Moving Away from Simulations: Innovative Assessment of Mechatronic Subjects Using Remote Laboratories

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***Abstract*— In response to the rapid growth of online teaching and learning, University of Technology, Sydney (UTS) has been developing a number of remotely accessible laboratories. In this paper, we present our newly developed remote lab robotic rig that uniquely addresses challenges in Mechatronic courses. The rig contains a mobile robotic platform equipped with various sensory modules placed in a maze with a pantograph power system enabling continuous use of the platform. The software architecture employed allows users to develop their simulations using the Player/Stage simulator and subsequently upload the code in the robotic rig for real-time testing. This paper presents the motivation, design concepts and analysis of students' feedback responses to their use of the remote lab robotics rig. Survey results of a pilot study shows the participants highly agreeing that the remote lab contributes to, "deeper understanding of the subject matter", "flexible learning process" and "inspire research in robotics".**

Keywords—Remote laboratories, robotic rig, engineering education, innovative assessment

I. INTRODUCTION

Laboratory based works play an essential part in engineering education. The laboratories often consist of specialized, complicated and expensive equipment. To obtain best learning outcomes and to cater for today's student expectations of more flexibility, the laboratories may also need to have frequent access for extended periods of time even beyond the normal timetabled class times. This causes formidable challenges to capital and operational costs of the laboratories.

Utilization of software simulations could be considered as a solution to the above problems. This allows the student to interact with simulation models which could be approximations to equipment experimentation. However, simulation based approaches are inherent with significant pedagogical issues relating to student perception. The main criticism is the artificial nature of the simulations giving rise to poor sense of reality [1] and obvious disconnection between real and virtual worlds [2]. In some cases, students may also question the fidelity of the simulations rather than their erroneous mental models which cause unexpected outputs. Therefore, it has been argued that in the context of deeper understanding of the subject matter, there can be no substitute to real laboratory equipment [3].

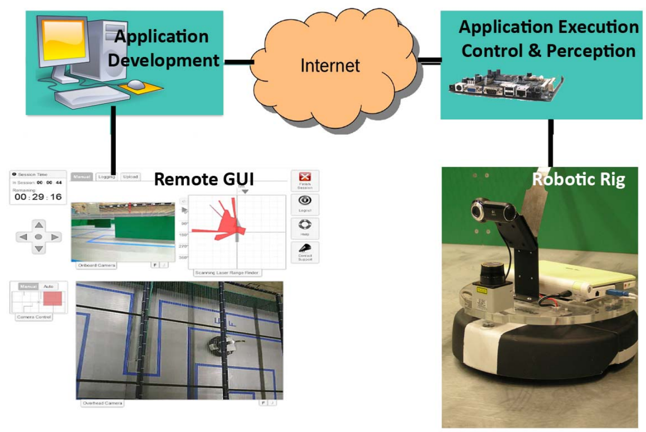

Fig. 1. In the remote lab Robotic rig, clients connect over the internet, log data, upload code and experimentally evaluate the performance. The system shares the resources through a booking system and provides continous 24/7 operation.

In this context, remote laboratories can offer attractive solutions as they are consisted of real equipment in physical lab settings (see Fig. 1). The remote labs may also be able to integrate with MOOCS (Massive Open Online Courses) type courses developing next generation of courses. There were many studies on the pedagogical aspects of remote labs studying learner satisfaction and achievement [4], relationships between the user and the technology, the instructor and students, and the relationships among the students [5]. Although, the literature does not support substantial conclusive evidence on remote labs being overpowering the proximal labs, there is some literature on achieving similar educational outcomes using remote or proximal equipment [6]. On the other hand, there are studies to suggest an alternative view of the dependency of the educational outcomes on the criteria and the form of access [7][8]. In some cases, the outcomes appear to be enhanced and in others they appear to be degraded.

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Although, the students do not proximally presence in a remote lab, it provides a Web interface to interact with the equipment. However it can cause differences in mental perception of hardware [9]. The students may not perceive the hardware that they have at proximity as the same as the hardware that are remotely accessible. This issue is in general addressed by introducing various technologies [10] such as real time video and audio streaming.

