Do It Yourself Educational Kits for Vocational Education and Training

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ABSTRACT
Human motor skill training forms a large portion of the curriculum for any vocational education and training course. Construction personnel such as carpenters, plumbers and masons require long hours of training in order to gain expertise and workmanship to perform complex tasks skillfully. Poor skill in the use of tools results in sub-optimal outcome; compromised work quality and consumes additional cost.

In this paper, we describe the design of a novel do-it-yourself educational tool that is built using low cost materials, open source software and hardware, the designs for which are freely downloadable. This educational toolkit uses haptic technology to augment the need for realism and is used to provide skill training in the use of vocational tools. The aim is to generate interest in vocational education and to provide greater accessibility for base level skill training.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Haptic I/O, Graphical user interfaces (GUI).*

General Terms
Design.

Keywords
Skill training, vocational education and training, haptic devices, simulation training, virtual reality, e-learning, motor skill learning, human motor control, open source, technology enhanced learning, do it yourself.

1. INTRODUCTION
Over the new millennium, vocational education and training (VET) has been identified as the solution to address the socio-economic development of the masses, especially in developing countries [1].

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Figure 1. A user explores the sensations on using a virtual haptic band saw tutorial.

In India alone, where the population of more than 12 million people enters the workforce every year, the cumulative capacity of vocational training institutes in the country can only handle training 3 million people [2]. The lack of access to VET institutions and quality instruction prevents the majority of the under-employed population residing in the rural and tribal regions of the country from moving into mainstream labor sector and leading more productive lives [3].

An additional burden borne by vocational education distinctive in Indian society is the social stigma associated with certain trades. People do not share the same enthusiasm that they display towards welding or electrical work to vocational jobs such as plumbing and sanitation. Hence it is critical to create interest in the training provided in order to encourage candidates to want to up-skill themselves. Vocational education and training, irrespective of the trade chosen, involves intensive skill training and comprehensive understanding of the use of tools.

Groundbreaking work has been done in designing e-learning tools for vocational education. Successful methods to achieve this include use of information and communication technologies (ICT) to impart VET as demonstrated by Karahoca et al. who have created an interactive e-learning tool for teaching vocational education providing computer parts and assembly instruction and Bhavani et al., who adopted an innovative multimodal based approach to deliver vocational education in rural India [4][5]. In favor of ICT based education, Hassan et al. hypothesized, in their study on role of internet based education on open vocational high school students, that the theory aspects of technical education can be provided by technical teachers over the internet, while adjustment of time and location can be the greatest motivation for generating interest in vocational education [6].

The aforementioned project funded by the Ministry of Human Resource Development, Government of India, titled ‘development of computerized vocational training and haptic simulators for hands-on training’ has helped create open source courseware that has been deployed in over five states in India through the joint initiative of the United Nations Democracy Fund and Amrita University. TO quote its success in India, the project has by the fourth quarter of 2013, trained over three thousand impoverished women and provided means of employment [7]. With burgeoning needs and steady population growth rates, countries across Asia and Africa need such sustainable and cheap means of teaching skills in various vocational trades.

This paper describes the effort to create low cost haptic simulators that can be made and assembled at home using locally available materials and when coupled with our freely downloadable open source simulation tutorials, can be used to learn the use of occupational tools. The intent is to create interest in skill-based trades and reduce the stigma associated with the use of vocational tools. Haptic virtual reality based simulators also hold the quotient to glamorize vocational training and therein attract candidates.

2. RELATED WORK

Technology based teaching tools have been introduced in education in a bid to popularize it and make learning fun. Klassner makes a case for this by introducing the use of the LEGO Mindstorms kit for introductory hands on learning at the high school and college levels [8]. Lovel et al. has created a DIY kit that is packaged with a tutorial on sewing electronics circuits for e-textiles and Ayah Bdeir designed littleBits an open source library of discrete electronic components hoping to democratize and create interest in electronics [9][10].

Furthering Lovel’s work, Kuznetsov et al. have explored the role of technology based hands on learning on socio-economically marginalized children using soft circuit kits and have found it helped improve enthusiasm, focus and provided comfort to them [11]. Minsky et al. conducted a similar study on adult women in South India where the response documented from rural women is positive and engaged. They asked questions about potential economic viability and expressed the desire to learn electronics and to make soft circuit based crafts [12].

Kam et al. pointed out in their work on design of eLearning games for rural children in India, that unless the content and background setting is contextualized to the learning scenario, it posed the risk that the users would not engage with the learning goals the game hopes to deliver [13]. Keeping this in mind, Jose et al. have created the TryStrokes application to teach painting skill using a paint brush in the context and setting of a vocational course on fabric painting [14].

