An Information Reporting Web Service Framework for Integration of Gate-to-Gate Process-to-Energy Metrics

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Abstract. Modern day manufacturing is required to respond to many facets of dynamic change including consumer and technological trending, increasing levels of legislation, fluctuation of competitor market strategy and total available market based on domestic and international trading conditions amongst others. High up on the supply chain agenda and a topic of continually increasing importance is energy efficiency. This paper presents an information reporting service framework for gate-to-gate[1] (G2G) process-to-energy[2] (P2E) metrics. Our use case focuses on obtaining energy performance information associated with welding robots used in assembly process.

Keywords: sustainable manufacturing, automotive, assembly, energy, metrics, reporting.

1 Introduction

This paper builds upon advances in research within resource efficiency assessments and energy metrics for product assembly process and equipment. We introduce an information service framework focused on enabling fine grained reporting of energy efficiency from G2G processes within a product assembly plant. The novel aspects of our approach lie in facilitation of ontology development for the manufacturing domain and integration of information between processes and components, enabling capturing of energy metrics. In this paper, we use welding robots as a demonstrative example to illustrate the information service framework. Welding is a process which is energy intensive involving melting joining metals. Manufacturing processes typically involve many robots and they can be used for multiple welding or other assembly activities, each of which would require varying degrees of energy usage. We highlight the Hybrid Laser GMAW (Gas Metal Arc Welding) activity as one involving a considerable amount of energy usage and therefore well suited for P2E analysis and reporting of energy metrics. This application scenario is both difficult to monitor

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[1] G2G is defined as one particular variant within manufacturing life-cycle assessment, looking at only the factory level processes in the production chain [6].

[2] P2E metrics refer to energy properties and values associated with the physical G2G processes.

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and challenging to infer energy efficiency from, and thus presents an excellent area to study in an attempt to drive information integration within a product assembly plant.

2 Utilizing Integration of Process Information as an Energy Efficiency Improvement Mechanism

Fundamentally, sustainable manufacturing promotes the use of value-added processes and integration of design and process controls into intelligent manufacturing operations. In this context, integration of process information across the supply chain is a key factor in improving manufacturing energy metrics.

A growing amount of comprehensive product assembly literature acts as a direct knowledge base for us to utilize in an attempt to assimilate G2G energy consumption to output data which can be used within energy efficiency improvement.

2.1 Formal Representation of Gate-to-Gate Manufacturing and Assembly Knowledge Sources

The core focus of addressing energy efficiency has now shifted to industry driven reporting models involving the computation of G2G energy efficiency at various levels of the product assembly processes. By addressing energy consumption at G2G processes we can "…measure, monitor, and improve energy and material efficiency across …production networks [6]." One of the key tasks is to integrate information from separate physical entities within the product assembly process. The basic issue is to find common characteristics among the processes as complex queries cannot be answered by any single data source alone. Table 1 enlists examples of equipment(s) and/or process(es) (with physical entities relating to welding shown in bold.) with the intention of building relationships between equipment and/or components.

Table 1. Common characteristics between assembly process data sources

Equipment/Process Name	Equipment/Process Characteristics
Product Assembly Process	Assembly of components: Tasks involve parts fitting, **joining**, etc. and related sub processes
Joining Process	An aspect of the product assembly process for joining-specific parts: Tasks involve adhesives bonding, **welding**, mechanical fastening, etc.
Material Handling Equipment	Moving materials and components within a plant: Equipment includes materials handling and other **robots**, belt/roller conveyors, chutes, etc.
Automobile Manufacturing Process	Vehicle Body Production: Tasks include painting, fitting and trimming, **door assembly**, etc. Chassis Production: Tasks include under carriage assembly, **frame assembly**, etc.

We adopt a formal methodology for developing a (machine processable) representation of the above equipment/process domains with the purpose of enabling inference. In this study, individual ontology is constructed based on observation of an automotive assembly plant and from relevant literature sources [1-6]. We use Protégé[3] to develop ontological representations of the knowledge sources (from Table 1), building a graph structure which links resources to properties. As an example, Figure 1 shows the class associations for the automobile assembly ontology for representing the automobile manufacturing process as described in Table 1.

