The history of developments of remote experiments

J. Machotka, A. Nafalski & Z. Nedić

University of South Australia
Adelaide, Australia

ABSTRACT: Remote operation is a technology that has attracted the attention of many researchers and developers in different fields for many years. Remote control provides access to such places like the bottom of the ocean or the top of the world, in impossible terrain, in health hazardous places such as those with lethal radiation levels and in quarantine laboratories. More recently, remote control has spread to the world's universities, in engineering and science remote laboratories (RLs). Since the introduction of the Internet, efforts have been made to integrate remote operation with Internet technology. The most advanced remote operation systems of these recent technologies include Internet-based robotic systems and RLs. However, history shows that before the Internet was introduced into the human environment, many scientists, researchers and companies had tried to develop remote control systems of machines in which operators interacted remotely with equipment regardless of the global location or time. This paper describes a brief history of remote control and consequently the Internet based RLs.

INTRODUCTION

Remote control or manipulation began to appear in situations when experiments required human operators across protective barriers of space and time or under conditions noxious to human health. Remote handling machines were then developed and named *robots*. A robot is a mechanical contraption, which can perform tasks on its own or with guidance.

A robot may be defined as a self-governing, programmable electromechanical device used in industry and scientific research to perform a task or a limited repertory of tasks faster, cheaper and more accurately than can be done by humans [1]. Robots can perform operations in locations or under conditions hazardous to human health. Remote laboratories using remote control started in the late 1990s in universities all over the world. They were developed to address most of the issues faced by the modern university such as limited capacity, and to provide laboratories that are cost effective [2], well utilised, and most importantly, able to provide students with adequate access to run and, if required, to repeat the experiments [3].

Remote laboratories provide students with 24/7 access via the Internet. They also open up opportunities to share expensive and/or specialist laboratories with other institutions onshore or offshore. Instead of each institution developing and running the same types of laboratories, they can be shared globally wherever adequate Internet access is available [4]. This is particularly beneficial to offshore programmes, such as at the Kaplan Singapore, where the University of South Australia (UniSA) engineering programmes were so successful, that the number of students was higher than the number of students onshore in Australia. They were never intended to replace real practical experiments, and still do not do so, but aim to enhance these experiments, using modern and available technology [5]. There have been many evaluations of possible laboratory experiments, but in recent years, the RL is at the forefront [6].

REMOTE CONTROL AND ROBOTS

The origin of the word *Robot* is from the Czech word *robota*. In the Czech language it means forced and compulsory work. The word Robot was introduced by Czech writer Karel Čapek in his play R.U.R. (Rossum's Universal Robots) in 1921 [7]. The play begins in a factory that makes artificial people called robots, who in modern terminology resembled androids or creatures that can be mistaken for humans. Karel Čapek did not coin the word but he named his brother, the painter and writer Josef Čapek as the actual originator of the word [8].

The word *robota* means compulsory work or serf labour, drudgery or hard work in the Czech language. Robota was originally a feudal service, which was rendered to local magnates by peasants. At the time Čapek wrote R.U.R., the term robota had broadened to include various types of work, but the sense of serfdom still remains today.

Attempts to create robots or artificial people-like helpers or companions have a long history. In ancient mythologies, and in Homer's Iliad, we can find mechanical servants built by the Greek god Hephaestus to help him to create new armour for the hero Achilles [9]. We can continue with other examples, like the Jewish legend that had created the clay golems or Norse legend with clay giants, and Galatea, still well known by the mythical statue of Pygmalion that came to life [10].

In the real world of ancient inventions, we cannot forget Leonardo da Vinci who sketched plans for a humanoid robot around 1495. Da Vinci's notebook, rediscovered in the 1950s, contained detailed drawings of a mechanical knight now known as Leonardo's robot, able to sit up, wave its arms and move its head and jaw [11].

The invention of electricity started a new era of studies and research on how this form of energy could build new communication devices and appliances. An electrical signal can be transmitted across distances. This phenomenon has attracted the attention of numerous researchers and scientists who have tried to find various ways to control electric and electronic systems from remote distances [12].

In more modern developments, Nikola Tesla demonstrated a radio-controlled torpedo in 1898. Based on patents for teleautomation, Tesla hoped to develop it into a weapon system for the US Navy [13].

In 1926, a Westinghouse Electric Corporation engineer, J.M. Barret, under the supervision of Jack Weeks created Televox, the first robot able to do vacuuming and use the telephone [14]. Later, they created another humanoid robot named Willie Vocalite, who had a barrel shaped body and movable arms. Through remote control, Willie gave a speech to the passengers of the first commercial flight from New York to San Francisco. In 1939, Weeks and Barret created a humanoid robot known as Electro for exhibition purposes, including the 1939 and 1940 World's Fairs [15].

