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Implementing Intelligent 3-D Web-Based-Training Solutions

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Abstract

This paper describes an approach to implementing web-based-training (WBT) environments using the Virtual Reality Modeling Language (VRML) and Java. A VRML enabled web browser provides an interactive 3-dimensional (3-D) world where the user can learn by discovery and by doing. A Java expert system adds the ability for the practice environment to use reasoning to coach and guide the learning process. Integrating an expert system with a VRML world provides dynamic assessment and coaching so the user can analyze his actions in the 3-D VRML world. A mechanical skills training example is used to illustrate these concepts.

Background

This paper describes a work in-progress. Our past research led to the implementation of structured 3-D practice environments that provided a training and problem-solving environment by integrating 3-D animations with multimedia Computer Based Training (CBT) techniques. We extended the problem solving environments into 3-D virtual worlds where the user could freely explore and learn by discovery. This extension enabled us to identify many of the advantages and disadvantages of the technologies currently available. We have documented these lessons learned in other papers. This paper focuses on implementing practice environments that can take advantage of the capabilities offered by Artificial Intelligence (AI) technologies such as expert systems. Our first implementation of an intelligent practice environment involved integrating a practice environment with an expert system. This was an ideal first step toward creating an intelligent practice environment because expert systems are widely used, the advantages are well understood, expert system engines are readily available, and programming an expert system is less complex than other AI approaches.

Objectives

Our long-term objective is to develop realistic 3-D practice environments where a user can learn by discovery and gain mission qualifying experience by doing meaningful tasks. The objective of our current research is to continue to improve skills training by adding intelligence to realistic 3-D practice environments. Adding intelligence should improve learning by giving the practice environment the capability to adapt coaching and feedback to the user's individual needs. Our initial implementation of a 3-D practice environment integrated with an expert system is described in this paper. This experience has given us an understanding of the potential offered by training with intelligent 3-D practice environments. As a future objective, we would like to take advantage of other intelligent technologies when they are mature.

Cost is always an issue and minimization is a major objective. Finding ways to make 3-D practice environments an affordable training solution is a critical success factor for adoption of the technology. One way of reducing cost is to develop modular components that can be reused. There is a high reuse potential for the components illustrated in this paper. The expert system JAVA applet and VRML interface applet are reusable. The rule base for processing procedural steps and goals is reusable. The facts defining the procedures and the VRML worlds are content specific and would have to be custom crafted for each lesson.

Practice Environments

Experience through practice is extremely important to the development of basic and advanced skills. 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. Some of the capabilities that are essential for an effective practice environment are given in Table 1.

Intelligent Practice Environments

VRML worlds naturally support learning by discovery and provide the basic capabilities for learning by doing. Adding intelligence by integrating an expert system with the VRML worlds can provide the dynamic assessment, coaching, and feedback capabilities that are essential for a positive learning experience. Table 2 identifies some useful learning by doing approaches for mechanical skills training with an intelligent practice environment.

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 products such as a 3-D practice environment. Jess is also distributed with sample applets and console applications. We used the VRML External Authoring Interface (EAI) [VRML 97] to integrate the Jess expert system with the VRML practice environments. Figure 1 shows the configuration of existing products and developed software integrated to create an intelligent practice environment. Table 3 provides information about each of the interfaces in the configuration.

