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Performance evaluation of ambient services by combining robotic frameworks and a smart environment platform

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HIGHLIGHTS

- Combining two robotic frameworks with a smart environment framework.
- Lightweight interconnection via UDP.
- Realistic agent behavior derived from real data.
- Performance evaluation of a security ambient service.

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ABSTRACT

Mobile robots and smart environments are two areas of research that can easily profit from each other. Smart environments, which are spaces unobtrusively equipped with sensors and actuators, providing ambient services to the people living within. Mobile robots inside those smart environments can use the existing infrastructure to increase their performance while decreasing the cost of local sensor systems. On the other side, evaluation of ambient services is often a laborious task. This work presents an approach that simplifies the evaluation by making use of two frameworks from robotics to perform tests in *simulated* smart environments. A method based on the *language as action* principle is used to extract realistic behavior of people living in real-world smart environments. Using this data, many different scenarios with varying configurations (different floor layouts, numbers and types of sensors, different number of people and pets) can easily be simulated and the performance of the ambient services evaluated.

1. Introduction

1.1. Robots in smart environments

The domains of ubiquitous computing and ubiquitous robots merge more and more. The importance of so called *smart environments*, in the form of *Smart Factories* [1,2], *Smart Homes* [3] or *Smart Offices* and especially in the form of *Ambient Assisted Living (AAL)* systems is increasing, the latter especially in the western world with its continuously aging population. The number of smart environments is expected to further grow, due to recent advances in smart energy distribution and usage, in the form of the *Smart Grid* [4,5] as well as smart domestic appliances [6]. With the help of Wireless Sensor Networks (WSNs), we are coming closer to Mark Weiser's vision [7] of smart environments that would serve the people in their everyday lives, functioning invisibly and unobtrusively in the background [8]. In the *Internet of Things* (IoT), small objects collect sensor information and perform control tasks. They can help in training [9] and commercial products like the ones from fitbit or the jawbone UP collect human body data to optimize our health,[1] while the IPv6-based tado° or QGate devices[2] control our homes and MYO let us control the technology around us.[3] On the other hand, mobile robots are currently more and more in use in a variety of environments including outdoors, in factories, in building automation, but also in homes, fulfilling domestic tasks. Given this trend continues, it is obvious that also a rising number of robots will be deployed in smart environments. It has been previously shown that putting a mobile robot into a smart environment offers a multitude of opportunities in the field of robotics, for

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1 http://www.fitbit.com/, https://jawbone.com/up/.
2 http://www.tado.com/, http://qgate.com/.
3 http://getmyo.com/.

example by optimizing velocities while maintaining safety in transportation tasks [10]. In that particular work, the robot communicated directly with the smart environment's hardware—no particular bridge between robotics and smart environment frameworks had been built. Combining the domains of ubiquitous computing and ubiquitous robots brings up a lot of advantages. Installation of redundant (possibly expensive) sensor systems at robots *and* the environment are avoided. Computational and energy resources can be saved by avoiding local sensor data processing at each mobile robot. Energy and bandwidth consumption of the wireless, battery powered ubiquitous sensors are also reduced by sending the data only once to a central processing unit instead of communicating with each ubiquitous robot. In situations where sensor data from the past or data from sensors out of direct communication range are necessary, a central data storage — in the form of a smart environment platform — is convenient. This is why we expect that in the future the cooperation between both systems is inevitable. There are also several scenarios where robots may directly profit from aggregated data. New ambient services can include time-critical tasks, for example rescue scenarios when robots need to find people *fast* during a fire or non-critical tasks such as bringing the ringing telephone to elderly people in AAL environments.

1.2. How well does an ambient service perform?

In [11] the author proclaims that the third generation of computing — the ubiquitous computing — is already here and research has to move into new fields. Challenges of the future are seen in how to make the development for ambient services easier. We agree with his opinion and also pose a further question: If a service is developed, how can its performance be measured in a fast and efficient way? In contrast to the classical software programming, designing ambient services can be much more complex, because the environments can vary a lot. Examples include interacting with various kind of robots, different floor footprints of buildings, different number and behavior of people, disturbances to the system like pets, different types of sensors and actuators which are available as well as different services using the same resources. Most research ignores these facts by assuming a fixed scenario with fixed behaviors for the people who are involved in a test case [12]. The lack of large, empirical test results shows that it is very hard to quantify how well a service performs under given specific, realistic conditions.