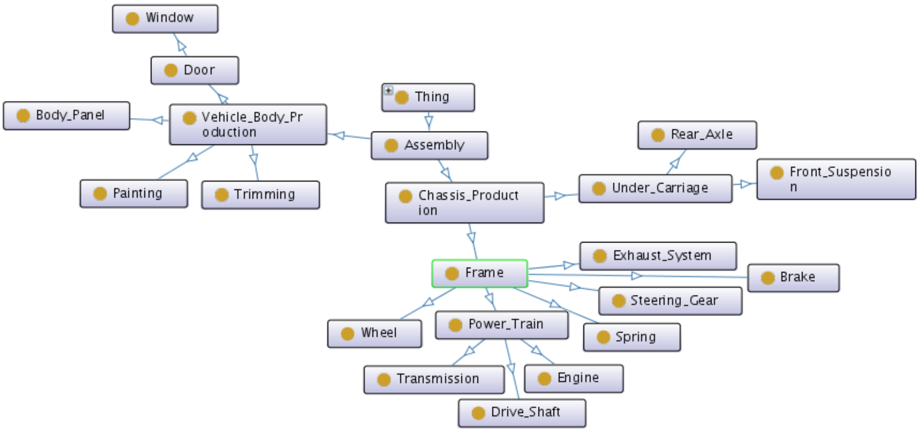

Fig. 1. Automobile Assembly Ontology Class and Properties

The ontology development process involves identifying the natural hierarchical structure found within (e.g. automobile) production line assembly. Figure 1 represents one of many domain ontologies developed where individual elements at each level represent physical ‘things’. Predicate relationships (linkages) are introduced to make physical connections between elements hence exposing relationships between manufacturing components. Figure 2 depicts an ontology development process which semi-automates partial aggregation and persistence of the target knowledge sources as ontology graphs. Existing knowledge sources, such as the equipment and processes identified in Table 1, are first run through a content transformation process implemented using Apache Any23[4]. As existing process and equipment domain information is heterogeneous in nature, it is essential to first identify the content MIMEType[5]. The information is then validated and useful content (such as specific names, types of equipment and processes) extracted. It is then further filtered to remove discrepancies and unwanted relationships. Finally, the RDF/XML data are serialized in triples format for persistent storage in Fuseki[6] and for queries using SPARQL[7]. It should be

[3] http://protege.stanford.edu
[4] http://any23.apache.org
[5] http://www.iana.org/assignments/media-types
[6] http://jena.apache.org
[7] http://www.w3.org/TR/rdf-sparql-query/

noted that we transform knowledge sources to the RDF/XML format not because it is the only solution, but because it gives structure to both the representation, and retrieval of information within the target domain. It should further be noted that the generated RDF/XML[8] streams still require some degree of human quality assessment and control such as checking for missing, incorrect and/or inconsistent relationships. Triples relations (as illustrated in the description of Figure 4 as the result of the query in Figure 3) can be produced using the development process in Figure 2.

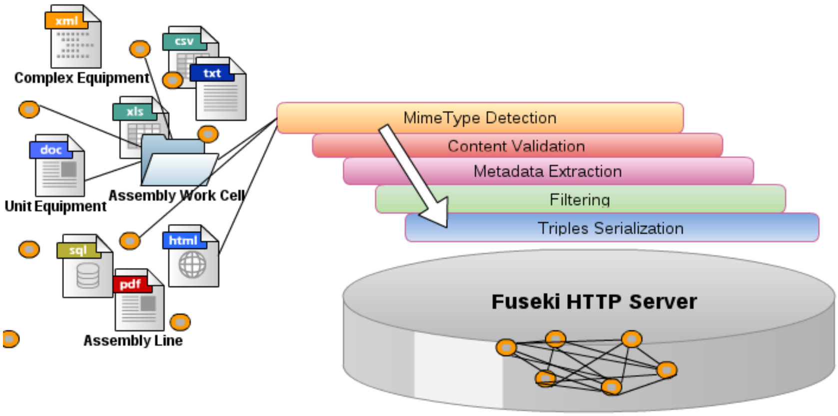

Fig. 2. Aggregation and Representation of Product Assembly Equipment and Process Knowledge Sources

2.2 Linking Product Assembly Processes and Equipment with Energy Consumption Metrics

As well as making clear internal associative relationships between elements from within a single knowledge domain, we also leverage the ability to associate elements between domains. For example if we consider that welding (as a parent process including many sub processes) is most commonly associated with the assembly process domain, we can associate welding with elements within the joining process domain such as specific welding techniques (Hybrid Laser GMAW), or particular manufacturing processes such as body panel or chassis under carriage assembly from within the automobile manufacturing domain. We adopt a methodology, referred to as the open world assumption[9] (where everything relates to everything else unless explicitly stated not to). This greatly enhances the possible integration, sharing and integration of knowledge within G2G activities.

