EQUIPMENT OPERATOR TRAINING IN THE AGE OF INTERNET2

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Abstract: Considering the established needs for operator training in the construction industry and vastly improved data communication using Internet2, the feasibility of an effective Internet based training system for backhoe operators is increasing. This paper presents ongoing work on a prototype system designed with the idea that eventually any electronically controlled backhoe can be adapted and connected to the Internet. Experimental tests have shown that 3-D, real time video in combination with force and sound feedback provide a data-rich control environment for the trainee. This paper also discusses how the availability of force and spatial position data can be used for running an online training program that provides the user with a series of structured tutorials and practice sessions. System features of a Virtual Coach might include the haptic feedback featured in the prototype system, depending on its demonstrated relevance to training efficacy, as well as digitized verbal information, including instructions, commands and real-time advice.

Keywords: training, skill assessment, information technology, motion control, construction equipment

Introduction

The most common task of backhoe operators is to cut soil with a bucket and dump it on to a pile or into a truck. Skilled operators dexterously control the arm and bucket using two joysticks, as shown in Fig. 1, by monitoring the backhoe motion and the state of the process. The skill itself, however, is difficult to assess and even skilled operators can't describe their own "skillfulness".

Efficient on-the-job operator training is not only costly but is often not possible, requiring specialized equipment and an on-the-job trainer. However, only appropriate and extensive training enables operators to control large equipment safely and efficiently. Similar to other industries, construction tries to take advantage of computer simulators and virtual reality as training vehicles. An apparent problem with such tools is the lack of realism, which is very costly to create. In addition, research has shown that the key to acquiring the necessary motor skills to control complex systems, such as a backhoe excavator, is hands-on and coached training. (Cuqlock-Knopp et al., 1991)

The advent of Internet2 opens the opportunity to revolutionize training of large equipment operators. The large bandwidth and high-speed data transfer allows large amounts of data to be "pumped" through the Internet. In particular, live video can visually "connect" an Internet user with a remote site in near real time. In order to study the effectiveness of a distance training & learning concept, an Internet-Based Backhoe Operator Trainer (I**B**OT) was built and tested using the Internet as well as Internet2.

What is Skill?

How does one assess the skill of a backhoe operator today? The commonly heard answer is: "By watching him operate the equipment or measuring the time it takes him to load a truck." It becomes apparent that these skill measures are rather crude considering some common definitions of skill or skilled performance.

Paul Fitts (1964), a prominent motor skill investigator before his untimely death, listed four critical characteristics of skill: 1) goal directed, 2) exhibiting highly integrated and organized behavior, 3) acquired through practice and training, and 4) applied with ease. Fitts' definition of skill will be used as the basis for establishing performance measures that could be used to differentiate between an excellent and a not-so-perfect backhoe operator.

Measures of Operator Performance

Sage (1984) provides a definition of skilled performance that can be utilized to assess a backhoe operator. He characterizes a skilled performer as one who "can produce an output of high quality (such as fast or accurate) with a good deal of consistency. Skilled performance is also characterized by an appearance of ease, a smoothness of movement, an anticipation of variations in the stimulus situation before they arrive, and an ability to cope with these and other disturbances without disrupting the performance. Indeed, increasing skill involves a widening of the range of possible disturbances that can be coped with without disturbing the performance." Considering Sage's elaboration, we can establish the following list of measures for performance measurement: 1) quality of output, 2) consistency of operation, 3) smoothness of bucket motion, 4) proactive thinking, 5) adaptability to changing environments, and 6) capability for skill improvement. It is easy to recognize that these six traits are really based on earlier work by Fitts, who already had established a useful framework for skill acquisition earlier.

An Internet-Based Backhoe Operator Trainer

An Internet-based training system needs to provide the trainee a means to operate equipment without being situated right next to it, thus losing the ability to use his inherent senses as feedback channels. Figure 2 shows the architecture of the first prototype I**B**OT developed by the Construction Automation & Robotics Laboratory (CARL). The main components of the I**B**OT consist of: a) computer-integrated-backhoe (CIB), b) one PC running video communication software c) one computer for digital data communication, and d) human-computer interface at a remote location with joystick, audio, video, and data display. NetMeeting was found convenient for demonstrations but, because it is already old technology, is not sufficiently dependable to allow experimental tests with I**B**OT. A commercial force-feedback video game joystick is used to control the excavator. The remote control software utilized a combination of Windows sockets, Windows GUI with the WIN32 API and multi-threaded programming. Here, a client and a server program work together to convert un-calibrated joystick signals originating from any computer with a Windows 98 operating system and standard joystick port into a calibrated, useful signal output from the analog digital (A/D) conversion board in the control computer. The client and server programs both engage independently operating communication threads which run in continuous loops, where the server thread echoes all data received from the client to maintain synchronization between the programs, as well as to provide a channel for feedback data, if necessary.

