

Low-Cost Robotic Articulator as an Online Education tool: Design, Deployment and Usage

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Abstract— Humanitarian challenges in developing nations such as low cost prosthesis for the physically challenged, have also led to substantial progress in robotics. In this paper, we implemented and deployed a low-cost remotely controlled robotic articulator, as an education tool for university students and teachers. This tool is freely available online and is being employed to generate robotic datasets for novel algorithms. Using a server-client methodology and a browser-based user interface, the online lab allows learners to access and perform basic kinematics experiments and study robotic articulation. These experiments were developed for allowing students to enhance laboratory skills in robotics and improve practical experience without concerns for equipment access restrictions or cost.

Keywords— *Education; Robotic articulator; Low-cost; Remote controlled; Kinematics*

I. INTRODUCTION

Humanitarian applications such as low-cost prosthesis require robotic technology and to aid disruptive innovations in such technologies, sustainable education in robotics may be essential for most developing economies [1]. Advent of robotic articulators have enabled performing tasks in the manufacture assembly line, surgical operations and other technologies [2]. Some robotic devices emulate tasks that mimic human behaviour [3]. Cost reduction in robotics have been

perceived as attractive for research group and for research problems. Low-cost prosthesis has become an urgent need for healthcare and Activities of Daily Life (ADL), trying to help people with disability [4]. Major challenges for developing a low-cost prosthetic device include economic cost for research and development, local availability of components, device functionality and prediction of time of failure, and design simplicity [5]. Avoiding sensors and sensorial feedback decreases cost, but increases localization variability in models [6]. This has led to an essential urge to have better education tools for robotics at academic level.

Some problems faced in sustainable education in developing economies include the lack of trained teachers, expensive equipment, and unavailability of reagents. To overcome some of these difficulties, online-based laboratories have been proposed and developed [7]. Demonstrating each experiment to every student separately or setting up laboratories for every domain in a university is a challenging assignment [8]. Usage of online labs could reduce difficulties associated with cost, time and resource and provide practical knowledge of lab [9]. Students from remote areas find it difficult to learn and design robots and to purchase expensive equipment [10]. Development of such technologies requires knowledge skills in design of articulators, control of end effectors, Denavit-Hartenberg (DH) transformation

matrices, forward control and inverse kinematics [11], [12].

This paper reports the design, development and deployment of a low-cost remotely controlled robotic articulator as a student's experimentation device, providing training on robotics anytime-anywhere using an internet-enabled computer [14]. Robotic platform used in this study is a 6-Degree Of Freedom (DOF) robotic manipulator which has been extensively used in research, development and teaching. Such models help train students and engineers to scale novel variations in order to develop affordable prosthesis.

II. METHODS

A. Robotic arm

Kinematics of low-cost robotic arm was modelled to represent elements of a human upper arm including joints, shoulder, elbow and wrist [13]. The 6 DOF low cost robotic articulator (Fig.1.) included the definition of a joint with DH parameters that included twist (α_i), length (a_i), offset, (d_i) and joint angle (θ_i) facilitating roll and pitch movements across 2 planes.

B. Experimental Setup

Remote lab enabled users to input variable values through a web-based Graphical User Interface (GUI). Freely available online experiments allowed a user with authorized email id to control experiments through the CAP-VL platform [15]. Controls were provided for motors enabling users to manipulate joints of robotic arm independently (Fig. 2A). Remote lab GUI (Fig. 2B) with live video streaming was setup to allow users visualize the experiment. Movement of arm was limited to prevent damage.

C. Virtual Lab experiments

Based on designed robotic device, a bio-inspired robotics remote lab was deployed and included eight experiments. This lab and the robotic articulator are freely available online (<http://vlab.amrita.edu/?sub=3&brch=257>), and was developed as a part of the National mission project on Education through ICT, Government of India [16]. The designed lab (see Table II) included experiments on controlling a servomotor based end effector and a mechanical articulator via remote manipulation. It also included several experiments to study basic functionality of neuronal circuits and their behaviour. Each experiment

was provided with a theory and step-by-step procedure, a remote panel, references and a self-evaluation component designed to assess user's knowledge on practical concepts.

The experiments allowed a user from an internet-enabled computer to interact with the remote devices through a web server. Information received by Master server was then communicated as a set of motor commands to a robotic arm, connected to another lab server interfaced with a microcontroller, through a serial port. User inputs were transferred to the controller in order to actuate the remotely connected robotic device. The robotic articulator's constituted 6 servomotors with a torque of 17 kg-cm. A Pulse Width Modulation (PWM) signal with a Time Period of 20ms and a Duty cycle of 1ms-2ms was given to each servo motor. These pulses were send sequentially to maintain the position of the servo in the given Cartesian space.

