Cyber - Physical Systems based Process Integration for Future Enterprise Systems

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***Abstract*—The integration of Internet of Things and Cyber Physical Systems principles and technologies in Enterprise Systems creates a new complex system category, with increased capability to process and manage information and knowledge. Modern Enterprise Systems offer innovative services that are developed in relation to core enterprise principles. This paper is focused on the investigation of using recently developed techniques in the area of process mining and work-flow identification, that contribute to the evolution of Sensing Systems towards Sensing Enterprise Systems. The processing steps related to document flow discovery in a mixed human – device - cyber enterprise environment are analyzed and an automated process mining solution is proposed and a case study is discussed.**

I. INTRODUCTION

Information and Communication Technology (ICT) has become a natural integrated component of our daily lives. New products and services, as well as new ways to assist human communication and interaction are being developed. As ICT evolves so does our dependence on technology.

A set of technical characteristics of the Future Enterprise Systems can be identified in the emerging paradigms and technologies [1], [2], [4], [5] :

- Production: Cyber-Physical Systems, Industrial Internet of Things
- Logistics: Smart Things, Wireless Sensor Networks, Service Science
- Management: Enterprise Modeling, Enterprise Architecture
- Data Analytics: Business Intelligence,
- Interoperability, Intelligent Documents, Adaptive Systems
- Human Resources: e-worker, Enterprise Social Networks
- Marketing: Internet of Future as “Universal Communicator”, Intelligent Social Media, Virtual and Augmented Reality
- Infrastructure: Cloud Computing, Trustworthy Infrastructure,
- Information systems: Applications with proactive behavior, IaaS or PaaS (Infrastructure/Platform as a Service), Interoperability Service Utility (ISU), Knowledge Representation and Semantic Modeling, Federated, Open and Trusted Platforms (FOT), Software as a Service (SaaS), Automated Service Discovery and Configuration, federation of heterogeneous service-based systems (SBS).
- Knowledge management: knowledge worker

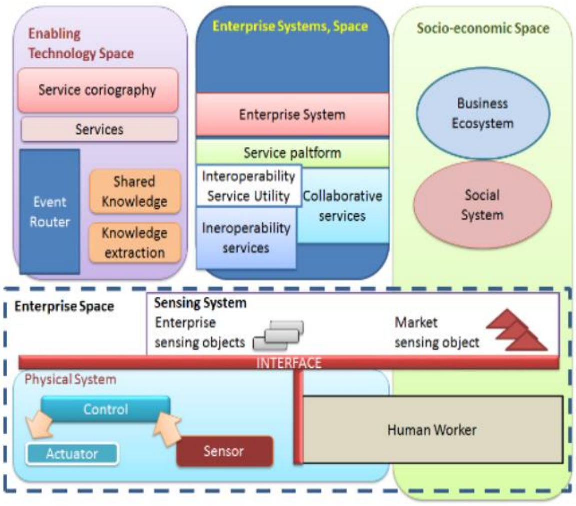

Figure 1. Enterprise Systems Enablers [1]

Complex systems cannot be seen as a simple set of subsystems, many different challenges and problems appeared, aspects that affect both society and industry:

- The self-organization and self-management of infrastructure and utility systems;

- The smart factory, including smart processes and smart products, needs new architecture and business models, thus increasing the demand for interoperability;
- New technologies and integrated models and architectures are emerging (H2M and M2M) into intelligent environments. Thus Cyber-Physical Systems cannot be modeled as simple systems, but from an interdisciplinary engineering perspective;
- High impact on science, technology and education.

