Intelligent Environment for Training of Industrial Operators

G. Arroyo-Figueroa, Liliana Argotte, Yasmin Hernandez and Israel Galvan

Abstract—Training of operators has become an important problem to be faced by power systems: updating knowledge and skills. An operator must comprehend the physical operation of the process and must be skilled in handling a number of normal and abnormal operating problems and emergencies. We are developing an intelligent environment for training of power system operators. This paper presents the architecture of the intelligent environment composed by computer based training components labeled as reusable learning objects; a learning object repository; a concept structure map of the power plant domain, a tutor module based on course planner, an operator model based on cognitive and affective components and operator interface. The general aim of our work is to provide operators of complex industrial environments with a suitable training from a pedagogical and affective viewpoint to certify operators in knowledge, skills, expertise, abilities and attitudes for operation of power systems.

***Index Terms*—tutorial systems, planning, virtual reality, learning objects, industrial application.**

I. Introduction

Training of operators is an important problem faced by thermal power plants: updating knowledge and skills. The process of learning how to control, maintain and diagnose in a complex industrial environment takes years of practice and training. An operator must comprehend the physical operation of the process and must be skilled in handling a number of abnormal operating problems and emergencies. The problem increases when the complexity of the system obstructs the efficiency, reliability and safe operation. So the novice and experienced operators need continuous training in order to deal reliably with uncommon situations.

For safety efficiency reasons it is not recommend to train operators on real equipment. Several ways to cope with operators training has been proposed. Most proposals for operator training are based on Computer Based Training Systems (CBT) and simulators. A CBT is a computer system that groups a set of programs and training methods that uses the computer capabilities to present the operator with the instructional material and to provide an environment for practical training. The main advantage of CBTs is their unlimited availability: they can be used whenever the trainee wants.

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Due to necessity of training of operation skills in power plants, simulators have been a common alternative. A power simulator is composed of a set of quantitative and qualitative models which simulate the physical behavior of the plant. The aim of training with a simulator is to get operators not only to perform the common procedures, but also analyzing abnormal situations and performing emergency procedures. The next generation in training systems is computer-based training systems that provide instruction just like a human trainer does. The training requirements ask for powerful interfaces, a more efficient and personalized training by means of incorporating artificial intelligent (AI) techniques, adaptive interfaces, simulation tools, learning objects based on multimedia and virtual reality components.

Most proposals for learning student are based on Intelligent Tutoring Systems (ITS). ITS are interactive learning environments based on instruction assisted by computers. One of the intelligences of these systems is their ability to adapt to a specific student during the teaching process. In general, the adaptation process is composed by three phases: (i) getting the information about the student/trainee/operator, (ii) processing the information to initialize and update a student model, and (iii) using the student model to provide the adaptation.

This paper describes the architecture and development of an intelligent environment (IE) for training of power systems operators. The IE takes elements of AI such as student modeling, intelligent tutors, planning, concept maps and reusable learning objects (RLO) to build a tool that allows meet requirements for learning and training of power system operators. In contrast with a traditional training system, the main goal of the intelligent environment is to certify operators in knowledge, skills, expertise, abilities and attitudes for operation of power systems. In contrast with a traditional training system, the main goal of the intelligent environment is to certify operators in knowledge, skills, expertise, abilities and attitudes for operation of power systems.

II. ARCHITECTURE OF THE INTELLIGENT ENVIRONMENT

The architecture of the intelligent environment is based on dynamic course generating systems proposed by Brusilovsky [1]. The intelligent environment is composed of four main components (see Figure 1): the domain knowledge module, the tutor, the operator model, and the learning management system (LMS).

The first module contains the knowledge of the domain in form of learning objects and concept structure maps. The tutor module is the component that generates the sequence of learning objects to be presented to operator in form of course.

Taking as a basis the concept map, the pedagogical component and the operator model, the training course planner generates a specific course for each operator. The operator model is used to adapt the intelligent environment (IE) to each specific operator. The operator model is divided into three subcomponents: cognitive component, operator profile and affective component. Finally, the LMS controls the interactions with the operator, including the dialogue and the screen layout. The main purpose of an LMS is to present to the operator the learning materials in the most effective way.

