Expanding the Frontiers of Engineering Education in Open and Distance Learning by an Online Laboratory Platform

W. A. Rasika Nandana*
Department of Mechanical Engineering, The Open University of Sri Lanka, Sri Lanka

W. R. de Mel and H.D.N.S. Priyankara
Department of Mechanical Engineering, The Open University of Sri Lanka, Sri Lanka

Abstract

At present, people have a tendency to carry out higher education in a distance mode due to their busy lifestyles. However, open and distance learning (ODL) educational organizations encounter difficulties when delivering laboratory experiments. This paper presents the development of an online laboratory platform as a solution. It can be used to deliver laboratory experiments, using electronic components and instruments such as a signal generator and oscilloscope. Students are able to perform experimental tasks remotely utilizing real equipment and components. The system users can view laboratory environments via a camera which provides a sense of reality. The platform provides facilities to customize and rebuild the laboratory experiments according to the requirements of the organization. It can also be utilized as a useful educational tool to acquire pre-experience before entering the real laboratory. The statistical analysis shows no significant difference between the face-to-face laboratory (FFL) and online remote laboratory (ORL) experimental results within a 95% confidence level. The system can enhance the existing open and distance learning system by sharing the resources in a flexible manner. This system reduces the difficulties that distance learning students encounter when participating in FFL sessions. It also reduces the number of FFL sessions and is helpful to working students. One of the main objectives of ODL is to provide a learning environment for those who missed the opportunity for higher education for a variety of reasons. This system will help to achieve this objective.

Keywords: online laboratory platform, online remote laboratory, open distance learning, laboratory experiments

* Corresponding author. Email: rasikanandana@gmail.com

Introduction

Open distance learning in the Open University of Sri Lanka

Open distance learning is an educational mode that employs pedagogical, technological and instructional design strategies to promote a blended learning environment for those who have missed the opportunity for higher education on account of employment, time, space, income and other obstacles (The Open University of Sri Lanka, 2014a). Face-to-face laboratory sessions in the present ODL systems do not help very much to achieve the above ODL objectives. In the Open University of Sri Lanka (OUSL), most of the laboratory facilities are available only at the central campus in Colombo (The Open University of Sri Lanka, 2014b). Vidanapathirana (2010) points out that:

> At a time when the Colombo regional centre is already saturated in terms of physical space and facilities, the OUSL should extend its outreach to those areas and regions that remain under-served for years. Currently, about 58 percent of the OUSL's admissions are restricted to the Western Province which shares only 34 percent of the country's population. If one removes the 'language', 'management' and 'education' programmes, this will become an enormous 75 percent. This, fundamentally, means that we have failed to become an ODL institution in the true sense of the word.

According to Ismail (1997), variables related to distance from the home to the institution have an influence on students drop-out from the OUSL. Students, especially employees, face many problems when attending FFL sessions. If students are unable to attend a relevant session, the University finds it pretty much impossible to rearrange a new session and they have to re-register. This is a common problem in ODL institutions, not only in the OUSL. Fozdar, Kumar and Kannan (2006) found that the cost associated with attending laboratory courses was the second highest personal reason (38.24%) for withdrawal from the Bachelor of Science programme of the Indira Gandhi National Open University, India. They mentioned that, if the student does not live in the same city as the study centre, the cost of staying for a week or more is often very difficult, and in some cases completely impossible. That study identified nine main reasons for student dropouts, among which 52.94% mentioned that they had difficulties in attending laboratory sessions due to distance. Hence, performing laboratory experiments is a major obstruction when delivering engineering and science curricula in a distance mode.

Therefore, an online remote laboratory was developed to offer real laboratory experiments via the Internet. Using this system, students are able to do experiments at flexible times and also those in remote locations can perform laboratory experiments without coming to the central campus. The system is also capable of enhancing the existing open and distance learning system by sharing the resources within and among universities in a flexible manner.