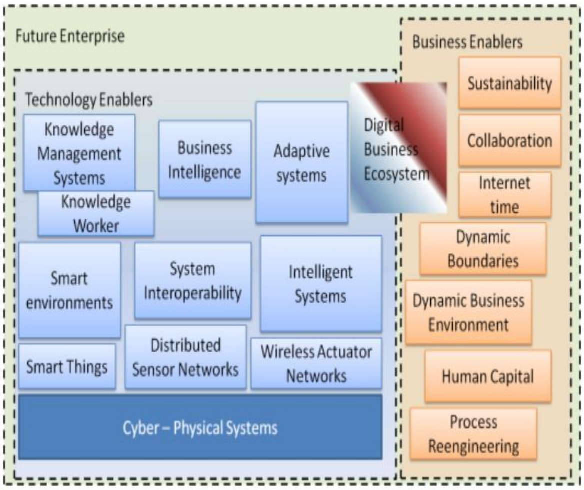

Figure 2. Adaptive Sensing Enterprise [1]

II. RESEARCH QUESTIONS

Modern Enterprise Systems offer innovative, secure services that are developed in relation to core principles. Such systems must facilitate the management and decision-making processes by analyzing and processing data acquired from heterogenous sources including sensors, human worker and cyber sources.

One important aspect related to Future Enterprise Systems is given by the level of complexity generated by the number possible interactions between Industrial Internet of Things (IIoT) devices physical and virtual entities, Information Systems and humans. The relation between these institutions has both a static and a dynamic component as enterprises must adapts to the new challenges of knowledge society.

The objective of this paper is to explore the possibility of integrating IIoT sensing capability, Cyber Physical Systems principles and process mining techniques to facilitate process discovery and monitoring in the context Future Enterprise Systems. In this context, the main problem address in this paper is the processing, in a semi-automatic manner, of sequences of observations, with the goal of extracting a sensor augmented process model and mapping it with an existing process model.

Such a process analysis procedure, targeting processes that are often implemented in an ad-hoc manner in informational systems, can be an extremely useful tool for all the stakeholders involved in operating and designing them.

III. METHODOLOGY

In this section, the most important processing steps related to flow discovery and sensor to workflow mapping in a human-intensive environment are analyzed and an automated process mining solution is proposed.

In order to achieve this, a framework for document flow discovery in a human-intensive environment is proposed. The input data set is assumed to be a set of semantically annotated events collected from smart devices and smart sensors.

Thus, the method provides real time access to data, avoiding loops that includes various applications.

The collected sequence of events is extracted using an existing process discovery algorithm and compiled into an event log and a process model. As such, the main focus of this investigation concerns the creation of the event log from the collected events. As a constraint on the investigated system, it is assumed that an annotation procedure is used, based on an ontology represented with the aid of a format developed in the field on Semantic Web research.

From the sequence of collected events, in order to construct an “event log”, the following steps should be per-formed:

Event acquisition – semantic annotation analysis and filtering the events that are not relevant for the current goal;

- Activity mapping – associating each event to an activity performed by one of the organization’s members;
- Process case identification – associating each event to an instance of a process / workflow;
- Process instance classification / clustering – partitioning the set of event sequences, resulting from the activity mapping and process case identification steps into several clusters, each one representing the observed behavior of a process;
- Process model discovery;

The pre-processing phase involved the retrieval of events and storing them in the enterprise specific flow analysis system’s working ontology.

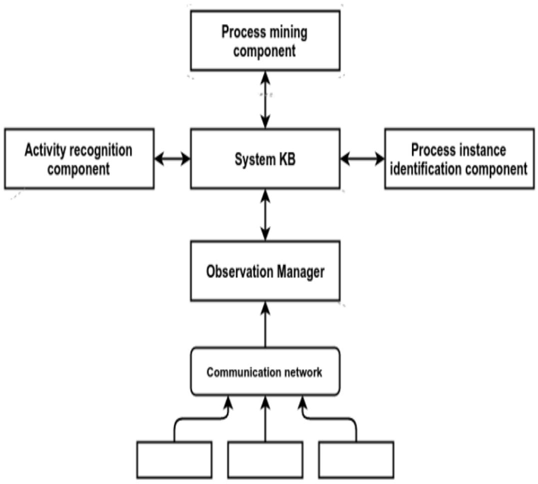

Figure 3. Flow Discovery Generic Framework

Along with a legacy monitoring system, several other event sources can be considered such as Internet of Things devices, smart sensors and sensor and actuator networks. [5]

After each event is collected, in order to be stored in the proposed system, it should be semantically annotated through a domain-dependent procedure.

