Towards a Comprehensive BPMN Extension for Modeling IoT-Aware Processes in Business Process Models

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Abstract. Internet of Thing (IoT) devices enable the collection and exchange of data over the Internet, whereas Business Process Management (BPM) is concerned with the analysis, discovery, implementation, execution, monitoring, and evolution of business processes. By enriching BPM systems with IoT capabilities, data from the real world can be captured and utilized during process execution in order to improve online process monitoring and data-driven decision making. Furthermore, this integration fosters prescriptive process monitoring, e.g., by enabling IoT-driven process adaptions when deviations between the digital process and the one actually happening in the real world occur. As a prerequisite for exploiting these benefits, IoT-related aspects of business processes need to be modeled. To enable the use of sensors, actuators, and other IoT objects in combination with process models, we introduce a BPMN 2.0 extension with IoT-related artifacts and events. We provide a first evaluation of this extension by applying it in two case studies for modeling of IoT-aware processes.

Keywords: BPMN · BPM· Internet of Things · IoT in BPM · Sensors · Actuators

1 Introduction

As electronic components have become smaller, more powerful, and less expensive, the Internet of Things (IoT) has received an upswing in recent years [1]. Many embedded components are equipped with sensors and actuators that enable collection of environmental data (sensors) as well as physical responses to specific events (actuators) [2]. IoT components can be embedded in everyday objects such as washing machines, refrigerators, vehicles, cell phones, or wearable devices. Moreover, they can be found in cyber-physical systems, smart cities, or smart logistics [3]. IoT refers to a network of physical objects or "things" being equipped with sensors, actuators and software to connect them with other devices and systems over the Internet. Such interconnected devices, in turn, constitute the basis for exchanging data [2].

While IoT allows capturing and exchanging data about the physical environment, BPM enables the analysis, discovery, implementation, execution, monitoring, and evolution of business processes [17]. BPM-enabled processes can be further enhanced by sensors, e.g., to measure the fill level of a tank and eliminate the need for manually performing this task [5]. In general, IoT technology contributes to make abstract process models real-world-aware and, thus, to align digital processes with the physical world[15]. Moreover, IoT devices can be used to automate different types of tasks, which may be physical (moving a conveyor belt) or digital (sending data or notifying a system) [14]. Furthermore, IoT enhances the monitoring, discovery, and optimization of processes, which are referred to as IoT-aware processes in the following. An important task for modeling IoT-aware processes is to properly capture IoT-related aspects. Modeling a process fosters the understanding of how the process works and allows discovering potential problems (e.g., deadlocks) before process automation. Finally, already modeled processes can be analyzed, improved, automated and optimized [17].

There are several languages for modeling business processes, such as Petri Nets, Event-driven Process Chains (EPC), Role Activity Diagrams, Resource-Event-Agent (REA), and Business Process Modeling Language (BPML) [16]. A standardized process modeling language is Business Process Model and Notation (BPMN) 2.0, which has undergone three releases since 2004 [6]. Modeling IoT-aware processes with BPMN 2.0 is a complex endeavor, and the resulting model is difficult to understand due to the potentially ambiguous use of modeling elements. As a drawback BPMN 2.0 does not allow for the explicit representation of IoT devices and IoT-related aspects, which aggravates the maintenance and servicing of IoT-aware processes significantly. In particular, the resulting process models lack structure, expressiveness, and flexibility. To overcome the lack of language elements for modeling IoT aspects, BPMN 2.0 needs to be extended. Existing BPMN 2.0 extensions for IoT-aware processes are either incomplete or do not comprehensively cover the required treatment.

In this work, we present a BPMN Extension for IoT-aware processes which enables the explicit integration of business process models with IoT devices. The approach supports the modeling of IoT-aware processes in terms of different views and levels of abstraction.

The remainder of this paper is organized as follows: In Section 2, we summarize the main issues that emerge when modeling IoT-aware processes with the existing BPMN 2.0 standard. Section 3 discusses existing works. In Section 4, we present our BPMN 2.0 extension for modeling IoT-aware processes and illustrate it along two case studies. Finally, Section 5 summarizes and discusses our approach.