Remote laboratory systems

Remote laboratories can be defined as network-based laboratories where the user and the real laboratory equipment are geographically separated and where telecommunication technologies are used to give users access to laboratory equipment (Khamis et al., 2003a).

The linear cascade laboratory facility is a remote laboratory of the Department of Energy Technology at the Royal Institute of Technology (KTH), Sweden. The key features of this remote laboratory is live streaming video which allows direct observation of experiments, remote control and data acquisition, instant feedback and suggestions during laboratory operations, online communication and online documentation (Navarathna et al., 2003). However, the KTH remote laboratory is specially designed for a specific experiment only, and is difficult to customize. Also that laboratory is not available on a 24-hour basis due to a demonstrator having to be present at the real laboratory when performing experiments.

Most of the present remote laboratories use expensive data acquisition cards and devices (Osentoski et al., 2012); and, therefore, high development and installation costs are one of the major drawback of existing remote laboratories. However, this online remote laboratory (ORL) system does not use expensive data acquisition devices and the development cost is very low. In the ORL system, special instruments are not used and existing instruments available at the OUSL laboratories are employed. Therefore, this system is very suitable for the universities/educational institute in developing countries.

Online Remote Laboratory

ORL system architecture

The architecture of the ORL system is illustrated in Figure 1. Experiment boards were developed according to relevant experiments, with allocating connections for relevant input, output and test points.

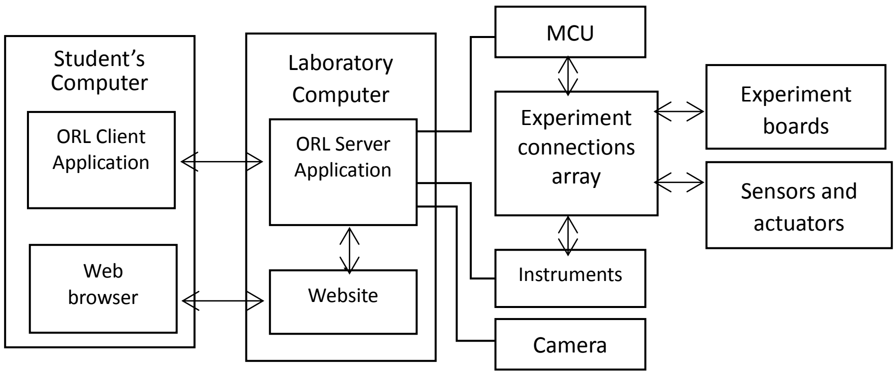

Figure 1 The ORL system architecture

The connection points were connected to the connection array which is controlled by a microcontroller (MCU). All measuring equipment and instruments were connected to experiment boards via the connection array and also to the server using RS232, USB or GPIB interfaces. MCU was connected to the server via a USB (universal serial bus) or RS232 communication bus (Bates, 2011).

The client application transmits data to the server application and vice-versa using TCP/IP protocol according to the user's interaction with the client application (Fall & Stevens, 2011). The MCU makes connections to the experiment boards according to the given commands by the ORL server software. The use of MCU in this system provides easy customizability and future expandability not only to change connections, but also to control actuators.

Instrument control

Most of the modern instruments are compatible with Standard Commands for Programmable Instrument (SCPI) standard (IVI foundation, 2012). The SCPI specification expands the IEEE 488.2 common command set by defining a single, comprehensive command set suitable for all instruments. Therefore, when connecting an oscilloscope to the ORL system, any SCPI compatible oscilloscope can be connected without changing the system.