Haptic simulation has been widely used as a medium to provide education. Gillespie et al. designed the low cost iTouch motor to introduce system dynamics principles to under graduate students. Williams et al. have explored the role of haptics for teaching engineering mechanics principles [15][16]. Grow et al. who used haptic devices as an educational tool to teach stem concepts to K12 students and found that haptic feedback provided the key for intuitive understanding of physical systems [17]. The work of Jones et al. who conducted a study to assess the impact of haptic technology in science instruction and found that when students had access to tactile feedback they spontaneously used tactile related terminology in their discussions to described the results of the experiments that they performed, is testament to the lure of the technology [18]. When compared with ICT based tools for education, haptic simulation for VET is an underdeveloped area of research in the simulation-training domain. Dachille et al. have created a haptic system for sculpting tools that they later put to use for creating irregular geometric shapes [19].

More relevant work in haptic simulations for VET has been done by Akshay et al. who have reported on the design of and study on a haptic simulator for training cutting skills using a hacksaw. They report that the simulation training offered higher consistency of skilled performance when compared with traditional means of training the same skills [20].

3. DESIGN METHODOLOGY

One approach to simulate the training of tools is to use commercially available generic haptic devices such as the Novint Falcon or Phantom Omni that can offer high fidelity but reduced force feedback and workspace [21][22]. These tools can simulate a wide variety of tools with different force characteristics but the prohibitive cost of such devices renders them as an expensive option.

An alternative approach is to categorize the vocational tools to be simulated with respect to the degrees of freedom, type of grasp, workspace radius and nature and magnitude of kinesthetic and tactile feedback experienced during their use. Ample work has already been done to categorize skills, hand motions and grasps associated with tasks. Cutkosky used observational surveys of professional machinists along with the previous work of Schlesinger and Napier to develop a more comprehensive grasp taxonomy [23]. Another generous contributor to this research, Bullock et al. have created human hand and arm classifications for dexterous manipulation to perform daily tasks and further studied grasp frequency and usage of machinists while performing machine shop tasks [24] [25]. On categorically separating the various tools based on this taxonomy, groups of tools can be identified that share common range of force reproduction, workspace and degrees of freedom.

After such an exercise was carried out on 585 tools in the VET space, spanning across plumbing, masonry, carpentry, sheet metal working and fitting, several groups of tools were identified. The educational kits were designed such that one haptic simulator can be created out of it that could simulate the tools such as the jigsaw, table saw, band saw, sander and hand planar among others.

Focusing on free learning, the software and hardware described in this paper are open source and is being made readily available to download at the author’s website. The educational kit contains the raw materials for making hardware that includes readily available materials such as wood, colored paper in yellow, blue and black, rubber bands to act as simple springs, a vibratory motor (optional), open source Arduino based board, an on-off switch, a 12V battery, a webcam and a computer to run the simulation software.

4. SYSTEM DESIGN

The system design has been created keeping in mind ways to easily setup and run the hardware. All parts are readily available in any local hobby electronics store and the wooden or acrylic parts can be laser cut using the released design templates.

4.1 Electronic Hardware

The electronic system consists of the open source Arduino microcontroller board, motor driver board, vibratory motor, on-off switch and batteries.

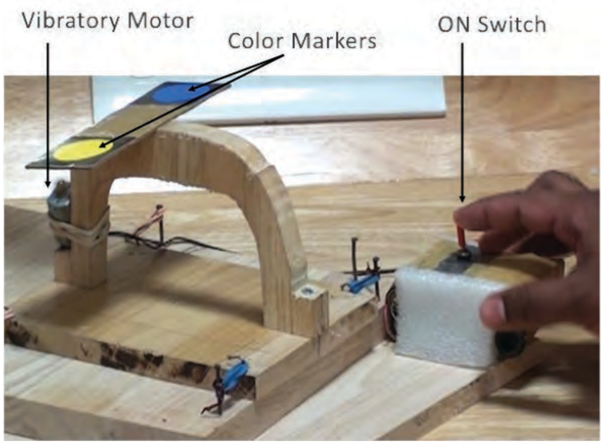

Figure 2. Parts of the DIY haptic educational toolkit.

The mechanical device has a relatively stationary end effector constrained by springs or rubber bands. The device simulates scenarios where the tool moves and job is stationary (e.g. jigsaw, circular saw and router) that require small incremental changes in velocity or angular velocity along a long trajectory of motion.