Practice Environment Capabilities	Learning Challenges	Practice Environment Implications
Objective or Goal	A 3-D world can be overwhelming for an interactive user. The user needs to understand the objectives and have goals for his interactions with the 3-D world.	In a typical VRML world, the user doesn't really know what he should discover or the tasks he should perform. For an effective learning experience, the 3-D practice environment must help the user understand the components and why he is interacting with the world.
Learning Approach	Users can be overloaded with so many possibilities and not know how to learn with a 3-D world. The user needs to be given a learning approach for his interactions with the 3-D world.	In a typical VRML world, the user is not given any guidance about the actions he is expected to perform and the user must explore the scenes to find the objects with sensors and the animation triggers. An effective practice environment must supply the user with a learning approach that is appropriate for the 3-D world and his interactions in the world.
Time Limit Expectations	3-D worlds can be fun and users can expend a lot of time exploring a 3-D world and not achieve the expected outcomes. The user needs to know how much time he should spend interacting with the 3-D world.	The 3-D world needs to give the user guidance for spending time in the world and working with specific components. He needs to spend sufficient time to discover the important aspects of the scene and not miss a valuable learning experience.
Association	The user needs to be able to associate the world of 3-D objects and his interactions with related information and resources.	The practice environment should have the ability to associate related information such as images, textual resources, and other data with the practice activities performed by the user in the VRML world.
Coaching	Coaching and guidance need to be provided to enhance a user's learning experience while performing complex tasks.	The practice environment should be able to coach and guide the user based on his individual interactions in the VRML world. Coaching should be used to increase motivation for a novice user by preventing frustrating situations in the freedom of a typical VRML world. Advanced users should have access to advice and guidance for the practice situation and the consequences of their interactions in the 3-D world.
Feedback and Assessment	For a positive learning experience, the user needs feedback and assessment to understand his progress.	The practice environment should offer timely feedback and assessment directly related to the user’s interactions. The feedback should increase the user’s ability to reason and analyze the practice situation. Feedback and assessment should help the user understand if his practice actions are correct.

Table 1: Effective Practice Environment Capabilities

Learning by Doing Approach	User Activities	Intelligent Practice Environment Implementation
Construction	The user performs meaningful tasks such as constructing a product from the 3-D components in the practice environment.	Java is used to integrate the VRML world with an expert system. The expert system monitors the situation in the world and provides instructional data, coaching, assessment, and feedback. This guidance is dynamically updated based on the user's interactions and current state of the world.
Procedures and Sequences	The user is guided through a sequence of goals in the 3-D world. The Construction learning approach is extended with a recommended sequence of actions.	The VRML world for a procedural set of tasks is created and integrated with an expert system. The expert system manages the correct sequence of actions the user should perform and controls the behavior of objects in the VRML world. The expert system provides instructional data, guidance, and feedback based on the user's interactions and the current position in the procedure.
Simulation	The user experiences a practice environment that responds in a realistic manner to the accumulation of his actions and the behavior of the objects in the 3-D world.	The VRML world for the simulation is created and integrated with an expert system. The expert system manages the state of the VRML world objects and the user's interactions. The world can be enhanced with external simulations that mimic realistic behavior for the objects in the 3-D world. The expert system provides instructional data, guidance, and feedback based on the user's interactions and the current situation in the simulation.

Table 2: Approaches for Learning by Doing with an Intelligent Practice Environment

