Remote Access Laboratories in Australia and Europe

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Abstract: Remote access laboratories (RALs) were first developed in 1994 in Australia. The main purposes of developing them are to enable students to do their experiments at their own pace, time and locations, and to enable students and teaching staff to get access to facilities beyond their institutions. Currently, most of the experiments carried out through RALs are heavily biased to electrical, electronic and computer engineering disciplines. RALs in different Australian and European universities were mentioned and their pros and cons were also discussed. It can be argued that RALs will develop further and faster in the future with improving Internet technology; the rising costs of real experimental equipment will also speed up their development because by making the equipment remote accessible, the cost can be shared by more universities or institutions and this will improve their cost-effectiveness. Their development would be particularly rapid in large counties with small population like Australia, Canada and Russia.

Keywords: Remote access laboratories, Australia, Europe, Web-based access, LabVIEW, SCADA and iLab.

1. Introduction

Remote access laboratories (RALs) here refer to remote access to real equipment rather than simulated equipment or virtual laboratories. Many remote online laboratory experiments have been reported in the literature recently (Trevelyan, 2003a). The development of these laboratories seems to be focused in engineering disciplines, particularly electrical, electronic and computer engineering disciplines (Lowe et al., 2008; Ma and Nickerson, 2006; Aktan et al., 1996; Ko et al., 2001; Borisov, 2008).

The cost of providing traditional laboratory teaching in engineering and the physical sciences, and the constraints that it places on implementing alternative learning styles, are of concern to tertiary institutions worldwide. Providing remote access to laboratory hardware via the Internet is an evolutionary change that offers a range of potential benefits. With 24-hour, 7-day access, expensive hardware resources can be shared between faculties, across different institutions, and even across different countries (Lowe et al., 2008; Borsic et al., 2006; Janos et al., 2007). Students can work individually or in dynamic groups, for longer periods of time, and as a consequence gain a broader and more complete understanding of the principles involved. Finally, it allows laboratory work to be integrated with other "Internet-aware" advances in teaching, providing opportunities for auto-assessment, more widespread staff involvement, and simultaneous reinforcement of practical principles with theory and simulation studies (Dain and Trevelyan, undated).

Remote experimentation is typically introduced to complement hands-on laboratory sessions in traditional higher education settings, to avoid travelling to the training centres in distance learning or to offer live demonstrations in classroom sessions. Remote laboratories are often used in control, robotic and mechatronic education to illustrate theoretical principles and deployment methodologies. As an example, the different control design and implementation steps taught to students in control courses (system identification, controller design, real-time control, performance validation, etc.) can be efficiently carried out remotely on mechatronic systems as they exhibit visually observable dynamical behaviour (Tzafestas et al., 2006; Salzmann and Gillet, 2007).

The history of RALs is not very long. Lindsay et al. (2007) claimed that web-based remote access laboratories have been offered by universities in undergraduate engineering courses since 1996. This refers to the work of Aktan et al. (1996) for control engineering laboratories in Oregon State University, USA. However, the work by these pioneers in the US might not be the first in the world because Trevelyan (2003a) started his telerobot for RALs with his colleagues in the University of Western Australia (UWA) in 1994 (Taylor and Trevelyan, 1995). This can be regarded as the first world RAL and a new development extended this telerobotic technology to make teaching laboratory equipment available to students via the web, 24 hours per day. In the early days of their development, RALs encountered significant problems in the form of high installation, operation and maintenance costs. The main software, Java, was also very unstable (Trevelyan, 2003b). Now, most of the technological problems have been predominantly and practically solved, many of the benefits associated with increased student flexibility and improved learning outcomes are yet to be consistently achieved (Lowe et al., 2008a).