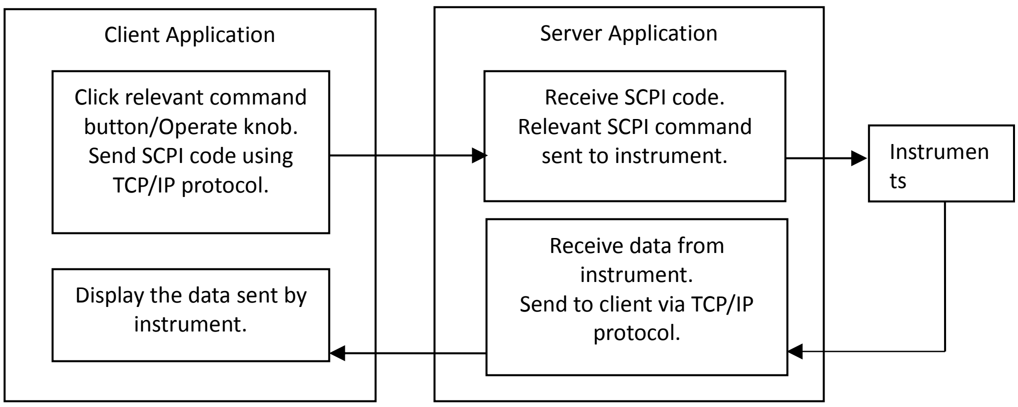

Figure 2 Instrument control architecture of the ORL system

Software design

Software was used to communicate between the server (laboratory) computer, client (student) computer, MCU and instruments. Students are able to log on to the ORL website by accessing the URL and downloading the ORL client software. That software is used to perform the experiments remotely and the commands given by the students are passed to the ORL server via the TCP/IP protocol. The website provides facilities to download learning materials and view the laboratory through the camera to get a feeling of the real laboratory environment.

Prototype ORL experiment

The bipolar junction transistor amplifier experiment was selected as the prototype ORL experiment.

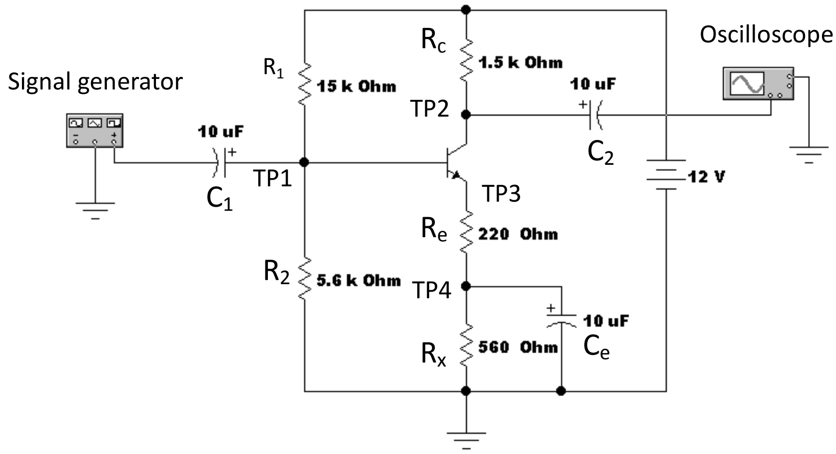

Figure 3 Prototype ORL experiment

According to the selected experiment, the given tasks are:

- Measure voltages at the test points TP1, TP2, TP3, TP4 as shown in Figure 3.
- Provide specific input signals from the signal generator and monitor input/output signals by a dual channel oscilloscope and find the AC gain.
- Measure the maximum output swing.
- Monitor the output voltage and test point voltages by disconnecting the C_e capacitor.

ORL client application

The prototype ORL client application is illustrated in Figure 4. Users are able to change the instrument connections to relevant test points and also change the input signal and measure the output signal.

