Sequence Learning with Intelligent 3-D Practice Environments

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Abstract: This paper describes our experiences with sequence learning activities for intelligent 3-D practice environments. An intelligent practice environment offers learning by doing and learning by discovery in a realistic practice situation. A Knowledge-Based-System (KBS) improves learning opportunities with dynamic advice and feedback. An expert system monitors user interactions to provide dynamic advice for the expected sequence of user activities and updates objects in the 3-D world for the current state in the sequence. A prototype implementation is described for intelligent 3-dimensional (3-D) practice environments developed using a web browser, the Virtual Reality Modeling Language (VRML), JAVA, and an expert system. The VRML enabled web browser provides an interactive 3-D world where the user can learn and practice sequential tasks.

Overview

This paper focuses on our experiences integrating 3-D practice environments with a sequence learning strategy managed by an expert system. Sequences are a foundation for learning complex skills and high-level problem solving. An example sequence learning approach was developed to illustrate the capabilities of intelligent 3-D practice environments for mechanical skills training. This is an on-going research activity whose long-term success is largely determined by the maturity of the technology needed to implement the intelligent 3-D practice environments. The ability to implement a few working prototypes has been proven by integrating the technologies described in this paper. Our goals are:

- Understand the capabilities required to ensure users can learn by doing and discovery
- Identify and investigate useful learning strategies, such as sequence learning, that take advantage of the exploratory learning process offered by practice environments
- Develop a basic framework or architecture that supports re-using basic components
- Devise ways to separate practice session content from the basic re-usable framework.

Cost is always an issue and affordability is a major objective. Finding ways to make practice environments an affordable solution is a critical success factor for adoption of the technology. There are two major cost considerations for this web technology, first we must be able to afford to develop the practice environments and second we must be able to afford to deploy the content to the users. One way of reducing development cost is to develop modular components that can be reused. There is a high reuse potential for the components we have developed. The expert system with its JAVA applet and VRML interface applet are reusable. The rule base for processing sequence learning procedural steps and goals is reusable. The sequence learning fact structure is reusable. The specific facts for the procedures and the VRML worlds are content specific and have to be developed as lesson content. Techniques for deploying content to the user will evolve as the technologies mature.

Sequence Learning Strategies

The objective of intelligent 3-D practice environments is to provide a highly interactive, realistic learning experience where the user learns by doing and by discovery. Sequence learning is an important component of learning complex skills and advanced problem-solving skills. Sequence learning strategies can provide practice and discovery activities for the user. To develop advanced skills, the user needs to practice solving a wide range of problems and handling different situations. A highly interactive practice environment encourages the user to explore complex relationships and increases the development of advanced skills through self-motivated discovery and problem solving activities. Sequence learning features of a practice environment are:

1. Monitoring and controlling the situation in the 3-D world
2. Recognizing goals accomplished by the user
3. Using facts and rules to recognize correct sequences of actions by the user
4. Offering advice and feedback for correct and incorrect sequences of user actions
5. Generating actions for the objects in the 3-D world based on the current sequence location
6. Dynamically controlling the behavior of objects in the 3-D world based on user actions.

Practice Environment Development Process

There are two main phases in our current prototype development process. First, the technology must be developed and integrated to create the desired capabilities of the practice environment. Our research activities have shown that it is critical for the technology to be sufficiently mature and robust to support the implementation of the desired practice environment capabilities and learning strategies. Second, after a practice environment has been developed and tested, learning content must be developed for the practice sessions.

Developing an intelligent 3-D practice environment requires software developers, instructional designers, 3-D graphics experts, subject matter experts, and rule base programmers. The initial development of an intelligent practice environment requires a technical team that can implement the practice environment with the desired learning strategies. A robust practice environment can be developed with re-usable software components, expert system rule bases, and expert system fact bases. Once a re-usable practice environment has been developed, the focus shifts to learning content development.

