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AI-Based Elderly Assistance Systems

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Abstract. The demographic change is no longer a prognosis, but a reality seen in everyday life situations and requires mechanisms to make the public and private space elderly-adequate. These required mechanisms need to consider the varying aging process for each individual as well as adapt to the dynamic daily life of individuals characterized by spatial, temporal and activity variance. Developing assistance systems that are user-adaptive within dynamic environments is a challenging task. AI-based cyber-physical assistance systems enable such adaptive, flexible and individual assistance by processing acquired data from the physical environment using cyber resources and delivering intelligent assistance as well as interfaces to further medical services. This contribution discusses a flexible, reusable, and user-specific concept for AI-based assistance systems. Relying on distributed and heterogeneous data, the user's context is continuously modeled and reasoned over to infer actionable knowledge within a middleware between the data layer and the application layer. To demonstrate the applicability of the concept, the use case of intelligently supporting patients' medication adherence is shown.

Keywords. Artificial Intelligence, Cyber-Physical Systems, Internet of Things, Elderly Assistance Systems, Context-Awareness, Middleware, Medication Adherence

Introduction

The goal of this work is to design elderly assistance systems with embedded intelligence to learn and adapt by modeling the dynamic user's context. In this chapter, relevant fundamentals to the concept, which are intelligent cyber-physical systems, ambient assisted living as well as context-aware systems are briefly described.

Intelligent Cyber-Physical Systems

Cyber-physical systems represent a paradigm for technical systems as being a fusion of both a physical and a virtual part. The physical system is represented by hardware components, such as sensors, actuators and control units, whereas the virtual part is realized by the system's digital representation and networking ability, enabling the use of distributed computing resources. Developing and using cyber-physical systems has enabled new added value for the overall improvement of technical processes they are intended to automate through better monitoring and analyzing them [1]. Furthermore, the scalability and flexibility of using networked cyber-physical systems have paved the way for applications in all domains, including health [2] and personalized care domains. Assistance systems represent a category of cyber-physical systems, where the user plays a vital role in the operation of the system and is part of it.

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Intelligent cyber-physical systems are emerging, as they technically implement the iterative human cognitive processes of learning, consisting of perception of the environment, analysis of perceived data and drawing conclusions to apply previous learning experiences in unknown new situations. Based on the work of [3], a cyber-physical system can be built around an artificial intelligence (AI) component to acquire and analyze data. The AI component implements all intelligence aspects (perception, analysis, reasoning and conclusion) using various methods of machine learning and knowledge management.

Ambient Assisted Living Systems

Elderly assistance systems belong to the research domain of Ambient Assisted Living (AAL), which covers diverse systems embedded in the daily living environments of individuals with the goal of increasing their autonomy and quality of life. An example is an automated pill dispenser for medication management. For our vision, an AAL system can be regarded as a product-oriented cyber-physical system. Some of the prominent AAL architectures are hereby openAAL [4] and universAAL [5] as they offer extensible and independent platforms to build AAL systems on. The layered architectures mentioned in the paper have common modules and can be merged with the concept of cyber-physical systems as follows: The physical layer reflects the system's physical environment with its sensors and actuators. Above this layer is the communication and networking layer, in which data from the sensed physical world is transmitted to the cyber layer, in which the processing of this data takes place. Within this layer, applications and services are also placed, where decisions based on the processed data are taken and executed in the physical environment. Based on surveys conducted on AAL systems, some relevant challenges could be identified, such as dealing with large and heterogeneous datasets generated from sensors within the user's environment with the need for applying AI functions and algorithms to process, analyze and generate knowledge from this data. [6, 7] Therefore, the potential for using AI on data generated to create adaptive and more assistive environment is considerable [8]. A second challenge is dealing with dynamic and variable environments and making AAL systems more adaptive towards the user's need [9], hence further justifying the need for learning systems. A third challenge is the lack of standardization on an architectural level [7]. Addressing these challenges, the design of contemporary context-aware systems will be investigated.

