

# Issues faced in a Remote Instrumentation Laboratory

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**Abstract**—An Online Lab is a multi-university shared laboratory environment, where students can exercise their knowledge as they would do in a physical lab. The idea is to have maximum resource utilization and collaboration between universities by sharing of ideas. This kind of remote laboratory negates the economic issues to set up a laboratory and allows every student to have an experience of real laboratory. As part of Ministry of Human Resource Development (MHRD) Robotics Lab project a study on state of art of remote labs was conducted. This paper discusses some key issues in the design and operation of such remote labs. The lab should be remotely usable by a large student body, with varied levels of sophistication, all the way from elementary learners, to PhD students doing research. In addition, the high design load implies that the architecture should be highly parallel, and structurally reliable.

**Keywords**-Virtual Lab; Education; Remote Instrumentation

## I. INTRODUCTION

Many institutes complain about the underutilized laboratory infrastructure in their campuses. And on the other hand, due to financial or geographical hazards not all infrastructures can be made available everywhere. The remote lab concept is beneficial in both cases. This is an online multi-university shared laboratory where students can experiment with relaxed time restrictions. Such remote lab not only provides student with every infrastructure required to aid in studies, but also can allow a healthy collaboration between faculty and students of different institutes. Along with the hardware, the students can share ideas also. A lab to be used by multiple universities which are geographically apart should be scalable enough to support large number of students. This paper explains in detail the issues involved in exploring remote labs and the lessons learnt are to be used in designing a Robotics Remote Lab, with which IITB is chartered by MHRD. The only remote triggered motion involving laboratory currently set up is an Inverted Pendulum Remote laboratory in Queensland, a remote Robotics laboratory is a much complicated assignment.

In this paper, section II discusses existing virtual laboratories, [1] [2]. Some experiments were performed on these platforms, the observations from these are stated in

section IV and V. The insights from the experiments are to be used to develop the robotics virtual lab as explained in the later section.

## II. PRIOR ART

### A. Prior Art - Simulation Labs

There are many remote lab websites set up in recent past. These provide pre-modelled experiments only. Below are examples of few simulation based remote labs:

- I Virtlab [3] is a series of simulated experiments and demonstrations for a course in chemistry. Students can also build their own simulations using electronic spreadsheets.
- II OLAB [4] is a distributed VLSI lab that connects all BITS campuses (Pilani, Goa, Dubai and Hyderabad) with an industrial centre at Bangalore. This boasts some of the best-in-class Electronic Design Automation (EDA) tools. These tools support simulations for Full Design Flow, RTL to GDSII, embedded design and board design.
- III Virtual labs produced by the Howard Hughes Medical Institute (HHMI) [5] have fully interactive biomedical laboratory simulations and include a bacterial identification lab, a cardiology lab, a neurophysiology lab and a virtual ELISA (Enzyme-Linked Immunosorbent Assay), using human antibodies to diagnose disease. The Virtual Labs Project in Stanford [6] began in 1998 with funding from HHMI.
- IV At the Johns Hopkins University virtual laboratory/science course [7] offers simulation-oriented problems without the overhead incurred in maintaining a full laboratory. The objective of the course is to introduce students to experimentation, problem solving, data gathering, and scientific interpretation early in their careers

### B. Simulation Vs Remote Labs

In the paper on *A Study of Remote, Hands-On, and Simulated Laboratories* [8] the author says a remote lab is a blend of both physical and virtual aspects. As in a remote laboratory the experiment actually takes place, and the data reflects interactions between physical devices, not

virtual entities it is very similar to hand-on experiments conducted in actual laboratory. On the other hand, as in case of simulation, in remote laboratories also the student need not be actually present near the laboratory apparatus to conduct an experiment. The experiments are often run from dormitory rooms; students use the internet to remote-control the apparatus. The student can pick the time to run the experiment, and as in a simulation may be able to run the lab procedure multiple times, thereby exploring the space of potential results by varying the experimental parameters. No student time is spent to set-up or tear down the apparatus.

### C. Remote Labs

The idea of remote laboratories is not new but there are very few actual working remote laboratories.