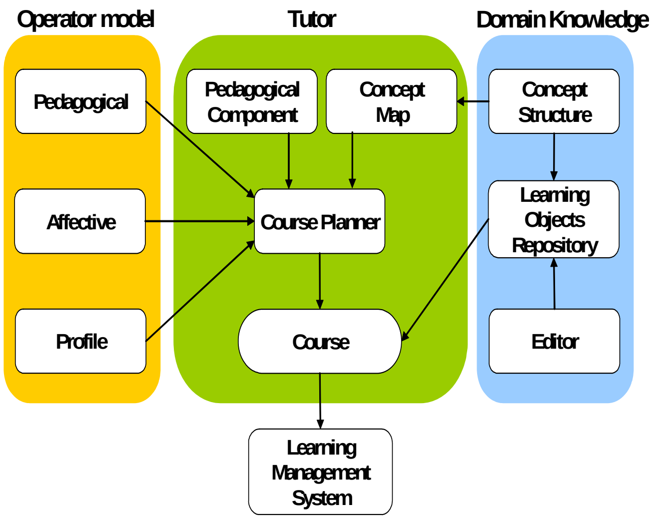


Figure 1. Intelligent environment architecture.

III. DOMAIN KNOWLEDGE

The domain knowledge module has two main components: the concept structure map and the repository of learning objects. The domain knowledge contains the expert's operation abilities in procedure and malfunction operations and its representation considers both theoretical and practical concepts.

The concept structure contains the concept/topic structure of the subject knowledge to be taught (see figure 2). It is possible to organize the domain concepts/topics into a set of smaller, possibly interrelated AND/OR graphs, representing relatively independent sub-areas of the knowledge, different views, or different levels of granularity. It is represented as an AND/OR graph, where nodes represent the concepts domain or elements of knowledge, such as electrical topics, components of control board, rules, procedures and so on; and arcs represent relationships between concepts, such as a prerequisite for learning a concept or a sequence. Every node is associated with a set of teaching and testing materials, which instantiate different ways to teach the concept/topic (e.g. introduce, explain, give an example, and give a simulation, exercise, or test).

For the training of power plant operators, the concept structure map is made based on the structural decomposition of the generation process of electricity. The generation process can be divided in unit, structure, systems, subsystems, equipment and component. The concept structure has a higher expressive power because it allows representing not only prerequisites, but also many different types of relationships between concepts; and it enables the use of AI planning techniques for the generation of alternative courses. Therefore, it guarantees a wide variety of different teaching goals and several courses for achieving these goals.

The teaching and testing materials are labeled as Reusable Learning Object (RLO), as well named Shareable Objects (SCO) according with the SCORM (Shareable Content Object Reference Model) standard [2].

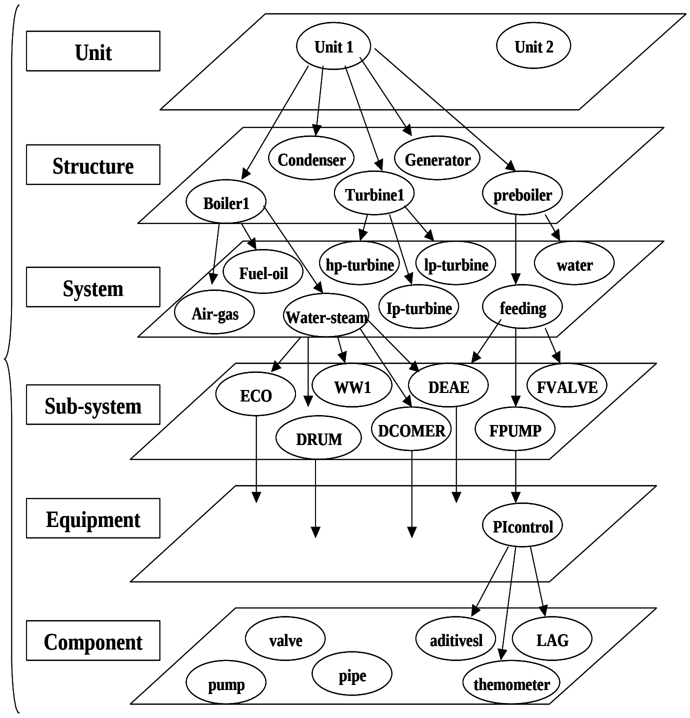


Figure 2. Concept structure map for generation process.

