Citation for the published Conference paper:

Title:
Remotely Controlled Active Noise Control Laboratories

Author:
Imran khan, Dineshkumar Muthusamy, Waqas Ahmad, Ingvar Gustavsson, Johan Zackrisson, Kristian Nilsson, Sven Johansson, Lars Håkansson

Conference Name:
International Congress on Sound and Vibration (ICSV19)

Conference Year:
2012

Conference Location:
Vilnius

REMOTELY CONTROLLED ACTIVE NOISE CONTROL LABORATORIES

Khan Imran, Muthusamy Dineshkumar, Ahmad Waqas, Gustavsson Ingvar, Zackrisson Johan, Nilsson Kristian, Johansson Sven and Håkansson Lars

Department of Electrical Engineering, Blekinge Institute of Technology, 371 79 Karlskrona, Sweden. e-mial:imran.khan@bth.se

Remotely controlled laboratories in educational institutions are gaining popularity at an exponential rate due to the multidimensional benefits they provide. The Virtual Instrument Systems in Reality (VISIR) project by Blekinge Institute of Technology (BTH) Sweden has successfully implemented remotely controlled laboratories, with remotely controlled real instruments and experimental setups. Currently these laboratories provide students the opportunity to conduct experiments in the field of electronics, antenna theory and mechanical vibration measurements. In this paper a prototype system of a remotely controlled laboratory for active noise control (ANC) is introduced. The proposed lab will focus on addressing the problem of a ventilation duct noise. The laboratory is informative and to a great extent introduces a student to the general steps in ANC when it is suggested as a plausible solution for a noise problem. The student can perform an investigation concerning feasibility of active control, design, configuration and implementation of an active control system. The laboratory is based on a modern and relevant DSP platform with the corresponding software development environment controlled remotely. In addition, it may be utilized remotely both for lab assignments in acoustics courses and digital signal processing courses.

1. Introduction

Laboratory experiments can be categorized into three basic types namely development, research, and educational or instructional[1]. Educational laboratory experiments are essential in successful education both in engineering and non engineering studies. In engineering disciplines, laboratory experiments may enable students to acquire knowledge of nature beyond theory. Laboratory experiments provide a platform for the students to the technical challenges of future professional life [1,2]. Therefore, since the early days of engineering education laboratory experiments are considered as an essential part of engineering curricula [1,3].

The developments in Information Technology during the past two decades have influenced the education sector as well. Extensive use of computers and communication technology has introduced new dimensions to class room teaching. The term "distance education" seems to be irrelevant in the era of Internet and web tools. Educational laboratory experiments have also adopted these technological developments widely. Software such as computer aided design (CAD), modelling and simulation tools and hardware in the form of data acquisition modules, Digital Signal Processor (DSP) training kits and emulators are an integral part of modern laboratory setups. Accreditation boards such as Accreditation Board for Engineering and Technology (ABET), USA have set forth certain goals and objective for laboratory experiments [1,4]. In the light of these objectives an engineering student must work on real systems and instruments. Therefore the use of afore mentioned tools particularly the simulation tools have created a debate among educators whether Instructional laboratories still fulfil their educational objectives [1]. Apart from these objectives the results of simulation depend upon the models based on mathematical equations. Most of the natural phenomena are not simple, e.g. nonlinearities make them difficult to be modelled for simulation and usually more simplified versions are used. Although today's powerful computers are for instance capable of precisely modelling and simulating the existing nonlinear physical real world models, still there are limitations. CAD tools such as Finite Element Modelling (FEM) require substantial amount of time for modelling, etc. which might be unsuitable for the limited duration of instruction labs. Therefore simulators and CAD tools no doubt an excellent complement in analysis and design, however fail to satisfy the needs of an engineering student [5]. In addition the demand for skilled professionals is on the rise and the universities have to cope with the thousands of new students [6]. Contrary to these facts the budget for education is successively decreasing and thus the universities have either to reduce or live with the already scarce resources. This situation may result in a greater challenge for smaller institutions. There is also another important fact although ignored, is that usually there are three to four labs for a single course. These limited lab sessions only cover selected topics of a course. The main reason is the limited resources and equipments. The concept of remote laboratories seems to be a good solution for all these problems. The benefits of remote labs are multidimensional and are discussed thoroughly in [7,8,9]. They provide students with hands on experience on real hardware and systems similar to a traditional laboratory, however, in a more flexible and safer way. The institutions can afford to reduce the costs per student/equipment without compromising on the quality of education as remote labs can be utilized 24/7. Smaller institutes around the world can share expensive equipments remotely. Interested students can cover a greater extent of their course work by utilizing laboratory resources of other institute at his/her comfort that are not available at his/her own institute.