- I MIT iLabs [9] is one such pioneer in the field of remote lab integrated with real hardware. MIT has hosted an electrical engineering lab online which is shared across many universities.
- II The Vlab [10] (under development) targets to have lab environment for every engineering course. This is a joint venture of the major universities of India that includes the IITs and IIITs. At IIT Bombay many experiments are performed remotely using a Single Board Heater Systems (SBHS) [11]. This lab-in-a-box setup is hosted primarily for teaching/studying the theory of control systems.
- III University of Technology Sydney remote laboratory [12], uses real, physical equipment that has been instrumented with cameras and connected to the internet. The experiments vibrate, move around and make noise, exposing students to a real-world learning experience in their own time and as often as they want. Over 1,000 UTS students use the facility every semester.
- IV The VISIR (Virtual Instrument Systems in Reality) is a project by Blekinge Institute of Technology (BTH), Sweden together with National Instruments in USA and Axiom EduTech in Sweden [13]. In this lab, the remote control option implemented is for an electronics laboratory, featuring remote circuit wiring using a virtual breadboard and a relay switching matrix combination, and the second one is for a signal processing laboratory with emphasis on mechanical vibration experiments.
- V Also, The W.M. Keck Observatory [14], located at the summit of the Mauna Kea volcano in Hawaii, houses the world's largest optical and infrared telescopes. Due to its location and elevation it sits at nearly 14,000 feet many researchers cannot go to the facility, but researchers share access to the observatory through remote instrumentation.

#### *Pros and Cons of Remote Laboratories*

While no across the board general statements can be made, some advantages of remote laboratories are:

- 1 Students can access the lab any-time, in principle 24x365.

- 2 As compared to simulations, remote labs are closer to real physical world.
- 3 Reduced infrastructure expenditure.
- 4 Centralized infrastructure essentially results in higher infrastructure utilization and reduced maintenance cost. Duplication of little used resources is avoided.
- 5 Reduction in administration time needed for scheduling, setting up, and refreshing labs.
- 6 Establishment of a safe, secure staging environment where learners can collaborate with peers.

Based on the current state-of-art, a few of the trade-offs of using a remote lab over a physical lab include:

- 1 Remote Lab is not a real lab. Full state observability is not available: students do not get to on-the-fly select, and probe different outputs of the hardware.
- 2 The experiments in a remote environment typically have limited flexibility. At the present time, most of the experiments are pre-defined (canned), with the user able to change only a few parameters. However efforts are put to improve flexibilities of the remote labs in future.

### III. CHALLENGES FACED IN A REMOTE LAB ENVIRONMENT

The design and operation of the experiments are of course topic/domain dependent, and some issues for a remote robotics laboratory are illustrated in Section VI. In addition, there are few generic issues to be faced in setting a virtual lab which have to be addressed.

- 1 Generic design issues include provision of adequate speed and fault tolerance, and appropriate structures (domain dependent) for achieving these goals. The software involved in remote labs should support
  - a Simulation as a gate to access the physical hardware.
  - b Audio/video feedback
  - c Software reliability
  - d Database backup with check points
- 2 Generic operational issues include the ability to handle an uncertain large load, both in terms of the runtime of an individual experiment, as well as the number of times a given experiment is repeated by a student. At present, little information is available on the stochastic of student experiment distribution, but it is likely to be considerably different from poisson, successful experiments are typically repeated with different parameter settings and also with subsequent experiments in the same lesson. However, a single student/group of students cannot monopolize the laboratory. Hence sophisticated priority scheduling schemes may be required.
- 3 The design load is quite high given the anticipated usage pattern in India. A university easily has 50-60 students per discipline. 15-20 such universities participating simultaneously result in a total load of 750 to 1200 potential simultaneous users. For all but the simplest device experiments, times taken are easily in the 10's of minutes. Hence handling the total

load in even a single day of 8 hours requires up to  $1200 * 1 / (6 * 8) = 24$  parallel systems.

To examine the state-of-art with respect to these requirements, two of the existing Remote Labs were tested and the results are discussed in the next two sections. The first is the Micro-electronics lab at MIT iLabs [9] which is an expensive infrastructure and requires expertise to set up. The second is the Single Board Heater system at IIT Bombay [11] which is a relatively inexpensive infrastructure for a thermodynamics control experiment.

