An ontology for the WWTP instrumentation, control and automation infrastructure

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Abstract: In this paper, we propose an ontology-based approach to model wastewater treatment plants (WWTPs) and their instrumentation, control and automation infrastructure, focusing on the electrical and mechanical components needed for measurement and actuations. In particular, we have extended an existing ontology (Semantic Sensor Network) and created a specialized representation of the WWTP domain, in order to realize a consistent description of sensors and probes, actuators and data acquisition systems. Using this model, we tried to achieve several results. First, we argue that it provides a better and more declarative way to translate the domain experts' policies into concrete actions. Second, it allows to express the knowledge in a format that is interoperable and shareable between different plants, decoupling the control policies from the specific details, depending on the particular devices installed on a plant at a given time. Last, the machine-readable representation facilitated the integration with larger service- and agent-oriented control infrastructures, based on environmental decision support systems. The methodology has been applied to a pilot-scale conventional activated sludge (CAS) plant, thus providing a concrete application of the defined semantic model.

Keywords: ontology; knowledge based control systems; wastewater treatment plants

INTRODUCTION

To ensure that the wastewater treatment plants (WWTPs) meet good performances and low operational costs, relevant signals must be measured with appropriate probes and collected in real-time (Olsson, 2006). Data may be used to guarantee a continuous monitoring of the biological processes and a reliable decision-making process to manage the plant (Poch et al., 2004). These devices usually provide interfaces for the control logic through hardware abstraction layers, which allow a simplified access to their functionalities. However, most manufacturers provide proprietary APIs which are not standardized and thus seldom interoperable. The control system could be aware of the differences and communicate with the various remote sites using their native protocols and formats, but this would affect the scalability and the maintainability of the architecture whenever new plants have to be included or devices are upgraded or replaced by new, possibly incompatible models. Instead, we argue that the commands should be delivered in a format that is dependent on the type of the devices and the intended control action, but independent of the specific device itself and its hardware specifications. In this paper, then, we propose an alternative, knowledge-based approach which decouples the control logic from the control devices by introducing an explicit representation of control actuations before they are applied. To ensure semantic interoperability, even in a distributed context, our approach is based on ontologies expressed using the W3C OWL2 (see http://www.w3.org/TR/owl2-overview) standard. To the best of our knowledge, not many previous works exist in terms of the semantic modelling of WWTPs and their related concepts. The WAsteWater Ontology (WaWO) (Ceccaroni et al., 2000), developed as part of the OntoWEDSS (Ceccaroni et al., 2004), is mostly focused on the biochemical perspective and on the classification of WWTP's working states, problems and potential malfunctioning causes. We aim to extend such an approach aligning our model with more general-purpose ontologies such as the Semantic Sensor Network ontology (SSN) (Compton et al., 2012) and the Measurement Unit Ontology (MUO) (see http://idi.fundacionctic.org/muo/muo-vocab.html).

MATERIALS AND METHODS

Pilot plant

This project involves a pilot plant and at least two full-scale plants. The pilot plant is located close to the municipal WWTP of Trebbo di Reno (Bologna, Italy) and is fed with the same real municipal wastewater, drawn after the screening process to remove debris. The plant is equipped with pH, redox potential (ORP) and temperature probes in the anoxic tank, and pH, ORP, dissolved oxygen concentration (DO), nitrogen (NH4-N and NO3-N) and suspended solids (TSS) probes in the aerobic one. All analogic probe signals are sampled and acquired in current (4-20 mA) by a stand-alone data logger (Datataker DT80), at the rate of 1 sample/min. All the analogic pumps and the blower are regulated in current (4-20 mA), by an Advantech ADAM 5000 module, driven by the DT80.

Ontologies

We have adopted description logic as our modelling framework, and we have authored ontologies in the OWL2-DL W3C standard language using Protegé (see http://protege.stanford.edu/). This formalism allows to define our conceptual domain models in a machine-readable and application-independent way. Moreover, it is suitable for automated reasoning, including consistency checking, as well as expert validation (Lopez de Vergara et al., 2002). We extended the SSN ontology, therefore contextualizing our model in the DOLCE (see http://ontologydesignpatterns.org/wiki/Ontology:DOLCE+DnS_Ultralit) Ultra-Lite upper ontology (DUL), which is extended by SSN. Our work has also been harmonized with other domain-related ontologies: in particular we adopted the MUO's approach to model quantities and units of measure, and introduced the concept of device "ports", which has previously been presented in the Port Ontology (Liang and Paredis, 2004).

