Taking Care of Elderly People with Chronic Conditions using Ambient Assisted Living technology: The ADVENT perspective

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Abstract. The population ageing trend has created an imperative need for ICT-based solutions that will support continuous care provision and help elders prolong the time they live independently in their own home environment. The ADVENT project aims at providing a comfortable, safe and secure environment to support the daily living of elders through a set of adaptive and demand-driven services. This paper presents the user and system requirements analysis results, based on which the high-level architecture of the core ADVENT system was drawn. This architecture highlights the home environment and the ambient intelligence platform, which are described in detail on a design level.

Keywords: Ambient Assisted Living, Home Monitoring, Sensor Networks

1 Introduction

Due to advancements in medicine, average life expectancy is constantly growing in the last 50 years and the elderly population is expected to grow dramatically in the near future. Without receiving sufficient care and support, elderly are at risk of losing their independence and gradually being dispossessed from the ability to carry out everyday tasks and participate in social activity, thus becoming excluded from society. Consequently, the number of people requiring care will grow accordingly. On the other hand, elderly care around the globe is already suffering from skills shortage today [1]. Without new care models, this will lead to a large under-supply of care services in many regions.

The need for support of elderly people is highly individualized and often related to specific events, thus very variable over time. Care services, instead, are nowadays usually provided according to a fixed plan, which is not always effective. Matching service provision and need for support in a more sophisticated way could make care

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much more efficient, but has not been possible in the past due to the highly complex and dynamic nature of elderly care.

New technologies such as ambient home monitoring systems with automatic situation recognition together with mobile ICT solutions offer the possibility to completely change the way in which support for elderly people is being provided – from services provided according to fixed time-schedule to demand-driven assistance. This may improve a broad range of services from household services for independent living to highly specialized ambulatory palliative care. In this context, the ADVENT project aims at the development of an ICT system and associated service models for adaptive, demand-driven services for elderly care that provide enhanced in-house comfort, security and safety using advanced sensorial and wireless networking technologies.

The proposed system offers an intelligent platform for coordination and workflow management for care companies that create integrated care networks. Low priority events that can be automated will be supported through automatic detection by an integrated sensorial network that will be able to autonomously, accurately and immediately react to a variety of triggering events to enhance the living quality experience inside habitant area without outside intervention. High priority events, such as responding to an emergency call, unexpected bio-sensory data sequences or medication management will be provided through hybrid in-home / cloud care technology solutions alerting the caring company, which means help is always at hand. The ADVENT system targets at the remotely provisioning of high quality care services as well as autonomous operation aiming to maximize comfort and security and it complements in-home care services with around the clock monitoring so beneficiaries know that assistance is any time available.

2 User requirements analysis

A scenarios-based development process was selected for gathering requirements for the design and development of the ADVENT system and services. The conducted process aimed at identifying functional and non-functional requirements, including operational system parameters and constraints. In order to ensure the practical applicability of the ADVENT platform, a comprehensive analysis of care giving scenarios between potential beneficiaries was realized by Frontida Zois, a home care company that is partner of the project. The main concern was to decide the detailed directions that the added-value services should focus in order to primarily support the elders and healthcare professionals' needs. The analysis measured the importance of each feature in order to ensure system usability, reliability and responsiveness in a wide range of eventualities.

The requirements analysis revealed that there exist three main categories of elders that should be targeted. The first category are individuals that do not have a known chronic disease but prefer to live alone, have some minor kinetic problems due to age and would like to be supported sparsely both in their house and outside. The second category is persons which in addition to the requirements of the first category, have a known chronic disease, like cardiac problems and should be monitored by biosensors around the clock. The third category is elders that have both health and kinetic problems, mainly stay at home and require full support for their daily living.