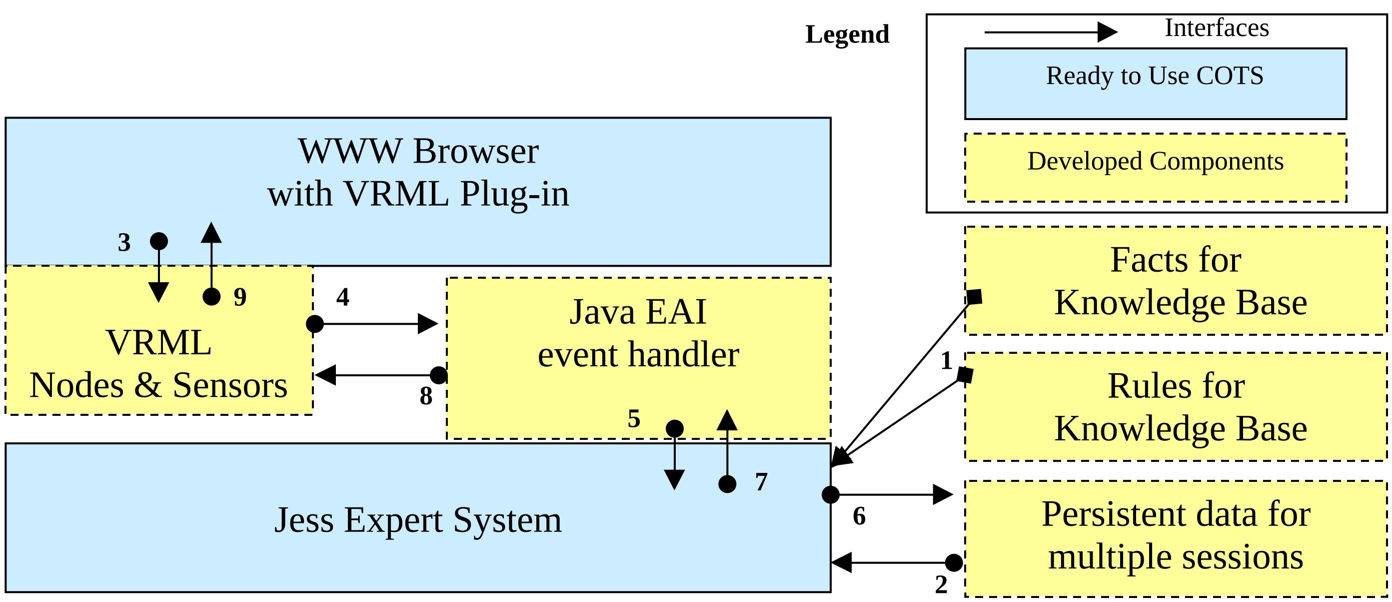
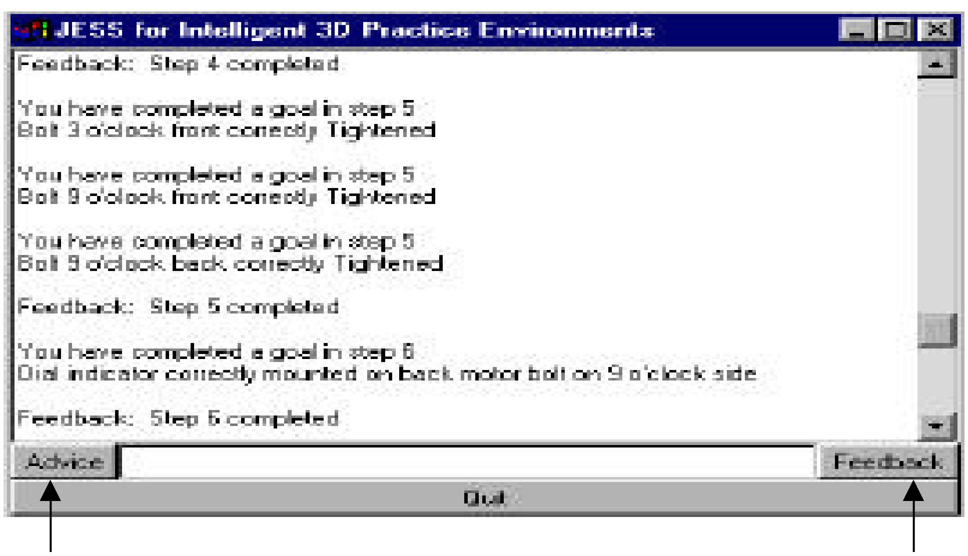


Figure 1: Configuration of an Intelligent Practice Environment

Interface Number	Interface Origin	Interface Destination	Purpose of Interface
1	Rule Base Fact Base	Expert System	Load rules and initial set of facts into the expert system knowledge base.
2	Persistent Data Store	Expert System	Load facts and other state data stored from last session
3	User interactions in VRML scene	VRML Nodes and Sensors	Access information about user interactions in the practice environment
4	VRML 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 objects in the practice environment
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	VRML Nodes and Sensors	Pass updated data from the expert system and Java EAI event handler to the practice environment
9	VRML Nodes and Sensors	VRML Scene	Update the scene with expert system and Java EAI event handler data.

Table 3: Interfaces in the Intelligent Practice Environment

Using readily available Commercial-Off-The-Shelf (COTS) products and standard interfaces is essential to satisfying the objective of achieving a cost-effective training solution. The Java EAI event handler is a Java applet developed using the VRML EAI to communicate with VRML worlds. A Java applet encapsulating the Jess expert system was developed and is shown in Figure 2. Java inter-applet communication routines were developed to communicate between the VRML EAI applet and the Jess applet.



User controlled Advice **User controlled Feedback**

Figure 2: A Modified Jess Interface for the Practice Environments

Figure 2 shows the Jess expert system interface modified to include buttons for feedback and advice. A simple knowledge base manages the sequence of practice activities, feedback, and advice for the practice environment. A set of facts define 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 by determining which activities are valid at the current point in time and updating the VRML world based on the current situation.

