The GAL Middleware Platform for AAL

A Case Study

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Abstract—**GAL, the Lower Saxony Research Network Design of Environments for Ageing, investigates how information and communication technology can provide for better environments for ageing. This paper describes a service oriented middleware platform for Ambient Assisted Living and its use in a number of different assistive systems developed in the GAL project: personal activity and household assistant, monitoring of preventive and rehabilitation sports, sensor-based activity determination, and sensor-based fall prevention and recognition. Besides a detailed description of the middleware platform and its elements and interfaces, central infrastructure services and their particularly applications in the different use cases are presented.**

Keywords-AAL; middleware; service oriented architecture; OSGi

I. INTRODUCTION

Most industrial societies are currently undergoing a significant change of their demographic structure, often subsumed under the term “aging society”. This development leads to new challenges for the provisioning of healthcare and elderly care, two sectors that are already under significant financial pressure in many countries. In response to these challenges, structural changes in the healthcare sector will be necessary, such as an increased focus on disease prevention, organizational structures that allow for an improved management of chronic diseases, a shift from stationary towards ambulatory care and, finally, new forms of care. One important field of research and development in this regard is Ambient Assisted Living (AAL), which can be defined as concepts, products and services supporting a healthy and independent life of elderly citizens with “intelligent” systems that assist them in carrying out their daily activities. AAL encompasses a wide range of applications ranging from a “classical” tele-monitoring of vital parameters for patients with chronic diseases to scenarios involving home automation and domotics (for example the generation of a warning message when the habitant leaves the home while the cooker is still switched on), the recognition of adverse events such as a fall causing a fracture, or specific assistance systems for people with hearing or vision deficits.

In it's most basic form, an AAL system is comprised of a set of sensors (either carried by the user or integrated into the home environment), a central or distributed processing module that receives and processes the sensory input and determines the actions needed, and some kind of actuator, which, depending on the system's purpose, may be anything from controlling building automation components, adjusting music or television to the user's needs, to telecommunication tasks such as raising an alarm if an emergency situation was detected.

While the development of sensors that are suitable either for an unobtrusive integration into existing homes or for use in a body area network still poses many research challenges, in particular related to power supply, battery lifetime and wireless networking, it is clear that at the heart of system development of AAL assistive technology lies the development of the logic that processes sensory data and determines the system's actions, taking into account context information such as the layout and furnishing of the home, user preferences and, for example, information about the user's health status and specific risks. This application logic is typically implemented in software, whether in a centralized or in a distributed manner.

In order to ease the task of developing the logic of an AAL system, various projects have developed middleware software platforms that provide reusable building blocks that the application logic will need as infrastructure, such as connecting to sensors and actuators, persistence or the management of context information. Three different approaches to the architecture of such AAL middleware systems can be distinguished: a) agent based systems such as OASIS [1], b) event and dataflow based systems such as PERSONA [2] and c) service oriented architectures such as SOPRANO [3]. The system described in this paper is also based on a service oriented approach and in contrast to SOPRANO it does not build upon an ontology-based architecture and semantic contracts. It is being used, in slightly different variations, in a number of AAL research projects: Hearing at Home [4], GAL [5], OSAmI [6] and PAGE [7]. This paper focuses on the assistive systems implemented within the GAL project, while most other applications are described in [8].

The Lower Saxony Research Network Design of Environments for Ageing (GAL) is an interdisciplinary research project that aims at promoting and sustaining the quality of life, health and self-sufficiency in the second half of life by identifying, improving and evaluating new applications of information and communication technology for environments for ageing. The design of a flexible middleware platform

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that is suitable for the assistive systems developed by the project and also applicable to further use cases beyond the scope of the project is just one out of multiple activities of the research network. In section II, the architecture of this middleware platform will be described and in section III, its use within the project's various assistive systems is outlined. A discussion of lessons learned and an outlook to future steps will be given within the conclusion of the paper in section IV.

II. GAL MIDDLEWARE PLATFORM

A. Architecture Overview

In Figure 1 the GAL Platform Architecture is shown: The hardware platform provides physical interfaces for different attached sensors, actuators and communication techniques. An operating system provides hardware drivers for the different interfaces and is the basis for the OSGi Service Platform which is running in a JAVA virtual machine.