The above process helped us provide a detailed Use Case Diagram (Figure 1) and decide on a set of services that should be offered to the ADVENT system's end users. One non-functional requirement was that the system should be able to provide 24/7 support. This requirement was observed during extensive talks with elders and caregivers, as in the current operational state, where care givers stay with elders at home, the absence of support, even for short time periods, lead to extensive stress. Supportively, safety matters like unregulated temperature conditions for patient with breathing or heart problems can be automated and monitored systematically by sensorial systems. Temperature, lighting and humidity control as well as multi-parametric house monitoring that will enable accident preventions such as fire or gas leakage are required to create a holistic approach for assessing the overall condition of the elders. Finally, the analysis revealed that a baseline set of services, like timely usage of prescribed medication or an automated calendar that reminds elders of medical appointments can help both elders and caring companies optimize the support lifecycle.

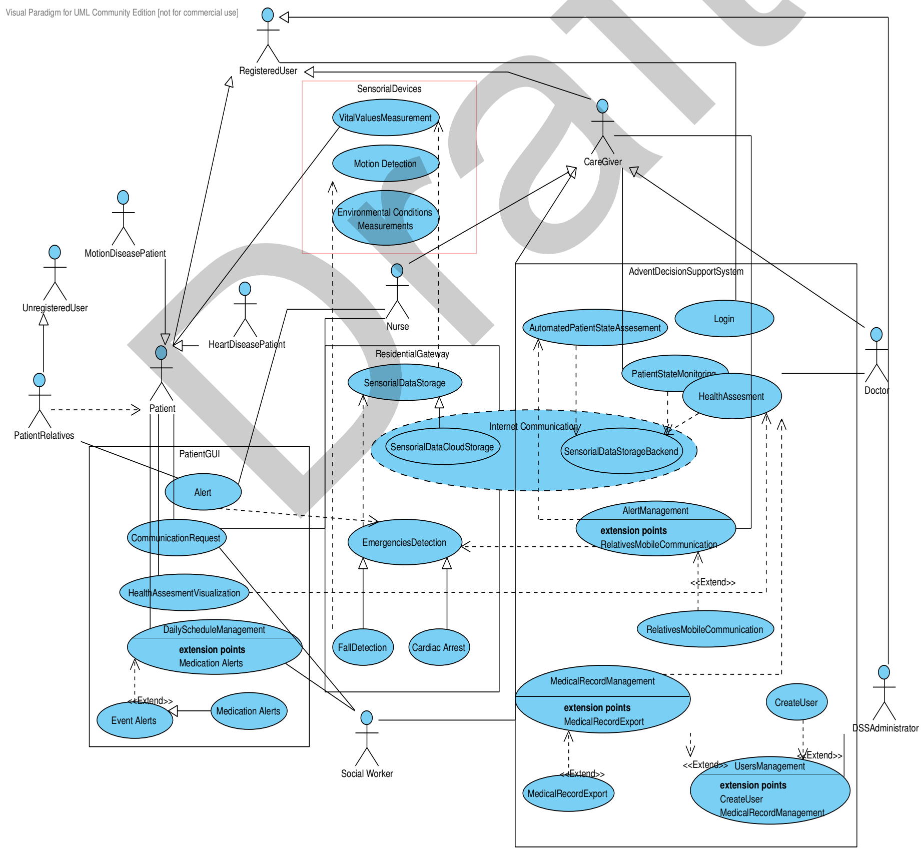

Fig. 1. ADVENT Requirements Use Case Diagram

3 System architecture

The user and system requirement analysis paved the ground towards determining the core ADVENT system architecture that is shown in Figure 1 in a top-level view. Two major building blocks are distinguished: the home environment and the Ambient Intelligence Platform (AmIP). Each building block consists of several components that provide distinct functionalities for the provision of a coherent set of personalized services both to elders and their caregivers.