The most popular model of the remote online laboratory is iLab, developed by Massachusetts Institute of Technology (MIT). Unfortunately, most popular does not always mean most integratable depending on the desired outcome of deploying iLab. The current architecture MIT iLab has employed is expensive with regards to development costs and time; not suited for a mass rollout of cheap experiments. One possible solution to this is known as the iLab Mini, developed by an MIT PhD student, and is in the early stages of prototyping (UQ, undated a). Other systems currently used include SCADA, LabVIEW and RACAL (Ahfock et al., 2008; Trevelyan, 2003a; 2003b; Zimin, 2007).

RALs in Australia

Many universities in Australia have developed or been developing RALs for different purposes. In addition to UWA, University of Technology, Sydney (UTS), Curtin University of Technology (Curtin), University of South Australia (UniSA), University of Melbourne, University of Queensland (UQ), Deakin University (Deakin), and University of Southern Queensland (USQ) (Lowe et al., 2008) have developed RALs.

RALs at UWA

The current RAL system in UWA, using LabVIEW, has been in use since early 2002. A LabVIEW client-server application interfaced to experimental hardware via FieldPoint modular I/O. The LabVIEW application is accessible to staff and students, robust enough for operation in a practical teaching environment, and cost-effective to support across multiple platforms in an evolving PC environment. Figure 1 shows a schematic of the server, client, and hardware layout. Netmeeting provides a real-time view of experiments as they are controlled.

An experiment using a domestic electric iron fitted with sensors and controllable jet of compressed cooling air is currently offered at UWA. The equipment can be used for several laboratory classes (Trevelyan, 2003a):

- Thermodynamics of a simple domestic appliance, heat transfer by convection and conduction.
- Modelling of a domestic appliance, from simple first order equation representation to finite element thermal modelling.
- Mechatronic discrete control and sensing
- Control system theory applied to a simple non-linear system.

The two important advantages of the system to student learning outcomes are that students can experience more operating time per week than in a conventional laboratory class, and those who are reluctant to participate in a normal laboratory can operate remotely without the fear of making mistakes in front of others. Another advantage is cost and the total investment in the UWA system is approximately AUD $ 220,000 which is 10% of the budget in some other universities in the USA. (Trevelyan, 2003a). However, most of the students preferred to use the real equipment if it was available and some complained about having to download the initial installation files (12 MB for LabVIEW runtime environment) though this was also made available in CD-ROM. On the other hand, once the initial installation has been accomplished, each new client only needs 1.5 MB download (Trevelyan, 2003a; 2003b).

RALs at UTS

Curtin is always in collaboration in developing RALs with UTS (Lowe et al., 2008). The RALs of UTS can be argued to be one of the most advanced in the world and the requirement of locating the students and hardware had been removed.

In order to prove to the world that the RALs of UTS can be accessed anywhere in the world, the official launching of the system featured a hook-up of universities on three continents – Europe (University of Hertfordshire, UK), North America (Massachusetts Institute of Technology, the USA) and Australia (Curtin University of Technology) (UTS, undated).

Examples of the experiments include deforming beam experiments, FPGA (Field Programmable Gate Array) experiment, coldfire experiments, remote water level control laboratory and remote PLC (Programmable Logic Controller) laboratory. (Lowe et al., 2008; Lindsay et al., 2008). There are six PLC test rigs; this means that the equipment can be shared with many users throughout the world (Lindsay et al., 2008). Each PLC test rig consists of two electro-pneumatic cylinders, two valves, one Allen-Bradley PLC (MicroLogix 1200) and NetENI Ethernet module (Figure 2). Two reed sensors are installed in each cylinder to measure the piston position. One camera and a microphone are used to take the video and sense the sound of piston movement, respectively. This remote laboratory allows students to write programs for PLC to interact with pneumatically driven cylinder apparatus. Students can view streaming video over the Internet, which provides them with visual feedback on the effectiveness of their programming (Lindsay et al., 2008).