RLO are self-contained learning components that are stored and accessed independently. The learning materials consider both theoretical and practical concepts contained in: electronic books, simulation tools, multimedia and virtual reality tools, to present to the operator pedagogical actions such as explanations, exercises, tests, and so on. RLO are any digital resource that can be reused to support Web-based learning using learning management systems (LMS). The learning content authors can create, store, reuse, manage and deliver digital learning content. The same object may be used a number of times and for several purposes as required. The editor contains tools for edition of teaching and testing materials based on learning objects.

. The Domain Knowledge module has a Learning Object Repository (LOR) [3]. The LOR is a central database in which learning content (SLO) is stored and managed. The Repository main component is the database. The figure 3 shows the architecture of the LOR.

Lately, some work has been done at CFE (National company for power generation and distribution in Mexico) to create a valve maintenance course and an energized power-line maintenance course using RLO based on virtual reality. Also, CFE has a collection of more than 400 instructional courses developed in house during the last 10 years, for the generation process. These courses will be integrated to the domain knowledge module as RLO. This module has a Learning Object Repository (LOR). The LOR is a central database in which learning content is stored and managed.

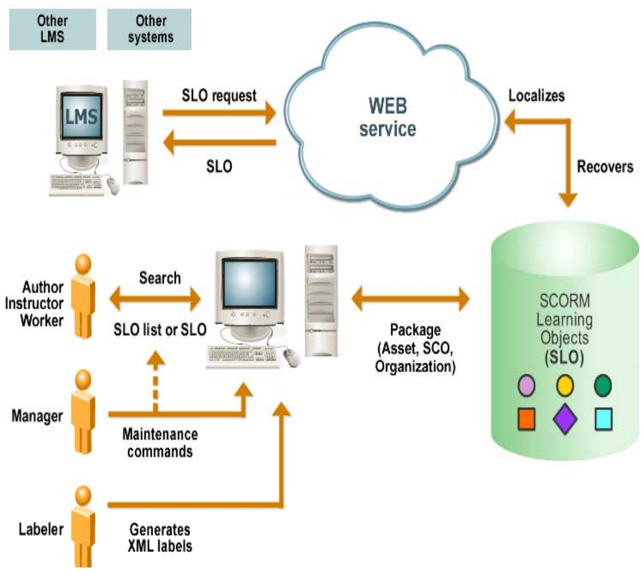


Figure 3. Learning object repository.

IV. TUTOR

The Tutor Module generates the sequence of learning objects (teaching and testing materials) to be presented to an operator in a form of course. Taking as a basis the AND/OR graph representing the concept map, the pedagogical component and the operator model, the training course planner generates a specific course. The concept plan is a sub-graph of the knowledge domain (concept structure).

The pedagogical component provides a set of teaching rules for the selection of content and presentation of the concept plans according with the learning style, affective state or learning preferences of the operator. The pedagogical component contains the learning goals and several pedagogical strategies to teach operators and select the pedagogical strategy to be used, based on the operator model. This strategy represents the specific necessities of the operator from both, affective and pedagogical point of view.

The training course planner (TCP) uses the formalism of Markov Decision Processes (MDPs) [4] which provide a powerful framework for solving sequential decision problems under uncertainty. Given a problem specification, the objective of the MDP is to obtain the optimal policy for getting the plant to a state under optimal operation. Formally, an MDP problem specification is a triplex $M = < S, A, \Phi, R>$, where S is a finite set of states $\{1, . . . , n\}$; A is a finite set of actions for each state; $\Phi: A \times S \rightarrow \Pi(S)$ is the state transition function specified as a probability distribution. The probability of reaching state s' by performing action a in state s is written as $\Phi(a,s,s')$; $R: S \times A \rightarrow R$ is the reward function; $R(s, a)$ is the reward that the system receives if it takes action a in state s. A policy for an MDP is a mapping $\pi: S \rightarrow A$ that selects and action for each state. A solution to an MDP is a policy that optimizes a performance measure such as to maximize the student's score on test. The training course planner (TCP) is based on SPUDD [5] which stands for "Stochastic Planning using Decision Diagrams". It includes a very efficient version of the value iteration algorithm for MDPs and POMDPs that uses algebraic decision diagrams (ADDs) to represent value functions and policies [6].

