Resource Monitoring and Rule-Based Notification: Applications in Subsea Production Systems

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ABSTRACT

An industrially driven consortium launched the Integrated Information Platform project in 2004. The main objective was to extend and formalize an existing terminology standard for the petroleum industry (ISO 15926) in to formal ontology. The ontology is used in monitoring of drilling and production processes. The paper presents research in progress on development of rule-based notification in subsea production systems to monitor and analyze production data. The task is elaborated and exemplified by data from the real case.

INTRODUCTION

Subsea petroleum industry and production systems used there are information-intensive. When a well is put into operation, the production has to be monitored closely to detect any deviation or problems. Furthermore, the next generation subsea systems include numerous sensors that measure the status of the systems and send real-time production data to operation centers. For these centers to be effective, they need tools that allow them to understand this data, relate it to other relevant information, and help them to deal with the situation at hand.

This paper reports on research in progress on rule-based resource monitoring and notification in the IIP project (Sandsmark & Mehta, 2004; Gulla *et al.*, 2006). The project's primary objective is to extend and formalize an existing terminology standard for the petroleum industry, ISO 15926 (2003). Using OWL Full sublanguage, this standard is transformed into a real ontology that provides a consistent unambiguous terminology for subsea petroleum production systems. The ontology is used in monitoring of drilling and production processes. The objective of this paper is to elaborate on the research in progress regarding rule-based condition monitoring of the subsea devices.

One of the research questions is how to use the ontology together with a rule language (e.g., SWRL (Horrocks *et al.*, 2004)). We are investigating how to combine rules with the ontology and what limitations are imposed by chosen OWL Full sublanguage to represent ISO 15926. A key requirement is to reason in a semantically consistent way by exploiting both the ontology and the rules. Since it is impossible to have at the same time decidability, soundness, completeness, performance and expressivity (Golbreich *et al.*, 2005; Horrocks *et al.*, 2003), we analyzing limitations and possible rule inference scenarios based on the current version of the ontology in OWL Full sublanguage. In case of too restrictive usage scenarios with regards to the expected features of the application, an alternative of automatic translation from ISO 15926 to OWL DL might need to be considered (Hakkarainen *et al.*, 2006). Currently, we are experimenting with Protégé-OWL, ontology and SWRL editor, OWLJessKB for rule inference and Racer for reasoning.

The paper is structured as follows. Next we introduce the IIP project and ISO 15926 standard. Later we elucidate the task of rule-based condition monitoring and notification in the project. Finally, we conclude the paper by discussing future work.

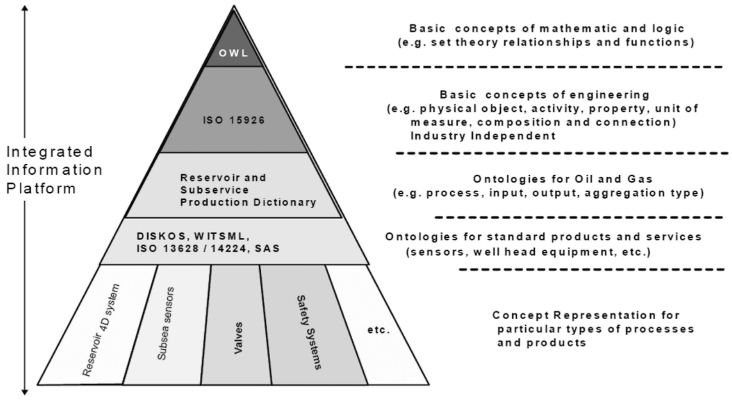
THE IIP PROJECT

The Integrated Information Platform (IIP) project is a collaboration project between companies active on Norwegian Continental Shelf and academic institutions, supported by the Norwegian Research Council. Its long-term target is to increase petroleum production from subsea systems by making high quality real-time information for decision support accessible to onshore operation centers.

The IIP project (Gulla *et al.*, 2006) addresses the need for a common understanding of terms and structures in the subsea petroleum industry. The objective is to ease the integration of data and processes across phases and disciplines by providing a comprehensive unambiguous and well accepted terminology standard that lends itself to machine-processable interpretation and reasoning. This should reduce risks and costs in petroleum projects and indirectly lead to faster, better and cheaper decisions.