#### IV. EXISTING LABS : USER EXPERIENCES I

MIT iLabs hosts various micro-electronic experiments ranging from a Micro-electronics Devices Lab to an Inverted-pendulum Lab. For the analysis at IITB one of the infrastructures provided by MIT, the *Micro-electronics Device Characterization* was tested at peak loads. This lab enables users to measure the current-voltage characteristics of various micro-electronics devices at any time, from any physical location, using a Java-enabled web browser. [15], [16]

##### A. Hardware Infrastructure

The Lab Server is a PC running Windows 2008 that houses all of the software components of the system. In addition, this machine is configured with an Agilent 82357B PC/GPIB Interface Adapter. This allows the Lab Server to control and receive data from all hardware components that are connected to the GPIB network. At the laboratory eight microelectronic devices are available for experimentation; the request for an experiment is routed to one of these devices, using an E5250A switching matrix. An Agilent 4155B Semiconductor Parameter Analyzer carries out the actual measurements. This device provides the test signals and receives/processes returned signals from a given microelectronic device under test. Specifically, the device under test is placed in an Agilent 16442A Test Fixture, which is connected to the signal outputs of the 4155B. The 4155B is directly controlled by the Web Server through the system's GPIB network. This enables the Web Server to configure the 4155B and initiate the test process [17].

##### B. Functionalities Provided

The iLab proved to be quite useful to learn basic semiconductor device physics. For example, one student tested a BJT, with a small positive collector-emitter voltage (figure 1). As the base drive was increased, the collector current was observed to first rise and then fall, and even become negative (current going out of collector). This shows that the base-collector junction becomes forward biased as the base drive is increased. This insight would not be available in most simulations, unless they use a detailed device model.

NMOSFET was also tested. The gate current is ideally zero, but there is always some leakage either in the device, or the measurement system. Students were asked to look at the gate current, in successive experiments,

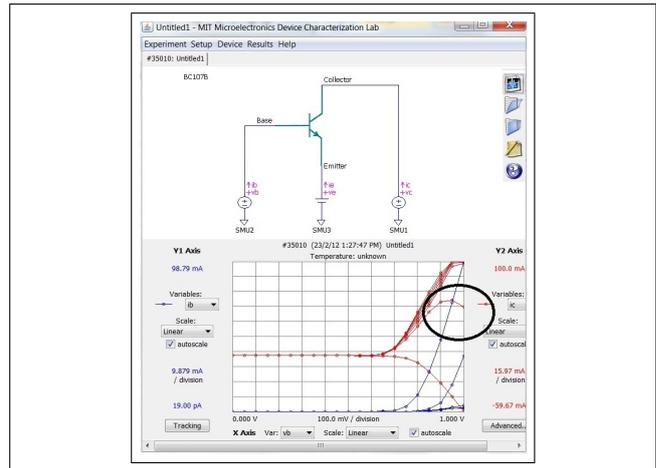


Figure 1: Rise and fall of collector current

keeping parameters (VGS, VDS) the same. Very low values were obtained for the gate current, and the values change from experiment to experiment, indicating leakage behavior (as shown in figure 2). The very low values of gate current (pA), also indicates the utility of a remote high performance infrastructure - off the shelf instruments cannot easily go to the picoampere sensitivity level.

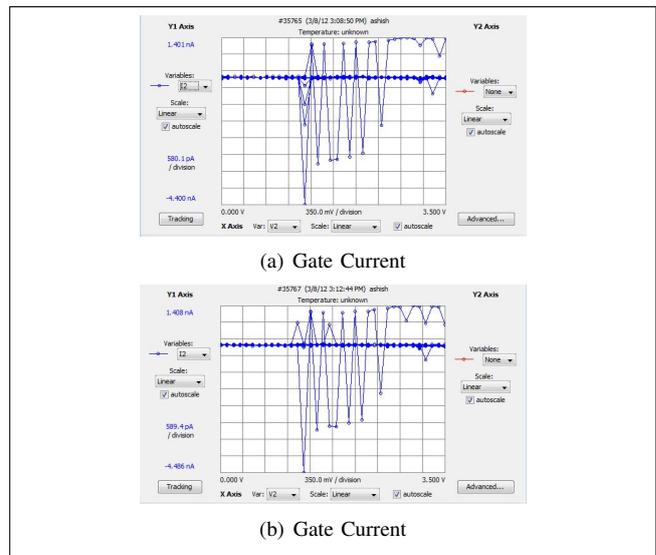


Figure 2: Noise in Gate Current

##### C. Performance Analysis

To observe the behavior of the remote lab, the lab was subjected to peak load. A group of fifty students from IITB tried to load the iLab Server to conduct the Micro-electronics Characterization experiment in February 2012. Each student asked for an average of 400-500 points to be read and plotted for a 3-terminal NMOS or BJT. A queue was observed that required students to wait for as long as 45 minutes for an experiment. The following graphs show the queue depth and total user wait time for the experiments submitted during this test. The graphs are plotted with the data obtained from the MIT iLabs server.

