THE VIRTUAL UNICOS PROCESS EXPERT: INTEGRATION OF ARTIFICIAL INTELLIGENCE TOOLS IN CONTROL SYSTEMS

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Abstract

In the context of the CERN Large Hadron Collider (LHC), a framework called UNICOS (UNIfied Industrial Control Systems) was developed to produce three-layer control applications [1]. It provides users with means to develop full control applications and operators with ways to interact with all items of the process from the most simple (e.g. I/O channels) to the most abstract object (e.g. a sub part of the plant).
This possibility of fine grain operation is particularly useful during commissioning but also to recover from abnormal situations provided the operators have the required knowledge, which is, unfortunately, not always the case.

The **Virtual UNICOS Process Expert** tooling suite aims at providing operators with means to handle difficult cases for which the intervention of process experts is usually required. This is typically the case when operators are faced with alarms avalanches that triggered interlocks in some parts of large plants.

The main idea of this project is to use the openness of the UNICOS-based applications to integrate tools (e.g. Artificial Intelligence tools) that will act as process experts to analyze complex situations, to propose and to execute smooth recovery procedures.A first version of the software suite was developed for the LHC experiments Gas Control Systems (GCS) [2].

Introduction & Driving Requirements

The LHC Gas Control System presently provides the LHC Experiments with homogeneous Control Systems for their 27 Gas Systems. These Gas Systems are built on a modular architecture [3], which consists of a set of functional modules the number and type of which differ from one system to the other. In addition, some of the functional module devices are optional. Although these 27 Control Systems provide end-users with a consistent and homogeneous look and feel, they differ in their operation and require specific process knowledge for each sub-detector. The commissioning phase of the gas systems is a long process and is achieved by a small team with only a few Gas System Experts.
Therefore, time and detailed procedures are necessary for the Process Expert to train its team for it to be able to operate each of these systems.

The Operators need guidance and help to understand which set of actions should be executed (and in which order) to drive the System to a given Target state.
The Experts need a tool for capturing their knowledge, acquired during several years of experience and knowledge of these systems.
Both Experts and Operators need a configurable tool, transparently integrated into any UNICOS-based applications.

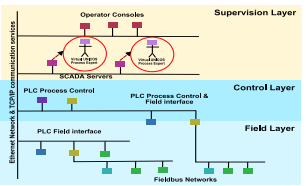
For this purpose, a Virtual UNICOS tool suite is being designed to provide guidance to Operators during the most complex operational procedures and to allow capturing the knowledge from the Process Experts so that it can be re-used.

Integration in the UNICOS architecture

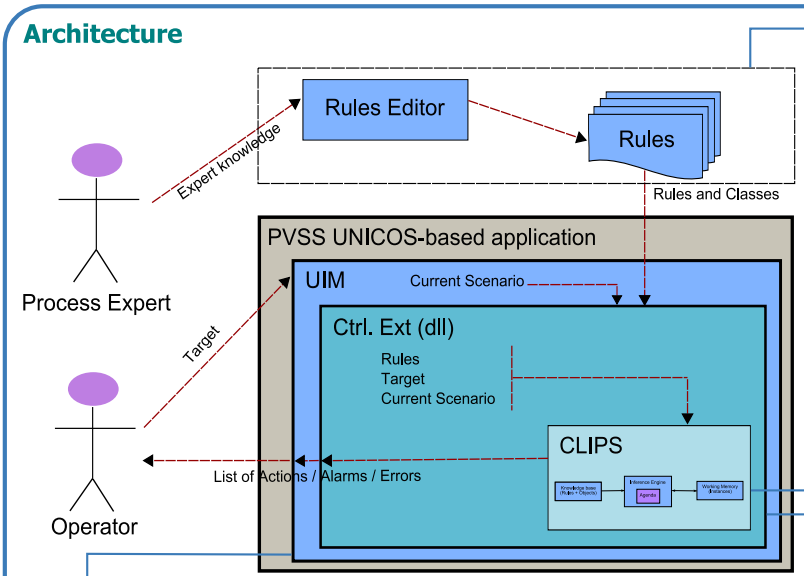
The **UNICOS-based applications** are distributed across three layers:
- The *Field layer* includes the process sensors and actuators connected to the control system via PLC I/O boards and/or field buses.
- The *Process Control layer* includes the logic, interlocks and the Finite State Machine (FSM) of the system.
- The *Supervision layer* allows the monitoring and control of the system by means of a Supervision Control And Data Adquisition (SCADA) called *ETM's PVSSII®*.