The development of remote laboratories started with the advent of Internet [9]. Several institutions across the globe have developed remote laboratories based on different architectures and technologies [6,9,10,11,12,13,14]. Blekinge Institute of Technology (BTH) Sweden started its work on remote labs from a feasibility study in 1999, and the virtual instruments in reality (VISIR) project in 2006[15]. The aim of the VISIR project was to develop an open source common platform such that the physical equipments located at different universities forms the nodes of a grid [16]. Several universities adopted the VISIR platform and developed their own remote labs and carried on integration of other architectures e.g. iLab Shared Architecture (ISA) from Massachusetts Institute of Technology (MIT) [17,18,19].

1.1 Importance of remote ANC laboratories

Active control and analysis of noise and vibration is an attractive field both for academia and industry. These areas require a solid theoretical background supported by extensive knowledge concerning measurement, analysis and control of real world systems. The department of Electrical Engineering at BTH not only conducts several courses in the area such as sound and vibration analysis, experimental modal analysis and adaptive signal processing but also has a substantial research activities in these areas [20,21]. A vital part of the courses i.e. the laboratory experiments are performed by traditional labs with signal analyzers, sensors, etc. supported by modelling, simulation and analysis software in limited time scheduled sessions. However, active control and analysis of noise and vibration requires substantial hands on experience on real instruments and physical systems for complete understanding as well as future employment. In order to complement the existing traditional laboratory a remote laboratory for vibration analysis of mechanical structures, the third by BTH has been developed [22]. The success of the current remote laboratories at BTH and the lack of ANC experiments provided inspiration to the development of a remotely controlled laboratory for ANC experiments. The proposed remote laboratory will enable students to experiment with real instruments and systems instead of simulation.

ANC is generally a vast field but the basic concepts of applying active control algorithms are similar in many applications. The scalability and collaboration with other institutes led us to apply ANC to noise produced in ventilation ducts. In order to cope with the objectives and curricular requirements the laboratory setup is designed to be informative and give the students a more realistic feeling of the real instruments and systems.

2. Remote ANC Laboratory Setup

The remote ANC laboratory proposed in this paper inherits the client/server architecture from the VISIR project [15].The laboratory setup can be divided into the following main blocks as shown in Figure 1.