A course generated by TCP looks like a traditional course; however, this course is generated for an operator in particular to achieve a specific training goal. Each course is generated in a dynamic way based on particular characteristics of the operator, and it can be changed dynamically to reflect changes in the operator model. During the presentation of the course to the operator, if the operator answers the test items correctly or performs an exercise correctly, no changes are necessary. However, if the operator fails to demonstrate knowledge about a concept, a re-planning of the course follows. The TCP generates a new sequence of teaching materials towards to the training goal, starting from the current state of student knowledge as recorded in the operator model.

V. LEARNING MANAGEMENT SYSTEM

The learning management system (LMS) manages user learning interventions. The LMS supervises the training activities, such as the access to the intelligent environment, manages the user accounts, and keeps track of the training course of every user and generates reports. The importance of the LMS is the functionalities they offer in contrast to traditional training systems, such as self-registration, training workflow, on-line learning, on-line assessment, management of continuous professional education, collaborative learning, and training resource management. The one of the main activities of the LMS is provide communication services between users, authors and trainers such as videoconferencing, discussion threads.

VI. OPERATOR MODEL

The operator model is used to adapt the intelligent environment (IE) to each specific operator. The operator model is built from observations that the IE makes about the operator. These can come in the form of responses to questions, answers to problems, behavior, etc. The operator model is divided into three subcomponents: pedagogical component, operator profile and affective component. The pedagogical model represents the state of knowledge of the operator.

The pedagogical model is constantly updated during the training session as the pedagogical state of operator changes. The pedagogical model is an overlay model, where the operator's knowledge is a subset of the knowledge represented by the concept structure. The pedagogical model is active during the training session and collects all the information related to trainee performance in the current session: i.e. instructional plan, errors, objectives requested, actions performed, etc.

The affective model of the operator is a representation of the affective state of the trainee. The operator model must contain knowledge about the affective state of the student, in addition to knowledge about her pedagogical state, in order to give her an affectively adequate response and at the pedagogically appropriate time. La figure 4 shows the pedagogical and affective model [7].

The operator profile represents the relevant operator's features which are important for the training process: capacity of pedagogical development, learning style, expertise, and so on. The profile component contains information related to: operator curriculum, expertise, skills, learning characteristics, operator's errors history, didactical material used with the trainee, and a history of the whole instructional process.

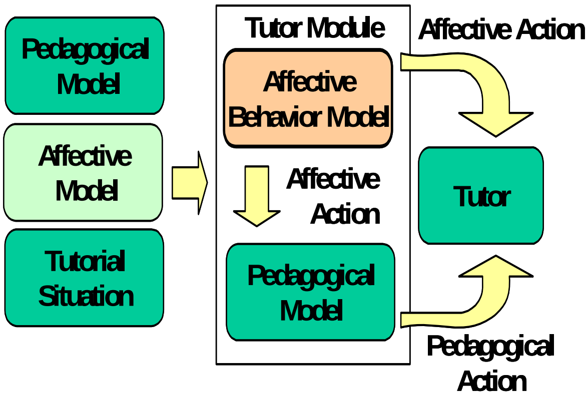


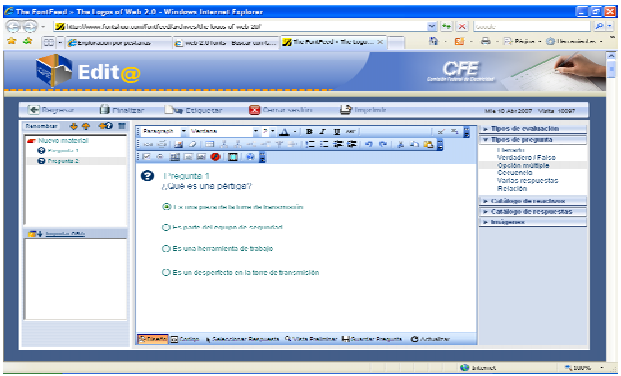
Figure 4. Operator model.