The remotely accessible laboratory concept was first reported in 1996 by Aktan et al [11] and followed by many others [12][13] including University of Technology, Sydney (UTS)[14]. UTS has decided to strategically pursue on establishing remote labs for undergraduate engineering courses in June 2001 [14]. As part of the remote labs, five rigs were developed. They include microcontroller design (12 x embedded operating system experiments), beam deflection (10 x beam behavior experiments), automation (5 x PLC experiments), dynamics and control (3 x coupled water tanks experiment) and programmable hardware design (5 x FPGA experiments). The technical challenges such as reliability, real-time video and audio streaming (bandwidth limitations), service quality and arbitration of multiple simultaneous connections to shared online equipment have been continuously improved.

This particular paper focuses on the development and integration of the new addition: mobile robotic remote lab rig. It was motivated by the requirement of mobile robotic platforms with many sensors to be used in mechatronic undergraduate as well as postgraduate subjects at UTS. The robot can navigate in a maze while collecting onboard data; laser range and bearing data, camera images and odometry. The users can remotely access (see Fig. 1) the robotic rig for remote controlling, autonomous navigation, code uploading, testing and data recording for post processing and visualization. Therefore, it has many uses in the areas of sensors and signal processing, control and other advanced robotics topics such as localization, mapping and navigation. The development of the *mobile* robotics rig had additional challenges to the existing UTS remote labs due to the mobile nature of the platform requiring reliable localization and battery charging mechanisms.

The paper is arranged as follows. Section II describes the software framework of the remote lab whereas Section III describes the hardware architecture of the remote lab. How the remote lab based assessments were integrated in the curriculum is described in Section IV. Details of the pilot study is given in Section V. Section VI concludes the paper.

II. SOFTWARE FRAMEWORK

The software framework of the remote lab is discussed in this section.

A. *Software framework of the whole system*

The UTS Engineering Remote Laboratory has developed an extensive framework to enable shared access to physical apparatuses remotely via the Internet (see Fig. 1). Sahara is the software used to access remote laboratories. It is a suite of open source software components that has been developed at UTS under the LabShare program [15]. Sahara (version 3.0) was designed to be a scalable, stable platform that enables the use and sharing of a variety of types of remote laboratories and maximizes remote lab usage by implementing queuing and booking (or reservations) for users over a group of identical laboratories, support for federated access, and additional administrative tools. The Scheduling Server (SS) is the `heart' of Sahara as it enables booking, session management, user management and data storage. The software system contains a front end (web interface as shown in Fig. 3) and a back end (running on the robot). This configuration allows for offline simulations and online real-time testing using the rig. The web interface front end enables manual control of platform, uploading and execution of code and retrieval of on-board sensor data. The front end development is initially presented below followed by the back end.

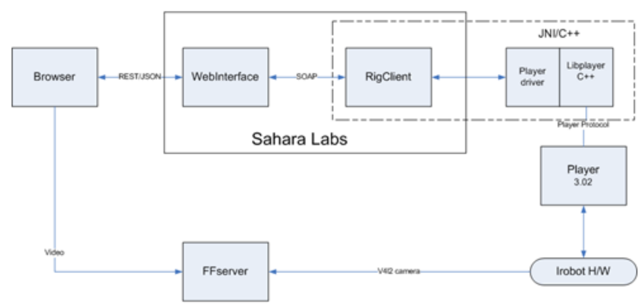

Fig. 2. Block diagram of the mobile robotic rig subsystem.