The design of UNICOS is based on the physical model of IEC61512-1(ANSI/ISA-88) standard where the process has been broken down into a **hierarchy of objects**. Each object has a unique parent. Three classess of objects:
- The *I/O objects* link the sensors and actuators to the plant for reading data and sending commands.
- The *field objects* can represent a proxy of the hardware element such as valves, motors and others or perform control loop actions.
- The *Process Control Objects (PCO)* which are the node of the project hierarchy are responsible for the process specific logic (FSM, interlock conditions, etc...). These UNICOS objects are implemented in the PLC with its proxy in the supervision layer and a middleware handles the exchange of commands and status between the PLC objects and their PVSS proxies.

The Virtual Operator introduces, at the level of the supervision layer, a User Interface (UI) as a PVSS CtrlExtension with an Expert System embedded. The principle of this Virtual Operator is to simulate a human Operator by analyzing feedback status from I/O object or field objects and sending commands to the top hierarchy objects, namely the PCO (Process Part for the Virtual Operator).

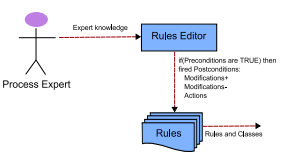


Architecture



Rules

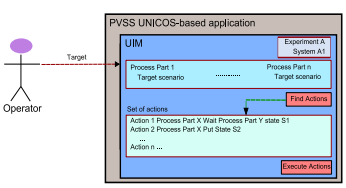
The Expert knowledge is acquired and then translated into rules files by a **rules editor**. The rules editor is a tool to ease the transfer of knowledge between the Expert and the AI tool. Currently, the rule editor is based on template Excel files. These files are filled by the Experts and then translated into rules by the UNICOS-based application developers.
Each **Process Part** is represented by a **Class** in the Rule-based System.
Each class has properties (*slots*) representing, for example, states, values, etc ... of the Process Parts.
Each rule is made up of a bunch of *preconditions* and *post-conditions* representing transitions between Process Parts states (constraints of the System) and decisions (Expert knowledge):



The **preconditions** are:
- the *Target*
- the *Current Scenario*
- *dependant values and states* (the most important knowledge bits obtained from the Experts): one Process Part could be waiting for another Process Part values or states before it can be moved from one state to another).

The **post-conditions** are:
- *actions* to be done
- *new sub-targets* (targets for the dependent Process Parts)
- *new states and values* (properties) for the objects. At the level of the Virtual Operator, the post-conditions represent an intermediate scenario that will be executed, in order to move forward to the get to the Target.

PVSS interface



The **Operator** selects the **Target state of the System** from the user interface. The Operator can select target states for one or more Process Parts of the System. The **Current Scenario** (current PCO values and states, alarms, etc.) is sent to the Virtual UNICOS Operator together with the Target.

The **Virtual Operator applies the rules** on it and it **returns an ordered list of actions** the System should follow, in order to get to the Target.
The Virtual Operator can executes all the actions automatically, checking the new scenario every time an action is executed.

If **something wrong happens** while executing (an alarm has been triggered, for example), the Virtual Operator:
- **stops** and **asks** the Operator for **fixing the problem** .
- shows the **new list of actions** for the new scenario created after solving the problem (**no need to start from scratch**).