Though some students were happy with RALs because they could do the experiments in their own time and afford more time to understand without the pressure of having to take it all in one occasion, many still found that there was a lack of interaction with laboratory assistants because it was always interesting to talk to some one who works with the equipment. They also felt isolated because they could not discuss the experiments with others. Some students stressed that RALs should be used after a demonstration in real laboratories to allow students to communicate personally with the lecturers (Bright et al., 2008).

However, some students found that in conventional laboratories one had to write down the results and think about what actually happened afterwards. With the remote laboratory one could watch the result first, and then depending on what one's outcome was alter one's settings. It made it a lot easier to clarify a misunderstanding of the theory. It was possible to test hunches or investigate 'what-if' scenarios. Students claimed that instead of only achieving the subject outcome, they could further discover knowledge with time. In addition, the laboratories also let one practice the experiments many times and compare the results in order to have a more fundamental idea (Bright et al., 2008).

RALs at University of Southern Queensland

Remote access of hardware and software resources is of particular interest to the Faculty of Engineering and Surveying at the University of Southern Queensland (USQ) because of its high proportion of distance mode students. Work towards setting up remotely accessible laboratories at USQ started in 2007. A small range of the University's laboratory resources are now remotely accessible. Software only resources include finite element, power system analysis and GIS computer programs. Industrial equipment such as the Schweitzer Electric Laboratories (SEL) 357 protection relay and the Omicron 256plus protection relay test set have been made available to students by remote access. There are two main advantages with this approach. First, such equipment is designed to be used through a computer and therefore making them remotely accessible is, technically, a trivial exercise. Second, experiments can be designed to be both educationally and industrially relevant.

Laboratory hardware that is remotely accessible includes a transformer protection training system and a model air powered launcher. These are shown in Figures 2 and 3 respectively. The above laboratory hardware is mainly used by the students and teaching staff of electrical discipline of the Faculty. A single cylinder four stroke gasoline engine will be used in the remote access engine laboratory by a teaching staff in the discipline of mechanical and mechatronic engineering.   The external students can perform the required tests using the experimental engine test bed depicted in Figure 4. This engine test bed allows measuring exhaust temperature, lubricant oil temperature, fuel consumption rate, and engine speed. An eddy-current dynamometer was used to apply variable torques to test the ability of the engine to produce power. A Bush gas analyzer unit will be used to measure the concentration of exhaust gases components, namely NO_x, CO, CO_2 and O_2. LabVIEW software will be used to remotely monitor and control engine temperatures, fuel flow rate and air follow rate.

Initial users had all reported ease of connectivity and adequate data communication speeds especially for laboratory work that is based on software only. Some observed that data transfer speeds can drop to levels that are marginally satisfactory if webcam images are of high resolution. Two approaches have been adopted to resolve this. The first one is based on the idea that laboratory work should be designed so that the webcam image, while it is to be made available to students to enhance the feeling of reality, should not be a feature that is essential to successful completion of such work. Students are then free to remove the webcam image from the screen and achieve faster data transfer. Where live camera images are essential for the remote user to conduct laboratory work, the image should be processed such that only its essential content is transmitted. Although some features of the remote laboratory communication infrastructure is not yet operational, students are currently using it to carry out a small number of laboratory exercises which are formal parts of their courses. Feedback from those students will be used to improve the system and also and encourage more teaching staff at the University to embed remotely accessible laboratory work within their courses (Ahfock et al., 2008). A booking system is currently under construction.

RALs in Europe

Many universities of different countries in Europe have developed or been developing RALs for different aims. In addition to University of Leeds in United Kingdom (UK), Imperial College London, UK, Ecole Polytechnique Federale de Lausanne, Switzerland, University of Sannio, Italy, Siberian State University of Telecommunication and Informatics, Russia, N.E. Bauman Moscow State Technical University, Russia, Firat University Technical Education, Turkey, Technical Education Faculty, Turkey, Budapest University of Technology and Economics, Hungary, University of Alicante, Spain, The Blekinge Institute of Technology, Sweden and University of Montpellier, France, have developed their RALs.