Figure 3(a) gives the details of the queue position at the start of the experiment. Figure 3(b) shows the duration for each experiment to finish.

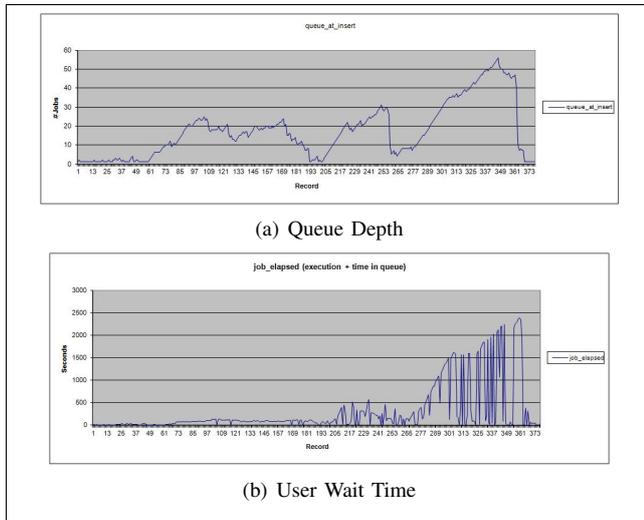


Figure 3: MIT Results

#### D. Insights from User tests

Below are the few observations of the load test on MIT iLabs consolidated after the load tests conducted from IITB.

##### 1) Architecture Limitations:

- 1 The records show that worst case scenario a student had to wait for 40 mins to do the experiment. This observation is for an experiment that takes 60 seconds to execute without a queue. The robotic/mechanics lab is expected to have experiments that take easily 20 mins, so measures are to be taken using parallel approach and multiple hardware to support high load. Of course whatever is the amount of backup hardware used; there will be some load for which the system will not have sufficient capacity.
- 2 MIT iLabs accepts an experiment only when it is feasible and will not affect the hardware. Already limits are set for the voltage values, so no student can damage the hardware. Finding and fixing such values for every kind of hardware is again not easy. The use of simulation as first gate is a good approach to give students an idea of what can happen to the hardware with their values. For these reasons the simulations should be as close to real world as much possible.
- 3 Sometimes a student would like to use his learning from the first experiment and would want to run a second experiment using the same. The slot allotment and queue should have a provision for it.
- 4 One output graph suggested the device might be heated. If the lab is dealing with hardware that gets heated due to continuous use or charge leak, then a system recovery mechanism should be in place to deal with such scenarios so that the hardware is not damaged.

##### 2) Suggested Enhancements in the Architecture:

- 1 It was observed in rare occasions, during peak loads a read time out error occurred. The main reason for such an issue could be overload in the network. A solution could be - If an experiment finishes the readings should be stored in the database, so a student can retrieve those without the need to actually redo the experiment. Another solution, supported by iLabs is allowing the student to extend the slot time and do the experiment again at the same time.
- 2 During the experiments, at one point the professor wanted to show his observations to the class but that required waiting in the queue. MIT iLabs architecture already supports a priority scheduling mechanism to help in such scenarios.
- 3 Some mechanism has to be in place to serve thousands of students satisfactorily. Apart from having the hardware to support it or to parallelize the process, one way could be to extrapolate i.e., do not actually take all the readings use the previous experiment results and knowledge of the instruments to get the output. If the inputs are exactly same use the same readings from the database.

#### E. Cost of the infrastructure

To visualize the importance of Remote Labs in case of a Micro-electronics Device Characterization experiment it is necessary to look at the cost in creating in the lab. The cost of individual parts

- 1 Lab Server - PC with Windows 2008 = 1000 \$
- 2 Agilent 82357B PC/GPIB Interface Adapter = 552 \$
- 3 Agilent 4155B / HP 4155B Semiconductor Parameter Analyzer = 37400 \$ (from [18])
- 4 Agilent 16442A Test Fixture = 3000 \$ (8 of these, 24000 \$)
- 5 Agilent E5250A switching matrix = 20000 \$

The cost of the infrastructure required in iLab for Micro-electronics Device Characterization experiment is of the order of 90,000 US\$ equivalent to 45,00,000 /- INR. This is a very large amount for universities in India or worldwide, which makes it desirable to be shared by multiple universities.

