An Ontology-Driven Framework to Support Scenario Representation in a 3D Operator Training Simulator

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Abstract: This paper presents a framework to support the development of three-dimensional virtual scenarios for an operator training simulator for electrical systems. Given the need to represent a variety of scenarios of interest, this can be an effort and time consuming task. The proposed framework promotes a systematic approach when building scenarios and is supported by tools from the ontology-based domain. An editing tool is also under construction. As it will be discussed in the paper, this approach resulted in the simplification of the scenario building process which is achieved by interchanging descriptions at different levels of abstraction. The descriptions concern the situation to be represented; plant objects' representation, both visual and behavioural, the latter represented as Coloured Petri Nets (CPN) models.

1 INTRODUCTION

Operators in electrical systems' substations must be prepared to manage a large volume of information during routine tasks and to solve critical problems in strict deadlines. Even when performing frequent and scheduled tasks, cognitive pressures are present to keep very high performances. Human errors in this context could result in serious consequences for operators and the system, leading companies to intensifying operator training.

Different approaches are employed when training; updating and certifying electrical systems operators. These include: reading technical materials and operating standards, offering theoretical and practical courses, promoting technical visits and company forums to discuss good working practices. A broader training practice consists in simulating critical situations during which, a dramatization of the real operating environment takes place. This method, also adopted when training other professional such as fire-fighters and lifeguards, consists in simulating an event during which operators are immersed in a close to real situation. During those drills, the operators are expected to identify problems and their cause, as well as to demonstrate their specific problem solving skills. This kind of training aims to prepare operators to deal with very specific situations, and allows identifying weak points in the operator skills that need to be addressed.

Effectiveness of training can be better achieved with the aid of simulation tools which replicate situations of interest for the operating environment. On the other hand, training effectiveness depends on the degree of realism provided by the simulator and on the relevance of proposed scenarios.

Scenarios can represent routine situations, with the system operating under normal conditions, during which operators perform simple and well known tasks. They can also portray critical and unusual situations, during which operators must perform complex tasks, exercising their skills. With a variety of scenarios, simulators can be employed in different levels of training; from preparing novice operators for the routine, to preparing experienced operators to handle new equipment or new operating tasks.

The focus of this paper is to address the effort and complexity of scenario building. The authors propose the adoption of a systematic approach to developing scenarios, to be performed in three-dimensional operator training simulators. This approach relies on instantiating domain ontologies in the context of operator training. The aim is to reduce the effort required in creating the simulated virtual environment, to facilitate the understanding of the

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training requirements and to promote the reuse and refinement of the 3D objects; animation components and simulation models.

This paper is organized as follows. Section 2 presents a brief review of related work. Section 3 introduces the simulator *SimuLIHM*. Section 4 presents the scenario generating approach and an application. Finally, section 5, presents the next steps, and considerations on the preliminary results.

2 RELATED WORK

As reported in the literature, ontology has been employed in modelling industrial plants and in process simulation. An example of ontology application is the development platform Simantic, presented in (Luukkainen, Karhela, 2008). This platform enables the representation of a process plant from a library of components available in the 3D environment. It provides ontologies for describing the graphical representation of plant components used to describe the components' visual behaviour (activities); and the configuration of simulation models which represent the physical behaviour of each component. From a user described plant, Simantic automatically generates the code of a simulator, mapping between ontologies.

Similarly, Parisi et al (2007) propose a methodology for the automatic generation of 3D animations to support the training of industrial operators. Its method consists in using ontology to capture and filter the generic training requirements, expressed in natural language. The result is an adaptive animation, which can be refined by a non-expert designer in the field, before being presented to the trainees.

Kalogerakis et. al. (2006) presents a method for integrating domain ontologies with 3D virtual reality scenes. Domain knowledge application results in the enrichment of the virtual environment. This method is supported by the development platform I3DVP.

