 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 mostly ARM based SBCs, and its inexpensive alternative MeeGoPad T07 [7] was bought as an alternative to RPi for the project. 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 required a network connection to operate; built in protocols allowed 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 had this option available).

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

- Raspberry Pi + IP camera,
- Raspberry Pi + Pi camera,
- MeeGoPad T07 + web camera.

Student developments resulted in the following outcomes. All the groups managed to enable video streaming over the same LAN. Wired LAN connection was found 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 connections is internally used in RPi as well.) The MeeGoPad demonstrated the best performance in terms of the image quality and responsiveness. Access to the firewalled streaming video server via virtual private network was found cumbersome, and too much access rights were to be given to an occasional user. When nginx and Apache web servers were compared side-by-side the RPi with the RPi camera, the former demonstrated much better performance. Custom web pages, created to display the video stream with some user controls, were developed using HTML, CSS and Javascript (fig.1).

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, have either low power consumption or be capable of operation in low power mode to save on the

running costs;
- number of custom devices should be kept to minimum.

The setup is to be powered from a standard laptop-like power supply. They are inexpensive, can safely be plugged into mains for long times, and waste little power in stand-by when their intended load is off. A typical output voltage of these devices is kept around 20V, which seems insufficient for measuring operating currents of reverse biased diodes. Laptop power supplies output a fixed value fixed polarity voltage.

To extend the applicable voltage range and enable its smooth control from negative to positive values without any noticeable cross over distortions, a boost converter with the 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, controllable via 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 the remotely set voltage times the second opamp gain irrespectively of any supply voltage fluctuations. Dual channel high-voltage opamp KA334 with built in thermal shutdown was selected for this only custom electronic circuit that requires less 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 a learner only. This time 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 like 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 a server, there will be a need for an additional microcontroller board connected to it via USB. Some Arduino compatible board with an additional 16 bits ADC shield seems adequate for this task.

VI. Further project progression

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

Conclusions

Although the project is far from being completed at the moment, we consider the following findings most useful for further developments:

- despite availability of numerous similar projects and various open source software, the performance of the most recent Raspberry Pi 3 for live video streaming was inferior to that of the MeeGoPad despite availability of a dedicated industry standard MIPI camera serial port on board;
- live video streaming using wired LAN connections significantly outperformed these using built in WiFi adapters;
- design of a modern responsive user front end for the remote lab will necessarily require 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 the next year's student project activities;
- an adequate solution for hosting the remote lab behind a corporate firewall is yet to be found.

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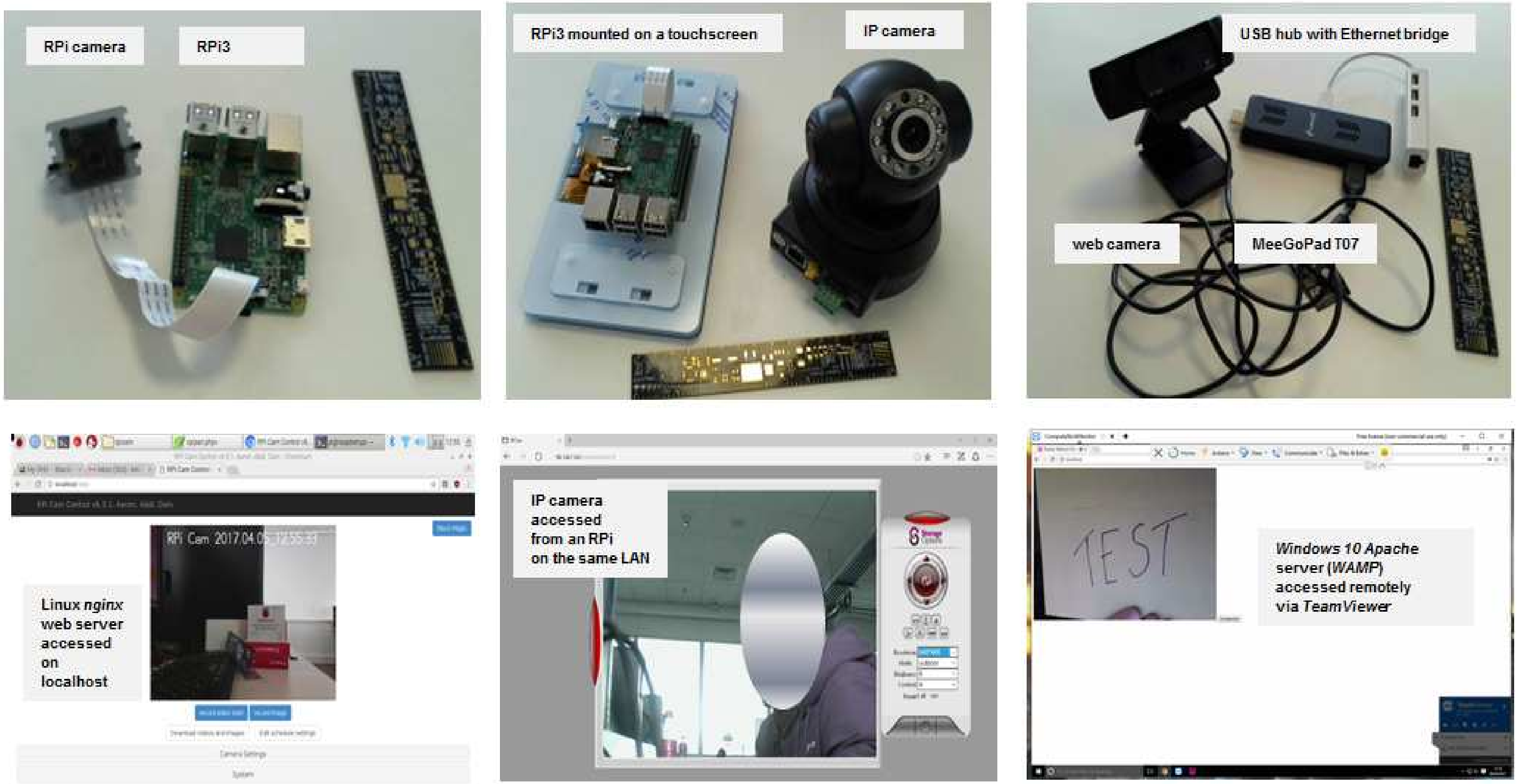

Fig.1. Hardware used by different student groups (top row) and corresponding screenshots (bottom row)