Many different sensors and actuators are connected to the platform via various different interfaces, e.g.:

- Home automation devices like IR-sensors, reed contacts, and normal switches, outlets via KNX, EIB or LON.
- Ultrasonic sensors for localization via I²C.
- Microphones for localization and user interaction via sound cards (internal and USB).
- Cameras with image recognition via Ethernet and FireWire (IEEE 1394).
- "Intelligent" white goods, like cooker, fridge or oven, connected via PowerLine and proprietary protocols.
- A wireless Body-Area Network with sensors for measuring vital parameters like electrocardiogram (ECG), heart rate, oxygen saturation, blood pressure, breathing rate and temperature, transmitted via IEEE 802.15.4.

For every attached sensor, actuator and any other device a representation inside the OSGi Service Platform has been designed and implemented. These representations presume specific and working operating system drivers which in most cases are integrated in the OS or in some cases (e.g. BAN over IEEE802.15.4) have been developed within the GAL project as well.

Most parts of the functionality are realized through so called bundles developed for the OSGi Service Platform. This service oriented architecture allows for and simplifies managing, updating and exchanging components during system runtime and solving dependencies between different bundles and versions. Within this very modular platform the software development can be done in various and flexible ways, which is very helpful for a distributed project like GAL. An even higher degree of modularity and reusability is achieved by introducing an additional abstraction layer: This layer allows that different sensors from different manufacturers can be applied. These sensors typically measure similar dimensions in various ways, yet, these particularities are not relevant to the specific applications: E.g. an application for monitoring rehabilitation sports is not interested in handling different and vendor specific data sets for an ergometer, but in generic data sets. Therefore, the abstraction layer delivers a standardized set of values for the application – not depending on vendor specific interfaces and data structures and only consisting of the needed values.

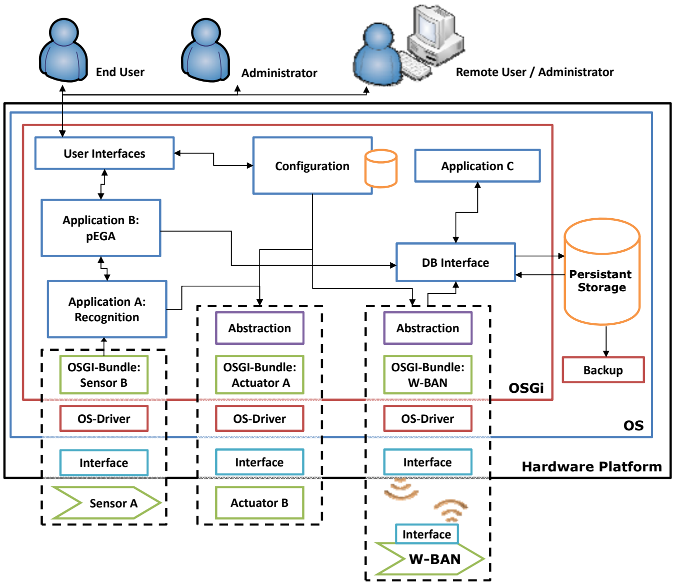

Figure 1. GAL Middleware Platform Architecture

Another part of our abstraction layer supports localization issues: Different sensors like cameras, IR detectors, ultrasonic sensors, microphones and even simple door contacts and light switches can be used to determine a person's whereabouts. Abstracting and combining this information in a probability-weighted map results in an easy and all-around usable interface for localization data.

An important factor for a middleware platform that is used by multiple development teams in parallel is the definition of a software development tool chain that permits updates and new services to be integrated and tested easily. For the GAL middleware platform we have settled on Eclipse as the development environment and on Apache Maven [9] with the Pax plugin [10] as the build system. While Maven requires a significant learning curve from developers, it also provides for an automation of many tasks such as the generation of the OSGi bundle manifests (metadata), and the distribution and deployment of new bundles in binary form. Furthermore, a virtual machine containing the complete execution Linux based environment helps with testing new software.