1.3. Evaluation through simulation

The basic idea of the approach proposed in this work is to simulate different environments to measure the performance of ambient services based on metrics which can be individually defined. The simulated environments are flexible in terms of their configuration and can include robots, different floor footprints, one or more persons, pets, various sensors and actuators as well as diverse ambient services. Specifically crafted metrics can then be used to evaluate if e.g. a certain event has happened, how fast it was recognized, how much energy was consumed for a task or how many sensors may fail while a service is still available.

It will be shown later in Section 6 how several different simulated environments can be created by using data gathered from just a single real-world setup, through the extraction of behaviors. The results obtained in simulation can in turn be used to optimize the real-world smart environment setup, see Fig. 1.

In this work, simulation is realized by combining two reliable frameworks from the robotics domain and the highly modular ubiquitous computing framework TinySEP. The generic robotic framework Finroc (*Framework for Intelligent Robot Control*) and the simulation and visualization framework SimVis3D have been in use for long periods of time on a variety of different robots. TinySEP, the *Tiny Smart Environment Platform*, is actually used in two real-world setups.

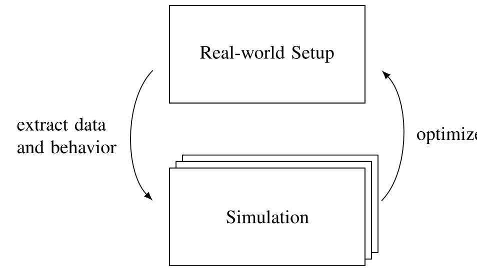

Fig. 1. Data gathered from a real-world setup is used to generate multiple realistic simulation setups. The results can afterwards be used to optimize the system in its real-world setup.

It is worth noting that no changes where made to the platforms themselves, retaining their stand-alone characteristics. Instead, their modular structure was used to combine them, by implementing only a few modules that enabled the necessary communication between the two of them.

Thanks to this approach, both the robotic and smart environment researchers can benefit. A proof-of-concept will be presented, that shows how the existing robotic frameworks are used to simulate people, pets, robots and wireless sensors and feed this raw sensor information to the ubiquitous computing framework, enabling the user of this framework to do easy and repeatable experiments in a large variety of simulated environments. For realistic results, the AmICA wireless sensor network platform [13,14] has been used. Special focus has been set on realistic human behavior. Data from real-world setups were collected and used to learn the person's behavior and thus later generate realistic agent simulations.

All of the mentioned frameworks will first be briefly introduced in the next sections. After explaining how the realistic agent behavior was archived, the interconnection of the frameworks is described, the experiments are presented and the results are discussed.

2. Related work

This section aims to give an overview about works that are related to this one as they also handle robotics together with smart environments or especially robots *in* smart environments. It is concluded with a brief debate on what distinguishes the approach presented here from these works.

2.1. Physically embedded intelligent systems

The idea of *Physically Embedded Intelligent Systems* (Peis) has been introduced in 2005 [15]. Peis are seen as the intersection and integration of the three research areas *artificial intelligence*, *robotics* and *ubiquitous computing*. Everything that consists of software components with a physical embodiment, interacting with the environment through sensors or actuators, does qualify as a Peis, so the systems do not necessarily have to be robots. A set of interconnected Peis is defined to be a Peis-Ecology. Instead of having e.g. isolated robots that perform tasks on their own, inside of a Peis-Ecology, they should interact, communicate and reach goals together.

The systems and their communication methods that are used are highly heterogeneous. The framework supports a multitude of operating systems (TinyOS, Linux, Windows) and also a wide range of computing architectures, ranging from 8-Bit microcontrollers to personal computers [16]. In experiments, systems consisting of