The system consists of a wooden platform with the end effector placed on it restrained by the springs at four corner as shown in Figure 2. The springs also serve to provide passive haptic feedback to the end effector. A web camera is placed above the end effector looking down approximately 60 cm above it. The webcam captures the wooden tool movement by tracking the motion of the two colored markers are placed on top of the wooden end effector. A vibratory motor is attached on the wooden handle to provide the haptic feedback of the tool. Using the Arduino platform makes the system user friendly and easy to setup. The wide acceptance of the Arduino platform by the DIY community and availability of very active online forums and tutorials, is another reason for it to be our choice of controller.

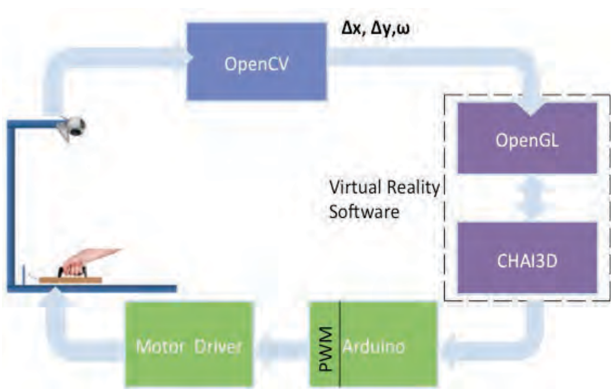

Figure 3. Schematic operation of the haptic simulator.

When the device is turned on, the webcam actively tracks the position and orientation of the end effector. OpenCV processes the change in position and orientation information and the resulting Euler angle is transmitted to the virtual reality program running on the computer. The change is then reflected on the virtual tool visible on the OpenGL graphical display. The change in position and orientation causes a change in haptic sensation that is rendered by the CHAI3D haptic library and is fed to the arduino microcontroller (uC). The uC in return sends the instantaneous commands to the motor drive, which drives the vibratory motor at the end effector, as shown in Figure 3. The firmware in the micro-controller is pre-programmed with preset vibration patterns to be generated when the haptic signal is received from the computer through the USB serial interface.

4.2 Actuator

The tactile haptic feedback is produced by a micro Eccentric Rotating Mass (ERM) motor that is cheap, easily available and lightweight when compared with other motors in the market. The table lists the electrical and mechanical specifications of the vibration motor.

Table 1. Vibratory DC Motor Specifications

Characteristics	**Specifications**
Operating voltage	2.5~3.5 VDC
Max. Current	120 mA
Coil Resistance	80 Ωmax
Mass	0.08 gram
Rotation Speed	@ 3 VDC 13000 ± 2500 rpm

For a seamless movement of the device, AA batteries connected in series are used to drive the motor. These batteries deliver typically about 2700 mAh that provides an operation time of about 1.2 hours.

4.3 Motion Tracking and haptic rendering

The aim of using the webcam system is to track the position and orientation of the wooden end effector that the user grabs and pushes or turns to manipulate the virtual tool in the virtual environment.

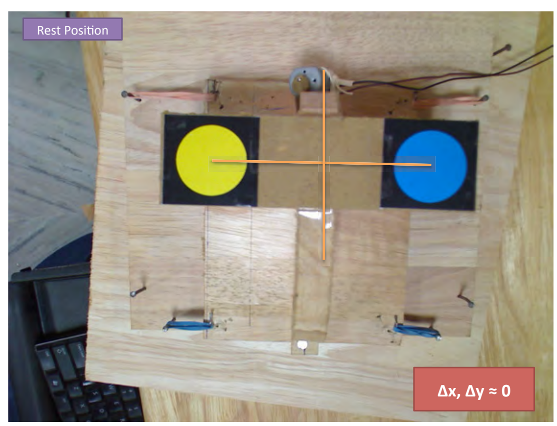

Figure 4. Position of the end effector at home or reset.

A simple image-processing algorithm is used to measure the end effector's forward and side ways translation and rotation and the rate of displacement. Image matching of the two colored circles is performed to calculate the position of the wooden end effector. During the beginning of the exercise, the calibration of the device is performed. The process starts with the tracking of the two markers that do not move. In the experiment, the camera is set at the top and the coordinate system has been setup with the wooden end effector as origin. The instantaneous position of the tool (Δx, Δy) is computed based on the initial position (x, y). The distance between the two colored markers dimension can be explained by the camera setup. Δx, Δy values denote the forward and the sideward displacement of the end effector.