The OWL web ontology language is chosen as the markup language for describing these terms semantically in an ontology. A major part of the project is to convert

Figure 1. The standardization approach in IIP



and formalize the terms already defined in ISO 15926 Part 2 (Data Model) and Part 4 (Reference Data Library). Since the ISO standard addresses rather generic concepts, though, the ontology must also include more specialized terminologies for the oil and gas segment. Detailed terminologies for standard products and services are included from other dictionaries and initiatives (DISKOS, WITSML, ISO 13628/14224, SAS), and the project also opens for the inclusion of terms from particular processes and products at the bottom level. In sum, the ontology being built in IIP has a structure as shown in Figure 1 and is exemplified in Figure 3c.

ISO 15926

ISO 15926 (2003) is a standard for integrating life-cycle data across phases (e.g. concept, design, construction, operation, decommissioning) and across disciplines (e.g. geology, reservoir, process, automation). It consists of 7 parts, of which parts 2 and 4 are the most relevant to this work. Part 2 specifies a meta-model or top-level ontology (Batres *et al.*, 2005) for defining application-specific terminologies. Part 2 includes 201 entities. It is intended to provide the basic types necessary for defining any kind of industrial data.

Part 4 of ISO 15926 is comprised of application or discipline-specific terminologies, and is usually referred to as the Reference Data Library. These terminologies are instances of the data types from part 2. Part 4 today contains around 50.000 general concepts. Standards for geometry and topology (Part 3), procedures for adding and maintaining reference data (Part 5 and 6), and methods for integrating distributed systems (Part 7) are under development.

RULES-BASED CONDITION MONITORING

There are envisioned several application areas of the above ontology. Interoperability in the highly multidisciplinary petroleum industry is the main goal, while the tasks of ontology-driven information retrieval and rule-based notification have main focus meanwhile. The rule-based approach will be mainly applied to information quality analysis (i.e. analyze anomalies in real-time data from subsea sensors) and condition monitoring of subsea production.

A scenario for the automatic production monitoring is depicted in Figure 2. A full case of condition monitoring will consist of three main steps: *Data processing*, *Health assessment* and *Treatment planning*. These three steps, including their activities, can be mapped to the corresponding machine condition assessment data processing and information flow blocks identified in ISO 13374 (2003): Data acquisition, Data manipulation, State detection, Health assessment, Prognostic assessment, Advisory generation.

Data processing is the first step including automated activities such as data acquisition and data manipulation. The latter activity includes mapping the actual measurements to data model (the ontology based on ISO 15926 and other standards regulating the petroleum domain), see a code excerpt in Figure 3b.