Rocha et al (2009) proposed an architecture to support the modelling of fire-fighters training simulations. This architecture is based on a set of ontologies in the domain of fire fighting.

From this review one can conclude that the use of ontologies seems appropriate to support the development of operator training simulators and the modelling of scenarios, for a variety of contexts and domains. Thus, in this work the focus is on the development of 3D virtual environments and scenarios based on ontologies.

3 SimuLIHM

SimuLIHM is an operator training simulator for electric systems operation. It was developed at the Human Machine Interface Laboratory (LIHM), at the Federal University of Campina Grande (Brazil).

This simulator supports the training of electric substations operators in identifying faults in a virtual 3D environment. It was conceived originally as a research tool, to support the study of human errors during critical situations when operating industrial systems (2007).

This simulator's architecture is distributed and is organized in three modules: trainee module, tutor module, and a server module (Figure 1). The tutor and operator environments can be accessed via Internet or intranet, allowing for distance training and for the simultaneous training of groups of operators, who can interact between themselves and with the tutor.

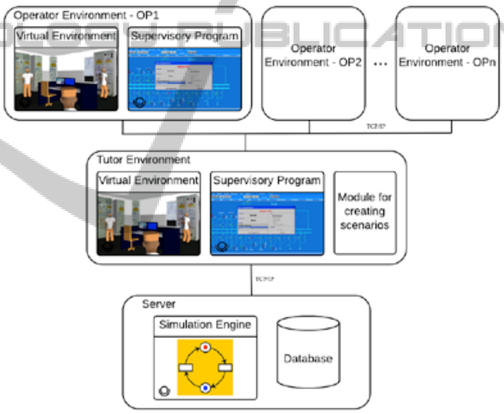

Figure 1: SimuLIHM architecture.

The operator module implements the virtual environment during training. It reproduces, in virtual reality, a typical control room of an electric system substation. In this three-dimensional virtual environment, operators, can move in the control room, interacting with its panels and with a real supervisory system (accessed through the virtual world. This can be achieved using a mouse or keyboard. There they can perform tasks in a similar way as they would in the real environment.

The tutor module enables the communication with the server and with clients during the training sessions. This environment offers tools to support the tutor in the designing and editing of training scenarios; monitoring trainees' activities during the training session and generating reports based on the sessions' logs.

Training scenarios should reproduce situations from the electric system operation routine or contingency situations. The choice of the situation can be based on the analysis of human error reports from this system's operation. In this project, error reports are a source of knowledge represented by ontology.

The server module contains the simulation engine and a database built with SQL Server, which stores the training log. The communication between modules uses the protocol TCP/IP.

During a training session, trainees interact with 3D objects, which are represented in the simulator in three layers or levels of abstraction, as illustrated in Figure 2. Each layer consists of an executable model that will be described below.

Figure 2: Model layers that constitute an interaction object in SimuLIHM.

3.1 3D Model

The models that constitute the layer of visual-geometric representation are described using the X3D (eXtensible 3D) language. These models are run by the viewer Xj3D (Brutzman and Daly, 2007), allowing navigation in the virtual space and the interaction with the elements that compose it.

A library of 3D models has been built to enable the representation of different scenarios. In Figure 3 it is shown a subset of these interaction objects in the context of this work. These models were designed using the 3D modelling tool X3D-Edit, and constitute a library of domain objects, which are configured to compose the virtual environment of a substation control room.

The models in the object library can be reused when composing different scenarios for a specific substation and for any other installation that shares the same kind of objects.

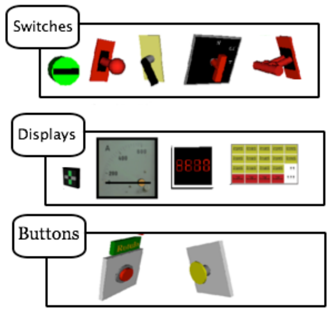

Figure 3: Examples of objects from 3D object library.