Figure 3 a) shows the programmable game joystick with which the entire excavator can be operated, while Figure 3 b) presents a view of the operator control seat where the operator is replaced by a video camera. Two large soil boxes serve as mobile containers for digging and dumping. Overhead cranes are able to pick them up and move them if desired. This allows the rapid change from one type of soil to another.

Electronic Skill Measurement

The modeling of the joystick motions required to move an excavator bucket through soil is a complicated problem, in as much as there exist many ways of creating the same path. In the same vein, the forces that have to be created to cut through the soil not only depend on the strength and density of the soil, but also on the digging motion, which includes factors like velocity, acceleration and smoothness of the bucket motion. Thus, it seems reasonable to expect that the forces that are created during the operation could be used as one important measure of operator skill.

The learning of motor skills is special in that it concerns itself with the process that underlies movement. Of critical importance is the fact that motor skills cannot be measured directly, but only inferred by observing behavior or performance. However, using performance alone as the measure of skill is not sufficient since other factors such as motivation, fatigue, boredom, noise, and temperature also impact performance. Anybody who has worked with equipment operators can easily see that the speed of skill acquisition depends upon a variety of conditions, with practice being the most important of them. In order to eliminate the extraneous effects as much as possible, trainees were assessed continuously, an act which provided data that could be plotted. The resulting graphs are called learning curves or performance curves.

Preliminary experiments, where two test persons were asked to perform an identical digging task, have shown that there is a definite relationship between skill and sensory feedback from the computer integrated backhoe. Figure 4 presents the hypothesis that smoothness of motion, which is related to skill, can be translated into smoothness of force. As shown, one should expect that a highly skilled operator creates a fairly consistent force pattern along the entire task while a poorly skilled operator produces spikes.

In order to test the basic hypothesis, a set of comparative experiments was executed. Two distinctively different operators, an "Expert" (E) and an "Apprentice" (A), were given the task to dig in the soil box under similar conditions.

Identification of Primary Skill Indicators

The tests conducted were based on the digging scheme presented in Figure 4. In a first effort, the research team attempted to verify the assertion that there are, in fact, unique force characteristics in each of the three cylinders: 1) boom, 2) stick, and 3) bucket. Fig. 5 presents two force data sets collected during one dig executed by two test subjects.

Force Pattern

Reviewing the graphs, several differences can be easily identified. For example E is filling the bucket in approx. 11 seconds while A needs almost 18 seconds to do the same. The above hypothesis seems to hold by the force data. E's maximum stick force during digging is 2,700 kN, while A needs 7,600 kN to move the stick through the soil. In addition, the "Expert", exhibits a much smoother and more uniform force distribution when compared to the "Apprentice."

Spatial Pattern

A second set of sensory data output that was analyzed resulted from the three angle encoders mounted on the three joints of the arm. Figure 6 depicts the result of a kinematic transformation, according to the Denavit-Hartenberg notation, converting the angles into Cartesian coordinates representing the path of the bucket.

While the path coordinates generated by E did fit a cubic polynomial path function, A's path shape only fits a cubic polynomial with a rather large deviation error. This correlates well with the stick-force data, since it also showed a comparatively "rough" pattern.

Coached Backhoe Training

The important first job of a coach is to instill in the trainee's memory an appropriate idea of how to execute a task. The two most commonly used techniques are verbal instruction and demonstration. A good coach also motivates and reinforces learned skills. Furthermore, coached training should be adaptive, in that the demands of the training environment and the complexity of the task "grows" with the skill level of the trainee. Thus, a coached training program is individualized and constantly monitored by the coach to assess progress. This personalized "looking over the shoulder" method of training is hardly possible on an actual excavator. A virtual trainer that is able to read and interpret feedback data representing the performance of the trainee may serve the role of an actual coach.

The module of a telepresence excavator trainer may be modeled as a closed-loop system. It is able to read measures representing the trainee's performance as input to dependent output coefficients, such as the difficulty of the training task. Figure 7 presents the framework of such a closed-loop training system for backhoe operators.

Towards a Virtual Coach

Considering the established needs for operator training in the construction industry and the versatile control and performance evaluation characteristics of the I**B**OT, the development of a "Virtual Coach" training system for backhoe operators using the I**B**OT system is a natural goal. System features of the Virtual Coach might include the haptic feedback featured in the I**B**OT, depending on its demonstrated relevance to training efficacy, as well as digitized verbal information, including instructions, commands and real-time advice.