Figure 2. Rule-based condition monitoring

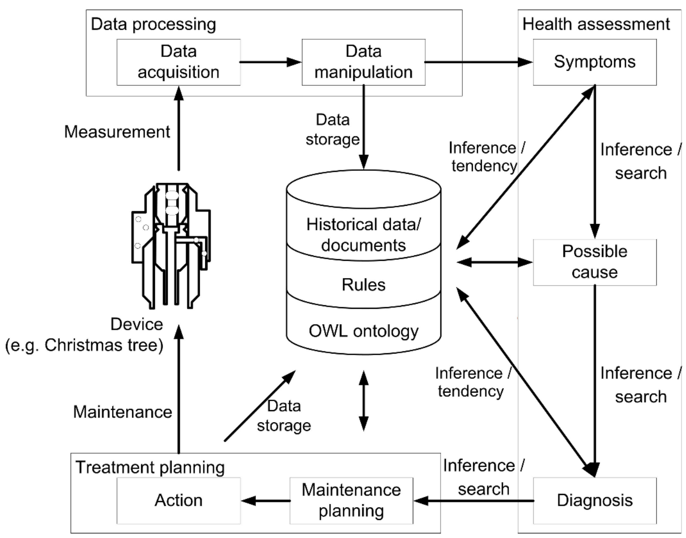


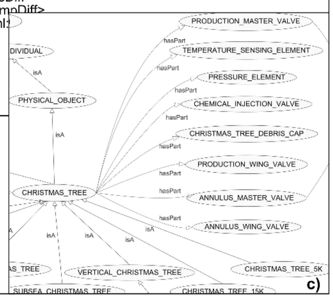
Figure 3. Exemplifications of a) daily production report in XML; b) definition of maximum operating temperature for a choke; c) ISO 15926 ontology

```
<witsml:facility>
  <witsml:name kind="wellhead" namingSystem="EnergyComponents">6506/12-L-3_wellhead
  </witsml:name>
  <witsml:facilityParent1 kind="well" namingSystem="EnergyComponents">6506/12-L-3
  </witsml:facilityParent1>
  <witsml:facilityParent2 kind="template" namingSystem="EnergyComponents">L
  </witsml:facilityParent2>
  <witsml:unit>ASG-A_L-3H_wellhead</witsml:unit>
  <witsml:contextFacility kind="well" namingSystem="EnergyComponents">6506/12-L-3
  </witsml:contextFacility>
  <witsml:flow>
    <witsml:name>ASG-A_L-3H_wellhead_production</witsml:name>
    <witsml:kind>production</witsml:kind>
    <witsml:port>L-3H_wellhead_outlet</witsml:port>
    <witsml:qualifier>allocated</witsml:qualifier>
    <witsml:temp uom="degC">116.95241</witsml:temp>
    <witsml:pres uom="bar">147.76852</witsml:pres>
    <witsml:portDiff>
      <witsml:port>ASG-A_L-3H_portdiff</witsml:port>
      <witsml:presDiff uom="bar">45.54977</witsml:presDiff>
      <witsml:tempDiff uom="degC">5.83645</witsml:tempDiff>
      <witsml:chokeRelative uom="%">67.48616</witsml:
    </witsml:portDiff>
  </witsml:flow>
</witsml:facility>
```

a)

```
<Class ID=?ABD134?>
  <subClassOfresource=?&iso15926-4;Choke?/>
    <iso15926-4:maximumOperatingTemperature>
      <iso31:Temperature>
        <iso1000:celsius>
              300.0
        </iso1000:celsius>
      </iso31:Temperature>
    </iso15926-4:maximumOperatingTemperature>
etc.
</Class>
```

b)



c)

The *health assessment* step is heavily based on the rules and involves most of reasoning. The rules are used to identify possible symptoms, then possible causes, and finally infer a diagnosis. The activity concerning symptoms identification takes care of monitoring of states, i.e. analysis of data flow. Here an example of the rule would be: *if a choke has a temperature sensor and temperature is equal or above the maximum operating temperature then the choke is in critical state*. This rule is illustrated below using SWRL built-in predicate `swrlb:greaterThanOrEqual` (Horrocks et al., 2004), and incoming data in XML format are exemplified in Figure 3a. Then rules defining dependencies among measurement classes are used to infer possible causes and diagnosis.

```
hasTemperatureSensor(?x,?y)∧hasTemp(?y,?temp)∧hasMaximumOperatingTemp(?x,?maxtemp)∧
swrlb:greaterThanOrEqual(?temp,?maxtemp)→hasCriticalState(?x,?temp)
```

The *treatment planning* step takes care of the last two activities in the condition monitoring cycle, i.e., maintenance planning and actions that need to be taken in order to resolve the situation. This step either notifies the responsible controller who needs to perform the actions (e.g. *increase choke opening by 10%*) or executes the action automatically.

It is planned to integrate the rule-based condition monitoring and notification with ontology-driven information retrieval system (Tomassen *et al.*, 2006). As shown in Figure 2 searching for the relevant information is designed to be supplemental way of interaction with the system, since covering all possible cases by rules is a labor-intensive and not trivial task. Therefore, it is important to enable users to access previous reports and documents related to the problem on-hands. Smooth transition between these two different interaction ways is a big challenge as well.

CONCLUDING DISCUSSION AND FUTURE WORK

One problem in the project is that the full expressive power of OWL (OWL Full) is needed in order to represent the structures of ISO 15926-2/4. Reasoning with OWL specifications is then incomplete and inference becomes undecidable (Horrocks *et al*., 2003). Therefore, here we are investigating the limits of inference using the ontology implemented in OWL Full. This will allow identifying possible scenarios and restrictions in using OWL Full for a such scale project. We are exploiting the logical properties of OWL and experimenting with the rule-based notification using Protégé-OWL, OWLJessKB and Racer.

Furthermore, a certain future work will be an alignment of the method with Mimosa's open systems architecture for condition based maintenance (Mimosa, 2007). Mimosa is an alliance for machinery information management open systems with the main objective to enable open standards-based operations and maintenance interoperability.

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