Learning content development for an intelligent 3-D practice environment involves three critical activities in addition to the traditional subject matter expertise required for creating a good learning session. For a sequence learning practice session, the subject matter expert first decomposes the tasks into interactive actions and sequences of actions that can be performed by the user. The behavior of objects in the practice environment is identified for each user action and accumulated sequence of user actions. Second, 3-D worlds must be created and populated with 3-D objects that support the required user interactions, controls, and object behaviors. Based on the desired practice and exploratory activities, sensors must be added to the 3-D objects to control their behavior and trigger actions, to manage user-controlled movement and placement of objects, to monitor user interactions with the objects, to monitor the user's position, and to control the state of objects. Third, knowledge engineering is required to define the facts and develop the rules necessary to support the learning and practice activities performed by the user in the 3-D world.

Example Prototype Architecture

Technology and especially the maturity of current technologies are critical to the development of intelligent 3-D practice environments. For the intelligent 3-D practice environment illustrated in this paper, we used the VRML External Authoring Interface (EAI) to integrate the Jess expert system with VRML practice environments. Jess (Copyright 1998 E. J. Friedman-Hill and the Sandia Corporation) [Friedman-Hill 1998] is an expert system shell written in JAVA. The source code for Jess is available for integration with a practice environment. Jess is also distributed with sample applets and console applications. We modified the Jess expert system interface to include buttons for feedback and advice. Figure 1 shows the configuration of existing products and developed software integrated to create an intelligent 3-D practice environment.

A simple knowledge base manages the sequence of practice activities, feedback, and advice for the practice environment. A set of facts defines the practice activities, the sequence of activities, advice for each activity the user can accomplish at the current time, and feedback when an activity is successfully accomplished. The knowledge base contains a set of rules that manage the user's practice activities and the behavior of objects in the practice environment by determining which activities are valid at the current point in time and updating the 3-D world based on the current situation. Table 1 provides information about each of the interfaces in the implementation.