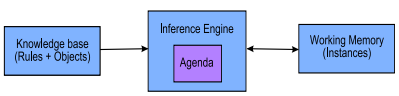
Expert System/Rule-based System

An **Expert System** or **Knowledge-based** [4] **System** emulates the decision-making ability of the Experts, intending to act in all respects like them.
Internally the Virtual UNICOS Operator Rule-base System contains:
- *Knowledge base*: the knowledge of the Expert needed to solve the problems coded in the form of rules.
- *Working Memory (WM)*: a collection of data objects that represents the current state of the System (values, sensor pressures, states, alarms, etc ... from each Process Part). It is a global database of instances used by the rules.
- *Inference Engine*: makes inferences by deciding which rules the objects placed on the VM satisfy. It also prioritizes the satisfied rules and it executes the rule with the highest priority. The Inference Engine contains:
  - *Agenda*: a prioritized list of rules created by the inference engine, which patterns are satisfied by objects in WM.
  - *Rete algorithm*: fast pattern matcher that obtains its speed by storing information about rules in a pattern network [4]. Instead of having to match instances against every rule on every recognized-act cycle, it looks only for changes in matches on every cycle.

The Expert System language selected is **CLIPS** [5] (*C Language Integrated Production System*). It provides:
- *high portability*: can be ported to any system that has an ANSI compliant C compiler
- *easy integration/extensibility*: can be embedded within procedural code, called as a subroutine or easily extended by the user
- an *interactive environment* for testing
- an *extensive documentation*
- low cost (*free*)

CLIPS provides support for three types of programming paradigms:
- *rule-based*
- *object-oriented*
- *procedural programming*

The **Virtual Process Expert** is based on:
- the *rule-based*: **allows knowledge to be represented as a set of actions** to be performed for a given situation
- the *object-oriented programming* capabilities, usually referred to as *COOL* (CLIPS Object-Oriented Language): **allows systems to be modelled as modular components to be easily reused to model similar systems or to create new components**.



PVSS -Virtual Operator communication

The **communication between CLIPS and UNICOS-based applications** is done by the **PVSS *CtrlExtension*** functionality.

The Virtual Operator, thanks to CLIPS portability, has embedded CLIPS source code into the *CtrlExtension* so CLIPS functions can be called easily and any functions can be modified or added if needed. Calls to CLIPS are made like any other subroutines.

The ***CtrlExtension* must be exported as a dll** so that it can be called by the PVSS UI Manager. Then, **any UNICOS-based applications can use CLIPS** by calling these functions from any PVSS script or UI.

Achievements

A **first version** of the Virtual UNICOS tool is being finalized and satisfactory tested with a few **real use cases** given by the **GCS Experts** (alarms, states, values, etc).
Very **positive feedback** received from the Experts.
Very **flexible to new changes**. The rules can be changed independently of the Interface. By modifying a rule it can modify the behaviour of the whole System.

Perspectives

The **rule editor** is being improved for providing a new look and feel to the Experts to easily add/mod/del the knowledge (the rules).
The PVSS *CtrlExtension* will likely be changed for the **PVSS *API*** (Application Programming Interface).
More **use cases** are being taken now which will increase exponentially the utility of the AI tool
It can easily be extended to **represent similar systems**.
The Virtual Operator will be ready to **analyse the alarms**, helping the Operator to understand why they have been triggered explaining the causes.

References

[1] P. Gayet et al., "UNICOS A framework to build Industry like control systems: Principles and methodology", ICALEPS'2005, Geneva, Switzerland.
[2] The LHC GCS project URL: http://itcofe.web.cern.ch/itcofe/Projects/LHC-GCS
[3] G. Thomas et al., "LHC GCS: A model-driven approach for automatic PLC and SCADA code generation", ICALEPS'2005, Geneva, Switzerland.
[4] Giarratano and Riley, "Expert Systems: Principles and programming. Third Edition", PWS.
[5] "CLIPS. Reference Manual. Volume II. Advanced Programming Guide", Version 6.24.