#### V. EXISTING LABS : USER EXPERIENCES II

The Single Board Heater System (SBHS) [19] hosted at IITB is analyzed in this section. This lab aims to allow students to remotely conduct various experiments in the Instrumentation and Control System. . PHP-mysql is used for web frontend and database. It uses Scilab at the client end to carry out various control experiments on SBHS. Java application is used for communicating the data to and fro from the server and client.

##### A. Hardware Infrastructure

The heater system, designed and developed at IIT Bombay, consists of a heater assembly, fan, temperature

sensor, microcontroller (ATmega16L) and associated circuitry. The setup has a provision for interfacing with either a serial or a USB port of the computer. MAX232, a TTL-RS232 converter and FT232, a USB-UART converter, respectively, take care of these. A jumper is provided for the port selection. This experimental setup is designed to operate at 12 V DC. The microcontroller firmware limits the maximum current consumption to 1.6 A.

### B. Functionality Provided

The SBHS lab allows a student to do temperature control experiments, both open loop and closed loop. The lab apparatus was subjected to a step function heater input and a step function fan input and the results obtained are shown in figure 4.

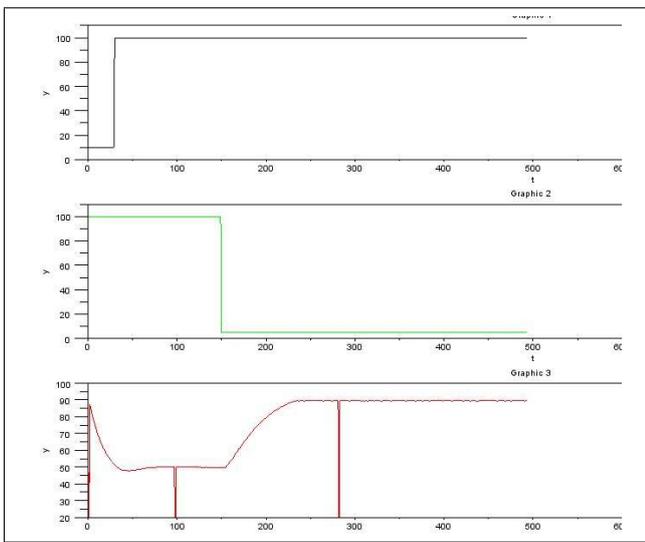


Figure 4: SBHS Output Graph

### C. Insights from User tests

To analyze the system, a group of twenty students from IITB campus logged in. Every student on log-in was assigned a specific machine.

#### 1) Architectural Limitations:

- 1 The experiment input were to be given by a SciLab control file and the client was connected to the server using python script, this experiment requires a lot of software setup to be done before the experiment. Thus this adds an overhead, also SciLab software is specific for an operating system.
- 2 The slots are fixed for one hour duration for example a student can log-in at 5.30 PM and would have options of booking the current slot, which is 5.00 PM to 6.00 PM or next slot 6.00 PM to 7.00 PM and so on, even if the session is free the user cannot register for 5.30 PM to 6.30 PM slot.

#### 2) Suggested Enhancements in the Architecture:

- 1 A continuous slot cannot be booked in any case, but there can be technical issues or network issues because of which the user could not finish the experiment in the selected slot.

### D. Cost of the infrastructure

The lab is expected to have 15 Single Board Heaters installed, which would allow 15 parallel sessions. The cost of each system is 30 US\$, the total cost would amount to  $15 * 30 = 450$  US\$, which is equivalent to 22500 /- in INR [20]. Since the infrastructure is inexpensive so this lab can be replicated. This lab when hosted on intranet can be very useful for the students within the university. This removes the time constraints on the lab access for the students.