In order to integrate the mobile robotic rig into Sahara, a Sahara Rig Client needs to be developed so that a rig can be accessed using the Sahara Web Interface and managed with the Sahara Scheduling Server. Thus the end user is only required to have a web browser to operate the rig instead of needing any custom software. The development for the Rig Client is in Java and PHP, HTML, JavaScript and CSS for the web interface. The mobile robotic subsystem and the encapsulation of Shara labs are denoted in Fig. 2. As the software system on the mobile robotic rig is C++ specific, a Java Native Interface (JNI) was designed as a wrapper to enable integration. In addition, equivalents of the underlying player utilities such as playerjoy (which is used for teleoperation) were developed with web technologies such as HTML5 Canvas in order to be integrated into the web interface. Thus the web interface front end enables manual control of platform, uploading and execution of code and retrieval of on-board sensor data via a web form. This framework enables code to be developed offline and only uploaded for execution resulting in greater throughput of students per rig and maximizes the utilization of the platform in session times.

B. *Software framework of the mobile robotic platform*

The software system back end is based on the open source Player/Stage Project [16], which has been extensively used in the field of Mechatronics from 2001. Player provides a level of abstraction between the hardware in the robot and the control programs accessing it, facilitates high-level control of the robot functionality, and provides some built-in commonly-used navigation algorithms. This allows users to quickly develop complex control algorithms in simulation environment (Stage) and shared with any real hardware robotic systems with similar capabilities supported by Player.

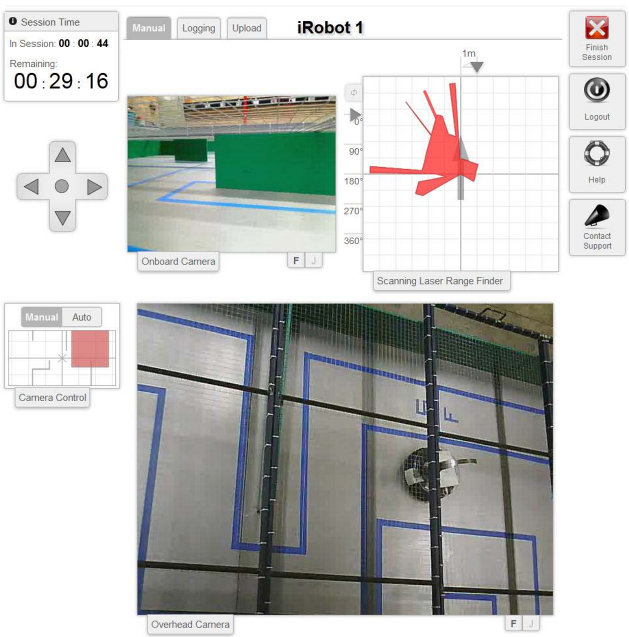

Fig. 3. User interface of the mobile robotic rig

III. HARDWARE ARCHITECTURE

The Mobile Robotics rig (see Fig. 4) was constructed in-house at UTS and is made up of the following main components; (1) iRobot 'Create' mobile robotics platform [17], (2) Asus eeePC netbook running the Player robot control software package, (3) Sensors: Hokuyo Laser rangefinder [18] and Logitech QuickCam Vision webcam.

The iRobot Create is a mobile robotics platform aimed at the education and development markets. It consists of a two-wheel differential drive system, a variety of sensors including wheel odometry, bump sensors, cliff detection sensors and infra-red detectors. A well-documented serial communication protocol allows access to its sensors and control of its motors. The Laser is a URG-04LX scanner which is capable of measuring ranges up to 4m at 0.33° angular resolution with a 270° field of view. It operates using the time of flight principle and is the primary sensor employed by the mapping and localization algorithms used in this rig. The Logitech QuickCam Vision webcam is running at a resolution of 800x600 at 5 frames per second and is used for both visual feedback, and as an additional laser rangefinder-like sensor. An Inverse Perspective Mapping algorithm [19] is employed to estimate the distance to close by objects based on camera images. These distances are then used to mimic a rangefinder sensor, and are provided to the user for comparison with the laser range/bearing data to have an appreciation of sensor measurement errors.