Mechanical Skills Example

The examples used to illustrate the 3-D practice environment concepts were developed to teach maintenance technicians how perform shaft alignment tasks. Shaft alignment is the process of positioning the shafts of two pieces of coupled rotating machinery to work together smoothly. A pump and motor are examples of coupled rotating machinery. Shaft alignment is a common maintenance task at locations such as electric power plants, industrial-processing facilities, manufacturing plants, and aboard ships. Many facilities employ a full time staff of maintenance technicians who align shafts to keep the equipment operating smoothly. When shafts are not aligned properly, the equipment’s useful life is reduced and reliability is uncertain. These factors contribute to a tremendous increase in operational costs.

Shaft alignment is an ideal mechanical skills training problem for investigating the effectiveness of 3-D practice environments because performing precision shaft alignment tasks requires:

- significant cognitive and perceptual skills in addition to motor skills
- visualizing the complex relationships between mechanical components
- practice taking precision measurements
- using the perceived misalignment condition to select and use the correct mathematical formulas
- practice correcting the misalignment conditions.

Figure 3 shows a horizontal parallel misalignment correction practice environment. The Jess expert system guidance and feedback is displayed at the top of the screen. The user receives feedback from his VRML actions in the Jess expert system display. The Jess expert system determines which activities the user can perform at the current time in the 3-D VRML scene. State information from the expert system is used to activate animations and selections in the VRML 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 user can also access feedback at any time with the feedback button. The effectiveness of the advice and feedback is dependent on the quality of the knowledge captured in the knowledge base.

The practice session in Figure 3 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 the problem is shown in Table 4. 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 4 reflects the current fact set for the situation shown in Figure 3 where the user has completed steps 1 through 5 and is ready to perform step 6.