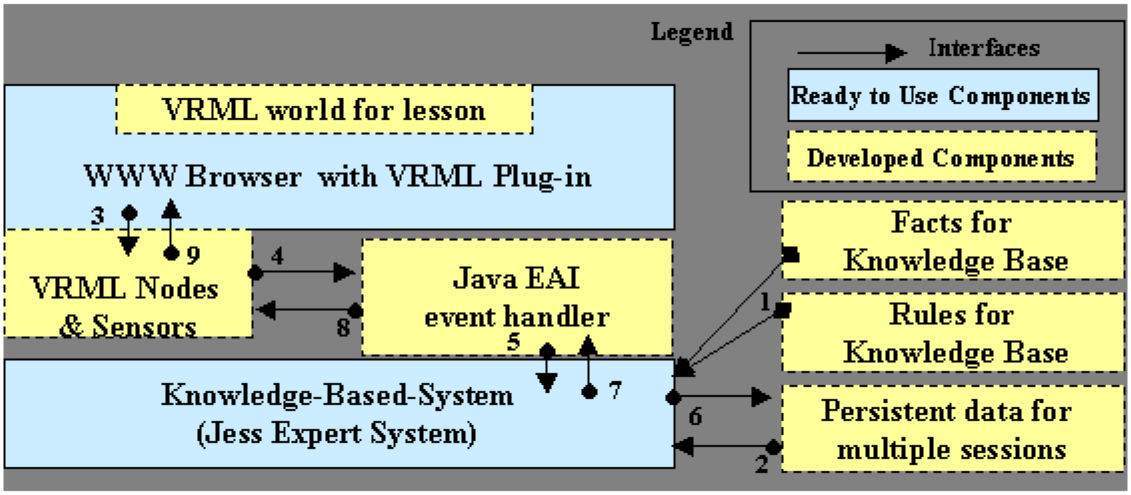

Figure 1: Prototype Implementation of an Intelligent 3-D Practice Environment

Interface Number	Interface Origin	Interface Destination	Purpose of Interface
1	Rule Base Fact Base	Expert System	Load learning strategy rules and initial set of facts into the expert system knowledge base.
2	Persistent Data Store	Expert System	Load current data for facts and other state information stored from last session
3	3-D scene User interactions	3-D Nodes and Sensors	Access information about user interactions in the practice environment
4	3-D Nodes and Sensors	Java EAI event handler	Pass user interaction information and other state information to the Java EAI event handler for analysis
5	Java EAI event handler	Expert System	Update knowledge base and assert new facts based on user interactions and state of the 3-D objects
6	Expert System	Persistent Data Store	Store facts and state information to be available in another session.
7	Expert System	Java EAI event handler	Update state data, feedback, and advice in the practice environment
8	Java EAI event handler	3-D Nodes and Sensors	Pass updated data from the expert system and Java EAI event handler to the practice environment
9	3-D Nodes and Sensors	3-D Scene	Update the scene with expert system and Java EAI event handler data.

Table 1: Interfaces in the Intelligent Practice Environment

Mechanical Skills Example

An example is the best way to illustrate the intelligent 3-D practice environment concepts. This example was developed to teach maintenance technicians how perform shaft alignment tasks. Figure 2 shows a horizontal parallel misalignment correction practice environment. The expert system advice and feedback is displayed at the top of the screen. The user receives feedback from his actions in the expert system display. The expert system determines which activities the user can perform at the current time in the 3-D scene. State information from the expert system is used to activate sensors, animations, and user selections in the 3-D scene. The expert system display has two buttons that give the user access to advice and feedback at any time. The user requests advice with the advice button. The user automatically receives feedback when he accomplishes one of the active tasks. The effectiveness of the advice and feedback is dependent on the quality of the knowledge captured in the knowledge base.

