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A Framework for Self-adaptive Workflows in Cyber-physical Systems

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Abstract: Workflows can be a useful means to formalize and enact processes among the sensors, actuators, smart objects and humans in Cyber-physical Systems (CPS). However, the dynamic nature of CPS and their resource constraint entities require the workflows and Workflow Management Systems (WfMSes) to be resilient and self-adaptive to deal with unanticipated situations and exceptions. We propose a generic framework based on the MAPE-K feedback loop to add self-management capabilities to WfMSes in the context of CPS. A case study in the smart home domain shows the general applicability of our framework for workflows and various WfMSes.

Keywords: Workflows; Cyber-physical Systems; Business Processes; Internet of Things

Motivation and Approach

The application of workflow and business process technologies to automate repetitive tasks and introduce high-level processes in the Internet of Things (IoT) and Cyber-physical Systems (CPS) has gained increasing attention over the years. With workflows, the data and control flow among sensors, actuators, embedded computers, smart objects, humans and other entities in CPS can be described and enacted on an abstract level facilitating simplified programming and flexible composition of existing functionality. However, due to the dynamic nature of CPS consisting of resource constraint devices, dynamically moving objects and physical entities that interact with the software controlled devices, formalized processes can only serve as basic structures for defining ordered sequences of activities.

We propose a framework and software component for adding the capability of self-adaptation based on the *MAPE-K* feedback loop to workflows and Worfklow Management Systems (WfMSes) [Se17]. The *Feedback Service* implements the MAPE-K loop and interacts with the WfMS (here: the *PROtEUS* WfMS for CPS [SHS16]) as well as sensors and actuators of CPS (cf. Fig. 1). Goals and objectives specify the expected outcome of the execution of a process step instance and error criteria referring to changes within specific context data. At runtime, the Feedback Service *Monitors* this data, *Analyzes* it with respect to the specified success and error criteria; *Plans* compensations in case of errors/exceptions; and *Executes* them [Se17]. Necessary data is contained in the *Knowledge Base*.

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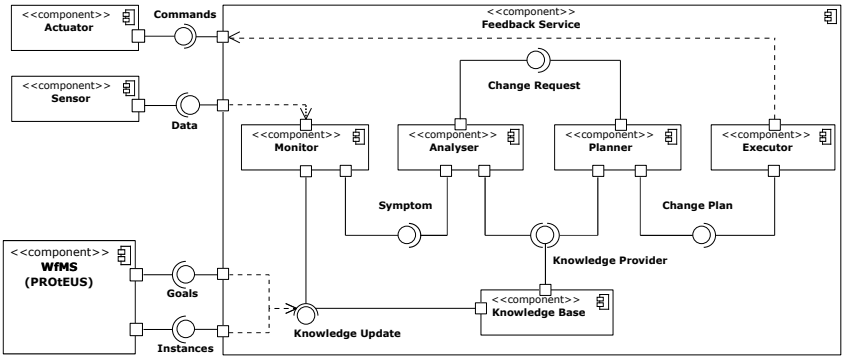

Fig. 1: Interactions of the Workflow Management System, Feedback Service and CPS Entities

To show the feasibility of our proof-of-concept implementation, we conducted a smart home case study. The example workflows include the automated assistance in case of a medical emergency [SHA18b], continuous light control [Se17], autonomous movement of service robots [SHA18b], and distributed execution of workflows on robots [SHA17].

The results show an increased success rate for error-prone processes when incorporating the MAPE-K feedback loop as part of the executions. The proposed framework for adding self-adaptation/-healing to workflows helps to increase the resilience of WfMSes as shown for the PROtEUS system [SHS16] but also as general retrofitting framework for other WfMSes [SHA18a]. Goals and objectives may refer to arbitrary performance or quality criteria and the strategies to find suitable compensations can be easily extended [Se17].

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