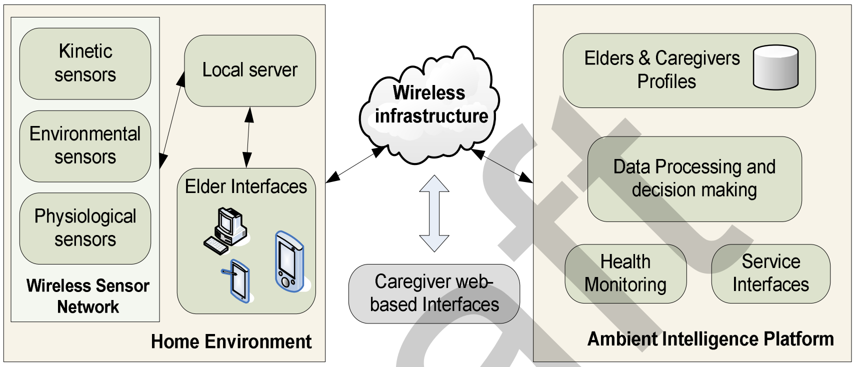

Fig. 2. ADVENT system architecture block diagram

The left building block of Figure 1 includes the Wireless Sensor Network, the local server and the elder interfaces. The wireless sensor network involves various heterogeneous sensing devices:

- On-body sensors the that provide physiological signals, such as electrocardiograph (ECG), blood pressure and oxygen saturation, as well as kinetic parameters aiming to determine potential falls.
- Environmental sensors providing ambient information, such as temperature, air-pressure and luminosity.

The local server is responsible of handling the sensor registration (type and number of sensors), initialization (e.g. specify sampling frequency), customization (e.g. run user specific calibration or user specific signal processing procedure upload), as well as the dynamical configuration of the sensor network according to the services needs. It collects all readings from sensing devices, pre-processes them (e.g. for removal of noise and deduction of redundant data) and transmits them to the AmIP for further processing and archiving. Furthermore, it has the responsibility to communicate the actions that must be performed by the system in the home environment. The local server also provides specially designed interfaces to the elders through which they interact with the system receiving service content and providing their feedback whenever this is required.

The AmIP hosts the elders and caregivers user profiles that contain various types of information, such as personal (e.g. preferences) and health-related (e.g. physiological thresholds indicating anomalies, health status history) data. Moreover, it processes the acquired information from the local server, in order to reason over the current overall status of the elder, performs decision making according to the identified status by determining the actions that should be performed based on predefined care plans, provides feedback to authorized persons for caregiving purposes and performs service personalization to tailor the offered services to the current needs and preferences of the users. It also includes the caregiver interfaces facilitating service content visualization, such as current health status and progress of the elders, as well as feedback provisioning and care plan administration. Finally, the AmIP provides service interfaces (APIs) that enable service delivery to the users and allow 3rd party service providers to integrate their services into the ADVENT system.

4 Home environment

Monitoring biosignals and environmental parameters of elderly people, especially when considering chronic conditions for extended periods of time, through an efficient and flexible system, comprises a very sensitive and delicate task. Consequently, various challenges are posed that must be tackled by the design of the system that will be deployed in the home environment of the elder. Addressing these challenges effectively influences the architecture of the implemented network in the home environment, as well as the architecture of the ADVENT system as a whole. This section aims at exposing the main challenges concerning the home environment and respective choices made in the context of ADVENT.

Probably the most fundamental characteristic that the home environment network must have is non-instructiveness, in order to bring as less discomfort as possible to the elder. This is even more important to the scenarios ADVENT project focuses on, since elderly people tend to be more sensitive and less tolerant of sensors in the home environment. Size is of cornerstone importance in this matter and advancements in miniaturization of sensors and wireless network nodes are essential to this end. It is noted that size drastically affects the degree of obstruction when envisioning environmental parameters (e.g. temperature, air-pressure, open window-door detection sensors) that must be as "invisible" as possible in the surrounding environment, but it is of critical importance as well when considering sensors that must be constantly in direct contact with the user (e.g. biosensors, kinetic sensors). Number of sensors is also a quite significant parameter. Excessive number of sensors deployed in a small home environment may cause a feeling to the user of being watched all the time lacking of privacy. This diminishes the feeling of independence and self-reliance that are essential to the ADVENT objectives and, therefore, our focus is on implementing a small number of nodes able to acquire multiple signals. Wireless Sensor Networks (WSNs) represent one of the most active areas of networking during the last years able to meet these objectives. Indeed, miniaturization of sensors and very large scale circuits have led to a wide range of very small, smart and versatile nodes able to acquire a wide range of signals while being carried around or even been worn by the user for extended periods of time causing minimum discomfort [2-4].