Context-Aware Systems

Context is commonly defined as any information, using which the situation of an entity during an interaction with a specific system can be characterized. The entity can be an object, user or the system itself [10]. For a cyber-physical assistance system, context can be regarded as available data about the user within an environment that are relevant and can potentially improve the specific assistance delivered by the system.

With the increased availability of data through embedded sensors and the increased use of AI to process them, context-awareness is increasingly expanding and the system can be capable of dynamically modeling the complete physical environment at runtime to deduce knowledge. Context-aware systems provide components to undergo a lifecycle of modeling, reasoning and managing context, which can be placed in a distributed and decentralized architecture to allow lifecycle modules to be executed by remote computing resources. A prominent architecture is the middleware one, which is a layered, service-oriented architecture, where the context lifecycle is embedded between a data acquisition and an application layer. [11, 12] The context middleware architecture represents a flexible and extensible architecture and is well fit for an IoT environment of cyber-physical systems. An example approach is given by CocamAAL [13] with remaining potential for applying AI to address variable situations in dynamic environments and learn the user's behavior.

1. A Context-Based Middleware for adaptive Elderly Assistance Systems

Developing context-aware systems requires a mechanism for uniformly modeling heterogeneous data in a machine-understandable way and an intelligent mechanism to extract knowledge about the user from his current context. In this section, an approach addressing these requirements is demonstrated in the concept.

The general idea is to create a base to flexibly and continuously acquire user data and learn his behavior by analyzing patterns and correlations in a context-based manner. The middleware architecture can be used to connect multiple assistance systems within a user's environment, which can apply the generated knowledge managed by its components for their assistance functions. The system design consists of three base layers being the data acquisition layer, the context middleware and the application and service layer as seen in Figure.1 and will be described in detail subsequently.

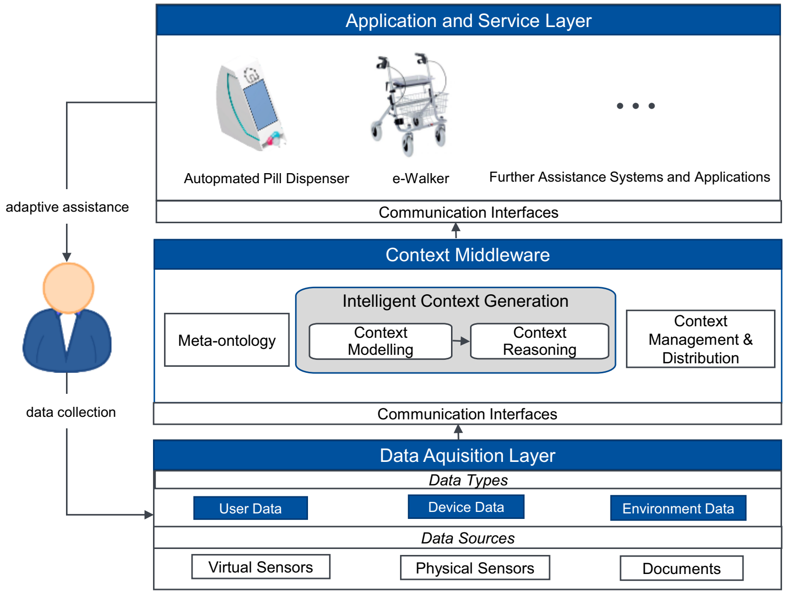

Figure 1. Context Middleware

1.1. Data Acquisition Layer

The data acquisition layer is the base layer of the system at hand and is responsible for acquiring heterogeneous data and pre-processing it for the context-middleware. It can be regarded as the perceiving part of an intelligent automation system. As incoming data differs in type, source and frequency, a pre-filtration and categorization based on these factors is necessary. We consider user related data as follows: The main three data categories are User, Environment and Systems/Devices. A user is always located within an environment and uses systems, which can be assistance systems but also connected home appliances. Each category has sub-categories further describing the entity, such as the user's activity and medication profile. Categorized data can be mapped to different data sources such as virtual sensors, health wearables as well as environmental sensors, which are registered by the data acquisition layer and managed by their IP addresses. Each computing unit with its connected sensors manages the storage and filtration of sensor data logs by removing outliers and validating sensor readings and annotating the data according to the categories using a modeling format such as SenML. Structured data can be sent using a lightweight and neutral format such as JSON. The data acquisition layer provides interfaces to request data from registered sources based the data types they provide via communication interfaces. Through this subscription, the data acquisition layer regularly requests new data and receives it formatted and semantically annotated.

