Integrating the Internet of Things with Business Process Management: A Process-aware Framework for Smart Objects

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Abstract. Due to the achievements in the Internet of Things (IoT) field, Smart Objects are often involved in business processes. However, the integration of IoT with Business Process Management (BPM) is far from mature: problems related to process compliance and Smart Objects configuration with respect to the process requirements have not been fully addressed yet; also, the interaction of Smart Objects with multiple business processes that belong to different stakeholders is still under investigation. My PhD thesis aims to fill this gap by extending the BPM lifecycle, with particular focus on the design and analysis phase, in order to explicitly support IoT and its requirements.

Keywords: Business Process Management System, Internet of Things, Process compliance, Process monitoring, Smart Object, Business Process Management, Multimodal Transportation, Smart Container

1 Introduction

During the last years, the growing interest for the Internet of Things (IoT) has been manifested by both the academic and industrial world. The IoT is based on the idea of Smart Objects, which are devices that decentralize computation and data acquisition by moving them into the physical world. Because of their diffusion, solutions for executing business processes relying on Smart Objects are becoming more and more common.

However, as stated by Haller et al. [1], the integration of IoT with business processes is far from trivial: data collected by sensors may be unavailable or have inconsistent quality and, since part of the process execution is delegated to Smart Objects and often involves multiple actors, it is difficult to assess the compliance of a process. It is also worth noting that Smart Objects differ from traditional services as they have reduced computational power and limited battery life. In such a scenario, mechanisms for configuring Smart Objects according to the process requirements and the capability of assessing the compliance of the control and data flows with respect to the process definition would significantly ease integration tasks.

According to Weske [2], the Business Process Management lifecycle can be divided into four phases: (i) design and analysis, where business processes are modeled according to real world requirements; (ii) configuration, where business processes are implemented by a software solution; (iii) enactment, where business processes are instantiated and their executions logged; (iv) evaluation, where process logs are analyzed to assess the consistency between process models and their execution.

During my PhD I aim to investigate the integration of the Internet of Things with business processes by developing process-aware Smart Objects and by extending the Business Process Management lifecycle in order to explicitly support Smart Objects.

The rest of this document is structured as follows. Section 2 outlines the main research questions that I want to answer. Section 3 focuses on the multimodal trasport domain to show the importance of the research questions for a significant application domain. Section 4 proposes a solution that will support process-aware Smart Objects. Section 5 analyzes the state of the art. Finally, Section 6 outlines a tentative schedule for my research activities.

2 Research Questions

The adoption of the IoT can impact all the phases of the Business Process Management lifecycle:

Design and analysis The process model will allow the user to define for each business activity which data will be collected by Smart Objects, which conditions will determine the start and end of the activities, and which constraints on sensor data must be satisfied to consider activities successfully completed.

Configuration Smart Objects will be configured to collect data related to process activities with the specified quality level, according to the process model definition.

Execution Smart Objects will be process-aware by being able to identify and log the execution order of business activities thank to their starting and ending condition. They will also constantly check data constraints in order to log whenever they are not satisfied.

Evaluation The process compliance will be assessed by analyzing the process trace logged by Smart Objects to identify control and data flow violations.

Initially, I will focus on the design and analysis phase by enriching current process modeling notations with constructs able to explicitly define Smart Objects, their roles, and their needs inside business processes. Subsequently, I will also extend the other phases to support, take advantage of, and validate the newly introduced process model notations.

To reach such achievements, I will investigate the following research questions:

RQ1 - How can we monitor the process execution? I aim to monitor the process execution flow by determining which activities are running. I also want to reach such achievement without relying on explicit start and termination messages addressed to specific activities, but instead inferring such conditions by analyzing events captured by Smart Objects (i.e., when their position is within a specific area).