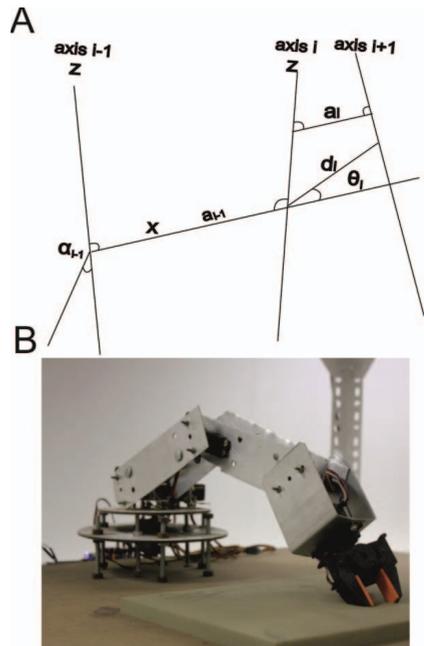


Fig. 1. Low-cost Robotic Articulator. A. Link representation B. Robotic arm used in remote control experiments

TABLE I. DH PARAMETERS FOR LOW-COST ROBOTIC ARM.

Joints _i	1	2	3	4	5	6
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a_1	0	90	0	90	90	0
a_i	0	0.17	0.17	0	0.072	0

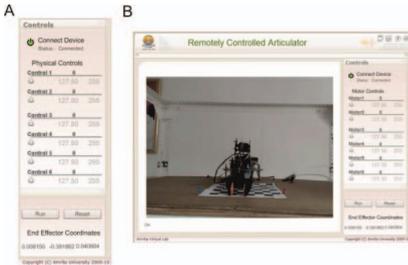


Fig. 2 Remote Controlled Robotic Arm. A GUI controls B GUI with live video.

6.	Constructing a six core brain like circuit	http://vlab.amrita.edu/index.php?sub=3&brch=257&sim=1670&cnt=1
7.	Pattern recognition in a hardware neural network	http://vlab.amrita.edu/index.php?sub=3&brch=257&sim=1488&cnt=1

Kinematics used in controlling the robotic arm involved joint angles that were transformed for each joint as shown in Fig. 3. Export data option in GUI enabled student users to export data as files post-experiment completion. Datasets obtained from experiment was used for developing computational models for training robotic arm and to develop novel cerebellum-inspired gain control models (manuscript in preparation).

D. Pedagogy analysis

To test effectiveness of online labs in education, we conducted several workshops for University students and teachers. During workshop, hands-on training was provided to each participants, and after practicing remotely controlled robotic experiments, a set of questionnaire-based feedback was collected from participants. In this study, both students and teachers were asked to perform the experiment, ‘‘Understanding the kinematics of a robotic upper arm’’ in Bio-inspired robotics virtual labs. Direct feedback from 100 students and 50 teachers and indirect feedback from 100 online users were employed. In both cases (workshop and online), participants have expressed on a Likert Scale (1- Very poor, 2- Poor, 3- Average, 4- Good, 5- Excellent) to all questions. Feedback questions were also focussed to analyze user behaviour (TABLE III) while using remotely controlled robotic labs as a learning platform.

TABLE II. BIO-INSPIRED ROBOTICS LAB AND LINKS

Sl: No	Experiment	Link
1.	Controlling a servo motor in a bio-robotic environment	http://vlab.amrita.edu/index.php?sub=3&brch=257&sim=1480&cnt=1
2.	Understanding the kinematics of a robotic upper arm	http://vlab.amrita.edu/index.php?sub=3&brch=257&sim=1458&cnt=1
3.	Light sensing process in a neural circuit	http://vlab.amrita.edu/index.php?sub=3&brch=257&sim=1321&cnt=1
4.	Mechanism behind the movement of a Walker robot with 4 neurons	http://vlab.amrita.edu/index.php?sub=3&brch=257&sim=1669&cnt=1
5.	Interaction study with Neuronal Circuits	http://vlab.amrita.edu/index.php?sub=3&brch=257&sim=1764&cnt=1

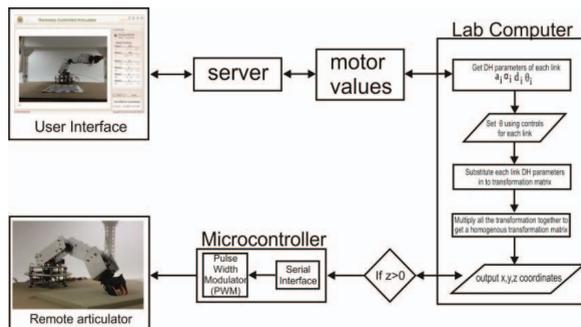


Fig. 3 Remote controlled lab setup

Apart from these questions an additional set question was asked to users to know their interest in adding remotely controlled robotics labs in their curriculum (Table IV):

III. USAGE ANALYSIS

The robotic arm employed as a remotely controlled lab was a low-cost device with no sensors and was constructed with aluminium frames and servomotors [14]. Understanding of motor control was studied by users using this device at different levels of abstraction.