1.2. Context Middleware

The context middleware consists of a modeling, reasoning and management module.

Context Modeling denotes the process of relating incoming data to the user by representing them in a unified model. A shared conceptualization is needed, where the entity is described as well as its relations to other entities within an environment over time. Ontologies represent a powerful and widely accepted method for representing context [14]. Entities such as the user, environment and assistance systems are modeled as classes with their respective attributes and sub-classes. Relations and properties are used to describe how the entities relate to each other. An expressive ontology can be represented using web ontology language, where classes and relations are described and reasoned over using Description Logic (DL). For continuously modeling the user's context from registered data sources for assistance systems, an instance of the meta-ontology is periodically created with the current user's context from data sent to the middleware. To validate the created instance, ontological reasoning and consistency check rules are applied to validate properties and relations against the meta-ontology and possibly update it with new axioms.

Context Reasoning represents a core module of the middleware as it is responsible for inferring higher level context and gaining knowledge about the user for adaptive assistance. An example of higher-level context is inferring that a user is taking his medication at home from elementary context information such as his current environment, where a pill dispenser is placed and at the time of a confirmed alarm.

As ontologies are used, ontological reasoning can be applied on the created model. However, applying ontological reasoning only is limited by the offerings of DL. Learning from context model instances can be further enhanced using additional reasoning methods, which can be selected based on the complexity of the modeled context. Rule and case-based reasoning define specific rules and pre-defined cases to infer specific situation, whereas probabilistic approaches for co-occurrence and relation analysis present a viable approach to deal with increasingly dynamic and unforeseen situations and the uncertainty that accompanies them. Hybrid reasoning approaches are suitable for combining several learning methods and benefiting from their respective advantages while compensating the drawbacks [15]. When defining the meta-ontology, a rule-set can be included, specifying elementary situations. In order to learn from historic context, machine-learning algorithms can be applied to analyze the progression of events, correlate them, detect patterns as well as anomalies in the user's behavior. A user's daily activities can then be correlated to his corresponding vital signs over a long period of time while using other context information such as his medical profile.

Context Management and Distribution is another module within the middleware, which stores knowledge in a semantic repository based on the meta-ontology and the model instances to enable knowledge provisioning to applications via the middleware interfaces. Compared to the typical relational database, semantic repositories allow for flexibility when querying and accessing stored data.

1.3. Application and Service Layer

The application and service layer can cover various assistance systems and other interfaces to medical services. Generated knowledge is made available to them based on a subscription principle in a scalable manner, as they are registered on the middleware. A service for example can subscribe to the user's activity or vitals and receives contextualized data, i.e. further related context information, in which the user's activities or vitals were recorded. Applications have their own internal intelligent algorithms to trigger actions and adjust their services accordingly.

1.4. Concluding Remarks to the System Design

The design of the context middleware provides flexibility and extensibility by acquiring variable data from remotely located sources and connecting multiple assistance systems, therefore enabling a more user-centered and improved assistance. Various applications can access inferred knowledge in a scalable manner, making it reusable. Privacy concerns around user data can be addressed within the middleware by imposing role-based access to the context model. Moreover, processing acquired data can be achieved by local servers or on cloud servers offering reliable security mechanisms.