Intelligent 3D Practice Environments

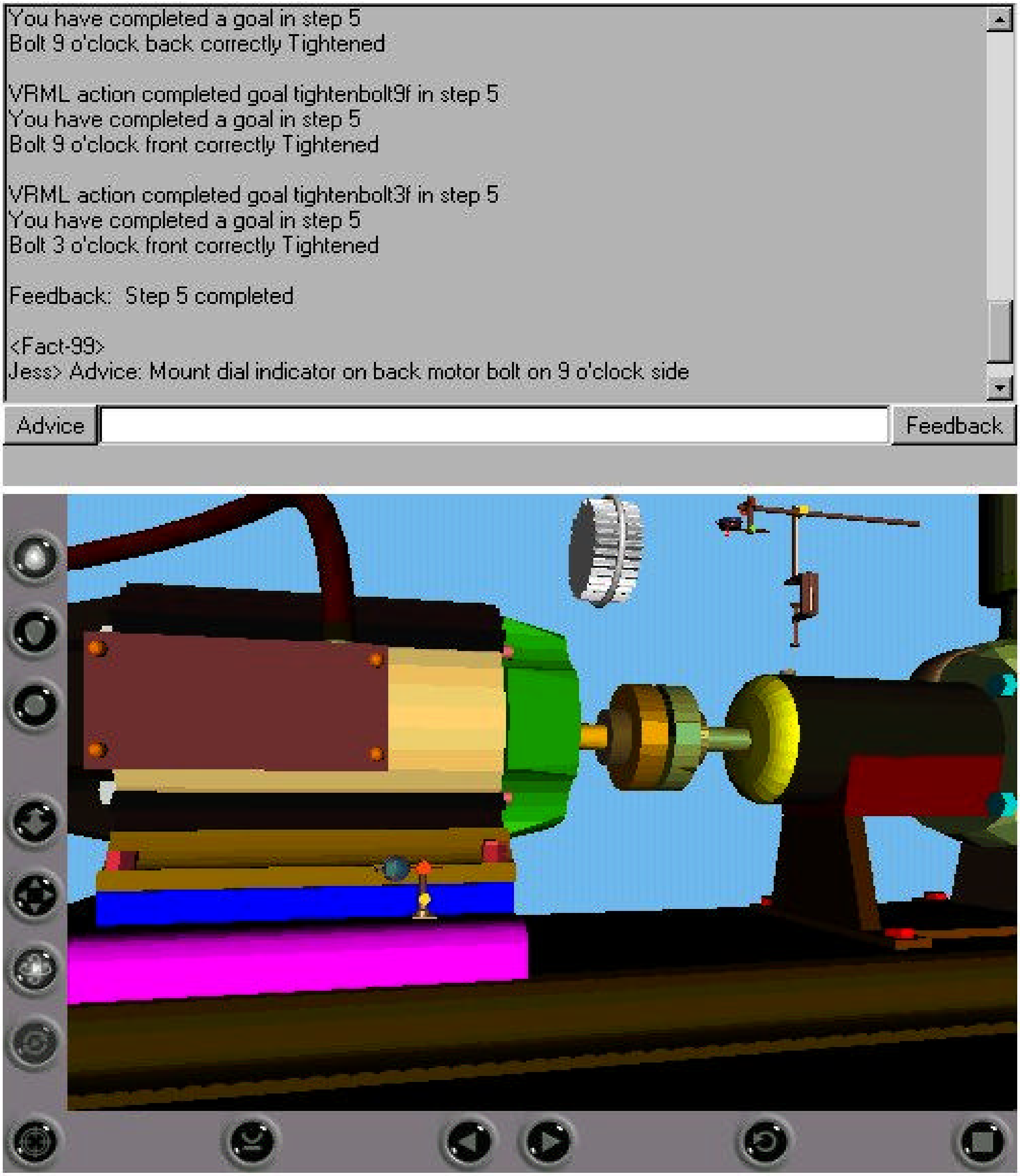


Figure 3: Horizontal Parallel Correction Practice Session

Step	Goal	Next Step	Advice	Feedback	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 4: Facts for a Sequential Activity

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 sequential activity 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.

Lessons Learned

The VRML External Authoring Interface standard [VRML 1997] is supported by several of the VRML plug-ins for web browsers but is still undergoing revision. We had to experiment to find a combination of web browsers and VRML plug-ins that would support the EAI interface needed for the intelligent practice environment. Consistent browser and plug-in support for the VRML EAI ISO standard would have greatly reduced the experimentation required to implement the intelligent practice environment.

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.

- The Java applet encapsulating the Jess expert system is completely reusable and is not training content dependent.
- 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.
- 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.
- 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.
- 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

The implementation described in this paper was custom crafted as a prototype to learn about the process of adding intelligence to practice environments and to begin to understand the potential advantages of intelligent practice environments. With a well-defined concept for an intelligent practice environment, it will be possible to develop tools that generate the content specific links between the 3-D practice environment and a supporting knowledge based system.

Summary

This paper presents an approach to implementing intelligent 3-D practice environments by integrating an expert system with VRML worlds. This added intelligence manages the user's activities in the 3-D practice environment and provides dynamic coaching advice and feedback based on the user’s activities in a 3-D practice environment. The capabilities required by effective practice environments were identified. We provided a configuration for integrating an expert system with a practice environment and provided implementation details. The re-use potential was described for the components implemented for the mechanical skills training example. A detailed explanation was given with the facts and rule behavior for a procedural problem solving activity common in mechanical skills training. We identified some of the many lessons we have learned in this process. We are making progress toward our long-term objective to develop realistic 3-D practice environments where a user can learn by discovery and gain mission qualifying experience by doing meaningful tasks. Our initial step of integrating a 3-D practice environment with an expert system has enabled us to understand the processes and challenges involved with building an intelligent 3-D practice environment.

About the Author

Janet Faye Johns is a Principal Engineer at The MITRE Corporation where she is responsible for software systems design and development. Ms. Johns has a B.S. in Mathematics, an M.S. in Math and Computer Science, and has completed the coursework for a Ph.D. in Computer Engineering. Ms. Johns has been the vice-chair of the Association for Computing Machinery (ACM) Special Interest Group for Ada (SIGAda) Artificial Intelligence Working Group (AIWG) since 1990. She has published numerous papers and teaches tutorials on the implementation of Artificial Intelligence applications and training applications using leading-edge technologies. Ms. Johns was the Product Manager for the Shaft Alignment Primer, which was developed to investigate how the latest technologies could be used to teach mechanical skills. Ms. Johns may be reached by phone at 817-430-1826 or by e-mail at jfjohns@mitre.org.

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