RESULTS AND DISCUSSION

The OntoPlant-WWTP ontology

The proposed ontology can be conceptually divided in three main parts, each dedicated to a specific subset of the target domain: 1) the "topology" module, which allows to represent the plant components (e.g. tanks, settlers, valves, …), the installed devices (e.g. probes, pumps, data loggers, ...) and their interconnections; 2) the "quantities and measurement units" module, which provides a standard way to express measurements' results and state the required values for actuation commands in terms of domain-relevant quantities; 3) the "device description" module, which can be used to model the single devices and their technical specifications with an adequate level of detail. The modelling of devices is based on SSN's approach: we use subclasses of the Property class in order to represent the devices' features and capabilities, including those which may vary under different environmental conditions. Transducers are described specifying their transfer functions and the interfaces of the ports implementing their functionalities, thus providing information about the port where a particular transducer's capability is available (e.g. the port from which a sensor's sampled values can be read, as opposed to a configuration port). Port interfaces capture additional information about the nature of the involved quantities (measured by sensors or as actuators actions' results) and of the electric signals representing them. We also extended the MUO ontology with the definition of derived quantities and units of measure typical of the wastewater treatment domain.

OntoPlant-WWTP ontology: a case study

We have used the OntoPlant-WWTP to create a descriptive model of the pilot plant: the plant and its components can then be represented as a set of related named individuals. The pilot is intended to test the EDSS and its control policies before they are applied to both plants. While they are equipped with the same types of sensors and actuators, their field control system and interfaces are totally different. The introduction of an intermediate semantic layer, would allow the EDSS to be "aware" of the equipment actually installed on each plant, so that the high level control decisions can be translated into more appropriate, actionable control actions. This approach facilitates the deployment of the EDSS on different plants, since the integration will only require a lightweight software adapter to convert the standardized actuations, deliberated by the EDSS, into the hardware-dependent, low-level instructions. As an example, let's assume that the EDSS states that the influent flow rate should be set to Q m^3/h. This can be done by imposing a current I on the control input port of the pump (named "inPump"). The relation between I and V is modelled by a linear transfer function f, which is a feature of the specific pump and relates the electric current to the volumetric flow rate, i.e. for a certain I value we have f(I) = Q. The actuation, then, requires a few steps: the EDSS will explore the plant control system topology, as stated by its semantic description in terms of Ports and PhysicalLinks, to find the other devices which are involved (in this case, the programmable data logger "dt80" and the controller "adam"). Moreover, it will retrieve (and invert) the function f to determine the actual value of the electric current I required to obtain the desired output Q. Knowing that inPump is controlled by the adam device, the EDSS will conclude that a certain instruction has to be sent to dt80 to Write a value on its RS232 Port. This instruction is semantically described as a nested Write, on the appropriate adam's Port, of the current value $I = f^{-1}(Q)$, calculated using inPump's transfer function (Figure 1).

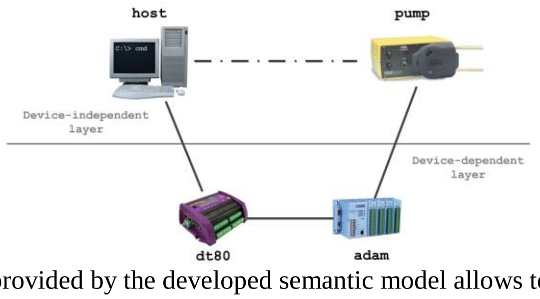

Figure 1 The abstraction provided by the developed semantic model allows to decouple control policies from hardware configuration.

CONCLUSIONS

The developed model provides a framework for the explicit and unambiguous representation of WWTPs, their structure, topology and their installed instrumentation and control systems. Being based on semantic web standards, it is suitable for machine manipulation and information interchange in a distributed context, where a shared unifying semantic is needed to overcome differences between different plants' configurations and control policies' definition. To provide such a degree of decoupling, our representation has been designed to be informative enough to serve as a domain model for interoperable applications, ranging from decision support systems that implement management policies to drivers which control the actuators to actually put those policies in practice. In order to allow a more detailed specification of suitable control policies, we will need to expand our model to cover the necessary chemical and microbiological concepts which are also part of the WWTP domain. To this end, we will align our work with previous efforts such as the WaWO ontology. Likewise, we are planning to include a better model quantities and measurement units, as well as the water treatment processes from a hydraulic perspective. At the same time, we will improve the integration of the proposed ontology with the EDSS we are developing. Using the semantic model, we will be able to expand the current service-oriented architecture into an agent-based one, where the ontology will become the shared conceptual model allowing the agents to communicate.

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