2. Use Case: Supporting Medication Adherence

To show the applicability of the proposed system and demonstrate aspects of its technical realization, the use case of supporting medication adherence is discussed considering the constellation of a user and an automated pill dispenser within an environment. Each of these physical entities are described in the meta-ontology with their relations. As data sources, a smartwatch and a pill dispenser developed in a previous research work [16] are applied to provide information about the user's profile, his activity, vital signs as well as his medication information. The Medication Intake Behavior entity can be modeled from the stored medication take times in the pill dispenser as well as the stored alarm settings. The environment is modeled with attributes such as time, location as well as ambient characteristics via environmental sensors and a microcontroller. Figure 2 shows a simplified version of the ontology. IoT Integration Platforms, especially open and extensible ones with available common communication interfaces can be applied to build the context middleware on top. Data sources are registered on the IoT platform "home-assistant.io", on top of which, a python-based middleware is developed to create the context model based on a meta-ontology designed using neo4j. Figure 3 shows the technical constellation. Each time a new medication intake is registered, data is retrieved from the registered sources to model the user's context around that time and check it for consistency based on the meta-ontology to ensure no prohibited relations are created.

Medication Adherence Support denotes an assistance function, which can benefit from the context model and the reasoning result of the middleware. Adherence to medication is a measure of how compliant a patient is regarding medication intake. Adherence to medication among patients is characterized as being low with up to two thirds of patients not taking their medications correctly or at all. The reasons for non-adherence are multiple and can be attributed to personal or socio-economic factors. Among the personal factors are ageing-related ones such as forgetfulness. This is significant considering the increasing number of medications for elderly and the proportional relation between the numbers of prescribed medications and non-adherence [17, 18]. Using an elderly assistance system for managing and taking medications and modeling the user's context around it enables the modeling and learning of user-specific influencing factors of non-adherence in order to adapt reminder functions or generate suggestions for behavior improvement accordingly. Although there is an agreement on the definition of medication adherence, there are general and non-individualized approaches for modeling and evaluating non-adherence among patients. For modeling medication adherence, Adherence Interaction Model (AIM) was used, which generally describes a correlation between prescription, what a medical practitioner prescribes, conscription, what the patient accepts from the medical plan and description, his actual behavior [19].

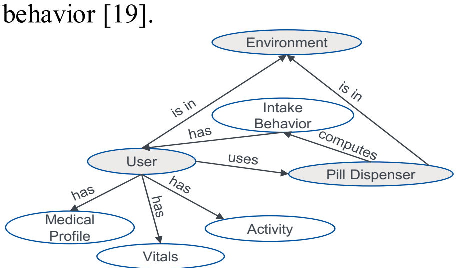

Figure 2. simplified ontology design

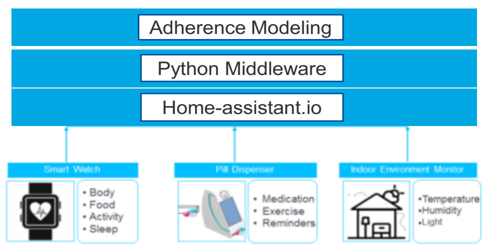

Figure 3. constellation of the middleware

Neglecting the distance between conscription and description, in the ideal case of adherence, the distance between prescription and description is zero and as the distance grows, so does non-adherence. As mentioned, the reason for the growing distance are conceptual are related to personal and lifestyle factors of patients, which can be retrieved from the learned context model. An iterative learning approach can be applied to model the individual adherence and weigh the influencing factors to non-adherence to generate user-tailored suggestions to improve his behavior it via interfaces. Simulated user data have been acquired for a week with positive results regarding the generated context model. Modeled medication intake with context information related to it can be successfully accessed by the application. Learning from the context model and weighing influencing factors to adherence is work in progress.

3. Summary and Outlook

This contribution addressed a reusable approach for AI-based elderly assistance systems. After highlighting key aspects related to cyber-physical systems, ambient assisted living and context-aware systems, a middleware-based architecture for context-awareness was shown, connecting a data layer with an assistance layer, where a pool of extensible assistance functions are placed. The concept was shown at the use case of supporting medication adherence through the iterative determination of the adherence state under consideration of personal influencing factors.

As an outlook, the currently developed middleware will be further expanded with other learning mechanisms and applications.

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