RQ2 - How can we define requirements on activity data? I aim to support the definition of requirements on sensor data related to process activities. In this way, the business process will drive the configuration of sensors, thus guaranteeing that sensor data needed for the correct execution of activities will be available and with a quality matching the requirements. If sensors are managed by external gateways (i.e., other embedded computing devices), requirements could also affect the computation done at node level.

RQ3 - How can we identify process execution violations? I aim to identify process violations by both checking the correct execution order of process activities and the compliance of activity-related data with constraints specified during the process design phase. I also want to do that directly on each Smart Object.

RQ4 - How can we support multiple actors? I aim to support the concurrent execution of processes that are designed by multiple actors and could partially or totally overlap during execution. Such a question is not trivial, since different actors might have different process definitions, constraints, and/or requirements on activities running at the same time. Therefore, I will define process merge and conflict resolution mechanisms.

3 Case Study: Multimodal Transportation

My main case study, which I will use for the problem identification and motivation, refers to multimodal transportation, since most of the research questions will directly address the currently unfulfilled needs of the stakeholders involved in such a domain.

Multimodal transportation concerns the planning and enactment of transportation of goods via multiple means of transport, each one typically belonging to different shipping companies, for each single shipping. Moreover, goods often belong to different manufacturers and/or are addressed to different customers. Such a task is far from trivial, since each stakeholder needs to track the status of the goods (i.e. position, conditions, etc.) during each shipping phase that involves its participation.

To fulfill these needs, research efforts have been spent in putting some intelligence into shipping containers, which are often used to aggregate goods during multimodal shipping, turning them into Smart Containers, that is, Smart Objects. Such Smart Containers are usually equipped with sensor networks, a Single Board Computing (SBC) device, and a communication device for exchanging data with information systems.

However, such solutions are usually based on a static approach: the sensor network configuration does not change during the transportation process, the nature of shipped goods is not taken into account, and they are usually tailored to a specific business process often involving a single stakeholder. In the real world this is not the typical case. Several factors, such as the content of the container, the capabilities of the sensor network, and the current phase of the shipping process may determine a variation on the requirements on sensed data. Moreover, as previously said, the nature of multimodal shipping involves the active participation of multiple stakeholders. Each party has its own business processes with different requirements on sensor data according to each specific process activity. Therefore, the compliance of each shipping process with respect to the data and control flows defined by stakeholders in their business processes cannot be taken for granted, and its assessment is far from trivial.

4 Solution

As discussed in the previous section, with particular focus on the multimodal transportation, current solutions based on Smart Objects lack the capability of dynamically configuring sensors with the precision required. Each activity of the business process must take into account the currently involved stakeholders. Moreover, mechanisms able to assess process compliance have not been introduced yet.

I envision a scenario in which Smart Objects are autonomous elements able to communicate with external entities. These external entities are the stakeholders that can: ask for the status of a Smart Object, and inform the Smart Object about the process in which it is involved. In order to do so, Smart Objects must be aware of the currently running process activities, and, for each activity, they must know the requirements on sensor data that have to be fulfilled.

To support this scenario, a Smart Object have to be equipped with: (i) a sensor network, (ii) a Single Board Computing (SBC) unit, and (iii) a communication interface. The sensor network collects information concerning the environment in which the Smart Object operates; the SBC executes a complete software stack, and different applications are installed; finally, the communication interface allows the interaction with external systems.

Among the others, the SBC will run a lightweight Business Process Management System (BPMS), a sensor configuration manager, a sensor data evaluator, and sensor interface modules, as shown in Figure 1.