RALs in U K

In University of Leeds, the mechanical engineering experiment involved in analysing the performance of a servo-motor and was designed to be particularly suitable for remote access. Students were provided with individualised experimental parameters to minimise plagiarism. However, they were also able to choose their working environment and work in the presence of peers or individually. They were able to access the experiment repeatedly as required. The 24/7 availability of the remote lab meant that students' access was not impaired by restricted mobility nor by illness, or commitments of part-time work or religious attendance. The experimental design allowed students' results to be combined to generate a collaborative, emergent result giving a full frequency response analysis of the servo motor. This outcome could not have been achieved with a traditional lab access mode. Students were furthermore able to assess their performance against their peers, and learn from their own mistakes and those of others, with anonymity (Hanson et al., 2008).

Remote-access and hands-on laboratories have inherent and fundamental differences, beyond the mere format of their interface, which result in differences in the learning process. Because of this, Hanson et al., (2008) did not recommend the use of remote laboratories as a like-for-like substitution for hands-on laboratory work. Instead, these differences should be exploited to make most effective use of each method. Remote laboratories have supporters and detractors; it can be argued that when used appropriately they have a valid place in the curriculum, and have demonstrated unique advantages over traditional laboratory access methods (Hanson et al., 2008).

RALs at Switzerland

The physical equipment considered for remote experimentation are mainly mechatronic systems with mobile parts as they exhibit visually observable dynamical behaviours. Other equipment such as heat flow systems that have less or no visually observable behaviours need to be enhanced to enable remote visualization. For example, a simple strand of wool has been placed at the exit of the heat flow system available at the EPFL to permit the visualization of the air stream. This physical equipment may be accessed locally in addition to the remote access and therefore needs to be robust to careless manipulation by students. This physical equipment must be fully observable remotely. The physical equipment should be fully controllable at distance (Salzmann and Gillet, 2007).

The software that control the physical equipment as well as the client interface software must be robust and written using a defensive approach toward unforeseeable usage. Security concerns must also be considered. The developer of the remote experimentation software must guarantee that maliciously crafted information sent to the server will not interfere with the control of the physical equipment and induce damage. The received information must be cautiously validated prior to being used. These requirements generally necessitate major software revision when developing the professional-quality solutions students are expecting. Remote laboratories maintenance is a difficult and time consuming task when a 24/7 availability is targeted. The first step in providing a wide availability is to detect problems; this implies that the physical equipment and its associated software are capable of self-diagnoses. If the remote experiment is not able to set itself back in a known stable state it should send an alarm to the administrator (Salzmann and Gillet, 2007).

Personal satisfaction and educational benefit are the major challenges from a student's point of view. Not fulfilling users' expectations will result in clients not using the remote access facilities. Students using remote laboratories are demanding and expect professional quality solutions. The additional flexibility provided by remote connections is highly appreciated and permits the students to manage the laboratory session at their own pace and from their own location. The drawback is that the learning modalities found on campus should be emulated. Collaborative learning support should be provided, as well as some form of tutoring and assistance. An effective remote laboratory facility is costly to develop and to maintain for a single academic institution. Commercial trials have also shown that the economical value of such a settings is not high enough for establishing a viable business model. As a consequence, an effective model for sustainability is the sharing of the investments and the laboratory resources between different universities (Salzmann and Gillet, 2007).

RALs at Sweden

Conventional electrical circuit experiments have been conducted over the Internet at BTH (Blekinge Tekniska Högskola: The Blekinge Institute of Technology) in Sweden from different locations simultaneously using an experimental hardware setup in a closed room at BTH. This is neither a simulation nor a SCADA application. The students control the instruments in the same way as they would in the local laboratory. The only difference is that they do not form the circuits and connect the test probes manually (Gustavsson, 2002). Remote experimentation is a relatively new phenomenon in distance learning. A number of so-called remote laboratories have been set up by some universities around the world. These offer remote access to laboratory equipment and experimental setups via the Internet (Berntzen et al., 2001).