The core of the GAL middleware platform is written in the Java language, and is as such fairly platform independent. The underlying OSGi environment is available for the Java Micro Edition, which is available for many embedded systems. While our current main platform is a "conventional" x86 PC using a Debian Linux derivative with real-time kernel, the platform has been used successfully on different Linux kernels and also ported to Microsoft Windows. Such a port, of course, requires modifications wherever a service connects to a native operating system driver API that is different on the respective target operating system. Furthermore, ports to embedded platforms, which we perceive as the real target execution platform for product-level AAL systems, are in progress, both to a small office / home office router [11] and to a set-top box for digital TV [12]. One limitation we have observed is that while Java runtime environments are available for many embedded platforms, the language version supported differs – Java 1.5 or 1.6 is often not available for embedded platforms, and the Java bytecode generated for one language version requires a corresponding or newer runtime.

B. Infrastructure Services

In a service oriented design, much of the "infrastructure" provided by the middleware platform comes in the form of services registered in the system that can be discovered and invoked by application modules. These services are intended to provide essential, re-usable building blocks needed in many different AAL applications. Below we will describe the most important services offered by the GAL middleware platform.

1) Recognition of Events

One important use case for AAL assistant systems is the recognition of adverse events such as a fall after which the inhabitant is unable to stand up, or behavioral changes indicating an increased need of care. When such an event is detected, the relevant information needs to be communicated to external users to enable a timely intervention or to provide early warning. For this purpose the GAL platform offers a flexible *"alarm service"* for communicating messages from the home environment of elderly people to external users utilizing different communication channels: telephone, fax, short message service (SMS) and e-mail [13]. Communication channels and recipients are selected based on the urgency of the message – for a report indicating a change of behavior over time, an e-mail that might be seen by the recipient only at the next working day is appropriate, whereas a recognized fall event, of course, requires immediate action.

One important issue to be addressed is the fact that it is not sufficient to just send out an e-mail or SMS or to call a certain telephone number and play back a pre-recorded message: the SMS or fax document may remain unread for a long time, and the telephone call might be taken by an answering machine. A confirmation by a human recipient, indicating that the message has been understood and action will be taken, is needed. Therefore, the alarm service includes a hyperlink in outgoing e-mails, with a text indicating that this link should be "clicked" to indicate receipt of the message. For all other communication channels, a phone number and PIN code are transmitted, and incoming phone calls are accepted by a voice box system matching the PIN number to the message sent. If no confirmation is received within a user-defined period, the message is escalated to the next recipient in a list. For example, a report about a fall event might first be communicated to a neighbor, then to a friend living in the vicinity of the house and being equipped with a key, and finally, if all other fails, to an emergency service.

Another aspect an alarm system needs to address is the limited availability of the underlying communication media. Most providers of telephony services in Germany only guarantee an average availability of 95-97%, and the same applies to cell phone networks. This means that the telephony network might be unavailable for a period of multiple days, which, although a rare event, would be fatal if it would cause an urgent alarm not to be forwarded. Our alarm system, therefore, supports two independent communication channels (GSM/UMTS and ISDN/DSL), which means that alarms can be forwarded even if one channel fails. This significantly reduces the likelihood of communication failure at the expense of an increased complexity of implementation and additional hardware requirements but seems worthwhile for a system on which, when used in real-life scenarios, human lives might depend.

2) Persistent Storage

The persistent storage of data is an important infrastructure service. Besides storing configuration data and system settings in a durable way, there is a necessity to store measured values and recorded events by many applications. Most of the sensors just gather raw-data with no or just little context information; after combination, data fusion and data processing these low-level values can be aggregated to valuable high-level information. Such processing mostly does not only take current data into account, but also performs a view on historic values, whereas "historic" can be anything from "one second ago" to "many years ago", depending on the application. Ideally a database is used to support and simplify the data access, hence, we applied this in our middleware.