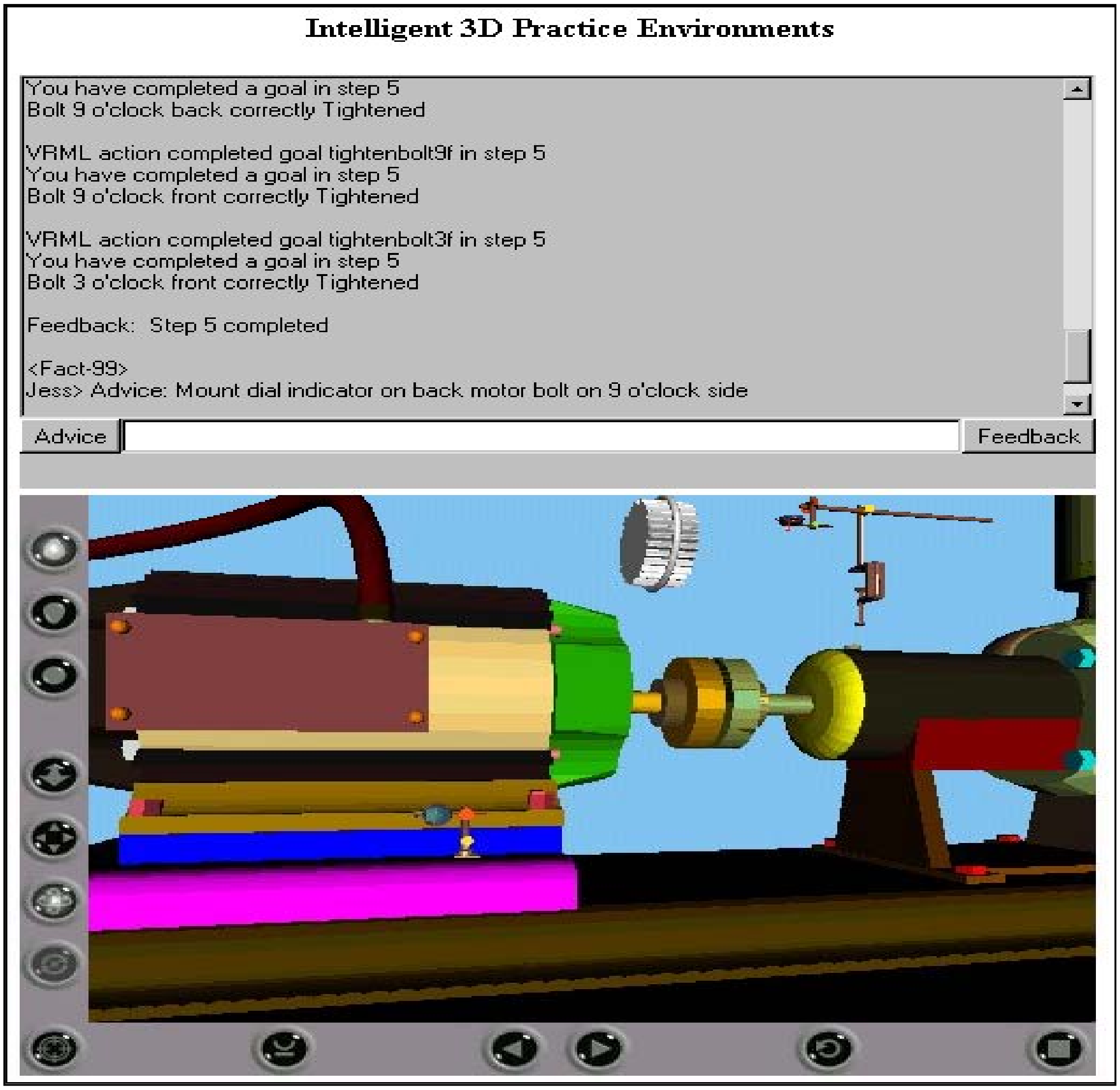

Figure 2: Horizontal Parallel Correction Practice Session

The practice session in Figure 2 illustrates problem solving for a set of sequential activities that the user will accomplish in the 3-D practice environment. An example of the fact data for this sequence learning problem is shown in Table 2. The initial fact data is loaded into the knowledge base when the practice environment is started and the facts are updated as the user works in the practice environment. The data in Table 2 reflects the current fact set for the situation shown in Figure 2 where the user has completed steps 1 through 5 and is ready to perform step 6 in the sequence.

The rules in the rule base interact with the 3-D practice environment to activate objects that the user must work with to accomplish goals in the procedure. These objects include the dial indicator, the reset or zero knob on the dial indicator, the motor, and the motor mounting bolts. For step 6, the only active component in the 3-D practice environment is the dial indicator that needs to be mounted on the 9:00 side of the motor near the back mounting bolt. There were 3 active components in step 5 where the user was required to tighten 3 bolts in an undefined order.

The current rules implemented in the sequence learning rule base have the following behavior:

1. All goals for the current step are activated and can be accomplished by the user.

2. All goals in a step must be accomplished before activating the goals in the next step.
3. The user can accomplish the active goals in the current step in any order.
4. When requesting advice, advice for any of the active goals can be given to the user.
5. Feedback is automatically given to the user whenever the user accomplishes a goal or a step
6. The user can request feedback identifying their current situation at any time.