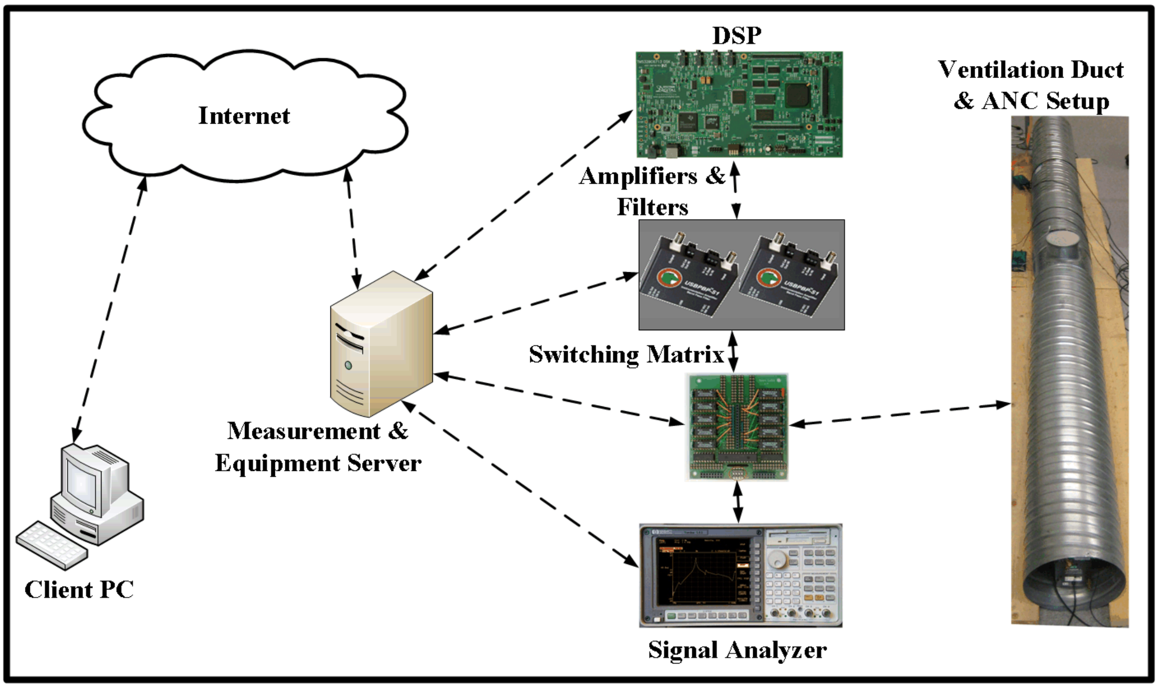

Figure 1. Block diagram of the remotely controlled ANC system.

2.1 Duct, speakers and microphones

The ANC experimental setup consists of a circular ventilation duct 4*m* in length with an inner diameter of 315*mm*. The ventilation noise or primary noise is produced by a speaker (Fostex 6301B3) placed at one end of the duct. The anti-noise is produced by a similar speaker placed at the other end of the duct. The noise is measured by low cost battery powered Integrated Electronics Piezo Electric (IEPE) microphones (VM-6052-5382). The experimental setup is aimed at single channel feed forward ANC system [23] utilising one reference microphone measuring the reference signal and one error microphone measuring the error signal for the controller that processes the adaptive algorithms. However the experimental setup in the presented work provides the possibility of selecting one out of four microphones in the duct as reference microphone. This arrangement emphasises the importance of positioning the reference microphone based on the acoustical properties of the duct and the range of frequencies that has to be cancelled by the ANC system.

2.2 Controller and signal conditioning module

The ANC algorithms are implemented on a Texas instruments (TI) DSP (TMS320C6713) and will be called as controller in the subsequent text. The signals to and from the DSP (controller) are conditioned by anti-aliasing filters/amplifiers USBPGF-S1/L from Alligator Technologies. The analog to digital and digital to analog conversion are achieved through a 16-bit daughter card module (S. Module 16-100) from SEMATIC, connected to the DSP board by mini-bus interface.

2.3 Telemanipulator (Switching Matrix)

In traditional ANC experiments different system configurations are required for performing various experiment steps. This involves manual changing of the electrical connections among microphones, speakers and data acquisition module. Changing the electrical connections is a challenging task in remotely controlled laboratories. In the proposed work this task is achieved by a telemanipulator, i.e. a switching matrix developed under VISIR [15]. In addition to the flexible connections the switching matrix is also used to control if the experimental setup is appropriate or not, and hence preventing any serious damage to the equipments.

2.4 Signal analyzer

The analysis of the control and measurement signals is carried out by a four channel dynamic signal analyzer (HP36570A). The signal analyzer is connected to the server via General Purpose Interface Bus (GPIB). The user can access the signal analyzer in a Flash front end through the client interface discussed in Section 3.6. The analyzer may be used both for analysis of the signals as well as to excite the primary noise speaker. It enables e.g. students to analyze spectra like power spectral density (PSD), frequency response of the ventilation duct, coherence, cross-correlation etc normally encountered in ANC experiment.

2.5 Measurement and equipment server

The measurement and equipment server acts as a link between the Internet and ANC laboratory equipment. All the control, communication and development software are hosted on the server. The actual hardware setup and the server are shown in Figure 2.