The BPMS is the core of the solution: it will be responsible for keeping track of all processes belonging to each involved stakeholder, thus allowing them to orchestrate the Smart Object. In order to do so, it will be able to figure out which activities are currently running, to activate a proper configuration of the monitoring system. However, as conditions that determine the execution of activities rely on events that can be external, the BPMS will also deal with process choreography. It is worth noting that in many application contexts, such as multimodal transportation, some of the actual involved stakeholders and their business processes are known only at run-time. For this reason, each time a new

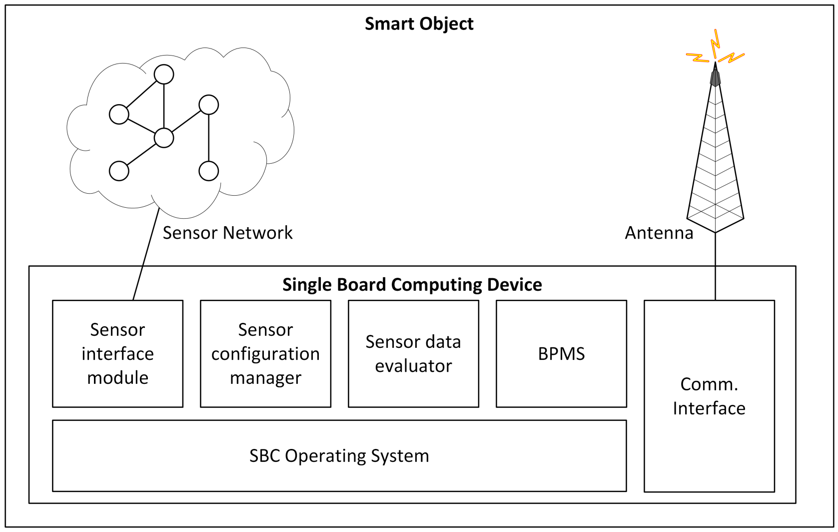

Fig. 1. Software modules.

stakeholder is involved, its business process definitions have to be downloaded and taken into account. Such a component will therefore answer RQ1 and RQ4.

The sensor configuration manager, on the other hand, will be responsible for determining stakeholders' requirements on sensor data. It will extract and interpret requirements from the process definition provided by the BPMS, and it will opportunely instruct the sensor interfaces to provide data that meet such requirements. Such a component will answer RQ2.

Finally, the sensor data evaluator will be responsible for verifying the compliance of sensor data to the constraints defined for the currently running activities, and for reporting violations of such constraints. Such a component will answer RQ3.

In order for these modules to automatically understand the process definitions and their specifications on data, I propose to extend such business process definitions with the following annotations on activities:

Start and termination conditions Such annotations will specify which conditions on process data determine the beginning or the end of a specific activity. This will allow the BPMS to implicitly infer the process trace (i.e. the sequence of activities carried out during process execution), and therefore to identify violations in the control flow.

Data requirements Such annotations will instruct the sensor configuration manager to provide data with the specified quality requirements, thus enforcing process compliance with respect to the data flow.

Data constraints Such annotations will impose constraints on data by specifying which conditions should or should not happen, thus allowing the sensor data evaluator to detect violations related to process data.

5 Related Work

Some research efforts have been spent on integrating the Internet of Things with business processes. Meyer et al. [3] propose to extend the BPMN 2.0 notation to model smart devices as process components. This approach keeps the process knowledge on the information system, and no process fragments are introduced on smart devices.

Thoma et al. [4] propose to model the interaction with Smart Objects in BPMN 2.0 as activity invocations for simple objects, or as message exchanges with pools representing the whole Smart Object for more complex ones. This way one can distribute parts of the process on Smart Objects. The limitation of this work is the lack of details concerning how to deal with data uncertainty or how to define data requirements.

Tranquillini et al. [5] propose a framework that employs BPMN for driving the configuration of a Wireless Sensor Network (WSN). Since BPMN is used only at design time for defining the business process, and then it is converted into binary code executable by the WSN, introducing changes in the process definition at runtime is difficult. Also, simultaneously supporting multiple processes within the WSN is not feasible with this framework.

Schief et al. [6] propose a centralized framework that extends the process design and execution phases of BPM by taking into account events generated by Smart Objects. Furthermore, this framework provides data quality mechanisms for evaluating events and sensor data. My proposal differs from this contribution by distributing process knowledge, which will be directly embedded in Smart Objects, and by explicitly defining requirements on sensor data, to better enforce and validate process compliance with respect to both the process execution and the data flows.