Based on the stored event information, the flow analysis system can execute the event aggregation procedure in order to determine the performed activities.

For the process case identification step, the iterative method for generating event correlation rules, will be used.

Additional heuristic rules will be added for automatically removing invalid rules. After extracting the final set of rules, these will be used to generate individuals in the system's working ontology, relating events associated with the same process case (instance).

Using the results from the instance identification processing stage, the proposed a system can compile an event log on which various process mining techniques can be applied. The final goal of extracting a process model depicted activity flow will require the execution of a process discovery algorithm on this data structure. [3] [5]

However, the information currently encapsulated in the event log represents the behavior of a large set of processes and possibly variants of them. Executing a process discovery algorithm on this data will result in a process model that is overly-complex.

Finally, the sets of event logs can be used as inputs for any process discovery algorithm, given their reduced behavior following the application of a clustering algorithm.

Related to the usage of automated planning techniques in this paper, the authors of [3] highlight other applications of these algorithms in field of BPM.

Noting the need for better tools to cope with the increasing rate of change of the environments in which BPM solutions are used, the authors highlight recent applications of planning techniques mainly in the design phase of the process models.

IV. SOLUTION/DISCUSSION

In this paper, a case study is presented, involving a system built up from a mix of heterogeneous components representative of those found in modern enterprise informational systems.

Specifically, a small-scale process involving both logistic / supply-chain operations and some token manufacturing steps is considered.

In order to validate the presented approach, some aspects of the proposed system have been implemented in preparation of a case study involving the proposed system. As such, the focus has been places on the event acquisition aspects of the system.

A set of events has been extracted from a monitoring system in XML format. For each item in the input data file, using a domain-dependent semantic annotation procedure, an OWL Individual is created an stored in the system's ontology.

```
<NamedIndividual rdf:about="&work-work-ont-1;DocumentEvent_8705">
        <rdf:type rdf:resource="&work-ont-1;DocumentEvent"/>
        <DUL:hasParticipant rdf:resource="&work-work-ont-1;OrgMemeber_2"/>
        <DUL:isObservableAt rdf:resource="& work-ont-1;TimePoint_743"/>
        <oex:hasPhase rdf:datatype="&xsd;string">UPDATE</ oex:hasPhase >
        <oex:hasParent rdf:resource="& work-ont-1;Project_2"/>
        <oex:hasInternalId rdf:datatype="&xsd;string">47023</oex:hasInternalId>
</NamedIndividual>

<NamedIndividual rdf:about="&work-work-ont-1;DocumentEvent_2736">
        <rdf:type rdf:resource="&work-ont-1;DocumentEvent"/>
        <DUL:hasParticipant rdf:resource="&work-work-ont-1;OrgMemeber_2"/>
        <DUL:isObservableAt rdf:resource="& work-ont-1;TimePoint_744"/>
        <oex:hasPhase rdf:datatype="&xsd;string">CREATE</ oex:hasPhase >
        <oex:hasParent rdf:resource="& work-ont-1;Invoices"/>
        <oex:hasInternalId rdf:datatype="&xsd;string">5326</oex:hasInternalId>
</NamedIndividual>
```

Figure 4. RDF listing example

Using a DL Reasoner (the Pellet reasoner included in the Protege package) and the set of axioms defined in the terminological part of the system's ontology, a set of classes is derived for each (OWL) individual representing an event.

Using a border condition that separates events based on their temporal distance and the associated organizational member, the events are groups in transactions in order detect the sequential patterns that will be then mapped to activities.