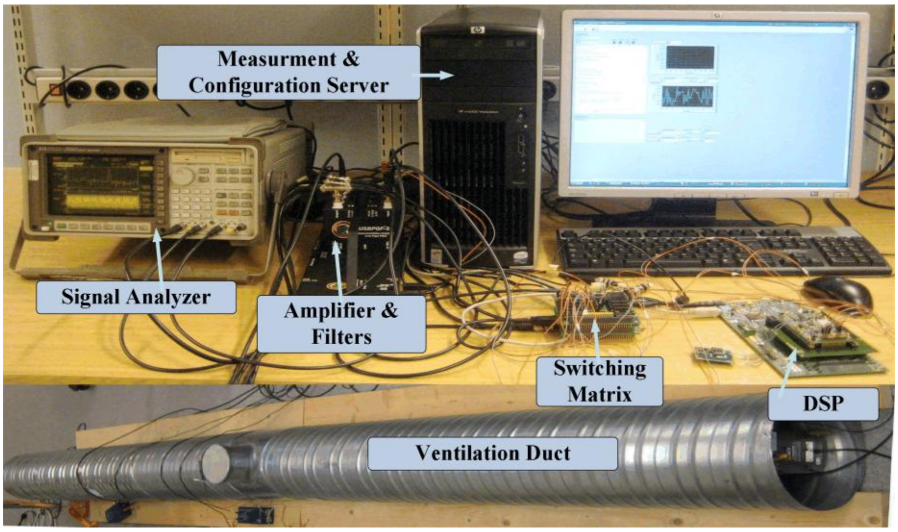

Figure 2. Remote ANC Laboratory hardware setup.

2.6 Client interface

The client interface shown in Figure 3. for the remote ANC laboratory is divided into two modules, one for measurement and configuration of ANC system and signals while the other one is for remote development and debugging of ANC algorithms implemented on DSP.

2.6.1 Measurement and configuration module

The measurement and configuration client interface is developed using HTML and JavaScript. The graphical interface facilitates students in configuring the ANC system, amplifiers and filter modules. The HTML graphical interface provides the students with a schematic view of the experimental setup. The Flash front end of the dynamic signal analyzer basically gives the students a similar experience as in the case of using the real equipment in the laboratory.

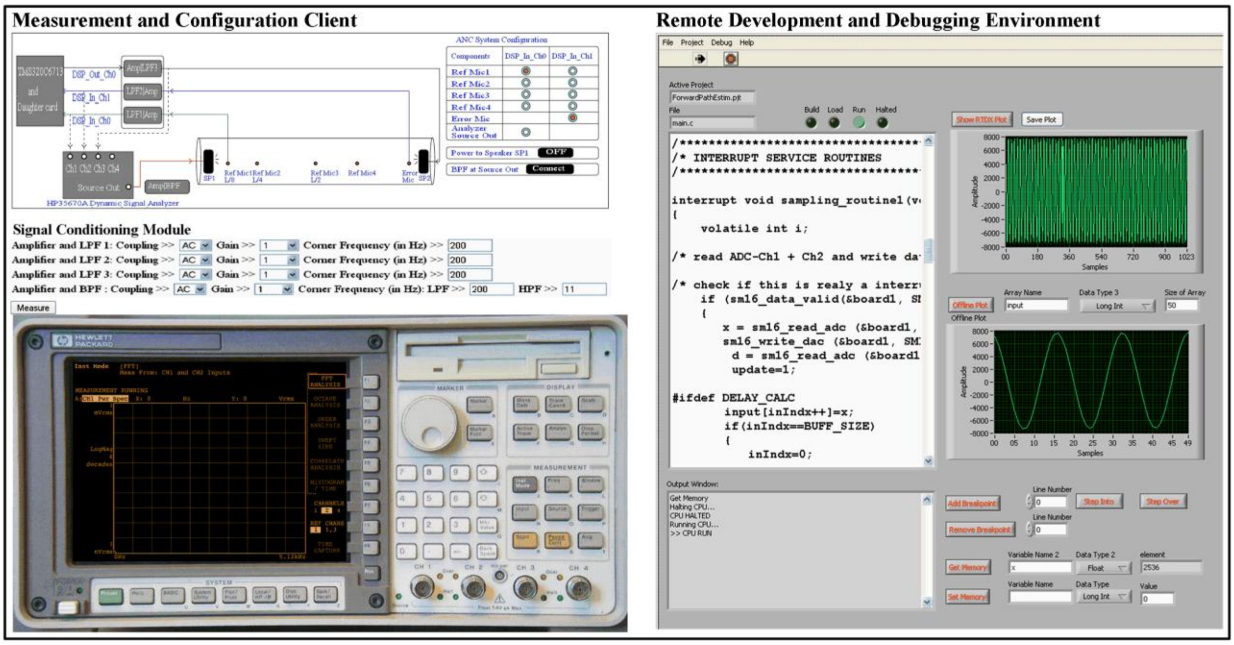

Figure 3. Client side interface of the remote ANC Lab

2.6.2 Remote development and debugging

In order to have a complete understanding of ANC algorithms in the DSP, the student must be able to program and debug the DSP from client side. This feature is provided by a LabVIEW based user interface. The remote development environment (RDE) facilitates students to program and debug the source code identical to the Code Composer Studio (CCS) integrated development environment (IDE) by TI used on campus. Students can implement, debug and test various ANC algorithms. This feature can also be utilized for training on DSP which makes the laboratory useful for courses in digital signal processing.