A number of clients can access the setup simultaneously, and each client can choose to conduct any one of five experiments in basic circuit theory. Most of the functions of the 54600B oscilloscope from Agilent Technologies are implemented. The lab server forms the required circuit and connects the test probes using a switch matrix. Then the lab server makes the settings requested and reads the instruments. Finally, the lab server returns the results obtained. To cope with requests from more than one client simultaneously the server must have a queue manager and a short response time. BTH has demonstrated that remote experimentation in electrical engineering is practically possible. Many experiments in electrical engineering education have no physical sensations and can be conducted remotely over the Internet, around the clock and without video transmission or other methods requiring high transfer bandwidth. In experiments with short time constants, several students can share the same remote hardware (Gustavsson, 2002).

Discussions

The information used to describe the development of RALs in the two continents in this paper was from publications between 1999 to 2008. On account of the above ground and the improvement in Internet technology and in software used to drive the RALs , the negative comments made by users of earlier RALs, e.g. 1999 might had been solved by RALs developed later, e.g. 2008. In the last three years, mechanical and mechatronic disciplines experiments had been introduced; they were remote water level control, analysing servo-motor performance, use of aberration corrected electron microscope (ACEM), nuclear magnetic resonance, material testing, plasma diagnostic, radio-physics, analysing bipolar transistor characteristics and hysteretic phenomena (Lowe et al., 2008; Hanson et al., 2008).

Even with advanced level of RALs in UTS, students still liked to do the experiments with real equipment because they would be able to interact with the laboratory assistants or technical officers and fellow students (Lowe et al., 2008). However, this problem could be solved by having a tutor in remote location, who controlled the experiments and interacted with students when needed (Zimin, 2007). This would reduce the RALs availability from 24/7 to a shorter period. Hence, a compromise have to be made by manning the system for 8 hours per day for 5 days per week but still allowing users to get access into RLAs at all other times. However, maintenance would still be difficult and time consuming (Salzmann and Gillet, 2007).

It can be argued that for most big city universities, RALs will be used to supplement 'real' laboratories for the on-campus students. The laboratory assistants will make demonstrations to them on the use of the equipment; the students would then know the procedure of carrying out the experiments as well as having a feeling for the equipment by viewing the demonstrations (Machotka et al., 2007). Some form of tutoring and assistance should also be provided (Salzmann and Gillet, 2007). These big universities can also provide their students with access to expensive equipment not owned by them via RALs (Lowe et al., 2008).

For some regional universities in Australia, like USQ with over 65% of USQ students are studying by distance education of e-learning, the RALs would be used to enable external students to do their experiments from their homes via Internet. Students would not need to travel from other Australian cities to Toowoomba, Queensland where USQ is located as this will cost them a lot of money and time. At the same time, the RALs will also be made available to on-campus students who will do the experiments with real equipment. The RALs will give them more time to repeat the experiments with different input and parameters. It can be argued that their learning outcome will be improved. USQ can also subscribe some RLAs of some bigger universities, e.g. UTS so that its students can get access to facilities not owned by USQ.

In addition to do experiments, RALs can also provide some academics in universities to get access into expensive and advanced facilities of other universities of other universities or research institutions, e.g. Imperial College of U K can get access to the ACEM at Oak Ridge in the USA (Mehta, 2007). It can be argued that some universities developed RALs for their overseas campuses like Vietnam campus and Malaysia campus of the RMITU and Swinburne respectively.

Another important factor to consider in the establishment of RALs is cost. With less contact by users, the life of expensive equipment will be lengthened and the maintenance cost would also be reduced. More experiments, particularly those requiring expensive facilities, can be done by students of a university via sharing the RALs with other institutions (Salzmann and Gillet, 2007; Lowe et al., 2008). The development costs of RALs were lower by Australian universities than their counterparts in the USA (Trevelyan, 2003a; Lowe et al., 2008).