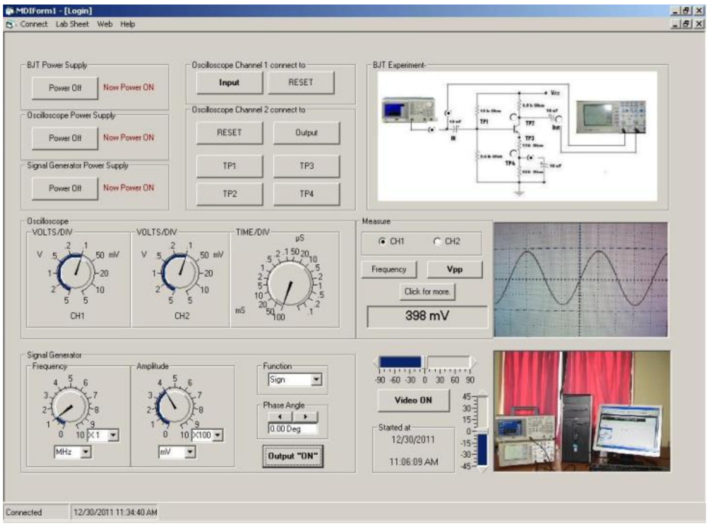

Figure 4 Online remote laboratory client application

Students have the facility to book an ORL session via the ORL client software as shown in Figure 5.

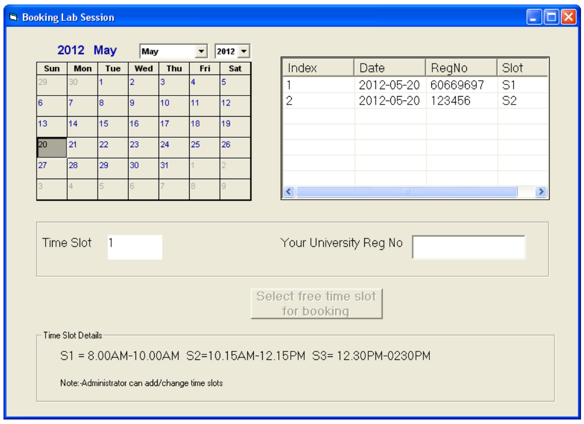

Figure 5 ORL session booking dialog box

Students have an opportunity to save the observed results on the server. Finally, the system automatically generate an observation sheet according to the saved data and sends it to the lecturer via e-mail with a copy to the student's email as shown in Figure 6.

From: OnlineRemoteLab OUSL [mailto:ouslorl@gmail.com]
Sent: 26 March 2012 15:06
To: rasika.ou@gmail.com
Cc: rasikanandana@gmail.com
Subject: Online Remote Lab Observations Sheet - RegNo: 60669697 2012-03-26

Online Remote Lab - MEX 3272 BJT Amplifier Experiment Observation Sheet

Input_Volt	Input_Frequency	Ce_ Connected?	Test_Point:	Channel	Variable	Value
0.2V	5kHz	Y	IP	CH1	Vpp	0.21V
0.2V	5kHz	Y	OP	CH2	Vpp	0.81V
0.5V	5kHz	Y	OP	CH2	Vpp	1.86V
1.0V	5kHz	Y	OP	CH2	Vpp	3.84V
1.5V	5kHz	Y	OP	CH2	Vpp	5.62V
2.7V	5kHz	Y	TP2	CH2	Vpp	8.59V
2.0V	5kHz	Y	OP	CH2	Vpp	7.12V
2.5V	5kHz	Y	OP	CH2	Vpp	8.56V
1.0V	5kHz	Y	TP1	CH2	Vrms	3.28V
1.0V	5kHz	Y	TP2	CH2	Vrms	8.18V
1.0V	5kHz	Y	TP3	CH2	Vrms	2.63V
1.0V	5kHz	Y	TP4	CH2	Vrms	1.70V
1.0V	5kHz	Y	IP	CH1	Frequency	5.11kHz
1.0V	5kHz	Y	OP	CH2	Frequency	5.14kHz
0.5V	5kHz	N	OP	CH2	Vpp	1.20V
1.0V	5kHz	N	OP	CH2	Vpp	1.80V

Name: W.A.Rasika Nandana
Reg No: 60669697
Email: rasikanandana@gmail.com

This is automatically generated email by ORL system – http://ouslorl.sytes.net

Figure 6 The generated observation sheet

System Validation and Limitations

Communication validation

The ORL server and client applications exchange data between each other. The theoretical transmission time to pass a command to the ORL system is calculated as 0.00923 seconds.