2 Problem Statement

In order to properly model the behavior of IoT-aware business processes a multitude of input and output devices may have to be integrated with a process model. In principle, BPMN 2.0 offers various mechanisms for representing IoT devices. On one hand, script, service and business rule tasks can be used to represent IoT-related activities. On the other, resources, data objects or events may be used to model IoT-involvement [7]. However, when following such a straightforward approach, no distinction between regular BPMN tasks and IoT-related ones can be made. The familiarization with such a process may therefore take longer, as the IoT-related model elements cannot be visually distinguished from standard BPMN elements. Consequently, the modeled IoT tasks constitute a black box, i.e., it does not become transparent whether the task refers to a sensor, an actuator, or a service call [7]. On one hand, this aggravates model comprehensibility, on the other it results in a limited usability and poor maintainability of the model.

The process model, depicted in Figure 1, deals with the treatment of the Chronic Obstructive Pulmonary Disease (COPD). COPD describes the obstruction of the lungs, which hinders the patient's breathing [7]. First, the patient's heart rhythm is checked (1). If necessary, an emergency alarm is triggered (2). Then the severity of the COPD is assessed (3) and, depending on the outcome of this assessment, either no treatment, treatment with an oxygen mask (4), or treatment with an inhaler (5) is administered. Finally, the results of the treatment are analyzed (6) and the patient record is updated accordingly (7).

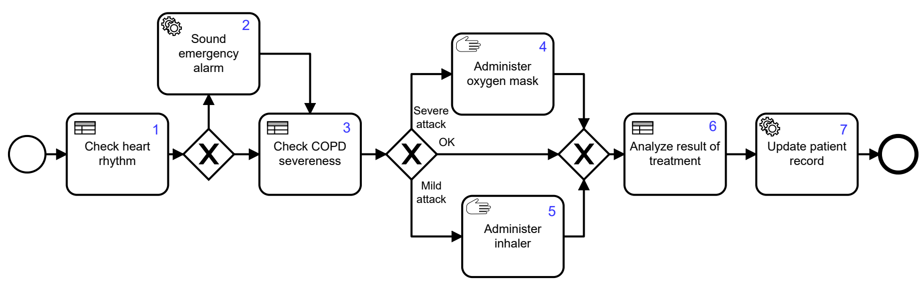

Fig. 1. Example of a process model with IoT aspects. (Adapted from [7])

When using standard BPMN 2.0 elements for modeling the physical (i.e. IoT-related) tasks of the COPD process (Figure 1), it is unclear, which tasks are IoT-related and which are not. In addition, it is unclear which sensors and actuators, respectively, are involved in the processing of the IoT-related tasks. Instead, it becomes necessary to carefully read and understand the underlying process model in order to make assumptions whether, for example, a business rule task refers to a specific sensor or a service task represents an action of an actuator. Note that this might cause ambiguities due to labeling issues.

When representing sensors in terms of business rule tasks, the involvement of IoT devices (cf. Figure 1, Activity (1) heart rate sensor) does not become apparent as well. Finally, there is no visual difference between an IoT-related Business Rule Task (1 & 3) and a BPMN Business Rule Task (6), or between an IoT-related Service Task (2) and a BPMN Service Task (7). This aggravates the comprehension as well as maintenance of the process model.

3 Existing Approaches

There exist several works that introduce notations, approaches, or language extensions for representing IoT devices in the context of BPMN 2.0. This section briefly describes these approaches and discusses them (Table 3).

[1] and [7] model IoT-aware processes with standard BPMN 2.0 elements. While [1] uses script tasks for integrating both sensors and actuators, [7] uses business rule tasks for representing sensors and service tasks for actuators. Cheng et al. [12] extend the BPMN 2.0 standard with a sensor task covering the following aspects: sensor device, sensor service, and sensor handler. Another approach for representing physical entities (e.g., a bottle of milk) in terms of a collapsed pool is presented in [10]. In particular, for sensing and actuation activities two new task types are introduced. Sungur et al. [13] explore the properties of wireless sensor networks (WSNs). For this purpose, they introduce a WSN Task and a WSN Pool. The WSN Task has an actionType element consisting of a question mark, an exclamation mark, and a square. It is used to specify a WSN operation as a sensing (?), actuating (!), or intermediating operation (▫). A real-world temperature control scenario is suggested by [4], which enhances existing BPMN 2.0 events with a conditional event, message event, and error event. [8], extends BPMN 2.0 with a resource called ResourceExtension, included for both human and non-human resources. The ResourceExtension has some privileges (ResourcePrivileges) and types such as RFID, Sensor and Actuator (ResourceTypes). uBPMN [6] suggests additional elements for Sensor, Reader, Collector, Camera, and Microphone. Each of these elements is represented by specific task and event types. In addition, a Smart Object is introduced to represent transmitted data. In [9], an Industry 4.0 process modeling language (I4PML) extending BPMN 2.0 with the following elements is presented: Cloud app, IoT device, device data, actuation task, sensing task, human computer interface, and mobility aspect.