The first modern robot, digitally operated and programmable, called the Unimate, was invented by George Devol in 1954. Devol sold the first Unimate to General Motors. In 1961, it was installed in a plant in Trenton, New Jersey, to lift hot pieces of metal from a die casting machine and stack them [16].

REMOTE LABORATORIES

Remote laboratories have gained in popularity since the rapid uptake of the Internet in the mid to late 1990s. The demand for RLs has been brought about with the increasing financial and physical strain on universities to provide adequate practical experience to engineering related courses. Remote laboratories aim to address many of the issues faced with the modern university laboratory experience as they:

- Extend the students' learning experience by making more efficient use of their time;
- Increase the students' exposure to a greater range of laboratory experiences and equipment;
- Reduce costs, as the start-up costs of RLs are minimal compared with traditional laboratories, and they cater for a larger group of students;
- Give external students, in our case students in Singapore, the ability to conduct laboratory experiments;
- Provide the ability for teaching material to be delivered/demonstrated locally and offshore;
- Provide the ability for students to conduct experiments at times that suit them.

The major milestones in the development and implementation of RLs are documented below. This is not intended to be a complete list or a definitive source of references, but is a brief overview of the history of RLs, how they came in to being and how they have progressed from the primitive to the complex.

To make RLs a possibility, the first work had to be undertaken on the remote controlling of machines. This has long been a subject of research and development, with one of first examples being of Goertz and Thomson's *master – slave* teleoperators demonstrated at the Argonne National Laboratory in 1954 [17]. This was followed by the work of Ferrell and Sheridan, who further refined the supervisory or system control of the teleoperator in 1967 [18]. Teleoperators are machines or robots that require human guidance to control them remotely. They draw upon the operator's sensory perception and dexterity to guide them. These are generally used in hard to reach or dangerous locations. This technology has been the subject of extensive research, and applications such as robots being teleoperated by astronauts in space, telerobotic surgery and bomb disarmament robots showcase the development.

The first successful implementation of teleoperation via the Internet was developed by Goldberg in 1994 at the University of South California [19]. This Mercury Project, as it was called, included the operation of a simple robotic manipulator with Computer Gateway Interface (CGI) and a video feedback. It was the first laboratory where Internet users could order the robot to perform tasks in order to uncover buried artefacts in a sand filled terrarium. The Mercury Project was on-line for seven months from September 1994 to March 1995 and received over 2.5 million hits.

The reliable control of laboratory instruments has been available since the invention of the General Purpose Interface Bus (GPIB) by the Hewlett Packard Corporation at the end of 1960s, and it quickly became the standard of instrument

control [20]. This enabled instruments to be controlled by a computer and enabled measurement data to be taken and saved on the user's computer; hence, making the RL's work possible. Another key tool that had made the RLs easier to implement and cost effective was the LabVIEW graphical development environment [12]. This was introduced in 1986 by National Instruments (NI) and pioneered the use of virtual instrumentation [13]. Through its easy integration with GPIB serial and the Ethernet, more than 1,000 instruments could be implemented with little code development.

In 1991, one of the first proposals for a remote shared control system laboratory was presented [14]. This paper, entitled *A remotely shared control systems laboratory* addressed the concern that engineering laboratory facilities were out-dated and lacked resources. The lack of modern laboratory facilities has caused engineering societies, governments and universities to discuss a solution to this problem. Discussion has led to the proposal that universities share their laboratories facilities as a solution, by operating them via the Internet. This solution came to life via the LabShare project Australia in 2009 [15].

Bucknell University has extensive control systems facilities and resources, hence, making it a logical place to develop the system and share their equipment. Experimental stations were set up in classrooms both on campus and in other universities. To do this, they proposed the use of Networked Engineering Workstations to implement the control laboratory, view the Graphical User Interface (GUI), remotely logon, and make it possible to gather data and transfer it to another computer for further analysis. The proposed GUI would make it easier for users to interact with the laboratory by showing data as generated. Aburdene et al further refined this proposal in 1995 to include the ability for remote users to download the program anywhere and perform the experiment [16].

Early attempts at RLs utilising the client-server were limited to one student taking measurements and using instruments, as was discovered by the research project RemLab at the University of Naples and Salerno in 1994 [17]. However, they did break new ground by developing RLs that could be accessed using Web browsers. In 1996, Knight and De Weerth presented a similar laboratory system to control complex electronic test equipment [18].

Robotic RLs were also the focus of many research projects. In 1992, testing had already occurred for the new object-oriented, data driven, distributed control architecture for robotics laboratories, which enabled remote access over a wide area network. Five institutions, forming the Space Automatic/Robotics Consortium ((USA/RC), took part in this undertaking across four cities. It included four universities - The Texas A&M University, The University of Texas at Austin, The Rice University and The University at Arlington, in conjunction with The National Aeronautics and Space Administration (NASA) Johnson Space Centre [19]. This consortium was developed to promote robotic research for developing telerobotics for space-based applications.