Khamis, Rodriguez and Salichs (2003b) stated that a maximum time delay of 1 second is usually taken as a reference for operability in remote control systems — therefore, the ORL delay is acceptable. The time between two events can be controlled by ORL software and it is not allowed to give the next command before the first one is processed. Therefore, the maximum amount of data that can be transmitted on one occasion is calculated as 12.8 kB.

However, that acceptable time delay can be obtained without considering a video transmission of the laboratory camera and it can be done via a separate network connection to avoid the impact on the command transmission.

According to the test results obtained when the ORL server was running while receiving and processing user commands and oscilloscope waveform transmission, 11 kB data is on average transmitted within one second. Therefore, that amount of data can be transmitted within an acceptable range.

The average upload speed was observed as 160 kbps when the ORL server transmitted experiment data with oscilloscope waveform, and the average upload speed was 440 kbps when transmitting camera video.

On average, the client side performs at 9 kB per second data transmission — within the acceptable range as calculated previously. The client network utilization was observed as 42% when the client uses the low speed (115 kbps) data communication link. More than that data communication speed is available in most of the remote locations of Sri

Lanka and, therefore, students in remote areas will not face much of a problem regarding communication speed.

On average, the single SCPI command has 30 bytes and the maximum size should be 100 bytes (Gossenmetrawatt, 2014). If both command and response use 100 bytes, then the transmission time will be 27.7 ms — an acceptable communication speed.

According to the calculations and experimental values, the selected network connections are within an acceptable range, and if the server network connection is replaced with a high bandwidth connection, the transmission performances of the ORL system can be enhanced.

Experimental observations validation

The BJT amplifier experiment was conducted by using both FFL and ORL methods and comparing the observed results. This comparison helps ratification of the ORL method.

Selected waveforms from FFL and ORL observations are illustrated in Figure 7 and Figure 8 respectively, for input 5 kHz, 2.5 V.

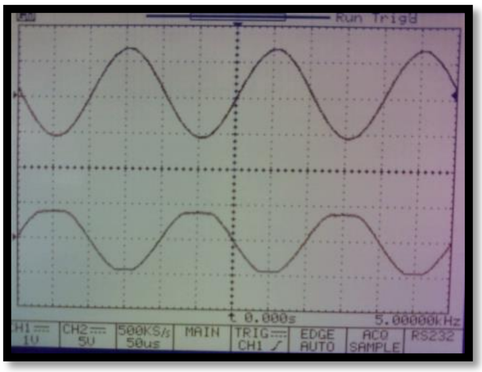

Figure 7 FFL

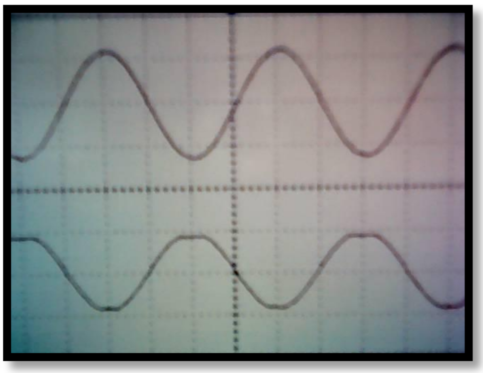

Figure 8 ORL

The observation results were obtained by conducting ten experiments using the FFL and ten experiments using the ORL system.

A t-test was used for comparison of the FFL and ORL population means in order to clarify whether there was any significant difference between the two population means (Huitema, 2011). The FFL experiment results are mentioned as sample 1 and the ORL experiment results as sample 2.

The null hypothesis, denoted as H_0, stated that there is no significant difference between the FFL and ORL experiment results as equation 3.1, and the alternate hypothesis as equation 3.2.