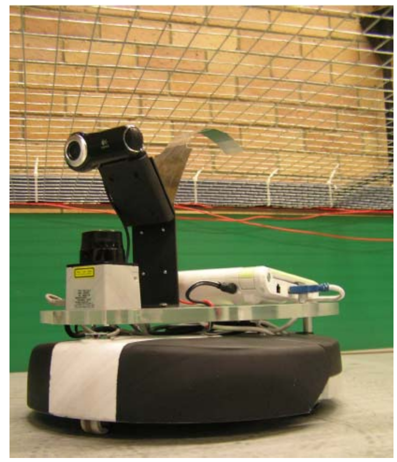

Fig. 4. Mobile robotic rig and the pantograph power system.

The robot operates within a simple maze-like environment, allowing localization and navigation algorithms to be tested (see the overhead view in Fig. 5). The walls of the maze are a distinctive green color to enable them to be exploited with a camera for obstacle avoidance. As the mobile robotic Rig traverses a large area and visual feedback from the onboard camera does not provide sufficient information for users on the global location of the platform, an overhead PTZ webcam is used as the main video stream displayed on the remote labs website, and shows a large part of the maze and the robot (see Fig. 5). The PTZ location for the camera to focus on is determined form the robot localization solution computed on the platform. Since the remote lab is required to be consistently operational, a continuous power supply is a necessity. As the rig is a mobile device, a battery-based power supply is not feasible due to its limited operational time. Therefore, power is supplied for continuous battery charging through the conductive mesh (the 'pantograph', which is the mesh above the robot in Fig. 4) above the maze and the metal sheeting which makes up the floor. In case, there are brief power interruptions, the robot can be operational with onboard battery for up to ~30 minutes.

Fig. 5. Overhead view from the ceiling mounted PTZ camera.

IV. CURRICULUM INTEGRATION

Advanced Robotics subject in the faculty of engineering and information technology at University of Technology, Sydney was chosen for the first implementation. The Advanced Robotics subject presents a broad overview of the technologies associated with mobile and industrial robots. Major topics covered are sensing, mapping, navigation and control of mobile robots and kinematics and control of industrial robots. The subject consists of a series of lectures on robotic fundamentals and case studies on practical robot systems. The objective of the subject is to provide students with essential skills necessary to be able to develop robotic systems for practical applications.

There are two assessments involved in the subject. One is about localizing a mobile robot using particle filters and the other is about path planning of a mobile robot. In the past, the two assessments were simulation based. The students were asked to develop and test their localization and path planning algorithms using Player/Stage simulation in Linux operating system. Due to relatively large number of students involved (40 in 2011) and the requirement of complex hardware/software interfaces, it is almost impossible to provide actual mobile robotic platforms to each of the students for evaluating algorithms without a huge budget.

The mobile robotic remote lab rig was proposed as a possible solution. The students first evaluate and test their algorithms in simulation (70% of the marks) similar to the previous years. After the testing phase in simulation, the same code is uploaded on the remote lab robotic rig for further evaluation (30% of the marks). The students often had some challenges due to the incompatibilities between ideal simulation world and real world. They have to investigate the problems and troubleshoot by fine tuning some relevant parameters. It is believed that this process contributes to enhance the students' deeper understanding of the subject matter.

The assessments were tested in several ways before introducing in the subject. In the first phase, the instructors and tutors of the subject have performed the assessments by themselves. Based on their feedback some technical aspects and documentation were improved. In the second phase, a pilot study and a pre and post survey were carried out with a small number of students. The survey results were used to fine tune the assessments, documentation and user interface. In the third phase, the assessments were introduced in the Advanced Robotics subject (in Spring 2012).

V. PILOT STUDY

As detailed in the previous section, a pilot study was carried out before the remote lab based assessments were introduced in the Advanced Robotics subject. Purpose of the pilot study was to fine tune the technological issues, assessment tasks and to assess the feasibility. It also serves us to understand student perception of the system and to have a priory knowledge about the student difficulties. The pilot study related to assessment 1 (robot localization) will only be discussed in this paper.

There were eight subjects participated in the pilot study consisting of one female and seven male students. The subjects have also participated in a pre-study and post-study survey. Their C++ programming skills, knowledge of Linux operating system and robot localization ranged from poor to very good covering a broad range. Five of them were "Very Unfamiliar" or "Unfamiliar" with remote lab rigs and two of them were "Familiar" with UTS remote labs.