Concerning process compliance, such a topic has been widely studied during the last decade. However, as stated by Kharbili et al. [7], very few process compliance solutions exist that extend compliance checking beyond control flow. They do not consider data flows and the timeliness of activity data, aspects that are critical for the research questions. Awad et al. [8] try to address these open issues by proposing an extension of the BPMN notation, named BPMN-Q, able to define constraints also on the data exploited by business process activities. Ly et al. [9] consider the usage of data flow constraints in their framework for checking compliance during the whole business process lifecycle.

Some process compliance solutions determine the execution status of each activity by means of explicit notifications by the activity itself. Other solutions try instead to assess the execution status by analyzing the message flow between the business process and the activities, often considering the execution of an activity as a service invocation. Weidlich et al. [10], on the other hand, propose a framework for detecting process execution violations that exploits complex event processing techniques on process data to infer the execution order of process activities.

These solutions address the research questions only partially, since no solution covers all of them. In particular, the support for multiple actors is absent or very limited: no solution support the definition of processes belonging to multiple actors, the overlapping of different processes having activities in common and, more importantly, concurrent and possibly conflicting constraints on the same activity data defined by different actors.

Concerning the freight transportation domain, during recent years research efforts have been put in developing Smart Container solutions ([11], [12], and [13] just to name a few). However, all these solutions are based on the requirements and business processes of a single stakeholder, and are not thought to promptly react to changes in the involved stakeholders and/or in their business processes, requirements, and data. Such limitations are particularly important for the multimodal transportation, since changes in the involved stakeholders or in the business process definition are frequent and can happen during the shipment enactment phase, thus requiring a proper reconfiguration of the Smart Container.

6 Research Methodology

During the PhD, I plan to carry on design and research activities in parallel, as suggested by Wieringa et al [14]. More in detail, the design activity will deal with requirements analysis and definition of a possible solution. The research activity, on the other hand, will deal with the review of the literature to be aware of the state of the art in current technologies and use that as starting point for my work. Research activity will also deal with the validation of the results with respect to case studies to prove their soundness.

Concerning the research methods, for RQ1, RQ3 and RQ4 I plan to follow an experimental research approach. In fact, to validate the solution answering such research questions, I will build a prototype and test it possibly in the real world or in a simulated environment. For RQ2, on the other hand, I plan to follow an empirical research approach. Indeed, I will collect and analyze case studies to better understand requirements on sensor data and, having done this, I will use them as input to properly design a model that addresses all such requirements.

In order to achieve my goals, I plan to structure the research work around the following phases:

1. I will concentrate on answering RQ1 and RQ3 first. The output of this phase will be a process modeling notation that will allow one to model the start and termination of activities, and conditions that violate their execution based on events generated by activity data. I will also propose a methodology for integrating Smart Objects with traditional business processes by generating IoT process models from traditional process definitions, and a tool for modeling processes with the proposed notation.
2. I will then try to answer RQ2 by extending the notation defined in the previous phase, to support the definition of requirements on activity data. The output of this phase will be an extension of the process modeling notation, a BPMS capable of running processes modeled with such notation, and a

prototype of the sensor configuration manager module. The BPMS will also be able to produce a process trace that will allow one to assess process compliance with respect to both process and data flows.

3. I will finally try to answer RQ4 by investigating problems related to the simultaneous execution of multiple business processes having conflicting requirements. The output of this phase will be a prototype of the proposed framework that will support multiple actors and will run on a SBC device.

Currently, the first phase of the research work has started, and I plan to conclude it by the end of 2015. I then plan to start the second phase and conclude it by the fourth quarter of 2016. Finally, I plan to start the third phase and conclude the whole research work by the end of 2017 with the publication of my PhD thesis.

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