## VI. PROPOSED REMOTE ROBOTICS LAB

In the robotics environment, multi-axis robots are difficult to reliably operate remotely, and adding to the complexity is the anticipated student population. Educating students through simulation only is not adequate: full blown simulations capturing significant aspects of sensing and actuation dynamics are difficult to design, and validate. In addition, a multi-axis robot is an expensive and sophisticated platform to learn from. The initial ideas towards this goal are outlined below - it will be refined as more knowledge is gained about such systems.

The infrastructure in a remote robotics lab has to include:

- 1 A simple, replicable, and reliable basic building block.
- 2 The above building block should exhibit some dynamics reflecting simple robot mechanisms
- 3 The above building block should be capable of exhibiting unrestricted motion (a 1-D linear motor has to be continually reversed for unrestricted motion).
- 4 The above building block by itself should be capable of teaching some basic lessons in robotics
- 5 Complex robot mechanisms should be constructible using multiple blocks.

Based on the above considerations, the current proposal is a simplest motion control system: 1-parameter system. The single parameter, can be either a linear dimension or an angular dimension. The angular dimension is chosen, since changing it does not involve changes in the position of the shaft, and can be repeated ad infinitum.

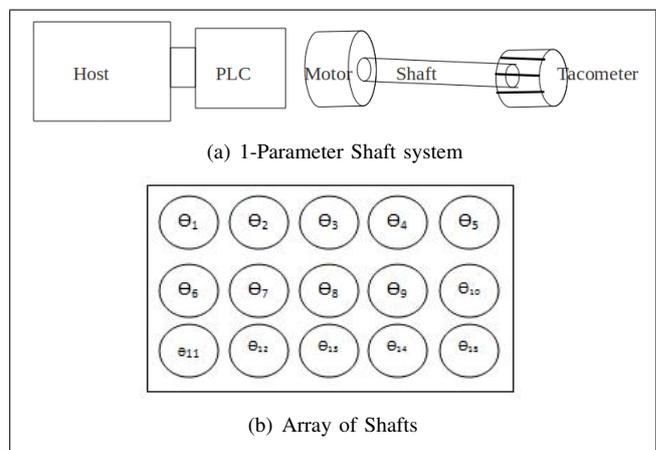


Figure 5: Shaft

Hence, the base line system, is a set of simulated "shaft robots", where a rotating shaft with an independent motor drive and a tachometer, simulates a degree of freedom of the robot. Either the angular position  $\theta$ , the angular velocity  $\dot{\theta}$ , or the angular acceleration  $\ddot{\theta}$  can be considered as the relevant simulated degree of freedom. Multiple degrees of freedom are simulated by multiple shafts being simultaneously controlled. Computer mediated torque feedback to these multiple shafts can synthesize the dynamics of arbitrary robot mechanisms. Obstacles are virtual, with disallowed angular positions/velocities being sensed, and feedback/alarms given to the user. These simulated "shaft robots" do not of course look like the "real thing". But the dynamics of a real world robot can be simulated using an array of shafts with varying amounts of loads; these loads are also conveniently implemented in a repeatable manner using eddy current/hysteresis/magnetic effects.

#### A. Outline of the experiments

This section describes a few experiments that can be performed in the proposed remote robotics lab. Lab can contain sensing experiments which illustrate principles of highly accurate estimation of angular position, angular velocity and angular acceleration, in a noisy environment. Also, experiments that illustrate issues in robot control algorithms for a wide variety of criteria, including time and/or energy. The lab also includes experiments to illustrate actuator principles.

1) *Simple Sensing Experiments*: The simplest experiment would be to find (rotary) position data of a shaft given an independently specified drive. This experiment requires motors to provide necessary torque and encoders (tachometers) to read the angular displacement of the rotating shafts. The angular position data can be differentiated once/twice to give angular velocity and acceleration, and hence the driving torque. Thus Torque balance equation for a simple rotating shaft can be given as

$$\text{torque} = \frac{Jd^2\theta}{dt^2} + \frac{b d\theta}{dt} + k\theta \quad (1)$$

Here J,b,k are constants. b being the friction constant and k is the resilience constant (k = 0, mostly as the shaft is unearthed). Initially for the ease of calculations b and k are considered to be negligible or zero. This is a simple design and it is repeatable. The learning experience of a student in this experiment is numerical differentiation as velocity and acceleration is calculated from the displacement. Also, the readings might be noisy, requiring the student to devise an algorithm or use some filter like kalman filter to eliminate noise. In the lab there can be two encoders for the same shaft and the readings of the more accurate encoder are compared with the filtered readings by the student to judge the algorithm used. The dual of this experiment can also be performed - what torque function realizes a given angular profile with time. This is a classical optimal control problem.