3.2 Animation Model

Model animation is performed in the viewer Xj3D. The API - Scene Access Interface (SAI) was developed in Java according to ISO / IEC 19775-2:2004 standard. It provides a set of methods for accessing the 3D scene and for running the behaviour of its objects. Object behaviour is trigged by user actions on them, such as turning a key in the control panel, or pressing a pushbutton.

This layer communicates with the 3D models described in section 3.1 and, with the simulation models described in the next section.

3.3 Simulation Model

In order to describe the behaviour of real world objects, in the virtual world, it was built a library containing the simulation models. These models, which are described in the formalism Coloured Petri Nets (Jensen, 1997), represent the behaviour of the interaction objects in the control room which are used during the operation of a substation. As a consequence of an operator command in the virtual world, the objects' statuses are updated.

In SimuLIHM, the plant behaviour is described using Coloured Petri Nets. This formalism's graphic and mathematical notations allow representing and verifying the plant behaviour according to a set of properties. The simulation model has a modular structure and its building process is based on an object library which facilitates the construction of a variety of scenarios.

The library contains two CPN model classes: models that represent the behaviour of the control room objects (switches; pushbuttons; dials; panels and others); and models that represent the behaviour of the plant equipment in the substation: transmission lines; protective equipment (circuit breakers, switch breakers); transformers, etc.

4 BUILDING SCENARIOS

Defining a scenario consists in specifying the following items: the initial state of the simulation environment; the sequence of events that must occur during the training session and the required resources (human and material). Since the operator's task is ruled by a set of documents with the operating procedures, the trainee must perform the task according to these rules and regulations.

It follows a description of the proposed approach for developing the training scenarios, which is based on ontologies in the domain. In this work, scenario building relies on the reuse of software components (3D models, animations and simulation models). These are combined and configured according to the ontology information, in a sequence of five steps, as represented in Figure 4.

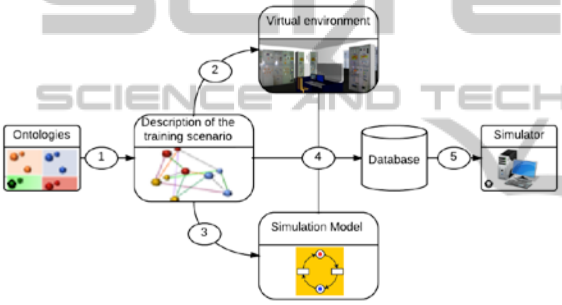

Figure 4: Ontological approach to building 3D scenarios.

4.1 Describing the Scenario

The starting point for the proposed 3D scenario building process consists in describing it by instantiating the domain ontologies. The terms, relationships and rules defined in these ontologies describe the elements in a scenario.

The scenario building process for the simulator SimuLIHM is driven by five ontologies: *Training*, *ScenarioTraining*, *3dModel*, *Plant* and *HMI*. The ontologies were built using the ontology editor Protégé (2014), version 3.5, which is associated with the plug-in Protege-OWL. This plug-in allows building ontologies in OWL (Web Ontology Language) - the World Wide Web Consortium (W3C) standard.

Each of these ontologies is a subset of the domain, as illustrated in Figure 5. Concepts of the ontologies: *3dModel; Plant* and *HMI*, are incorporated into the ontology *ScenarioTraining*. Furthermore, some concepts of the ontology *ScenarioTraining* are incorporated into the ontology *Training*. It follows a description of each ontology.

4.1.1 Ontology *Training*

The ontology *Training* defines a set of concepts and properties for describing electrical systems operators training. The vocabulary includes types of training methods; training objectives; training themes and the required resources (human, material and financial). It also defines constraints to be adopted in the description of training, such as: (a) a training session consists of a set of scenarios; (b) participants play specific roles during a scenario session.