The primary advantage of a teleoperation training system over a virtual reality training system is the guaranteed realism it provides. Complex and unpredictable processes, instead of being mathematically modeled and simplified, actually occur and present the trainee with stimuli commensurate with real-world equipment operation. Indeed, this type of "virtual" instruction would provide the trainee with an experience nearly identical to an on-site training program with a human instructor, saving the money and danger of such training practices and simultaneously providing more extensive performance evaluation capabilities.

Studies indicate the reliable transfer of skills acquired through virtual training or telepresence to actual on-the-job tasks (Rose et al., 2000), provided a high similarity between the virtual and real environments. Employing real-time, high-resolution stereoscopic visual feedback, audio feedback, and joystick control, the I**B**OT system generates the same intrinsic feedback provided by an on-site backhoe training session, and creates a teleprescence experience practically identical to an actual backhoe system in operation. Thus, provided an appropriate program design, the I**B**OT system would undoubtedly enable the cost-effective remote training of backhoe operators.

Because of the range of extra evaluative tools and feedback features the I**B**OT offers, the integration of automated training and Virtual Coaching aspects into the I**B**OT system and software presents a complex design problem, requiring particular knowledge in the subjects of motor learning, motor control and backhoe operator skill. System features as straightforward as performance feedback, user instructions and feedback augmentation would require careful planning and design, taking into account the current knowledge base on the efficacy of different types of supplemental aid to motor learning. Motor learning research (Cuqlock-Knopp et al., 1991) suggests a number of subtle but consistent dependencies of long-term motor skill retention on knowledge of results (KR) scheduling, performance feedback structure, augmented feedback usage, task instructions and attentional focus. The Virtual Coach system will enable precise software control over each of these aspects of motor skill instruction, providing a means to not only train operators, but to actually evaluate and refine the techniques of the trainee

Summary

Retrofitting existing equipment with ruggedized sensors and data-storage devices has enabled the implementation of various schemes for improving equipment life and performance. By installing computer-integrated controls, a path for operating them tele-robotically has been created. This paper discusses still another opportunity for utilizing such an electronic infrastructure, namely electronic skill assessment and training. One measure of good operator performance is the smoothness of motion. Using experimental data it is shown that there are, in fact, distinctive differences between the force-pattern generated by an “Expert” and an “Apprentice” backhoe operator. The extensive amount of data that was collected using force sensors and angle-encoders allowed the identification of unique features not only of forces but of path and energy consumption as well. It is argued that it is possible to develop a feature-based “pattern-language” enabling the automatic characterization of individual skill levels.

On-the job training with expensive equipment is not an economical approach to training, since it increases the chances of damage to the equipment, possible accidents, and a drastically reduced production. This paper offers a new approach to the dilemma of cost effective hands-on training. The discussed alternative takes advantage of the Internet as a communication tool that allows a trainee to practice with a stationary backhoe from his home. Named the Internet-Based Backhoe Operator Trainer (I**B**OT), the system has been tested using the Internet as well as Internet2.

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Fig 1. Computer Integrated Backhoe at CARL