VII. APLICATION

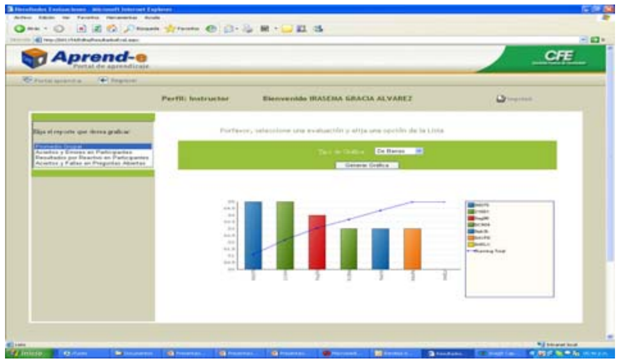
Nowadays, some relevant results have been implanted at CFE. The concept structure map of a power plant domain, where the nodes represent concepts of the domain and the links relationships between concepts was used as the basis to build the semantic network that supports the storage and retrieval of SCORM compliant Learning Objects (SLO). For administrate the learning objects, we development a system, called as "Aprend-e" [8].

The Aprend-e system manages, spreads and promotes the knowledge of the CFE, by mean of the search and recovery of RLO. The system is composed by a Learning Object Repository (LOR). The LOR is a central database in which learning content is stored and managed. The system has a Portal with access to the different profiles; editor, instructor, and worker. Also has a search module for recover and reuse of learning object of the LOR. The figure 5 shows some interfaces of the Aprend-e system.

a)



b)



c)

Fig. 5. Interfaces of the Aprend-e, a) portal; b) editor; c) instructor

Currently, the system is loaded with 115 power plant courses wrapped as RLO and it is fully operating at CFE. These courses will be integrated to the domain knowledge module as RLO.

Some work has been doing to create operational courses; for example for power plant operation assistant [9] and maintenance of power-line energize based on virtual reality [10, 11]. The figure 6 shows the concept structure map for power-line energize.

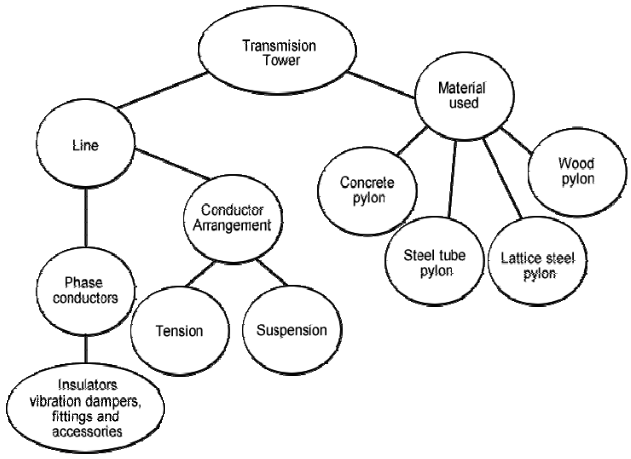


Fig. 6. Concept structure map for power-line energize

For this concept structure map, we developed a training virtual system for power-line operators. The system called ALEN 3D includes two components: the learning module and the evaluating module. The first module allows a user to navigate freely with a 3D representation of a structure of power line. It also includes materials, tools and equipment that the user can be select for each procedure. The user receives written or audio information of the stages of the procedure. The second module evaluates the knowledge of the user and registers its actions. The figure 7 shows a screenshots of the system.

Fig. 7. ALEND 3D Interface.

VIII. CONCLUSION

In this paper we have presented the architecture of an intelligent environment for training of power systems operators. The aim is build an advance training system which includes: computer based training components labeled as Reusable Learning Objects; a learning object repository; concept structure map of the power plant domain; a tutor module based on course planner and an operator model based on pedagogical and affective components.

Operator model proposed is based on cognitive and affective components that has several advantages: flexibility, it allows to consider different models for each operator in a common framework; adaptability, by obtaining an initial model of a new learner from similar operator models, and modularity, it can be easily extended to include more trainees, and more experiments and other domains. We have presented some preliminary results of RLO based on virtual reality, concept structure map for the operation of power plants and operator model (cognitive and affective) under different situations and an initial evaluation of the affective behavior model. The next phase is to integrate the intelligent environment to certify operators in knowledge, skills, expertise, abilities and attitudes for operation of power systems.

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