Figure 2 depicts the main components of a WSN node effectively comprising its hardware architecture. Based on these components a series of design choices have been made with respect to the ADVENT's system objectives.

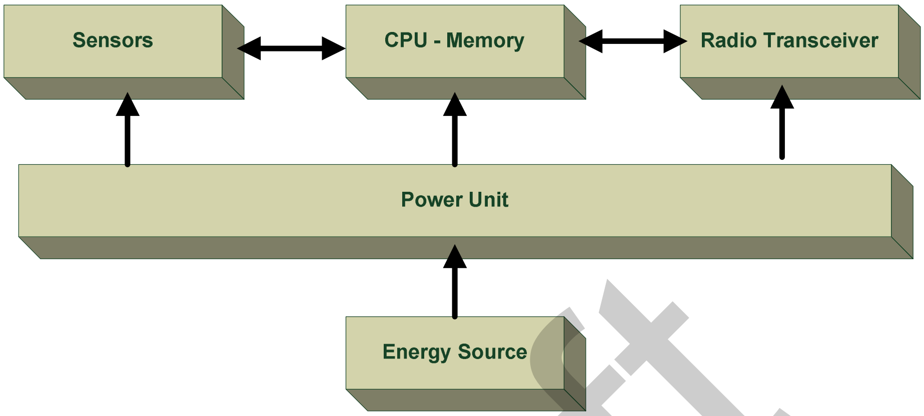

Fig. 3. Wireless Sensor Network Node's Components

Starting out the analysis from the right hand side of the figure, the "Transceiver" component is responsible for conveying data from and towards the node. To this end, the ADVENT system will rely on dominant wireless transmission technologies such as IEEE 802.15.4 and Bluetooth protocols, each offering respective advantages and key characteristics. They both operate on the 2.4GHz ISM frequency band, but while IEEE 802.15.4 main concern is very low complexity and energy consumption, Bluetooth provides a more complex communication protocol offering higher communication performance with higher energy consumption (although still lower that other well-known technologies such, as IEEE 802.11). A critical (especially when highly sensitive applications are considered) difference concerns the offered bandwidth. Regarding IEEE 802.15.4 this is 250Kbps, while Bluetooth based solutions vary significantly depending both on the version of the protocol supported and even more on the specific implementation's characteristics. Therefore, concerning data rates solutions covering a wide range from 300 Kbps up to 1.5 Mbps can be found. However, IEEE 802.15.4 being connectionless oriented offers higher flexibility when multi-hop communication is required.

Aiming to be as power conservative as possible, affordable and very small in size, WSN nodes processing capabilities rely on Micro Controller Units (MCUs) of significantly limited resources. Consequently, the ADVENT home environment will also be based on such MCUs widely used in typical WSN platforms. One such dominant solution is the Texas Instrument MSP430 MCU based on a 16bit RISC architecture offering very low power consumption performance since in active mode it draws 1.8mA while in sleep only 5.1μA. Of course such MCUs offer limited processing capabilities at frequencies of few tens of MHz and available program and RAM memory equal to 48KBytes and 10KBytes respectively [5,6]. ATMEL's AVR MCUs also comprise a frequently used solution of WSN networks. Relying on 8bit RISC architecture offer competitive operating frequencies and adequate memory to support WSN applications and software stacks [7]. Another critical characteristic of such MCUs is the support of adequate number as well as of appropriate resolution ADCs in order to integrate multiple sensors which comprise the left hand side component of Figure 2.