Though existing approaches already enable the modeling of various IoT-driven process scenarios, there remain some gaps or scenarios that cannot be fully represented. Except for [1] and [7], all other approaches extend BPMN 2.0 with specific IoT elements. While uBPMN only introduces a Start Event, none of the approaches explores the execution and/or control of an actuator in combination with an End Event. In addition, none of these approaches allows for the combined use use of sensors and actuators in the context of a task. Furthermore, none of the approaches supports responses to an IoT event during task execution. Another important scenario that cannot be modeled with existing approaches is the verification of an IoT-driven condition when processing a task. There is also no concept for representing of IoT-driven processes with different levels of abstraction in the already existing approaches. Note that modeling IoT-driven processes with different abstraction levels could enable different views for various stakeholders (e.g., domain expert, BPMN expert, or IoT expert).

Table 3 provides a systematic summary of the different approaches (with ✓indicating support of the respective feature and ✗expressing missing support). As can be easily seen, non of the approaches comprehensively covers the treatment needed for IoT-aware processes.

	Sensor	Actuator	Combining Sensor and Actuator	Start Event	End Event	React to IoT within a Task	Intermediate Event	Condition Element	Physical Entity	IoT Data Object	Abstraction level	Score
Meyer et al.[10]	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	3/10
Sungur et al.[13].	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	3/10
uBPMN[6].	✓	✗	✗	✓	✗	✗	✓	✓	✗	✓	✗	5/10
Cheng et al[12]	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	1/10
BPMN4WSN[11]	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	3/10
Suri et al.[8]	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	2/10
I4PML[9]	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	✗	4/10

Table 1. Currently supported IoT elements through the extensions

4 Solution Proposal

To tackle the gaps and problems discussed in Sections 2 and 3 respectively, we extend BPMN with artifacts and events as shown in Figure 2. Note that these artifacts and events are not limited to specific use cases or processes, but may be used in any domain. Due to lack of space, the various elements cannot described in detail. Instead, we demonstrate the use of selected IoT artifacts and events along two IoT-aware processes from different domains. Note that all elements are decorated with a WLAN icon and labeled as "IoT". In addition, the latter in the upper left corner indicates the artifact type.

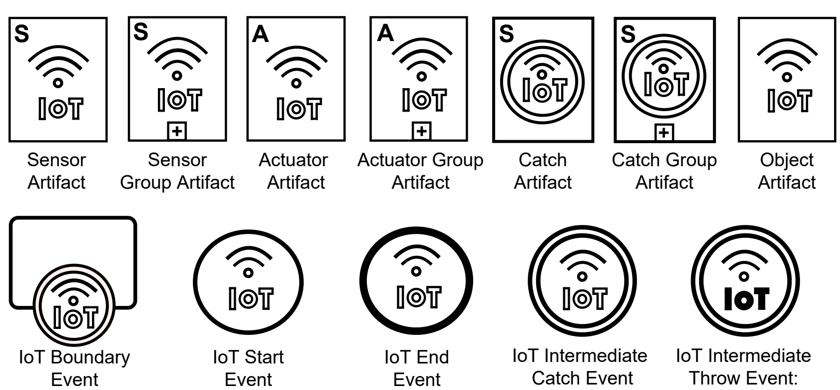

Fig. 2. Extended BPMN 2.0 elements

4.1 Case Study 1: Healthcare Process

In Case Study 1, we consider an IoT-enabled measurement process in a medical facility. The process can be modeled with our extension as shown in Figure 3. The process begins when the physician registers the treatment with the help of an RFID scanner. The patient is then transported to the treatment room. In the treatment room, sensors are used to check whether the patient has arrived. If this does not happen within 10 minutes, a notification appears on a specific monitor and the process ends. If the patient has arrived within the specified time period, a measurement process is started. Afterwards, the measured data is received, the evaluation is started, and a severity score is calculated. This score serves as a basis for the next steps. If the score is above 8, an alarm is triggered with an IoT actuator artifact. If the score is 6 or 7, an indicator light is switched on. If the score is below 6 nothing happens. Finally, the process ends with a logout at the RFID sensor.