Within the various work packages many different types of data must be stored in this database: This can range, e.g., from high-frequent raw-values (e.g. three values and a timestamp at 500 Hz from the ECG) on the one hand, to audio files in a much lower frequency on the other hand. There are several reasons not to integrate the database into OSGi, but performance, standard conformity and SQL-accessibility are among the most important. The OSGi database interface implements two different (but concurrently usable) ways to access the database:

- The object oriented "Dynamic EclipseLink JPA Service" provides a further abstraction, handles objects and is not depending on the underlying database.
- The "Plain SQL Service" passes SQL-queries to the database and thus allows arbitrarily complex queries (depending on the functionality the database provides)

3) Backup

Not only measured vital parameters and detected activities are stored over time, also individual settings and the current state of self learning algorithms are worth to persist. Unfortunately, many situations can occur where data loss might happen. Starting with unintentional deletion, file system errors and harddisk head crashes through to external effects like fire or theft. A central backup service takes care of all stored data: Besides periodic local database backups there is also a connection to external storage-providers where encrypted backups are deposited via a secured internet connection.

4) *Personal Electronic Health Record (pEGA)*

All important personal data is stored inside the Personal Electronic Health Record in a specified and structured way. Events like a detected fall or a recorded ECG are as well included as prescribed medication, results from medical examination, training reports from exercise training and training parameters. As it is intended to strictly keep all personal data private, a rigorous but promising approach is chosen: All this data is stored inside the GAL middleware platform at a person's home and is transmitted to outside places in encrypted form only.

The owner can assign permissions to others (e.g. an attending physician or a related person), but retains control of all private data. This automatically leads to different perceptions for all involved parties, as every person only catches the sight of a specific and (for him/her) relevant part of the data. Also an exchange of information with healthcare IT is planned by using IHE standards like XDR and XPHR.

Dr. Bernd Heinzelmann (Sie selbst)
Alter: 64

Persönliche Daten
Ihre demografischen Informationen
Vorname: Dr. Bernd Heinzelmann
Nachname:
Geschlecht: ○ Keine Angaben ● Männlich ● Weiblich
Benutzerbild
Geburtstag: 7 7 1945
Straße: Hausnummer:
Stadt: PLZ:
Telefonnummer:
E-Mail Adresse:

Figure 2. pEGA: Exemplary view

Figure 2 shows an exemplary view of the administrator's web-interface of the current pEGA implementation. Different views for various roles are presently being developed and tested with regard to usability and acceptance.

III. USE CASES

In this section, the use of the GAL middleware platform within the project's various assistive systems is briefly outlined.

A. *Personal activity and household assistant*

The personal activity and household assistant (PAHA) [14] is an assistive system that maintains a calendar of events (social contacts, meals, appointments, health related activities such as taking one's medication, sports activity, household, etc.) for the user and provides unobtrusive reminders and information to the user using multi-modal user interfaces (sound, light, vibration, but also speech and graphic displays). The system can be controlled with voice commands. Notifications are conveyed to the user in a two-level approach: At the first level, an ambient reminder (light, sound or vibration) is played, depending on the user's preferences and context information such as the user's current location and the time of day. At the user's request, additional information is provided either using audio output, or as conventional graphic display either on a monitor or on a TV set.

From a platform perspective, the PAHA makes intensive use of the available sensors to determine the user's current location, based on ultrasound sensors, microphones, optical sensors that are also used for a fall recognition, and the operation of electrical devices reported either via building automation protocols or recognized from the "signature" of the device in the electrical signal. The PAHA furthermore adds an additional service named "multimodal user interface" (MUI) to the platform. This service API allows for a notification of the system's user about an event or other information. The service user only needs to specify the information and its urgency, and the MUI service selects the most appropriate way of informing the user, based on context information and user preference. This service is primarily used by the calendar component, but available for use by other assistive systems as well.

B. *Monitoring of preventive and rehabilitation sports*

Monitoring of preventive and rehabilitation sports especially aims for patients with chronic obstructive pulmonary disease (COPD) and their rehabilitation. Today COPD-rehabilitation is mostly done in a controlled environment within a clinic: Patients have to follow a special training (e.g. on an ergometer) and are constantly monitored by health personnel, which are able to adjust and modify training parameters referring to the monitored vital parameters like electrocardiogram, heart rate, oxygen saturation, and breathing rate. Travelling to the hospital for some elderly people can imply much more physical stress than in the controlled environment inside the hospital during the training, especially when they travel by public transport. Safety and efficiency for the training are the primary goals, but besides that there is also a monetary demand for reducing the effort of rehabilitation. To decrease the number of hospital stays and the accompanying uncontrolled physical stress to travel there, patients shall be enabled to do their rehabilitation sports at home. This might also lead to a higher compliance as the overhead of traveling is reduced.