Conclusions

It can be argued that the development of RALs by universities around the world cannot be stopped because of their relative advantages over traditional laboratory experiments. The improvement of Internet technology will drive this even further. Big countries which are sparsely inhabited like Australia and Canada will favour RALs more because they enable more and more of the population to get access to higher education at reasonable costs. USQ will certainly develop its RALs further to attract more off-campus engineering students and to help to fulfil the government ambition of raising the number of young people with a least a bachelor-level qualification to 40% by 2020 (Lane, 2009). Moreover, USQ will also pay health and safety issues to its RALs as its utmost priority.

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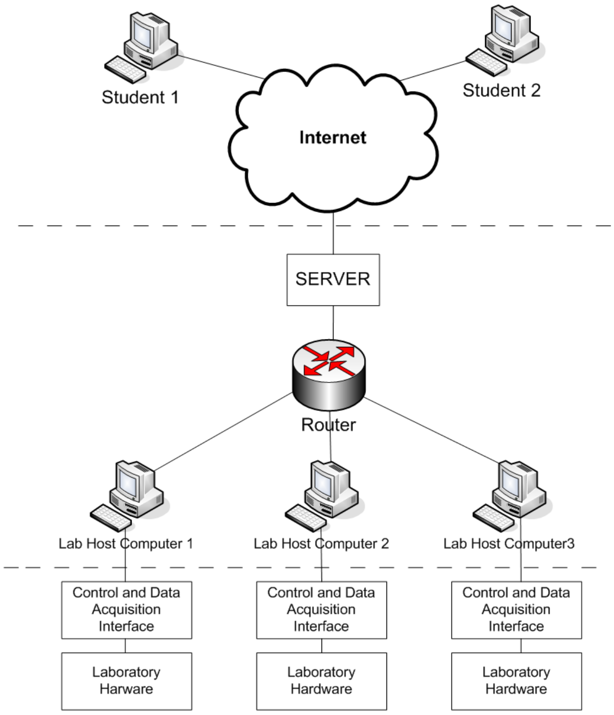

Figure 1: Schematic of the Server, Client and hardware layout showing two alternative I/O connection options.

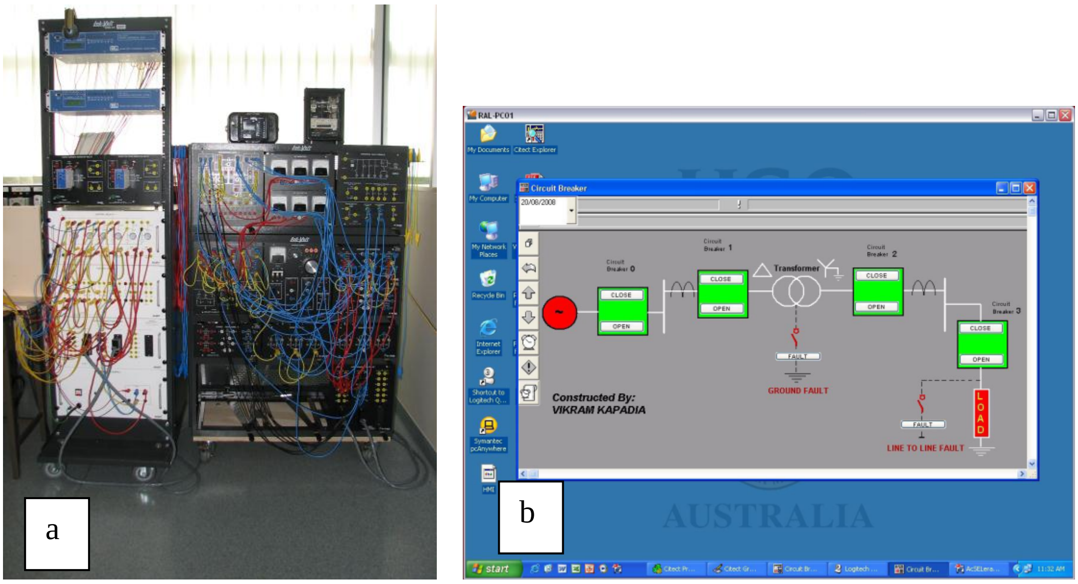

Figure 2: SCADA controlled network fault simulator. The (a) hardware under (b) software control.