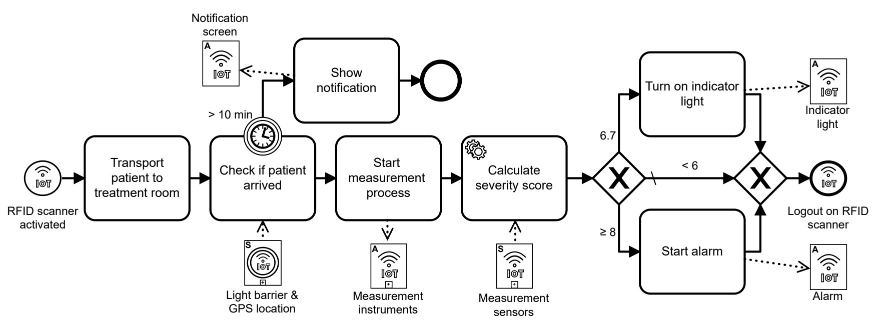

Fig. 3. Healthcare process of Case Study 1

4.2 Case Study 2: Production Process

Case Study 2 considers a process that sort workpieces based on their color in a production setting. This process could be modeled with our extension as shown in Figure 4. Process execution starts as soon as the light barrier on the conveyor belt is triggered by an incoming workpiece. The conveyor belt is then started and remains in operation until the end light barrier is triggered or the weight on the conveyor belt exceeds 1000 kilograms. A light is then switched on inside the machine and a color sensor is used to determine the color of the workpiece. Finally, the workpiece is sorted according to its color.

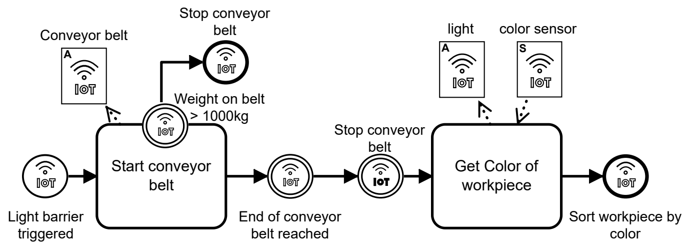

Fig. 4. Sorting process of Case Study 2

As shown, the proposed BPMN 2.0 extensions enable a proper modeling of the two IoT-aware processes analyzed in the case studies. In particular, both processes can be modeled more intuitively and specifically compared to the approaches discusses in Section 2 and 3.

5 Conclusions

This paper presented a BPMN 2.0 extension for modeling IoT-aware processes. Based on the problem description and a literature review, we identified gaps and problems of existing BPMN extensions for modeling IoT-aware processes. We then extended BPMN 2.0 with additional IoT artifacts and IoT-related events that address the identified gaps. In particular, the added elements enable the acquisition of physical data with the sensor artifact and the control of actuators with the actuator artifact. Furthermore, subjects and/or objects can be represented by IoT objects. IoT conditions, in turn, can be validated during task processing by the IoT intermediate catch artifacts as well as along the sequence flow by the IoT intermediate events. All artifacts can be aggregated into corresponding group artifacts to increase the abstraction level. Moreover, the process start may be triggered by an IoT condition associated with an IoT start event. In addition, a process end may execute and/or control an actuator with the IoT end event. Finally, we introduced an IoT boundary event, which allows redirecting the sequence flow based on an IoT condition. We have applied our extension in two case studies to show how the introduced artifacts and events can be used.

In future work we will perform various experiments and studies with different users such as BPMN modelers or domain experts to investigate the completeness of our extension and to study model comprehensibility. Furthermore, we integrate our extension with a process engine, i.e., the framework should support both the modeling and execution of IoT-aware processes.

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