In the context of ADVENT, a wide range of different and diverse types of data (representing respective sensors) are supported. Biosignals are of critical importance for elderly people with chronic conditions and ECG comprises probably the most fundamental monitoring signal. Additionally and complementary to it, blood pressure and oxygen saturation related data provide further information allowing to make more fine grained and accurate monitoring, as well as emergencies detection. On the other hand, one of the most frequent reasons of injuries concerning elderly people is falling incidences. For this reason, ADVENT focuses on rapidly and accurately detecting such cases and taking appropriate actions based on accelerometer and gyro signals. Furthermore, several other characteristics of elders are considered and addressed, such as increased tendency to forget and uneasiness in moving around even within their home environment. Therefore, environmental sensors will be monitoring various parameters such as temperature, air-pressure, light, open window-door indicators, aiming to notify elders and caregivers of predefined abnormal situations.

Another critical component upon which the operation of all others depends, is the "power generation" which typical in WSN nodes is a small rechargeable battery. As seen in figure 1 each component is powered from a common energy source and thus, the aggregate power consumption of the sensors rather than the individual power consumption is the most important aspect. Indicatively, a WSN node can base its operation on small capacity batteries ranging from 450mAh up to 2AA batteries offering ~3300mAh. Extending the lifetime of a WSN node is very important with respect to the application requirements. Therefore, in the ADVENT project considerable effort is devoted upon methods and techniques minimizing the power wastage as well as selecting appropriate energy sources to meet the users' demands.

All the above concern hardware design characteristics of the nodes comprising the ADVENT home environment. However, being a research project ADVENT also led to important considerations as far as software design and development is concerned. In order to be able to study, evaluate and extended the performance and behavior of the home environment, it is crucial that home environment WSN nodes follow the open source paradigm. In that respect, all the software stack will be available enabling researchers and engineers to enhance, modify and extend its functionality as required. One the most well-known open source environment is the TinyOS operating system upon which numerous dominant WSN platforms are based [8]. TinyOS a flexible application specific operating system supporting concurrent execution of multiple programs though efficient scheduling while retaining a very small code footprint making ideal for low memory embedded systems such as WSN nodes. Figure 3 illustrates a high level architecture of a TinyOS based software stack.

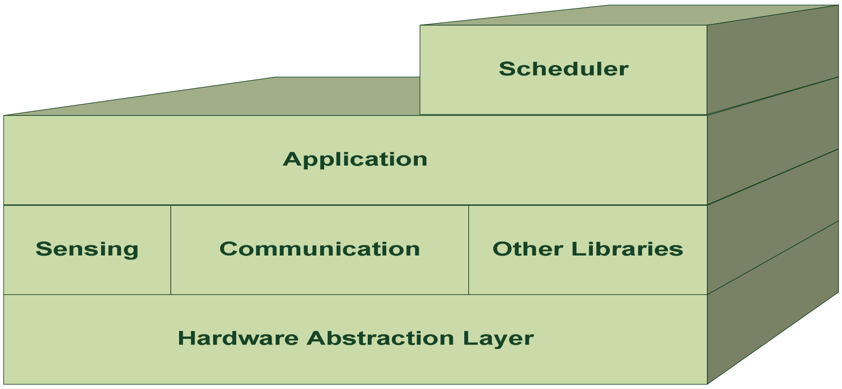

Fig. 4. A high level TinyOS based Software Stack Architecture

As indicated previously TinyOS is application specific, while an application comprises by a number of tasks and events. Events have higher priority and can preempt tasks or other events when enabled while tasks cannot preempt each other. Scheduler is a simple FIFO with limited number of tasks. When in "idle" state scheduler can shutdown contributing the power conservation. Through appropriate interfaces specific components related to acquiring monitored signals (i.e. Sensing component), transferring data through appropriate interfaces such as the wireless transceiver or a serial port (i.e. Communication component) and any other specific functionality, can be accessed. Another very powerful characteristic of TinyOS is the Hardware Abstraction Layer enabling to access a wide range of different hardware component though a unified interface thus increasing flexibility and limiting the needed for additional code for each specific device.

