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Dynamic and Constraint-based building of Ambient Applications with Self-Reflective Smart Objects

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Abstract

The increasing availability of novel smart objects in the Internet of Things offers exciting possibilities for a plethora of use cases. Smart environments support the interaction with and control of wirelessly interconnected devices, escaping the boundaries of current limited human computer interaction and enabling natural ambient interaction in smart environments. This opportunity on the other hand also creates new challenges for the user, who is faced with potential overload due to the need of starting, configuring, interconnecting, and using device ensembles in an appropriate and convenient way. In this paper, we contribute a novel approach for the automatic formation of appropriate ensembles of input and output devices to be used for novel ambient applications on-the-fly. We present a Fusion Engine as an extension of our Ambient Reflection Framework, which supports the dynamic and constrained-based setup of device ensembles by orchestrating a set of self-describing smart objects. The fusion takes into account the semantic information of applications, the services offered by smart objects and the physical constraints, users might face. We also discuss, how this process can be used to enable device ensembles to dynamically explain their functionality and interaction capabilities themselves to the user.

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Keywords: Internet of Things; Smart Objects; Interaction Fusion; Self-Reflection

1. Introduction

Following the rapid developments in the area of the Internet of Things (IoT), everyday devices are becoming increasingly augmented to so-called smart objects by integrating network and sensor technology [1]. Smart objects offer an increased range of functions, applications and use cases in many different domains. Devices can be interconnected in a context-specific manner and tailored directly to the user's needs and capabilities [2]. However, these technological advancements raise new challenges in Human Computer Interaction (HCI) as well. Due to the wireless networking of devices and the decoupling of input and output devices in the area of the Internet of Things, users are required to interact with very dynamic device ensembles potentially unknown at the first time of usage. This can lead to

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a mental overload in (re)learning the control of smart objects[3]. In this context, smart devices are possibly even embedded into the environment and may adapt their interconnection to specific situations. Consequently, a direct connection between devices and their range of functions is not visible and probably not comprehensible to the user. In these smart environments, users interact with so-called multipurpose computers, which - similar to a universal remote control - only provide control options for other devices or software[4]. Language assistants or gesture controllers are enabled to control other devices by interconnecting them to smart objects. At the same time, pure output devices (actuators), such as the Philips Hue, exist, whose complete range of functions can only be unfold by means of an external control via software or another device using existing software interfaces. Therefore, this networking of smart objects, referred to as device-to-device communication, also increases the configuration effort for the user[5]. Resulting from the increasing use of network technology in devices, new possibilities arise for the collection and evaluation of produced data. Semantic information obtained from this can be used for the systematical formation of device ensembles in the Internet of Things[6]. In this paper, we present the possibility of automated networking and the simultaneous self-explanation of device ensembles, which is based on metadata through semantic encapsulation of provided functionality, by extending our Ambient Reflection Framework.

2. Self-Reflection by using the Smart Object Description Language

Due to the large number of devices used in smart environments, the concept of self-organization, which is known from autonomic computing, becomes more and more relevant. Summarized under the terms of Self-X or Self-$\star$. Systems are autonomous to ensure their configuration, organization or maintenance, etc.[7]. In order to enable smart objects to have knowledge about their structure and their behavior, we have developed the approach of *self-reflection*, derived from the concept in programming. Interconnected devices are therefore given an understanding of their interaction capabilities as well as their effects on device states, which enables them to adjust their behavior at runtime if required[3]. If such a self-reflection of devices resp. device ensembles takes place in the ambience of an intelligent environment, it is referred to as *ambient reflection*. However, a structured self-description of existing capabilities for the semantic interpretation of the devices is required. In order to achieve this, the so-called *Smart Object Description Language* (SODL) was developed by us. Smart devices, their integrated components, possible component states, as well as the needed interactions for changing a components state, can be specified using the associated XML-Schema[8]. All interaction information is described in different degrees of detail according to Nielsens seven stages of interaction in combination with the Hierachical Task Analysis (HTA) technique in order to structure interaction paths along the self-description[9,10]. By using our *Ambient Reflection Framework*, all self-descriptions of smart objects available in the network are collected by a central instance, namely the *Description Mediator*. Based on the information about the current interconnection state of the devices, instructions about how to control such devices in a smart environment can be generated at runtime and tailored to the users' needs. In order to make devices self-explaining, such instructions can be delivered to device ensembles in a targeted manner. In the following, we present a possibility for the constraint-based and dynamic creation of IoT applications by means of code annotations based on the fusion of existing self-descriptions in SODL.

3. Interconnection of Input- and Output-Capabilities

While interconnecting smart objects, several network states are conceivable, which must be considered in a smart environment for control purposes. In the following, input possibilities and output modalities resp. state changes (in the future referred to as an actor) are logically separated from each other. Physically, these can be included within one or more devices resp. cases. As seen in fig. 1, following interconnection scenarios are possible. Ideally, one input modality is available per controllable actor in order to build up a clear mapping (see fig. 1a). If, however, more actuators than input media are present, existing interaction capabilities must be used more than once and may be selected depending on the context (see fig. 1b). Similarly, if more input options than actuators are available in the environment, a user might select between several devices for controlling smart objects (see fig. 1c). Due to the heterogeneity, complexity and the dynamics of intelligent environments, cross-connections and multiple assignments between input capabilities and output modalities are possible (see fig. 1d). In the following, these cases are taken into account in the dynamic configuration and fusion of smart devices on the basis of their self-description.