In 1995, McKee and Barson developed a remote controlled laboratory allowing a robot and its sensory devices in the laboratory to be controlled remotely [20]. NETROLAB, NETworked RObitics LABoratory, at the University of Reading in the United Kingdom, aimed to develop a robotic facility that could be accessible remotely via the Internet to support teaching in the areas of robotics and artificial intelligence. This laboratory also pioneered the use of a camera with pan, tilt and zoom controls to view the robot live. The camera was used to take a static images of the robot and transmit it them to users. The data taken from the sensor modules were then analysed while the users were off-line, saving resources and allowing users to concentrate on operating the robot during the experiment. McKee and Barson went on to refine further the remote robotics laboratory by addressing resource allocation schemes and making the robot configurable.

By 1996, RLs were being developed to give a feeling of *being there*. Remote laboratories were constructed in such a way that they utilised both video and audio access [21]. This was called Second Best to Being There (SBBT) and was one of the first times undergraduate students were able to utilise a fully operational laboratory. This remote laboratory used a network application to access the laboratory, so only users with the particular program within the university could perform remote experiments.

Other RLs were using the local area (LA) network for access utilising a client-server structure [22]. This was an improvement on the above system but still did not allow for remote users from distant locations. It was not until 1998, when the SBBT facility was redesigned in Java, that access could be achieved via the World Wide Web (www) [23]. SBBT had progressed from other remote laboratories as it allowed students to collaborate with other students as they would in a physical laboratory.

Further advances into the development of RLs include an automated measurement system for semiconductor devices developed in 1997 [24]. This was the first RL to allow multiple users and multiple instrument experiment sessions. In 1998, Zoghi et al devised a self-contained camera system that can be controlled via the Internet [25].

The National University of Singapore (NUS) launched their *virtual laboratory* with an oscilloscope experiment in 1999 to over 1,000 engineering students making it one of the most heavily used RL in the world [26]. In addition, it is one of the most easily accessible with users only requiring a common Java enabled Web browser for access. This user friendliness has earned the NUS RL a considerable amount of positive feedback, proving that RLs can be a successful tool in engineering and science education.

Since 1999, many RLs have been developed in universities around the world. However, in Australia, the development has been slower. Perhaps the earliest and most well known Australian remotely controlled robot is the University of Western Australia's (UWA) Internet Telerobot [27]. This robot can be viewed live by a video camera and can be operated to pick up and move objects. It also has a chat facility so users can talk to each other. The UWA believes that their robot has been accessed by up to 500,000 users between 1994 and 2000.

In 1999, the UWA conducted a feasibility study on the RL's concept using supervisory control and data acquisition (SCADA) automation software [28]. The Telelabs project requires the LabVIEW Runtime Engine to be installed on the user's PC and relevant client libraries to be downloaded before anybody can use the RL.

At the University of South Australia (UniSA), the implementation of a RL began in 2002, after a team from the School of Electrical and Information Engineering was awarded one of three Teaching and Learning Improvement Grants offered at the University. On 6 September 2002, the NetLab was used successfully during a lecture in the Signals and Systems course. On 24 September 2002, during the 6th Baltic Region Seminar on Engineering Education, held in Wismar, Germany, the function generator, the device in the NetLab, was successfully controlled via the Internet. On 5 September 2003, the NetLab was demonstrated as a fully functional RL during the presentation at the university's lecture theatre in St Petersburg, in front of approximately 100 academics and researchers from around the world at the 7th Baltic Region Seminar on Engineering Education [29]. The NetLab is not only intended to be used for conducting real experiments on-line, but also to conserve the time spent in the real laboratory by providing a self-study tool in the form of very realistic genuine GUIs. International students in many overseas countries have successfully used it [30].

CONCLUSIONS

From very a humble beginning, with robots and remote control of different apparatuses, RLs have conquered many universities all over the world. They have never completely replaced real practical experiments, which are still conducted in the early years of all engineering and science tertiary programmes, but they are used in most advanced courses in later years.

Remote Laboratories proved to be a 21st Century teaching and learning experimental environment, with the advanced technology allowing them to bring the collaborative real environment to the front of the student's computer or even their new Iphone 5.