Step	Goal	Next Step	Advice for next action in sequence	Feedback for correct action in sequence	Active	Completed
1	Mount dial indicator	2	Mount dial indicator near front motor bolt on 9 o'clock side	Dial indicator correctly mounted on front motor bolt on 9 o'clock side	No	Yes
2	Zero dial indicator	3	Zero the dial indicator on front motor bolt on 9 o'clock side	Dial indicator correctly zeroed on front motor bolt on 9 o'clock side	No	Yes
3	Loosen bolt 3f	4	Loosen 3 o'clock front mounting bolt	Bolt 3 o'clock front correctly loosened	No	Yes
3	Loosen bolt 9f	4	Loosen 9 o'clock front mounting bolt	Bolt 9 o'clock front correctly loosened	No	Yes
3	Loosen bolt 9b	4	Loosen 9 o'clock back mounting bolt	Bolt 9 o'clock back correctly loosened	No	Yes
4	Move Motor	5	Push front of motor on 9 o'clock side	Motor 9 o'clock front correctly pushed	No	Yes
5	Tighten bolt 3f	6	Tighten 3 o'clock front mounting bolt	Bolt 3 o'clock front correctly Tightened	No	Yes
5	Tighten bolt 9f	6	Tighten 9 o'clock front mounting bolt	Bolt 9 o'clock front correctly Tightened	No	Yes
5	Tighten bolt 9b	6	Tighten 9 o'clock back mounting bolt	Bolt 9 o'clock back correctly Tightened	No	Yes
6	Mount dial indicator	7	Mount dial indicator on front motor bolt on 9 o'clock side	Dial indicator correctly mounted on front motor bolt on 9 o'clock side	Yes	No
7	Zero dial indicator	8	Zero the dial indicator on front motor bolt on 9 o'clock side	Dial indicator correctly zeroed on front motor bolt on 9 o'clock side	No	No

Table 2: Facts for a Sequential Activity

Related Research

There are several research areas that should continue to have a positive impact on our ability to add intelligence to 3D practice environments to make them more effective training tools. 3D worlds offer a rich environment for visualization and expression of ideas. Researchers have already begun to populate and inhabit 3D worlds so they can gain knowledge about the unique challenges and potential of 3D learning environments. The interaction between man and machine is often viewed as a dialog. An effective practice environment needs to be able to participate in a meaningful dialog with the user(s) in a problem solving session. Two important areas of research aimed at improving the ability for man and machine to communicate are mixed-initiative interactions [Hearst 1999] and intelligent dialog systems [McRoy, Ali, Restificar, and Songsak 1999]. Researchers in these areas are developing new techniques to improve communications between man and machine through more meaningful and flexible interaction strategies. Collaboration among real and simulated users in multi-user worlds is another hot research area. Pedagogical agents [Lester, Towns, and FitzGerald 1999] are being created to act as teachers and tutors in future 3-D learning environments. Other researchers are simulating the actions of peers for team problem solving activities. Dynamic, real-time explanations [Callaway, Daniel, and Lester 1999] should increase learning effectiveness for future generations of practice environments.

Summary

This project is an on-going research activity. We have not conducted any large-scale user evaluations or trials. However, we are able to provide the following assessment of the current state of the technologies used for our experiments. The mechanical skills training example demonstrates the integration of existing technologies with a minimum amount of software development. With the objective of making 3-D practice environments an affordable training solution, reuse was a prime consideration in the design of the implementation.

1. The Java applet encapsulating the Jess expert system is reusable and is not training content dependent.
2. The Java EAI event handler applet is reusable. A table linking the Jess fact base with the VRML nodes and sensors in the practice environment is content specific and must be created for each practice session.
3. The rules developed for the sequential activity knowledge base are totally reusable. These rules provide the logic for managing the user activities and VRML objects for a sequential procedure practice environment. The rules also provide the logic needed to determine the advice and feedback requested by the user with the Jess applet interface buttons.
4. The fact structure for the knowledge base is reusable for other sequential procedure practice environments. The facts are content specific and must be created for each practice session.
5. Reusing 3-D Computer Aided Design (CAD) objects adds realism to the practice environments. Reuse is never easy. The original CAD model designer's objectives are very different than those of a training practice environment designer. Inevitably, the objects must be edited. A good approach is to create a hierarchical scene with each object of interest in a separate VRML file. The 3-D scene is created as a composite of all of the individual VRML objects. The user's interactions are easier to monitor and analyze with a hierarchical scene composition

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