a) Motion Control **b) Visual Feedback (2D-3D)**

Fig 3. Communication Hardware

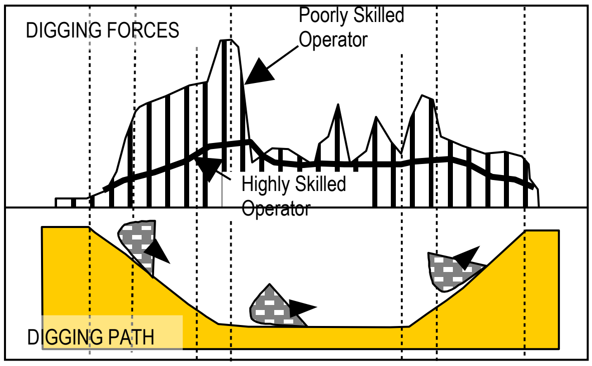

Fig 4. Comparison of Hypothetical Forces

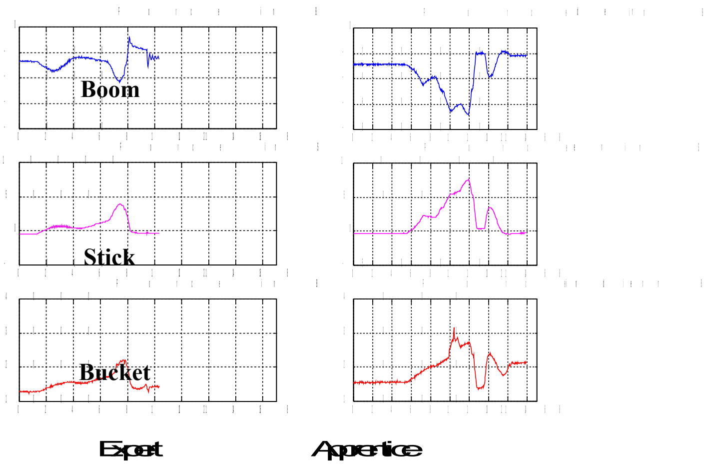

Fig 5. Measured Force Patterns

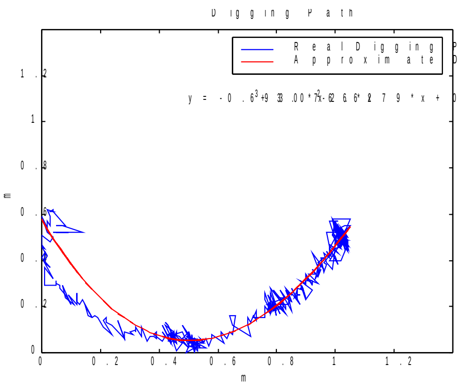

Fig 6. **Digging Path of "Apprentice" Operator**

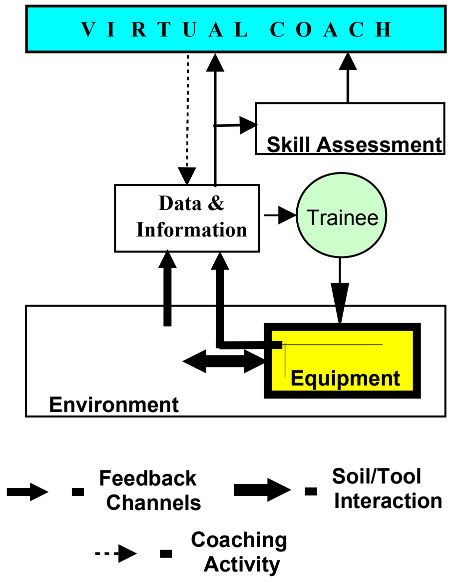

Fig 7. Layout of a Coached Training System

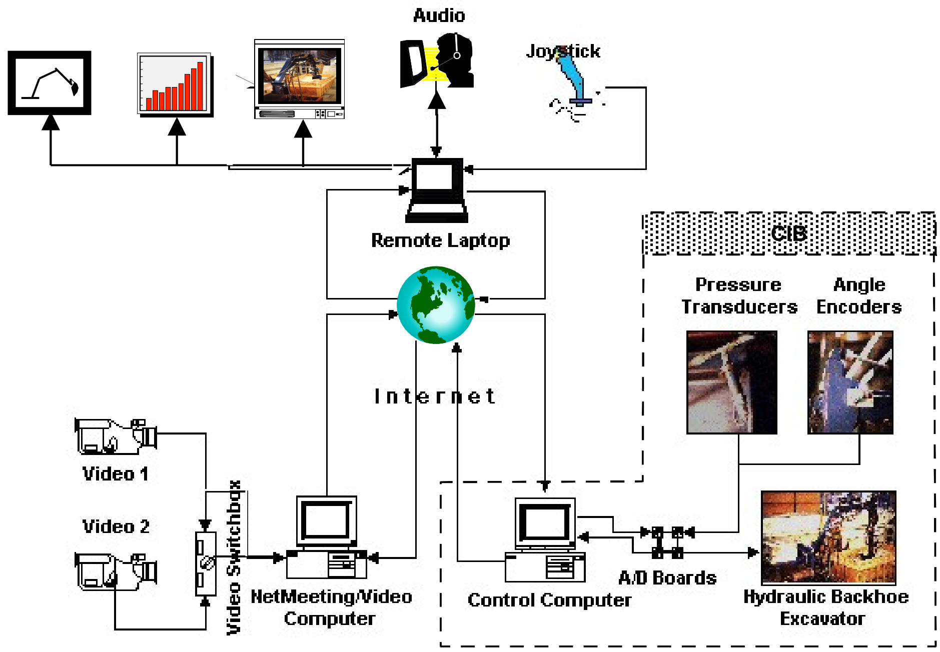

Fig 2. Schematic of Internet-Based-Operator-Training System