$H_0 : \mu_1 = \mu_2$ 3.1
$H_1 : \mu_1 \neq \mu_2$ 3.2

The t-score for observations of the test point 1 was calculated as below.

$$\overline{x_1} = 3.313 \qquad \overline{x_2} = 3.254$$

$$S_1 = \sqrt{\frac{0.03141}{10-1}} = 0.05908 \qquad S_2 = \sqrt{\frac{0.05804}{10-1}} = 0.08030$$

$$S_P^2 = \frac{(10-1)0.05908^2 + (10-1)0.0803^2}{(10+10-2)} = 0.004969$$

$$t = \frac{3.313 - 3.254}{\sqrt{0.004969(\frac{1}{10} + \frac{1}{10})}} = 1.87147$$

The critical t-score from the t-statistic table for a two-tailed test with α = 0.05 (95% confidence) and df = ($n_1 + n_1$ -2) = 18 is given as 2.101.

Since the calculated value of t = 1.87147 is smaller than the critical t value of 2.101, the null hypothesis was accepted.

According to the above calculations, there was no significant difference between the FFL and ORL experiment results in respect of the test point 1. Table 1 and Table 2 illustrate the t-score values for all the experimental results.

Table 1 Statistical analysis of FFL and ORL test point results

	Test point	Standard deviation of the FFL results	Standard deviation of the ORL results	t-score
1	TP1	0.05908	0.08030	1.87147
2	TP2	0.08230	0.10472	0.16620
3	TP3	0.06132	0.08030	1.94045
4	TP4	0.06110	0.07616	-0.32388

Table 2 Statistical analysis of FFL and ORL output results

	Input (Vpp)	t-score (with C_e Capacitor)	t-score (without C_e Capacitor)
1	0.2	0.21449	-1.91298
2	0.5	-1.44718	-1.71648
3	1.0	0.21943	-1.97849
4	1.5	1.38527	1.62564
5	2.0	-0.56347	-0.64189
6	2.5	-1.44099	1.21115
7	2.7	-1.69074	-1.22438

According to these tables, the modulus numerical value of all calculated t-score values was less than the critical t-score value of 2.101 obtained from the t-statistic table (Huitema, 2011). Therefore, the null hypothesis — that there is no significant difference between the FFL and ORL experiment results within a 95% confidence level — was accepted.

Conclusions and Future Work

The statistical analysis shows that there is no significant difference between the FFL and ORL experiment results at the 95% confidence level. Those results were not obtained from virtual or simulation experiments, but from real laboratory equipment.

All the components used for the prototype ORL experiment were real and not ideal components. As in FFL, temperature, noise and all other disturbances also affected the ORL experiment, mainly because the observations were taken from the same working environment in both methods. Therefore, the ORL system is suitable for use as an alternative method for offering laboratory sessions.

However, from the perspective of educational psychology, the ORL system has some limitations. It does not improve the hand-on skills of the students and, for this reason, the FFL cannot be completely replaced by the ORL system. Hands-on experience, such as connecting components and familiarization with equipment have to be gained through FFL conducted at the preliminary levels, with ORL being most suitable for offering experiments at intermediate levels.

In future, this system can be further enhanced by considering the psychological aspect of learning. At present, the ORL system involves a video camera showing the laboratory environment, and so the students are aware that it is not a virtual but real environment. In addition to video transmission, some other methodologies such as Artificial Intelligence (AI) (AI teacher, agent, expert system) and audio-visual components can be included in the ORL system.

This system can be utilized as a framework to distribute laboratory experiments in the ODL mode. It is feasible to implement it with a customizable facility and then the system administrator/lecturer will be able to distribute many experiments using a single system by changing input/output connections according to relevant tasks.