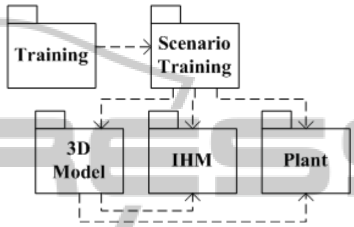

Figure 5: Ontological representation for the semantic description of the training domain.

4.1.2 Ontology *ScenarioTraining*

This ontology defines the terms used in the general description of a training scenario and its elements; which are structured as shown in Table 1.

Table 1: Generic structure of a training scenario.

<table>
<tr><td rowspan="20">Training Scenario</td><td rowspan="13">General Description</td><td rowspan="3">Scenario theme</td><td colspan="2">Scenario Title</td></tr>
<tr><td rowspan="2">Scenario description</td><td>Plant's Initial state</td></tr>
<tr><td>Plant's Final state</td></tr>
<tr><td colspan="3">Pre requisites</td></tr>
<tr><td rowspan="2">Objective</td><td colspan="2">General objective</td></tr>
<tr><td colspan="2">Specific objectives</td></tr>
<tr><td rowspan="5">Task</td><td colspan="2">Task description</td></tr>
<tr><td colspan="2">Task type</td></tr>
<tr><td colspan="2">Level of difficulty</td></tr>
<tr><td colspan="2">Urgency of the problem</td></tr>
<tr><td colspan="2">Problem frequency</td></tr>
<tr><td colspan="3">Anticipated duration</td></tr>
<tr><td colspan="3">Supporting Documents</td></tr>
<tr><td rowspan="7">Scenario Elements</td><td rowspan="2">3D Environment (Id of the 3D model)</td><td colspan="2">HMI in the scene and their respective statuses</td></tr>
<tr><td colspan="2">Plant Configuration</td></tr>
<tr><td colspan="3">Participants' roles (operator, engineer, etc.)</td></tr>
<tr><td rowspan="4">Events</td><td rowspan="2">Scheduled event</td><td>Time_driven</td></tr>
<tr><td>Conditional</td></tr>
<tr><td rowspan="2">Human driven event</td><td>Expected action</td></tr>
<tr><td>Performed action</td></tr>
</table>

4.1.3 Ontology *Plant*

In the context of this work the term plant refers to an electric system installation, such as a substation. So this ontology defines the electrical system components and their relationship. This ontology is based on the semantic data model defined in the standards IEC 61970-301 and IEC 61968-11, collectively known as CIM - Common Information Model. This abstract model represents all the major objects in an electric system.

By providing a standard way of representing electrical system resources as objects; classes and attributes; along with their relationships, the CIM facilitates the interoperability and compatibility between applications and systems, independently of any particular implementation (IEC 61970:2011).

4.1.4 Ontology *IHM*

The *IHM* ontology defines the concepts necessary to describe the human-machine interface in a substation of an electrical system. This interface consists of objects to interac with the control panels: switches, push buttons, displays, alarms and message panels. It also defines the relationship between these components and their statuses.

4.2 Generating the 3D Scenario

Instantiating the described ontologies creates a knowledge base with the elements of a scenario description and the models that represent them.

The scenario is generated with the aid of a software module that interprets the information stored in the knowledge base and automatically generates the 3D virtual environment.

There are several APIs that support the development of software applications based on ontologies represented in OWL. In this work, the framework Jena (2009) was used to implement the software module. Jena is a Java framework, open source and free, which provides features for editing and consulting ontologies based on inference engines.

As already mentioned, 3D models were described in X3D language, which follows the XML standard. Thus, an API for editing documents in XML format instantiates 3D models from the ontological model. The JDOM Java API (2014), enables changing, creating and navigating the X3D document structure.

Figure 6 illustrates the generation of a 3D object, represented in the virtual world. It illustrates the representation of a switch on a panel. The SW14C1 switch's attributes are parameters from the geometric model of switches, as indicated by the arrows in the figure. The resulting visual representation is also presented in Figure 6.