There are several steps to be taken to achieve such an at-home-monitoring, which – as the name misleadingly suggests – is not only a unidirectional sensing and sending of vital parameters, but also a bidirectional control communication to interfere the training session and adjust the training parameters.

First of all the infrastructure at home has to support the monitoring of vital parameters. This is done by a Wireless Body-Area-Network (W-BAN) which is connected via a radio interface to the GAL Middleware Platform. The W-BAN records data like an ECG, heart rate, oxygen saturation, blood pressure, breathing rate and temperature. For further processing this data is being transmitted to the middleware platform, whereas minor data processing can also be done within the W-BAN. Due to its very limited capacities regarding processing power, storage and energy, only simple calculations like e.g. gathering the heart rate from ECG data can be made.

The middleware platform itself prepares and processes the raw data coming from the W-BAN and provides it to the medical personnel via an internet connection. The health professional then can monitor the patient remotely and control the training parameters via a feedback channel. To achieve such a control capability, e.g. the ergometer at a person's home has to provide specific interfaces that can be used to adjust the settings and the target values of the training. In case of a detected emergency (e.g. an impending heart attack) the "normal" alarm and emergency functions of the middleware platform take care of informing the rescue workers.

In a second step the training can nearly completely be monitored by the middleware platform and even adjustments of the settings can be done automatically within certain bounds. Only deviations from normal conditions are then transmitted to the specialists who can decide how to react.

C. Sensor-based activity determination

Behavior changes of elderly persons can indicate an incipient disease, like e.g. dementia. Detecting that certain abilities become limited can help to find the right approach and the right time for an intervention by thirds.

To detect a change in behavior of an elderly person, first of all a continuous and long-time activity monitoring of that person has to take place. Such a monitoring has to be as noninvasive as possible and is surely not meant to lead to any kind of "big brother"-like scenarios. In fact, all of the monitoring and data processing has to take place inside a person's apartment, without involving any other person or transmitting any monitoring data to the outside world. Therefore many and several sensors are used and combined with a person's home.

Via IR-sensors, cameras, light barriers, ultrasonic sensors, door switches and microphones it can be determined whether a person is in a certain room and actually (more or less precise – depending on the specific sensor) where exactly a person is standing, sitting or lying. Even switching a light on or off can indicate whether a room is being left or entered. Cameras with image recognition techniques can also detect certain motion patterns, e.g. moving a hand to the mouth can indicate that the person eats or drinks. "Intelligent" white goods provide status information like which cooker's hot plate is turned on or which program the washing machine is running. Normal household aids can be monitored by using an electricity sensor that can determine which devices are currently running. Reed contacts connected to a water tap or flush can exactly state if a sink or toilet is being used. These and many more sensors are connected to the middleware platform via various interfaces.

Single sensors can deliver significant information regarding warning and alarm: A constantly switched on coffee maker or hot plate implicate a warning message to the inhabitant, detected smoke alarms the firefighters. These single datasets form single sensors which are surely fundamental, but not sufficient for an activity monitoring. How often a light has been switched on and off is not a crucial information; how often a breakfast is prepared and eaten much more.

Activity monitoring requires more and further processing of the data: Inside the platform multiple data streams are synchronized, aggregated and fused. The data fusion leads to assessed high level activities which are recorded and tagged with timestamps and stored for a longer period of time. E.g. the information that a person is in the kitchen (detected by an IR-sensor), sitting at the table (detected by an ultrasonic sensor), in the morning (detected by the system clock), combined with the additional information that the fridge has been opened at least once short time ago (detected by the "intelligent fridge") and the information that the toaster was turned on and the coffee maker still is turned on (detected by the electricity sensor) leads to a certain probability that the activity "preparing and eating breakfast" is just taking place.