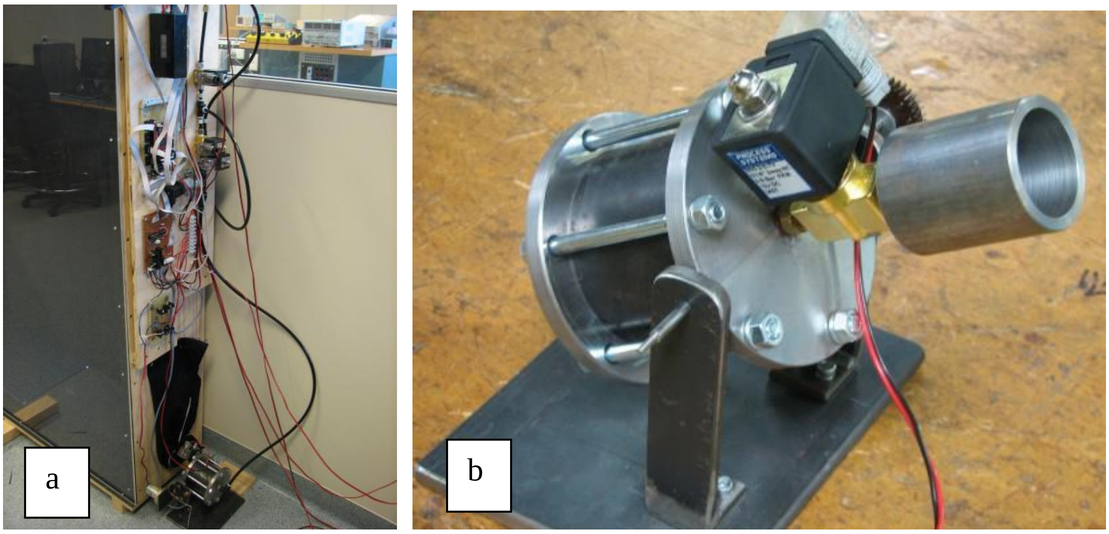

Figure 3: Annotated photographs of the (a) range and (b) canon used in the model firing range remote experiment

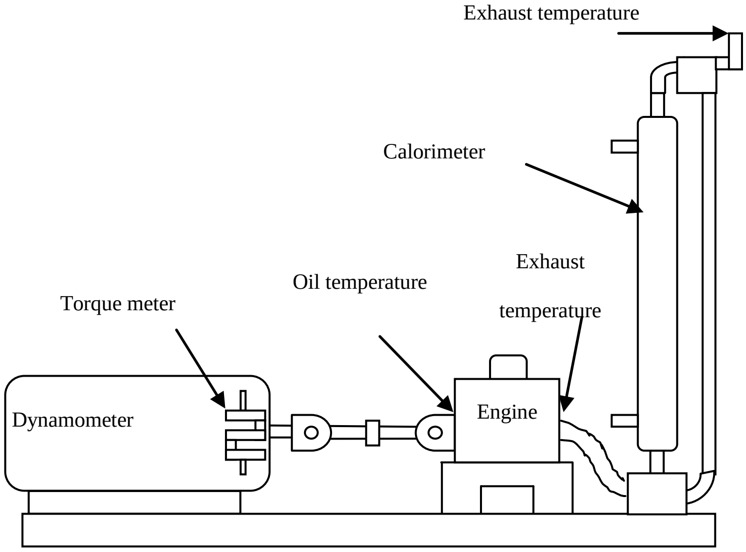

Figure 4: A single cylinder four stroke gasoline engine