We use energy efficiency calculation methods and deploy them as services which can be instantiated depending directly upon the output of queries we can now execute over the underlying data within Fuseki. The next section explores example structured queries which can be executed over the RDF/XML data providing detail on the

[8] http://www.w3.org/TR/rdf-syntax-grammar/
[9] http://bit.ly/134dYCj

powerful and verbose granularity relating to G2G process energy metrics which can be obtained by carefully crafted queries.

2.3 Querying Assembly Process Ontology/Information Resources

It is logical to assume that the calculation relating to energy metrics will also change based on user requirements, consequently affecting varying process artifacts and manufacturing equipment. Subsequently it becomes extremely important that the underlying ontologies persisted within Fuseki are rich in both property associations and data type values which can in turn be used as input for the calculations. Additional examples of data associated with equipment may include “*U – The Voltage of welding power source (Volts)”, “I – Peak current in welding power source (Amps)”, “Ϫ*t_a *- arc time (sec)”, etc.* SPARQL 1.1 Query Language provides many useful mechanisms for executing queries to obtain results that are expressive and sufficient to be used as input parameters for the energy calculators.

The DESCRIBE query is an informative query mechanism which returns a single result RDF graph containing RDF data about resources. This suits many requirements within our example application as extremely verbose results can be obtained enabling us to manipulate and structure them as input for the calculators. The following example shown in Figure 3 asks the query service to describe any instance of a single *MaterialsHandlingEquipment* variable, which matches the following criteria:

- it is a subclass of a welding robot equipment, and
- executes welding as a process, and
- executes Hybrid Laser GMAW as a specific joining process, and
- is involved in the body panel manufacturing process.

```
DESCRIBE ?MaterialsHandlingEquipment
WHERE {
  ?MaterialsHandlingEquipment
     rdfs:subClassOf    MaterialHandlingEquipment:Welding_Robot.
  ?MaterialsHandlingEquipment
     MaterialHandlingEquipment:executesAssemblyProcess AssemblyProcess:Weld.
  ?MaterialsHandlingEquipment
     MaterialHandlingEquipment:executesJoiningProcess JoiningProcess: Hybrid_Lazer_Gas_Metal_Arc_Weld.
  ?MaterialsHandlingEquipment
     MaterialHandlingEquipment:involvedInManufactureOf AutomobileManufacturing:Body_Panel.
}
```

Fig. 3. A SPARQL query describing the Hybrid Laser GMAW process

Dependent upon how comprehensively annotated the underlying ontology graph is, we receive varying resource description results (which in this case) relate to a Hybrid Laser GMAW robot including a long list of accompanying sub components, their data properties and relations. Figure 4 shows a snippet of the results for the query presented in Figure 3. (Note that the results have been summarized. Typically result streams contain many resources.)

```
"http://eil.stanford.edu:443/svn/eil-repo/Users/Lewis/ontology/MaterialHandlingEquipment.owl
    #Hybrid_Lazer_Gas_Metal_Arc_Welding_Robot" : {
  "http://www.w3.org/2000/01/rdf-schema#subClassOf" : [ {
    "type" : "uri" ,
    "value" : "http://eil.stanford.edu:443/svn/eil-repo/Users/Lewis/ontology/
      MaterialHandlingEquipment.owl#Welding_Robot"
  }
   ] ,
  "http://www.w3.org/2000/01/rdf-schema#comment" : [ {
    "type" : "literal" ,
    "value" : "A robotic laser welding system consists of a servo-controlled, multi-axis mechanical arm,...
    "datatype" : "http://www.w3.org/2001/XMLSchema#string"
  }
   ] ,
  "http://www.w3.org/1999/02/22-rdf-syntax-ns#type" : [ {
    "type" : "uri" ,
    "value" : "http://www.w3.org/2002/07/owl#Class"
  }
   ] ,
  ...
}
```


Fig. 4. A snippet taken from extensive output from a DESCRIBE SPARQL query

An example of triples semantics from the query result can be seen in Figure 4. The result snippet in Figure 4 explains that the single *MaterialsHandlingEquipment* variable requested within the query is a Hybrid Laser GMAW Robot, whose parent is Welding Robot, and has a comment "A robot laser welding system consists of a servo…", and within the RDF/XML ontology it was obtained from "is of" type Class.