Only after behavior patterns have been identified and classified, a change in behavior can be detected. E.g. when more or less than one breakfast per day is detected over a longer period of time, the condition of the monitored person possibly degrades and specific help can be requested by the monitoring system.

D. Sensor-based fall prevention and recognition

One major problem of elderly people alone at home is gravity: Age often goes along with limited mobility and increased infirmity. The risk of a fracture is very high when an elderly person falls, thus, fall prevention and fall recognition are two major GAL use cases.

Fall recognition means the automated detection of a person's fall. When no other person is there to realize that a person collapsed, sensors have to take care of that. An accelerometer, worn by the elderly person, constantly records acceleration in three axes – including acceleration due to gravity. These data is wirelessly being transmitted to the middleware platform and processed there. Fast changes in acceleration and certain patterns can relatively easy lead to the conclusion that the person wearing this sensor has collapsed. Even the position of the person's body is determinable due to changes in the direction gravity affects the sensor after the fall.

Another sensor for fall recognition is a (calibrated) camera. By combination of several image processing algorithms a fall of a person can be detected: Due to pixel movement speed, the position of the person within the area, shades and additional context ("is this a place where a person normally lays down (bed/sofa)?") fall recognition can be improved.

Also microphone arrays can be used for fall recognition when detecting a specific sound from a certain region.

No stairs, no flying cables and no skateboards are a useful precondition for preventing falls, but sensor based fall prevention is much more difficult. There are several tests developed by gerontologists that result in a value for the risk to fall by assessing the gait of a person. These tests are mostly based on observation and time measurements. E.g., a person has to stand up, walk towards a certain point, turn around and sit down again. Besides the needed time, the observer assesses the gait, e.g., whether the person limps or has a discontinuous gait.

Due to complex algorithms both, camera and accelerometer can assess a person's gait, too, within certain bounds. A calibrated camera has knowledge about which pixels belong to the floor. In this way it is able to recognize the feet of a person, and measure the time for a single step and can determine a potential asynchronism which points to problems regarding the gait. By using accelerometers, the gait of a person also can be assessed, due to irregular movement patterns when a person is walking.

When detecting a risen risk to fall, the middleware system informs healthcare professionals using the implemented methods. Possible measures are special walk-trainings to reduce the risk or the provision of walking frames.

IV. CONCLUSION

In this paper, a service oriented middleware platform for Ambient Assisted Living and its use in the various assistive systems developed in the Lower Saxony Research Network Design of Environments for Ageing (GAL) has been described. The main tasks of such a platform are the provision of a runtime execution environment for the decision support systems that make up the "core" of any AAL assistive system, the integration of the sensors and actors the platform needs to connect to, and the provision of AAL specific services as reusable building blocks, such as the alarm service, persistence, user interaction (graphical or multimodal user interfaces) etc.

OSGi with its modular, service-oriented architecture and its technical features for remote management and remote maintenance offers a good basis on which the add-on services for AAL can be implemented. Since OSGi is designed to be integrated into small and inexpensive embedded devices such as routers or set-top boxes, it provides a promising path towards a cost-efficient delivery of AAL services to the end user. The GAL middleware platform seems to perform well for the purposes of the projects. The authors believe, however, that a critical point for any AAL middleware architecture will be to establish a "community" of developers and users that can guarantee a long-term maintenance and support of the platform. It remains to be seen whether or not the GAL platform will be a success in this regard.

A. Outlook

Currently the basic platform works fairly well so far and by now we have already integrated many new interfaces and functionality. We were also able to present a set of simple (restricted in functionality) but fairly working demonstrators at this year's CeBIT in Hannover, Germany. The showcase even included a fall detection, shown with a dummy in a separate "fall area" and all demonstrator-parts were surely running the presented GAL middleware platform.

The GAL project will end in autumn 2011 and we are looking forward to present all the described Use-Cases working and interacting on the same platform – software as hardware. We are expecting good outcomes, but the results will be published to the community either way.

As Java and OSGi are very easy to port to different platforms, we think that we may have delineated an universal architecture for an integrated AAL-platform and we are expecting others to use the GAL middleware platform as well.

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