The prototype ORL experiment is an electronic one and does not include any mobility. In future, this system can be developed to offer experiments with mobility. The ORL is capable of controlling actuators and the initial testing was done with a stepper motor. The stepper motor was controlled successfully using the present ORL system via the Internet. This system, therefore, has the possibility of conducting experiments which require moving capabilities (e.g. mechanical and chemistry experiments) using actuators (e.g. motors and pneumatic components).

The ORL system is very suitable for ODL institutions as the difficulties distance learning students encountered when participating in FFL sessions will be reduced by using this system. It will also reduce the number of FFL sessions, which will be helpful for working students. One of the main objectives of ODL is to provide a learning environment to those who missed the opportunity for higher education due to employment, time, space, income and other obstacles, and this system will help to achieve this objective.

References

Bates, M. P. (2011). *Interfacing PIC microcontrollers: Embedded design by interactive simulation* (Vol. 16). UK: Elsevier.

Fall, K. R., & Stevens, W. R. (2011). *TCP/IP illustrated — The protocols*. Reading, MA: Addison-Wesley.

Fozdar, B. I., Kumar, L. S., & Kannan, S. (2006). A survey of a study on the reasons responsible for student dropout from the Bachelor of Science Programme at Indira Gandhi National Open University. *International Review of Research in Open and Distance Learning*, *7*(3), 1-15.

Gossen Metrawatt (2014). *SCPI Programming Guide — GMC-I Messtechnik GmbH*. Retrieved December 04, 2014, from http://www.gossenmetrawatt.com/resources/la/spl250_400/sb_gb_spl-scpi-programming.pdf

Huitema, B. (2011). *The analysis of covariance and alternatives: Statistical methods for experiments, quasi-experiments, and single-case studies* (Vol. 608). Hoboken, NJ: John Wiley & Sons.

Ismail, A.G.H. (1997). *A critical study on factors influencing the student drop-out from the educational programmes offered by the Open University of Sri Lanka*. PhD thesis, University of Colombo. Sri Lanka. Retrieved December 05, 2012, from http://archive.cmb.ac.lk/research/bitstream/70130/618/1/Thesis020.pdf.

IVI foundation (2012). *SCPI.* Retrieved December 05, 2012 from http://www.ivifoundation.org/scpi

Khamis, A.M, Rivero, D. M., Rodriguez, F.J, & Salichs, M. A. (2003a). Pattern-based architecture for building mobile robotics remote laboratories. *Proceedings of IEEE International Conference on Robotics and Automation (ICRA'03),* 3, pp. 3284-3289.

Khamis, A. M., Rodriguez, F. J., & Salichs, M. A. (2003b). Remote interaction with mobile robots. *Autonomous Robots*, *15*(3), 267-281.

Navarathna N, Fedulov.V, Martin A, & Fransson, T. (2003). Design of a remotely-controlled laboratory exercise in aerodynamics. Retrieved January 04, 2013, from http://www.energy.kth.se/proj/projects/Remote_labs/Publications.asp

Osentoski, S., Pitzer, B., Crick, C., Jay, G., Dong, S., Grollman, D., et al. (2012). Remote robotic laboratories for learning from demonstration. *International Journal of Social Robotics, 4*(4), 449-461.

The Open University of Sri Lanka (2014a). *Open & Distance Learning*. Retrieved November 10 2014, from http://www.ou.ac.lk/home/index.php/ open-and -distance-learning.

The Open University of Sri Lanka (2014b). *Prospectus, Faculty of Engineering Technology 2013/14*. Retrieved November 20, 2014, from http://www.ou.ac.lk/apps/downloads/downloadfile/Student%20Guide%20Book-%20Faculty%20of%20Engineering%20Technology.pdf

Vidanapathirana, U. (2010). Envisioning the future of the Open University of Sri Lanka, Challenges, aspirations and opportunities. Colombo: The Open University of Sri Lanka. Retrieved January 05, 2013, from http://digital.lib.ou.ac.lk/docs/handle/701300122/278