For ADVENT such an environment is adequate to enhance the efficiency of a node through various ways. On one hand, fall detection algorithms can be evaluated and a node will not have to steam continuous data of respective sensors (e.g. accelerometer), but only when an incident is identified. Such behavior could lead to drastic power conservations (assuming radio can be turned off when not used) as well as wireless channel bandwidth boost. On the other hand, data to be transmitted could be compressed on the sensor before actually transmitted also contributing significantly to performance enhancement. Finally, communication related evaluation concerning critical metrics such as throughput, delay and node lifetime can be carried with high accuracy. Such study is quite significant since the underlying communication channel must be able to convey the aggregated data workload without losses and in specific time constrained limits.

5 Ambient Intelligence Platform

The Ambient Intelligence Platform provides the core functionality of the ADVENT system for the delivery of differentiated types of Ambient Assisted Living (AAL) services. Driven by the user requirements analysis we concluded in three generic service packages aiming to provide an integrated solution to support the daily living of elders with chronic conditions:

1. Telemonitoring of physiological and environmental parameters and continuous assessment of the elder's overall status.
2. Decision support and feedback provisioning in case of emergencies (e.g. fall)
3. Notifications and reminders for several user-defined subjects (e.g. medication)

There exist several approaches regarding both the platforms used for service deployment and the involved software components in similar AAL systems. For instance, a widely adopted solution is the OSGi service platform [9], which offers a standardized, component-oriented, computing environment for networked services. Its main characteristic is that it delivers a common platform for service providers, content providers, software and hardware developers to deploy, integrate and manage services to a wide range of environments in a coordinated way. Another common practice is the use of web-based platforms [10]. ADVENT will adopt the later aiming to develop an open and standardized approach for communication and interaction of software components through web services, as well as to address heterogeneity and achieve interoperability between applications running in different devices and frameworks.

Regarding the software components an AAL middleware should have, these vary according to the developed system's requirements, limitations and objectives. In the context of ADVENT, we identified a primary group of components that will provide the required functionality for the effective realization of the aforementioned service packages. These span from the local server to the AmIP and are shown Figure 4, which illustrates the high level architecture of the ADVENT middleware.

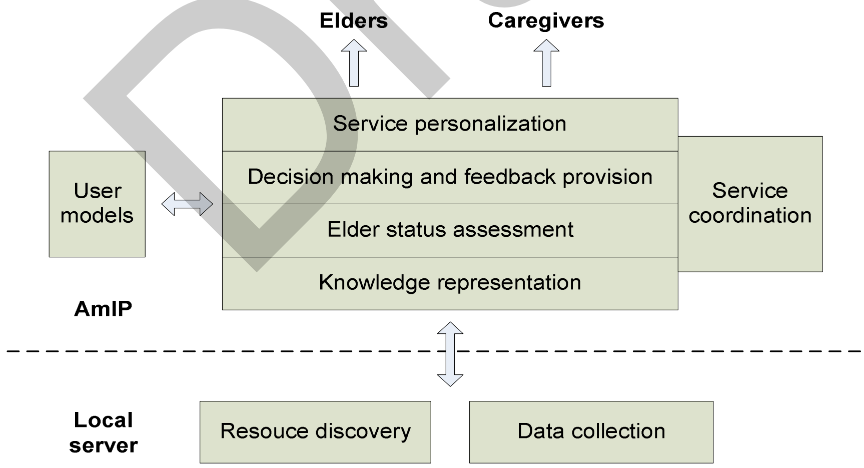

Fig. 5. ADVENT middleware high-level architecture

The *resource discovery* and *data collection* components are located at the local server and are responsible for managing sensing devices and provided data. Resource discovery is responsible of monitoring the entering/leaving of sensing devices in the local server's proximity. To achieve this a sensor registry is maintained that hosts information that describes each device, such as device communication protocol, information type it provides (e.g. location) and device address. This process offers the necessary scalability flexibility to the ADVENT middleware so that various sensing devices can be integrated during runtime in a seamless and transparent fashion. Furthermore, data collection deals with scheduling data acquisition allocating corresponding timers and pointers triggering data provision and includes the required APIs for data aggregation from sensors operating under different communication paradigms. It also administers data acquisition and their pre-processing and transmits them to the AmIP.