TABLE III USER BEHAVIOR QUESTIONNAIRE

SL. No.	Questions
1	Could you able to control robotic experiments in the graphical user interface?
2	Are the Remotely controlled robotics labs a better platform that offers skill practices for user communities?
3	What made you to driven to use remotely controlled robotics labs?
4	Are the experiments easy that you could finish the lab session with minimal errors?

TABLE IV DEVICE ACCESSIBILTY QUESTIONNAIRE

SL. No.	Questions
1	How many times you accessed the remote robotics labs?
2	How much time you spent effectively to complete the lab exercise?

A. Users tend to practice online robotics labs as a new learning pedagogy

Feedback analysis indicated that 85% of students, 86% of teachers and 86% of remote users found to control the robotic experiments with the interactions provided in the graphical user interface, 84% of students, 82% of teachers and 86% of online users agreed that remotely controlled robotics labs were a better platform that offers skill practices for user communities. Also, 90% of students, 92% of teachers and 94% of online user communities indicated that repeatability of robotic labs free of cost was a critical factor that have driven them to use remotely controlled robotics labs in their education perspectives. 86% of students, 88% of teachers and 84% of distant users reported that they completed the experimental task with minimal errors. Few of students (10%), teachers

(10%) and online users (5%) rated online robotic labs as average or poor material (Fig. 4).

B. Remotely controlled robotics labs as a supplementary education tool

Feedback report indicated varied student usage enabled a better understanding: 10% of students accessed remote robotic arm only one time during the workshop event, 76% of students accessed remote robotic arm based experiments twice, 8% accessed three times and 6% accessed the robotic labs four times during the one day workshop.

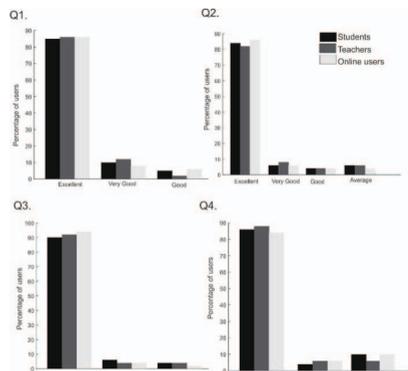


Fig. 4. User behavior: Trends in remotely controlled robotic labs (see Table III for feedback questions)

Teachers feedback indicated that 16% of them accessed the robotic arm based experiment only once, 72% twice, 10% accessed thrice while only 2% accessed the lab four times so as to train the students by introducing the remote labs as a prelab session. On the other hand, 5% online users accessed remotely controlled robotic lab for one time, 78% accessed it twice during the usage, 12% accessed three times while 5% online users accessed the lab four times to gather the information provided in the remote robotic platform and to train the remotely controlled arm from distant locations (Table V).

After repeated usage, 5% of students reported that they spent less than one hour to complete the lab exercise, 72% indicated they used 1-2 hours to complete the lab exercise, 12% took 2-3 hours to understand the basics of remotely controlled robotics labs, while 11% took more than 3 hours to complete the lab exercise. According to teachers' perspectives, 10% teachers reported that they completed the remotely controlled robotic arm training in less than 1 hour, 78% took 1-2 hours to complete the

laboratory exercises, while 12% teachers completed it in 2-3 hours.

TABLE V: REMOTE LABS AS A LEARNING COMPONENT. ANALYZING THE ACCESS RATE

Study participants Users	Access to remote labs				
	1	2	3	4	5
Students	10	76	8	6	0
Teachers	16	72	10	2	0
Online users	5	78	12	5	0

Considering, online users, 80% indicated they completed lab exercises within 1-2 hours, 12 % took 2-3 hours to perform the experiment, while only 8% took greater than 3 hours to complete the experimental task (Table VI).

TABLE VI. REMOTE LABS AS A SUPPLEMENTARY EDUCATION TOOL. ANALYZING TIME UTILIZED TO COMPLETE EXPERIMENTS BY DIFFERENT USERS

Study participants Users	Time spent to complete experiments in remotely controlled robotics labs			
	<1	1-2	2-3	>3
Students	5	72	12	11
Teachers	10	78	12	0
Online users	0	80	12	8

IV. CONCLUSION

As an experiment for aiding education in remote areas, we developed a robotic articulator that can be remotely controlled from a web-enabled computer. Remote labs help providing education to challenged users in urban and rural areas. Students, teachers and online users were very keen in learning introductory kinematics and tend to repeat the experiments a number of times to get a deeper understanding on implementing basic concepts of robotic control. User performance analysed based on feedback obtained from workshop participants and online users have indicated that online labs augment education roles as supplementary textbooks for enhanced laboratory skill training.

We perceive this developed robotic arm as an educational tool, for both undergraduate and postgraduate students with limited access to laboratory training time and facilities.

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