The RDE has provisions for plotting the variables during the execution of the algorithm on DSP. Such plotting is provided to facilitate the students to observe e.g. the convergence of adaptive filter coefficients during system identification and instantaneous error from error microphone. The client interface provides the option for saving data from the graphs. In real time execution of ANC systems, the algorithms have to be tested for various values of parameter settings. For this purpose the RDE provides interface for memory read and write operation during run-time of the DSP. Thus the client interface provides a flexible environment to perform a complete set of ANC experiments.

3. Performing the ANC experiment remotely

The preliminary experimental setup addresses single channel feed forward ANC applied to noise produced in a ventilation duct. The experimental setup enables students to perform all important steps in an ANC experiment in a more flexible manner. The experimental procedure follows the schematic diagram shown Figure 4. The reference microphone senses the noise in the duct and provides a reference signal *x(n)* to the adaptive FIR filter and the signal *x(n)* is filtered using the forward path estimate *F'* to provide the control algorithm's coefficient adjustment algorithm with an adequate reference signal $X_F'(n)$. The error signal *e(n)* for the control algorithm is sensed by the error microphone, positioned close to the anti-noise speaker in the duct, while the control signal *y(n)* generated by the algorithm is fed to the control speaker to cancel the noise present in the duct. The control signal *y(n)* is filtered using the feedback path estimate *B'* to get the output signal $X_B'(n)$ which is subtracted from the input reference signal *x(n)* to remove acoustic feedback effect.

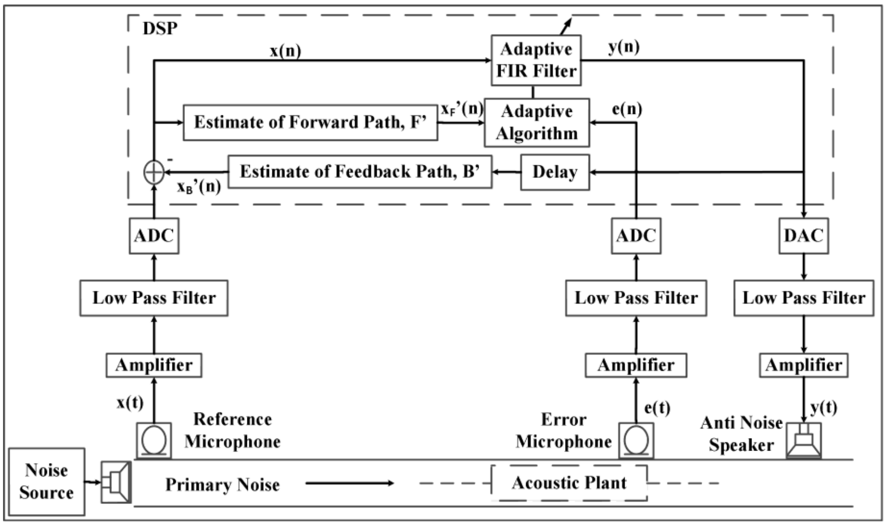

Figure 4. Schematic diagram for a single channel feed forward ANC system in the remote ANC lab.

3.1 Signal conditioning

Conditioning of the input and output signals to and from the DSP is an important procedure in performing ANC experiments. The signals from the microphones are weak and susceptible to high frequency noise. To avoid aliasing and utilize the full dynamic range of the ADC, etc. the signals are band limited and amplified by the filter/amplifier modules USBPGF-S1/L. Both the gain and cut-off frequency of the filter/amplifier modules can be configured remotely through the client interface.

3.2 System identification

Key part of the feed forward ANC systems is the forward path or control path. The control signal path from the Digital to Analog Converter (DAC), low pass filter, amplifier, anti-noise speaker, acoustic path, error microphone, low pass filter, amplifier and Analog to Digital Converter (ADC) form the forward path. To estimate the forward path an identification signal, in this case a band limited random noise within the frequency range [0-200] *Hz* may be used to excite the physical forward path. The output from the forward path may be used as desired signal to an adaptive algorithm controlling an adaptive FIR filter. The aim of the adaptive algorithm in this case is to minimize the mean square error between the adaptive filter's output signal and the desired signal. After convergence of the adaptive filter the resulting FIR filter forms an estimate of the forward path.