On the AmIP's side the main data processing is performed that involves the software components described below. The *knowledge representation* is crucial for systems that utilize diverse data from heterogeneous sources. It allows expressing acquired information in a semantic level and creates a unified vocabulary in a structured and organized form. There are several approaches to modeling contextual information acquired from various types of sensors, but especially in the healthcare domain the most widely used approach is ontologies. Ontologies offer many benefits against other solutions since they facilitate knowledge reuse and sharing among system components and count classes, inheritance, relationships between classes and instances as some of their major components. The ability to reason over relationships defined in an ontology and, therefore, relate instances to their abstracted types is the primary benefit of using ontologies.

In ADVENT we will develop a knowledge representation module based on ontologies [11], which will involve the systematic representation and processing of the elders' records, health condition and contextual information. Our aim is to develop the following ontologies: (a) Healthcare domain ontologies to encode health-related information, (b) Service ontologies to describe the services offered by the system; Youpi, a semantically-rich extension of UPnP service description will be used, (c) Ontology alignments to serve in matching heterogeneous domain and service ontologies; an attempt to use existing third party ontologies, such as WordNet [12]will be made and (d) Policies to encode decision making and privacy enforcement policies.

Elder status assessment realizes an inference process regarding the current overall status of the elder in a reactive manner. During this process low-level data directly acquired from sensors are transformed to high-level meaningful information that depicts the situation the elder is in. The term overall status is used due to the fact that in ADVENT we have three types of statuses concerning the elder: health, kinetic and environmental status. All are assessed by the same component either simultaneously or independently, but each of them has its own specific inference policies and action schemas. This reasoning process has been addressed by various approaches, such as rule-based and case-based reasoning, data mining techniques (e.g. bayesian networks) [13] and ontology-based reasoning [14]. In the context of ADVENT, several data mining algorithms and ontology-based reasoning will be examined to find the most suitable solution with regard to the project's scope and objectives.

Decision making and feedback provisioning utilizes information stemming from the elder status assessment component to define the actions that have to be performed according to the identified elder status. The action plan ranges from simple archiving when the elder's status is normal to alerting authorized caregivers to intervene and offer predefined types of treatment in case of worrying situations and emergencies. For the purpose of this process, we plan to implement rule-based algorithms [15], while exploiting ontologies' reasoning potentials. The decision making process will be based on strict policies set by expertized medical staff following the medical protocol. These policies will define specific situation-dependent actions aiming to provide an integral care plan that will offer to the elders the feelings of safety and security throughout their daily lives.

Service personalization aims at a customized service delivery that will adapt to the current needs, requirements and preferences of the users. Service personalization has two dimensions. The first concerns the service content and the second the way the service will be presented to the user depending on time, location, surroundings and the access device. It is closely related with the user modeling process through which a user's information is represented electronically in a structured way. We consider several types of information the user models will host, such as health, personal, contextual, service-related and application specific data. Due to the fact static user models may fail to represent the actual user preferences in a temporal span, we are already focusing on developing dynamic user models which will be both implicitly evolving through processed context information and explicitly updating through user feedback.

Finally, *service coordination* is responsible of managing and orchestrating the interaction among the software components employed in the ADVENT middleware. Such interaction is essential for efficient service delivery, since each service is based on the smooth cooperation of various components. In addition, as the system evolves several new components may appear in its environment and through the service coordination these can be integrated to serve hybrid architectures for added value service provisioning. For this reason, this component includes specific APIs that allow third party service providers to use ADVENT as a bridge to offer their services.

6 Discussion

In this paper, we presented an overview of the requirements analysis that served as the basis for creating the generic ADVENT system architecture, which consists of two major parts: the home environment and the ambient intelligence platform. We further analyzed the main design and implementation details of the key components of these parts, which are expected to undergo several modifications throughout the next phases of the ADVENT project, since it is still in its design phase

The next steps, in the ADVENT project, are to make individual subsystem and interoperability tests and deploy the sensorial networks to pilot users, providing feedback for the applicability of the installation to support the required services.

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