#### Accurate Position Tracking

A single shaft experiment can itself be very challenging. For example, an experiment for tracking angle using two coaxial rotating shafts can be devised. A disc is mounted on each shaft and both are rotating at independently controlled speeds, as shown in figure 6. A laser on the first disk produces a collimated beam, which has to be detected by a photocell, placed behind a hole on the second disk. The objective of the experiment is to ensure that the laser output remains constant within the resolution of the photocell. Depending on the size of the holes, the accuracy bar can be easy or challenging.

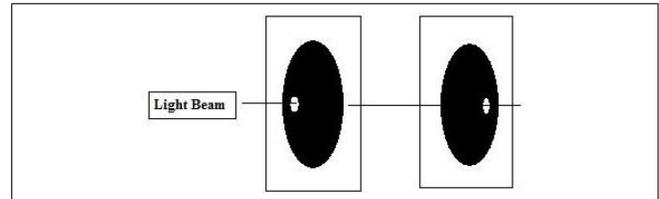


Figure 6: Light Beam through holes

2) *Multiple Shafts*: A single shaft is a one parameter robot. More sophisticated robots can be devised as shaft aggregates, with the number of parameters being the number of aggregates. The number of shafts defines the number of parameters of the system. Loads can be applied using eddy/hysteresis effects. A multiple shaft structure as shown in the figure can be used to simulate the configuration space of a real robot. In the array of shafts in Figure 5(b), there are fifteen parameters,  $\theta_1, \theta_2, \dots, \theta_{15}$ . Note that since the number of shafts assigned to an experiment is dynamically changeable, the robot can "dynamically" change its degrees of freedom.

3) *Simple Motion Planning*: Real obstacles are difficult to implement in a reliable fashion, and have reliable navigation through them. So having virtual obstacles is suggested as a first step. An obstacle in a 1-Dimensional space, partitions the space into disconnected components. To have meaningful virtual obstacles the minimum number of dimensions required is 2. The figure 8 shows an assembly of two shafts,  $\theta_1$  and  $\theta_2$  represents angular positional parameters for two shafts. The obstacle can be created in  $\theta_1, \theta_2$  domain.

Initially the virtual obstacle will be sensed using direct computer feedback, without reference to the encoder. Noise filtered encoder feedback can be incorporated subsequently, and will make the problem more challenging. If the obstacle is an illegal velocity combination, an alarm can indicate approaching illegal combination.

4) *Path Planning Experiment*: Of course, a set of shafts does not look like a robot. So, a more realistic experiment would be a 2D linear motor moving objects on a table. The objects can just be magnetic pieces. A motion planning experiment could be to move an object along a shortest path from a given source to a given destination in

Table I: Hardware Specifications

1	Number of Shafts	10
2	Dimensions	5 mm dia x 10 cm length per shaft
3	Speed	3000 to 6000 RPM, 8-bit resolution
4	Power Level per shaft	10W
5	Time Constant/MI	1 second
6	Sensors	Minimum 8-bit resolution
7	Control	PID

most energy efficient way with either real and/or virtual obstacles. In figure 9 the dark nodes are the obstacles.

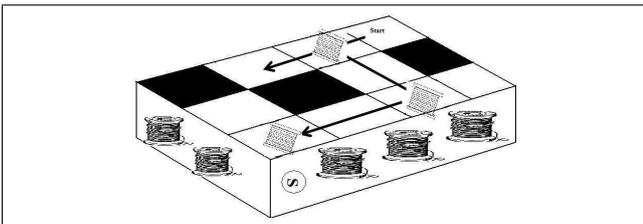


Figure 7: Maze Experiment

### B. Design Parameters

The table I give the preliminary specifications of robotics platform: these are subject to major revision as we learn more:

Some key points to be kept in mind when designing the architecture of a remote robotics lab are,