3 Information Service Framework for Gate-to-Gate Process-to-Energy Reporting

This section details the information service framework, consolidating the ontology, knowledge and resources (such as calculation methods) into a comprehensive user-oriented workflow. On the left of Figure 5 (in the blue area), Users are presented with a query form where they are required to submit stored structured SPARQL queries to initialize the reporting framework. In addition to browser oriented interaction, the framework also supports SRARQL Over HTTP (SOH), a server independent, SPARQL 1.1 compliant protocol offered to systems (such as Fuseki) with HTTP access. Finally, we provide a SPARQL endpoint which can be consumed by other HTTP clients. Moving clockwise, requests are sent to an HTTP servlet contained within a communication layer, which coordinates Fuseki queries and responses. Upon processing the query, Fuseki sends a result stream back to the HTTP servlet as an object containing *n* fields directly dependent upon the result of the DESCRIBE query (e.g. Figures 3 and 4). Again moving clockwise, the result stream is then read into another servlet which, based upon the particular input parameters, coordinates the appropriate communication to the energy calculators which take the form of (web) services (shown in powder blue). Services are executed on the basis of parameters being present in the results stream, with the returned data (post calculation) being numeric in nature and representing various energy efficiency criteria. Figure 5 shows both an overview of the framework as well as examples of the consumable services made available through the calculations such as required energy, processing energy lost, unit equipment energy efficiency, theoretically required energy, amongst others.

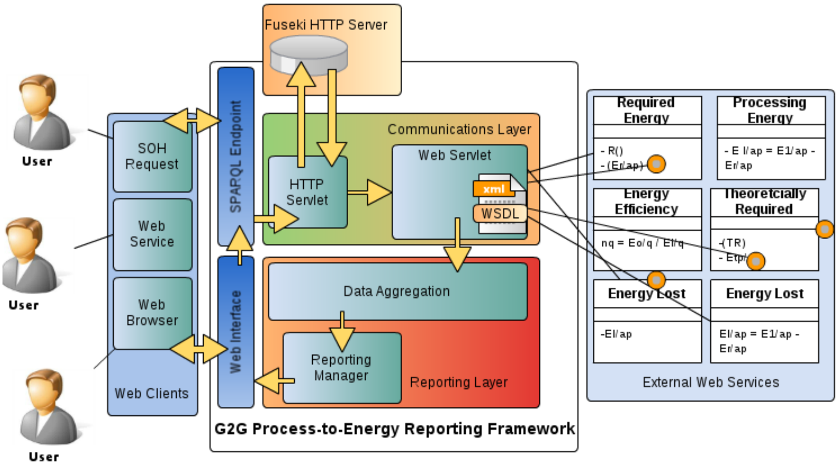

Fig. 5. An Information Reporting Web Service Framework for Integration of G2G P2E Data

The numeric output is communicated back to the web servlet before being sent to the reporting layer (red) where aggregation, sorting and processing occurs. Finally a reporting manager formats and presents reports as consumable PDF's using the popular Apache PDFBox[10].

4 Summary and Discussion

In this paper we present an information service framework for G2G P2E reporting, with illustrative examples for automobile assembly processes. The work builds upon extensive prior research from within the field [1-6] to establish resource efficiency assessments and energy metrics for product assembly processes and equipment. In essence, the novelty of energy metrics reporting in this manner is facilitated by an ontology development methodology based on integration of heterogeneous information. Building on our representation methodology, we present an example of the framework execution relating specifically to energy reporting for the Hybrid Laser GMAW process. This example exposes an architectural overview of our framework as well as a simple functional implementation. We indicate how in the future our framework can be adapted to advance the inference of equipment and process energy efficiency based on improved reporting of energy metrics.

P2E reporting is a concept which has seen a lot of interest as we strive to infer more from energy metrics relating to G2G product manufacturing equipment and assembly processes. It is widely recognized that plethora of data relating to many domains is both widely available and that it can and should be used to drive energy efficiency across such domains. Structuring of manufacturing data and inter-domain information integration not only offers the ability to execute federated queries relating to process

[10] http://pdfbox.apache.org

and equipment knowledge from heterogeneous sources, but also provides enhanced opportunity to drive information integration within the manufacturing assembly processes and supply chain. It is important for sustainable manufacturing to move towards making better use of fine grained reporting mechanisms in an effort to improve process and equipment energy efficiency. It should also be noted that there is significant benefit to receive direction from the industry on better reporting tools such as energy calculators, performance metrics and benchmarking statistics, etc. for assessing performance within supply chain and manufacturing as a whole. The automobile manufacturing industry has seen promising progress in these areas, however transparent reporting technologies should be further embraced.

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