REFERENCES

1. Robot, Wikipedia, the free encyclopedia, 1 June 2011, http://en.wikipedia.org/wiki/Robot
2. Patil, A.S. and Pudlowski, Z.J, Instructional design strategies for interactive Web-based tutorials and laboratory procedures in engineering education. *World Transactions on Engng. and Technol. Educ.*, 2, **1**, 107-110 (2003).
3. Nedic, Z., Machotka, J. and Nafalski, A., Enriching student learning experiences in remote laboratories. *Proc. 2nd WIETE Annual Conf. on Engng. and Technol. Educ.*, Pattaya, Thailand, 9-14 (2011) (opening address).
4. Labshare Australia, 1 June 2011, http://www.labshare.edu.au/
5. Machotka, J. and Nedic Z., Online remote laboratory (NetLab). *Proc. 5th UICEE Annual Conf. on Engng. Educ.,* Chennai, India, 179-183 (2002).
6. Nedic, Z., Machotka J. and Nafalski A., Remote laboratories versus virtual and real laboratories. *Proc. 33rd ASEE/IEEE Frontiers in Educ. Conf.*, Boulder, Colorado, USA, T3E-1-6 (2003).
7. Karel Čapek. Wikipedia, the free encyclopedia, 1 June 2011, http://en.wikipedia.org/wiki/Karel_%C4%8Capek
8. Josef Čapek. Wikipedia, the free encyclopaedia, 1 June 2011, http://en.wikipedia.org/wiki/Josef_%C4%8Capek
9. Iliad. Wikipedia, the free encyclopedia, 1 June 2011, http://en.wikipedia.org/wiki/Iliad
10. Pygmalion. Wikipedia, the Free Encyclopedia, 1 June 2011, http://en.wikipedia.org/wiki/Pygmalion_(play)
11. Leonardo da Vinci. Wikipedia, the Free Encyclopedia, 1 June 2011, http://en.wikipedia.org/wiki/ Leonardo_da_Vinci
12. Knight, C.D. and DeWeerth S.P., A shared remote testing environment for engineering education. *Proc. ASEE 1996 Annual Frontiers in Educ. Conf.*, Washington DC, USA, 1003-1006 (1996).
13. Chenay, M., *Tesla, Man out of Time*. New York: Dorset Press (1989).
14. Schaut, S., Robots of Westinghouse 1924-Today. Mansfield Memorial Museum (2006).
15. Robot Dreams. Wikipedia, the Free Encyclopedia, 1 June 2011, http://en.wikipedia.org/wiki/Robot_Dreams
16. Robot Hall of Fame, 1 June 2011, http://www.robothalloffame.org/
17. Goertz, R. and Thompson, R., Electronically controlled manipulator. *Nucleonics* (1954).
18. Ferrel, W.R. and Sheridan, T.B., Supervisory control of remote manipulation. *IEEE Spectrum*, 4, 81-88, (1967).
19. Golberg, K., Masch, M., Gentner S., Rothengberg N., Sutter C. and Wigley J., Desktop Teleoperation via the World Wide Web. *Proc. IEEE Inter. Conf. on Robotics and Automation,* Nagoya, Aichi, Japan (1995).
20. IEE-488, 1 June 2011, http://en.wikipedia.org/wiki/IEEE-488
21. Welcome to LabVIEW, 1 June 2011, http://labviewwiki.org/HomeWiki
22. National Instruments, 1 June 2011, http://www.ni.com/

23. Aburdene, M.F., Mastascusa, E.J. and Massangale, R., A remotely shared control systems laboratory. *Proc. ASEE 1991 Frontiers in Educ. Conf.*, Austin, Texas, USA, 589-592 (1991).
24. Alegria, F. and Ramos, H.G., A remote controlled automated measurement system. *Proc. 1997 IEEE Instrumentation and Measurement Technology Conf.*, Ottawa, Ontario, Canada, 1009-1013 (1997).
25. Aburdene, M.F., Mastascusa, E.J., Schuster D.S. and Snyder, W.J., Computer - controlled laboratory experiments. *Proc. ASEE 1995 Frontiers in Educ. Conf.*, Atlanta, Georgia, USA, 2088-2095 (1995).
26. Arpaia, P., Baccigalupi, A., Cennamo, F. and Daponte, P., A distributed measurement laboratory on geographic network. *Proc. IMEKO 8th Symp. on Measurements and Calibration Methods on Electrical Quantities and Instruments,* Brussels, Belgium, 294-297 (1996).
27. Taylor, K. and Travelyan, T., Australia's Telerobot on the Web. *Proc. International Symp. on Industrial Robots,* Singapore, 39-44 (1995).
28. The Telelabs Project, 1 June 2011, http://telerobot.mech.uwa.edu.au/
29. Machotka, J., Nedic, Z., Calabrese, R. and Chen, M., The development of a remote laboratory NetLab at the University of South Australia. *Proc. 7th Baltic Region Seminar on Engng. Educ*., St Petersburg, Russia, 133-136 (2003).
30. Nafalski, A., Nedic, Z., Machotka, J., Ferreira, J.M.M. and Gustavsson, I., Students and staff experiences with international collaboration in the Remote Laboratory NetLab. *Proc. 1st WIETE Annual Conf. on Engng. and Technol. Educ.,* Pattaya, Thailand, 40-45 (2010).