Each transaction will contain an item for each OWL individual representing an event and each deduced class. Based on the proposed method a Petri-Net model as well as a BPMN model are generated.

As depicted in the next figure, the analysed process involves manufacturing a product at one of two sites with materials from two suppliers. A set of vehicles will be used to transport the raw materials from the suppliers to the manufacturing sites.

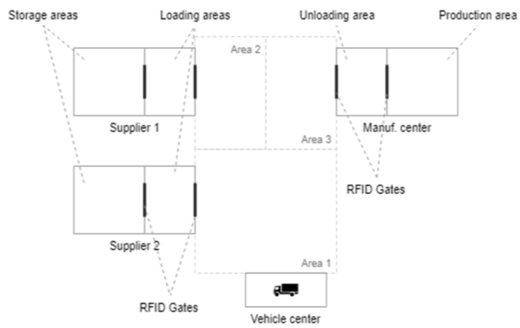

Figure 5. Case study diagram

The input data for the proposed system will be a sequence of events generated by various physical and "virtual" sensing elements.

In this case, the following event sources will be considered:

- RFID readers placed on gates in the loading / unloading and packing / unpacking areas of the suppliers' warehouses and the two manufacturing sites,
- GPS sensors placed on the vehicles (signaling the movement between a set of predefined areas)
- Manufacturing Execution System (MES) deployed at the manufacturing sites (capable of providing events at a higher level of abstraction than those from various devices from the production line).

In this scenario, it is assumed that the components are transported in containers – both individual components and the containers are tagged.

To ensure a uniform and consistent representation of the event stream, the proposed system employs an OWL (Ontology Web Language) repository. [10]

The first processing step performed by the system entails the assignment of each event to a set of process instances.

The process model that the system must uncover centers around the manufacturing of a single product and thus, the events related to the movement of vehicles and containers will be common to multiple executions (or instances) of the process under investigation.

For this example, each process case / execution will be uniquely defined by the RFID codes of the two components and the final product. Furthermore, a set of constraints must be imposed on the process to ensure that a unique relation can be established between each final product and the two components involved in its manufacture. In this case, a FIFO order for the loading, unloading and movements between the monitored areas will be considered.

The next step in consists in converting the sequences of events corresponding to each process instance into partial-ordered sequences on activities using a domain-dependent library of activity models.

This step allows, through the development of the activity library, the adjustment of the abstraction level at which the observed behavior (contained in the sequences of collected events) will be presented in the final process model.

This "Activity recognition" step involves solving an automated planning problem for each unique process instance (identified in the previous processing step).

The PDDL domain and problem files can be automatically generated based on a set of specifications comprising of the (maximal) set of objects from the planning problem and the set of activity definitions.

```
(:init
        …
        at 1523767463  (event23_cond)
        at 1523767563 (not (event23_cond))
)
...
(:action event_23_action
        :precondition (and (event23_cond) (at_loc vehicle2 Manuf_Unload_Area))
        :effect (and (constr_23_satisf)))
)
...
(:goal and (
        …
        (constr_23_satisf)
        ...
))
```

Figure 6. Listing 1

To these, the proposed system will automatically add special, "constraint" activities based on the event sequence of the process instance and generate a goal ensuring that the resulting plan (/planning solution) follows a trajectory in the observed system's state space that corresponds to the observed state changes.

These "constraint" actions leverage the "timed initial literals" construct introduced in PDDL 2.2 (Listing 1). Each will set a "constraint" predicate that always appears in the planning goal and can only be instantiated by the planner only in a small time frame corresponding to the timestamp of its related event (and the "constraint" action's precondition will reflect the observed state change).