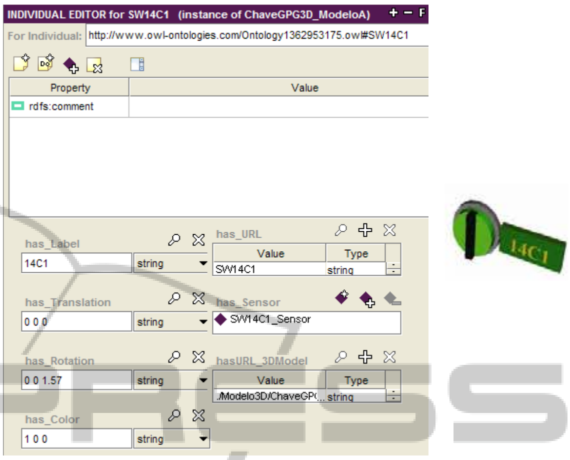

Figure 6: Instantiation of a 3D object using ontology.

The knowledge base is structured hierarchically. 3D objects, such as switches, buttons and displays compose more complex objects such as control and message panels. In turn, compound objects are placed in the 3D virtual environment of a control panel (Figure 7).

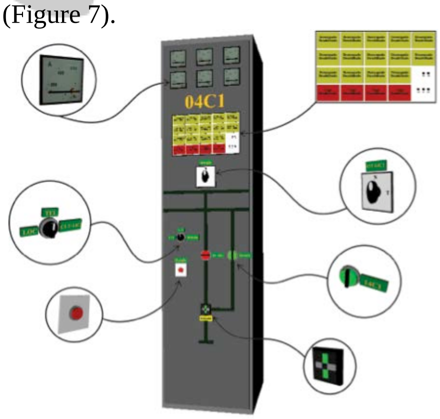

Figure 7: Components of a control panel and their association with components of the 3D object library.

Therefore, the process of consulting, instantiating models and associating objects can be recursive, and is completed when all the objects have been instantiated, automatically generating the 3D virtual environment.

4.3 Configuring Simulation Models

The simulation (behaviour) models of the objects in the virtual plant, act as the simulation engine. These were built and run on the CPN Tools environment (2014). These models, represented in XML format, can be configured to represent a specific scenario using the JDOM API (2014). This API enables to edit the **.cpn** file, according to the information extracted from the knowledge base (ontologies). Models representing object behaviour in the virtual environment can be found in (Turnell et al, 2010).

4.4 Saving the Scenario

The 3D virtual environment, animation models and simulation models, configured according to the content of the knowledge base, represent the training scenario to be run by the simulator.

Once completed, this scenario must be stored in a database that supports XML file format. The devices in the training scenario must also be configured and stored with their statuses.

4.5 Running the Scenario

Both the trainee and the tutor interact through a graphical interface when selecting the scenario in the simulator database. Once selected, the scenario is presented to the trainee in the 3D simulator environment. From within the virtual environment it is possible to interact with a real supervisory system there represented on the trainee's desktop. The supervisory software must be previously configured to represent the plant and must be initialized in the same status as the virtual world representation.

During the scenario simulation, the knowledge base is queried and updated, recording the simulation log. The log is later used to analyze the trainee's performance.

5 FINAL CONSIDERATIONS

This paper presented a framework for the construction of three-dimensional virtual reality training environment, based on its ontological description. This approach:

- provides a scenario description which can be processed and interpreted by simulation environments;
- promotes the rapid development of scenarios by domain experts, without demanding the knowledge of modelling in 3D, Petri nets, or any specific programming language;
- promotes the reuse of components from a library, which have been tested and validated.
- promotes the interdependence of simulation models, 3D models and animations, simplifying the maintenance of each individual component and its replacement.

The current step in this research consists in developing an integrated environment with a tool to support the approach application and that integrates a scenario editor for the simulator SimuLIHM.

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