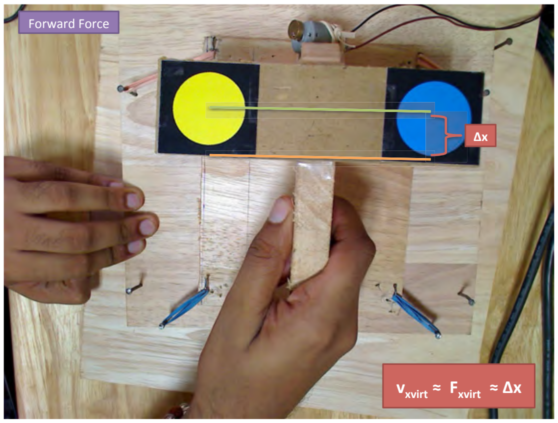

Figure 5. Measurement of end effector forward displacement

At rest position, shown in Figure 4, Δx, Δy, ω, $\tau \approx 0$ …….(1)

When the end effector is pushed forward it experiences a forward displacement in x denoted as shown in figure 5. by,

vxvirt≈ Fxvirt ≈ Δx …….(2)

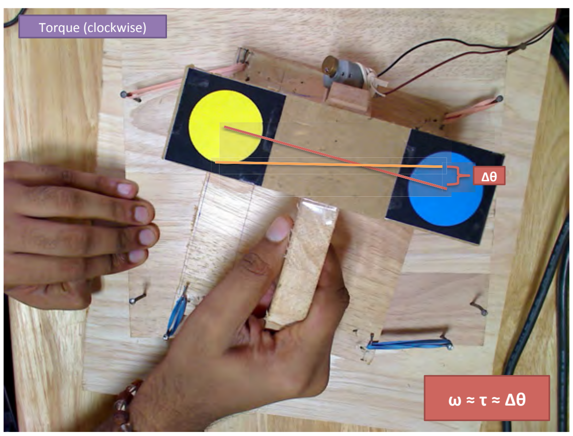

Figure 6. Computer vision based sensing of rotation of end effector.

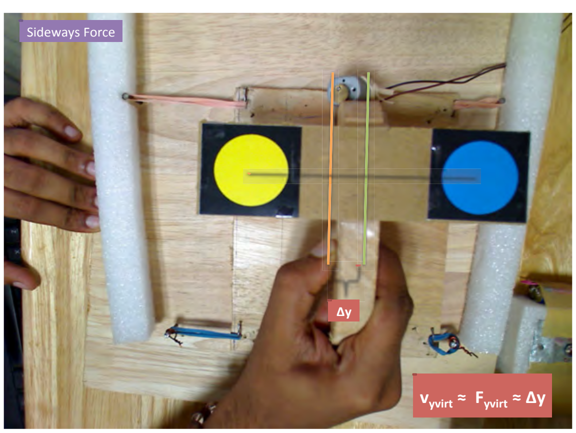

Figure 7. Measurement of end effector sideward displacement

Any rotation of the end effector is calculated as shown in figure 6, of the end effector $\omega \approx \tau \approx \Delta\theta$ …….(3)

Similarly, sideward displacement is denoted as shown in figure 7.

as, vyvirt ≈ Fyvirt≈Δy …..(4)

5. LIMITATIONS

The biggest limitation in the system is the investment involved in a computer. We assume this educational kit can be popularized by govt. bodies and NGOs that already operate the computerized education and vocational training programs, and so will have the required infrastructure. Another hurdle can be setting up the electronics for bare novices, but the Arduino platform has been exploited even by farmers in Africa who have created a Arduino based system to monitor their agricultural parameters and hence we hope that it will not pose a massive challenge for the layperson.

6. CONCLUSION AND FUTURE WORK

In this paper we have introduced a do-it-yourself educational kit based on haptic technology for vocational skill training. Using the online guidelines and open source resources made available on the authors website, a student should be able to build a haptic educational kit with minimum assistance. The integrated virtual reality allows interacting with the virtual objects in a meaningful way. The educational tool kit opens possibilities for a broader audience to experience the haptic sensations during the use of occupational tools and visualize the effects of the tool on the virtual vocation-contextualized environment. Practical benefits for the students included self paced learning, self-evaluation and flexible timings, which we have discussed, and are the greatest motivators for retention in a vocational course. The educational kit aims to reinforce student learning and technical curiosity of simple vocational tools concepts, while making it fun for the student to construct the educational tool.

Our future work includes a large-scale validation and evaluation of the educational kit. Moreover, all the construction details including 3D printable CAD models, software and hardware are being published online. This kit holds the potential for the DIY community to utilize to create new education tools for vocational or find other creative ways to utilize these resources.

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