All the student participants in the pilot study were given the Assessments as it would be given as part of the Advanced Robotics subject. Assessment due date was strictly enforced and 75% of the participants could complete the assessment task in less than 10 hours. Fig. 6 shows the distribution of number of hours that the participants spent on the first assessment. The participants who have attempted the assessment were given $40 (AUD) as an appreciation.

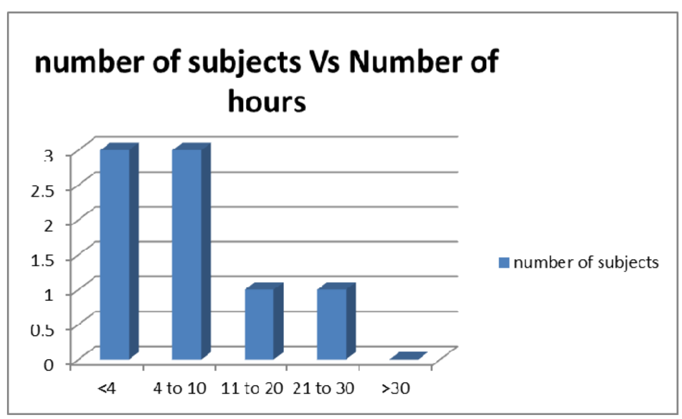

Fig. 6. Distribution of time spent on the Assessment

All the participants thought that it is advantageous to upload and test the algorithms on the remote lab. Three of the participants though that there was very low resemblance between simulation results and remote lab results. Another three participants were unsure about it. This reflects the students' perception on simulation vs remote lab experiments. Although the same algorithms can be used, the students often need to fine tune or tweak the parameters which were used in simulation to be used in actual hardware. The students thought the simulated algorithms should work seamlessly once uploaded in the remote lab set up. Therefore, slight fine tuning required was thought as low resemblance between the two systems.

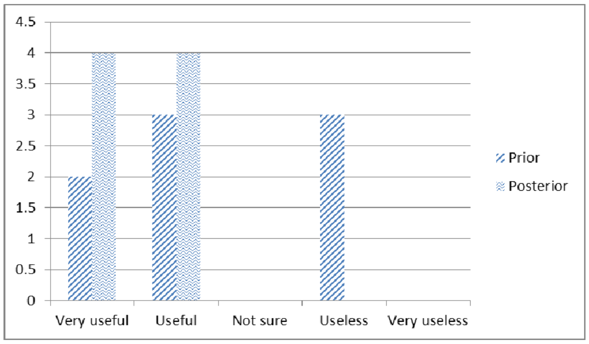

Fig. 7. Usefulness of the remotelab as part of the flexible learning process: Prior and post study results

Prior to the study, the survey indicated that three out of eight participants thought that the remote lab was a useless tool to improve the students' flexibility in learning process. However, the post study showed a drastic change in the student perception indicating all the eight participants either said "Very Useful" or "Useful" in a five scale (Very Useful, Useful, Not Sure, Useless, Very Useless) for the usefulness of the remote lab as part of the flexible learning process. Similarly all the eight participants have rated either "Very high" or "High" in a five scale (Very High, High, Not Sure, Low, Very Low) for the amount of contribution of the remote lab to inspire research in robotics. All of the participants rated "Very High" or "High" in a five scale (Very High, High, Not Sure, Low, Very Low) for amount of contribution of the remote labs for deeper understanding of the subject matter.

VI. Conclusions

A mobile robotic remote lab rig consisting of various sensors has been fully developed at UTS. The software architecture allows the users to remotely control the robot, gather sensory data and most importantly, upload their simulation code over the internet and test on a real robot. Subject assessments were developed and fine-tuned through attempts by tutors and through the pilot study. Feedback from the pilot study demonstrated that the novel assessment approaches are more flexible, lead to deeper understanding the subject matter and contributes to inspire research in robotics.

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