During active control of noise, the noise generated by anti-noise speaker is also detected by the reference microphone, known as acoustic feedback. The feedback path from DAC, low pass filter, amplifier, anti-noise speaker, acoustic path, reference microphone, low pass filter, amplifier, ADC may be estimated and hence this estimate may be utilised as a feedback neutralization filter in the digital domain using DSP. The estimates obtained during forward path and feedback path estimation using RDE can be compared with the corresponding cross-correlation function estimated with the aid of the signal analyzer. Thus with the combination of the two client interfaces i.e. measurement and configuration and RDE students can cross check their estimates.

3.3 Operating frequency range

The single channel feed forward ANC system's feed forward transfer path shown in Figure 4. is assumed to be linear. However in reality the feed forward transfer path may not be linear. Coherence function estimate between the reference and error microphone signals as well as frequency response function estimate produced for different excitation signals, etc. may be used to investigate the transfer path's properties. The frequency response function may also be used to estimate the resonant frequencies of the duct. By using the measurement information from coherence and frequency response function respectively a suitable operating frequency range for ANC may be selected.

4. Results

The remote ANC laboratory provides a similar functionality to that of a traditional ANC laboratory. All the required signals can be observed and analyzed using the signal analyzer at the client side. The laboratory can be accessed at *http://194.47.149.140:8086/testANC/testANCVer5.html.* Some of the important results during the different steps of an ANC experiment are shown in Figure 5.

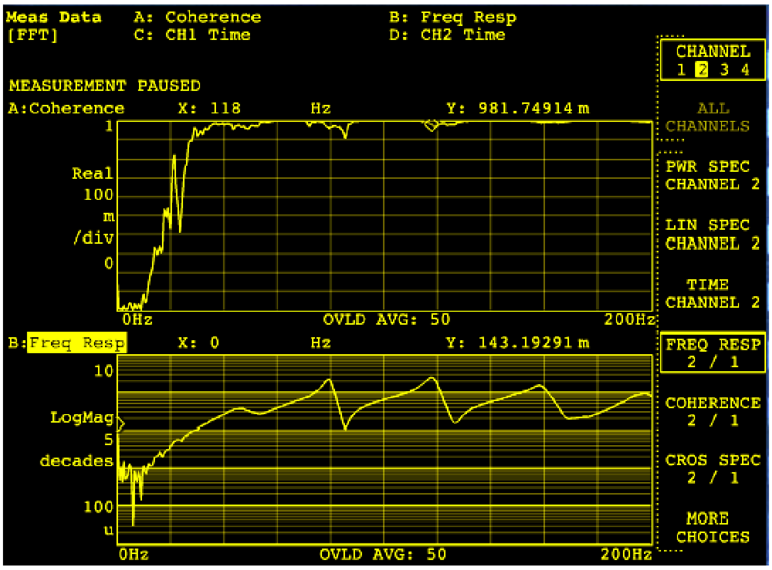

Figure 5. Screen shots of the signal analyzer while performing experiment in the remote ANC lab.

5. Summary and conclusion

A remotely controlled ANC laboratory setup capable of performing the important steps for the design and implementation of in ANC system is presented. The proposed laboratory is scalable and can be used for different courses ranging from upper secondary school to university level. The main focus of the presented work is on performing ANC experiments by controlling real equipments and hardware through remote computers 24/7. Students are exposed to the real world technical challenges not possible with simulation tools. The proposed ANC laboratory can be extended to include multi-channel ANC experiments.

REFERENCES

[1] Feisel, L. D. and Rosa, A. J. The role of the laboratory in undergraduate engineering education, *Journal of Engineering Education*, **94**, 121–130, (2005).

[2] Saavedra Montes, A. J., Botero Castro, H. A. and Hernandez Riveros, J. A., How to Motivate Students to Work in the Laboratory: A New Approach for an Electrical Machines Laboratory, *IEEE Transactions on Education*, **53**, (3), 490–496, (2010).

[3] Gustavsson, I., Zackrisson, J., Akesson, H., Hakansson, L., Claesson, I. and Lago, T., Remote operation and control of traditional laboratory equipment, *International Journal of Online Engineering*, **2**, (1), (2009).