- 1 The case studies suggested that the software architecture for a robotics lab should include simulation as a major component. As the lab requires physical changes in the environment done remotely, observation of equipment safe limits and personnel safety becomes a very critical issue. Simulations for every experiment allowed in the lab, should be made available online. The student can do the simulations on the client machine or on the server itself. The access to the hardware should be permitted only when the results of the simulations are approved.
- 2 A fair scheduling mechanism should be in place. The hardware required in a robotics lab would be as costly as the semiconductor labs; dedicating a whole hardware to a single student/student group will not be cost effective. The large number of heterogeneous experiments (each requiring different resources) would require a good scheduling mechanism, following all operating system principles, as briefly outlined below:
  - i The hardware resource is maintained in a resource pool, and as the requests for the hardware is received, the hardware should be allocated from this pool, and after the experiment is complete the hardware resource is returned to the resource pool. The following figure shows the allocation cycle for 3 experiments that require different number of shafts. Experiment A requires one shaft, B requires two shafts and C requires three shafts. Initially the pool has

just three shafts, so first experiment A and B are executed and the resource is allocated to experiment C (Figure 10)

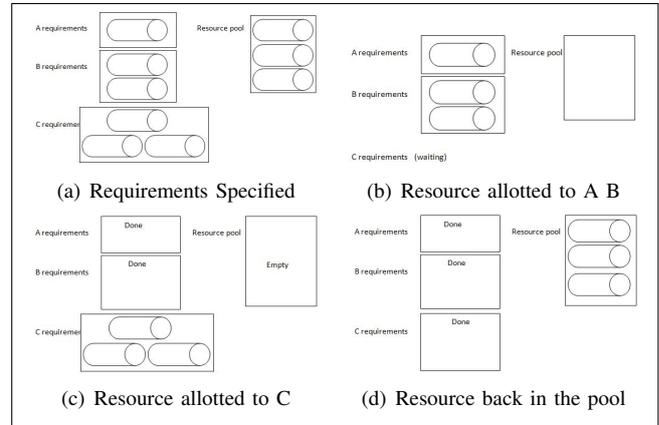


Figure 8: Resource Allocation

- ii Another scenario, an experiment A requires resource R1 and R2 and another experiment B requires only resource R1. Now if there are 5 requests for experiment A and 5 for experiment B, the scheduler would generally schedule all 5 experiments A first and then all experiment Bs. But what if once the 5 experiment A get over and fresh requests for experiment A comes, in such case the requests for experiment B may have to suffer.
- 3 Also what happens when the hardware assigned breaks down during the course of experiment, what should be the plan of action of the scheduler?
    - i Can we implement check points to roll back experiments in the case of errors? In case of faults in programs, the system can then be restored to the nearest check point, but implementing the check points in this type of physical world is not easy. Consider a simple shaft experiment, if the check point information has the value of  $\theta$  then the displacement has to be restored, if it is  $\theta \cdot$  then the shaft has to be rotated at that velocity and if the information is about  $\theta \cdot \cdot$  then the angular acceleration of the shaft is to be restored. Finding a cost-effective check-pointing scheme is part of our future-work.

## VII. CONCLUSION

A remote spacecraft is operated by highly trained people, while the remote labs are to be used by students to learn. Thus the remote labs should be illustrative of basic principles, and tolerant to a set of users who try to test and break the system. The paper explained the analysis of some issues in the design and operation of such labs, based on user experiences with two labs built on different architectures. The first, at MIT was a lab with an expensive infrastructure, conducts a relatively hard experiment using web-server. Another at IITB was a set of thermodynamics experiments on a replicable inexpensive hardware.

The load tests helped us to understand the behavior of the server at peak loads. If an experiment taking only 45 - 60 seconds to complete can be over loaded with fifty students and gives unexpected time-outs, then an experiment that take 10 plus minutes to execute (like robotics lab) would require a lot of parallel hardware support. Also, the scheduling requires priority queuing mechanism. A person may want to use the understanding in an experiment to conduct the next experiment this requires an extension of slot but the extension should not exceed a particular limit. Again if a professor wants to access the lab there should be an administrator right which allows the request to go right in front of the queue. The remote lab is expected to be scalable enough to handle a load of thousands of students at a time, this would requires large amount of architecture support and parallel systems in place.

Both these labs when compared to simulations are better as they give the real lab experiences. The student may not be able to touch and feel the hardware as in a physical lab but the learning curve is similar. But the biggest disadvantage of these labs (as of current state of art) is that the experiments provided have limited flexibility, the student cannot probe the hardware unless the infrastructure allows it.

Based on these issues, we have presented a proposal for the robotics remote lab.

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