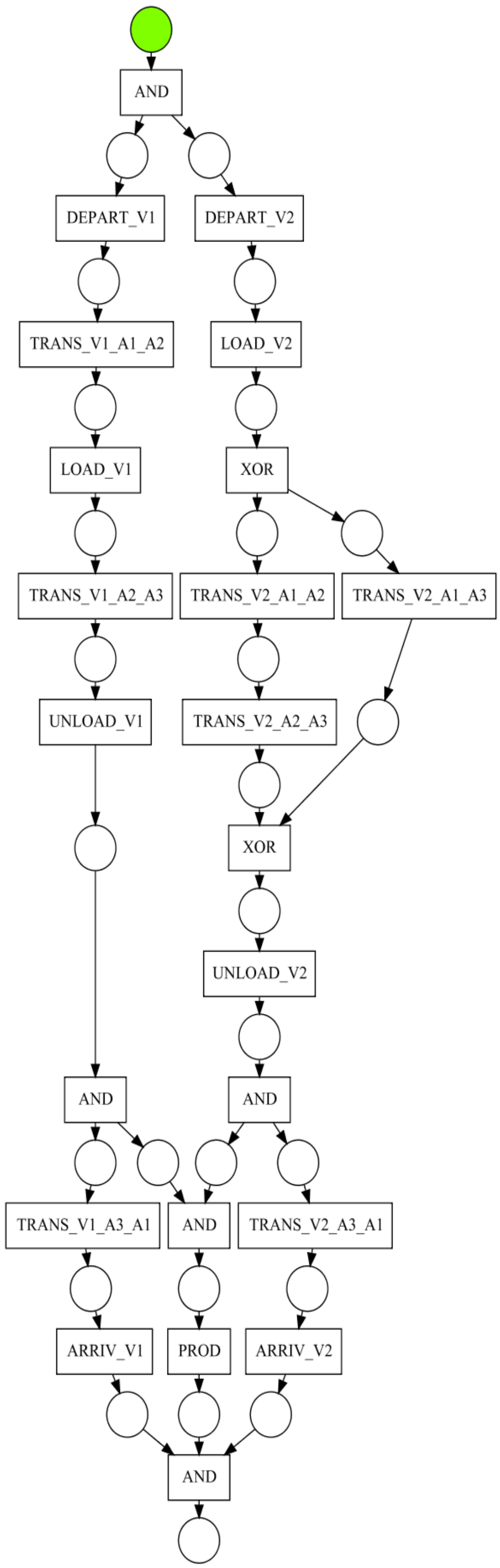

Figure 7. Process model

Any temporal planner supporting PDDL 2.2 can be used to solve the problems generated during the "Activity recognition" phase, SGPlan6 [6] and POPF2 being used for this small-scale evaluation.

The result of solving each planning problem will be an activity trace, from which the causal and independence relations between the activity instances can be derived. This information is subsequently used to build a workflow net using the method described in [7].

Unlike many process discovery methods that use an "event log" [3] as input, newly proposed approaches based on Petri Net "unfoldings" accept (labelled) partial ordered sequences of events and as such offer better results from a smaller sample size in the case of processes with high concurrency (of course, having the downside that this information must be provided by an expert, or derived from another source as in the case of this proposal). [8]

The resulting process model for the example discussed in this section is depicted in the previous figure.

The proposed solution has several limitations, mainly related to the activity recognition phase. For each event sequence from which a planning problem is generated, there might be several plans that satisfy the same state-space constraints. This issue can be partially mitigated by carefully designing and evaluating the activity model library and / or by optimizing for various plan metrics (depending on the planner's support of this feature).

Another limitation that was discovered refers to the scalability of the planning-based activity recognition solution. [11]

Although small scale scenarios, with highly constrained plans (like the PDDL domain used this case that contains relatively simple actions – transport / load / unload – that most of the time map to consecutive events) require few computational resources, in more complex domains this issue might become significant. [12][13]

However, it can be mitigated by choosing a definition for the process instance that compromises between the process analysis objective and the mean number of collected events involved.

ACKNOWLEDGMENT

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