[4] Gustavsson, I., et.al, On Objectives of Instructional Laboratories, Individual Assessment, and Use of Collaborative Remote Laboratories, *IEEE Transactions on Learning Technologies*, **2**, (4), 263–274, Dec. (2009).

[5] Krivickas, R.V. and Krivickas, J., Laboratory Instruction in Engineering Education, *Global J. of Engng. Educ.*, Published in Australia, **11**, (2), 191-196, (2007).

[6] McAfee, M. and Reid, S., Challenges in Providing Practical Labs Online to Distance Learning Students, *3rd International Symposium for Engineering Education*, University College Cork, Ireland, (2010).

[7] Ma J. and Nickerson, J. V., Hands-on, simulated, and remote laboratories: A comparative literature review, *ACM COMPUT. SURV*, **38**, (3), (2006).

[8] Nafalski, A. et al., International Collaboration in Remote Engineering Laboratories: an Approach to Development, *IEEE Transactions on Learning Technologies*, (2009).

[9] Gomes, L. and Bogosyan, S., Current Trends in Remote Laboratories, *IEEE Transactions on Industrial Electronics*, **56**, (12), 4744–4756, Dec. (2009).

[10] Harward, V. J. et al., The iLab Shared Architecture: A Web Services Infrastructure to Build Communities of Internet Accessible Laboratories, *Proceedings of the IEEE*, **96**, (6), 931–950, June. (2008).

[11] Almarshoud, A. F., The advancement in using remote laboratories in electrical engineering education: a review, *European Journal of Engineering Education*, **36**, (5), 425–433, (2011).

[12] Baccigalupi, A., De Capua, C. and Liccardo, A., Overview on Development of Remote Teaching Laboratories: from LabVIEW to Web Services, in *Proceedings of the IEEE Instrumentation and Measurement Technology Conference*, 2006. IMTC 2006, 992–997, (2006).

[13] Hong, S., Zheng, X., Dalager, B., Kristiansen, V., Strom, O., Shur, M. S., Fjeldly, T. A., Jian-Qiang, L. and Ytterdal, T., Conducting laboratory experiments over the Internet, *IEEE Transactions on Education*, **42**, (3), 180–185, Aug. (1999).

[14] Scanlon, E., Colwell, C., Cooper, M. and Di Paolo, T., Remote experiments, re-versioning and rethinking science learning, *Computers & Education*, **43**, (1–2), 153–163, (2004).

[15] Gustavsson, I., Lagö, T., Håkansson, L., Zackrisson, J. and Claesson, I., The VISIR project – an Open Source Software Initiative for Distributed Online Laboratories, *in REV 2007*, (2007).

[16] Gustavsson, I., Zackrisson, J., Nilsson, K., Garcia-Zubia, J., Håkansson, L. , Claesson, I. and Lagö, T. , A Flexible Instructional Electronics Laboratory with Local and Remote Lab Workbenches in a Grid, *International Journal of Online Engineering (iJOE)*, **4**, (2), 12-16, (2008).

[17] Hernandez-Jayo, U., García-Zubia, J., Angulo, I., Lopez-de-Ipiña,D., Orduña, P., Irurzun, J., and Dziabenko,O., LXI Technologies for Remote Labs: An Extension of the VISIR Project, *International Journal of Online Engineering (iJOE)*, **6**, (5), 25–35, (2010)

[18] Tawfik, M., et al., *International journal of online engineering*, **8**, (1), 25–32, Feb. (2012).

[19] Gomes, L. and Garcia-Zubia, J. Eds., *Advances on Remote Laboratories and e-Learning Experiences*. University of Deusto Bilbao, ISBN: 978-84-9830-662-0, (2007).

[20] *Research by Department of Electrical Engineering, BTH*, [Online]. available: http://www.bth.se/fou/forskinfo.nsf/departments!OpenView&Start=1&Count=30&Expand=14#14. [Accessed:26Mar,2012].

[21] *Research by Department of Signal Processing, BTH*, [Online]. available: http://www.bth.se/fou/forskinfo.nsf /departments !OpenView &Start=1&Count=30&Expand=14#14. [Accessed: 26Mar,2012].

[22] Akesson, H., Gustavsson, I., Hakansson, L. and Claesson, I., Remote Experimental Vibration Analysis of Mechanical Structures over the Internet. In *ASEE Annaual Conference*, (2005).

[23] Kuo, S. M. and Morgan, D. R., *Active noise control systems: algorithms and DSP implementations*. Wiley, 1996.