Visualization of Data for Ambient Assisted Living Services

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ABSTRACT

Ambient assisted living (AAL) services that provide support for people to remain in their homes are increasingly being used in healthcare systems around the world. Typically, these ambient assisted living services provide additional information though location-awareness, presence-awareness, and context-awareness capabilities, arising from the prolific use of telecommunications devices including sensors and actuators in the home of the person receiving care. In addition there is a need to provide abstract information, in context, to local and remote stakeholders. There are many different viewing options utilizing converged networks and the resulting explosion in data and information has resulted in a new problem, as these new ambient assisted living services struggle to convey meaningful information to different groups of end users. The article discusses visualization of data from the perspective of the needs of the differing end user groups, and discusses how algorithms are required to contextualize and convey information across location and time. In order to illustrate the issues, current work on nighttime AAL services for people with dementia is described.

INTRODUCTION

Demographic ageing is the term given to the anticipated huge increase in the number of older people in our society over subsequent generations. It is accepted that our health services cannot continue to provide hospital-based care for this growing cohort of older people. Increasing numbers of people will experience a new, evolved health service provision in their later years, which will be technologically-driven and will provide care services or access to care services in the person's own home. Such services could include, for example, activity reminders for people with mild dementia, or medication reminders for people complying with complex medication regimes.

These new ambient assisted living (AAL) services, underpinned by home-based assistive technologies offer data streams that will provide rich sources of useful knowledge about the behavior and wellbeing of people accessing care, either singly or in aggregated form. The deployed Information and Communications Technology (ICT) also facilitates new modes of interaction between the person at home, their family, carers, and other healthcare professionals involved.

The AAL services that provide support for people to remain in their homes are increasingly being used in healthcare systems around the world. Typically, these AAL services offer additional information though activity-sequence-awareness, location-awareness, presence-awareness, and context-awareness capabilities, arising from the pervasive use of telecommunications devices including processors, sensors, and actuators in the home of the person receiving care. There are many AAL endpoints now utilizing and feeding information to converged networks and the resulting explosion in data and information has resulted in a new problem. These new converged AAL services struggle to convey meaningful and timely information to divergent groups of end users, with different information needs.

In this article AAL technology and services are explained, before examples of the services in commercial systems and in academic research are explored. Visualization in AAL services is then described from the needs perspective of a person availing of the support — the care recipient — explaining how visualization must convey information across location and time. In order to illustrate the challenges for inclusive design, current research on night-time AAL services for people with dementia is then described in a case study.

User	Role
Care recipient	User of the services; needs to be able to interact with the services to gain assistance to provide feedback where needed.
Formal carers on-site	Interacts with the services in tandem with the care recipient to assess progress in care regime; interacts to add information into system, for example, to add medication reminders.
Formal carers off-site	As above for formal carers on-site but may also interact remotely to update information and interact with services that measure or provide care to more than one home.
Telecare/Telehealth remote monitors off-site	Managing remote care provision; providing care triage in decision support for interventions; monitoring relatively large numbers of care recipients.
Informal carers on-site	Accessing information on health and wellbeing of care recipient; working with care recipient to understand health and wellbeing of care recipient and communicate to care recipient.
Informal carers off-site	Remote access to monitor key information on care recipient, for example, family member concerned about quality of life of care recipient.
Technical maintenance	Deploying tools to assess quality of data being gathered, decision support, and reporting on metrics from homes of care recipients; detection of errors.

Table 1. *AAL service users and their roles.*

Defining AAL Technology and Services

Assisted living is the term given to the provision of care to people either in their own homes or in supported housing, underpinned by technology. The provision of care, augmented by assisted living technologies, is growing because of the increasing demand and also because of the maturing of many of the underlying technologies that make assisted living possible. In parallel with the development of assisted living, researchers in computing have been exploring the emerging area of ambient intelligence which applies automated reasoning and other artificial intelligence techniques to the understanding of the behavior of people in their environments.

Ambient intelligence has evolved with great pace over the past ten years, from the early beginnings when the European Commission ISTAG group presented their vision for ambient intelligence [1] to research on the many applications. Ambient intelligence applications have become more complex and are now integrated into many other systems in the home, medical and occupational environments. Ambient intelligence based systems provide feedback to users and carry out specific actions based on observed patterns and pre-programmed algorithms. Some systems are also aware of their surroundings and can function independently, offering capabilities including "sensitive, responsive, adaptive, transparent, ubiquitous, and intelligent" [2].

These two areas of assisted living and ambient intelligence are converging towards a new paradigm in social computing called Ambient Assisted Living (AAL). AAL services have benefited from advances in sensor technology, hardware, software, and communication paradigms to such an extent that AAL services have gained market penetration into the home, work and health environments. AAL may be implemented to either replace or complement the care provided by the carer. As technology becomes increasingly mobile, ubiquitous and pervasive, it is of course likely that the wider population will become beneficiaries of AAL and may lead an increasingly technology-augmented lifestyle.

AAL technologies have been outlined as technologies that may help to extend the time that older people can live at home by "increasing their autonomy and assisting them in carrying out activities of daily life" [3]. The services that AAL technologies may use include functional, activity, cognitive, intellectual, and sensory support. Examples of functions that the AAL technologies may provide include alarms to detect dangerous situations that are a threat to the user's health and safety, monitoring and continuously checking the health and well-being of the user, and the use of interactive and virtual services to help support the user. AAL technologies may also be used for communication, enabling the user to keep in touch with family, friends, and carers, and for example, in support of reminiscing.

Visualization of AAL Service Data: Users, Roles, and Examples of Use

AAL services have to support very different kinds of technologies encompassing sensors, actuators, communication hubs and interfaces. There are a number of different classes of users of the services. In essence, AAL services utilize data and information from these devices using different protocols and orchestrate this information for the different users. The primary user of AAL services is the care recipient, but there are other important users including on-site formal carers, remote carers or monitors of AAL services, informal carers (including family, neighbors and friends) and those in charge of maintaining the quality of service in a technical

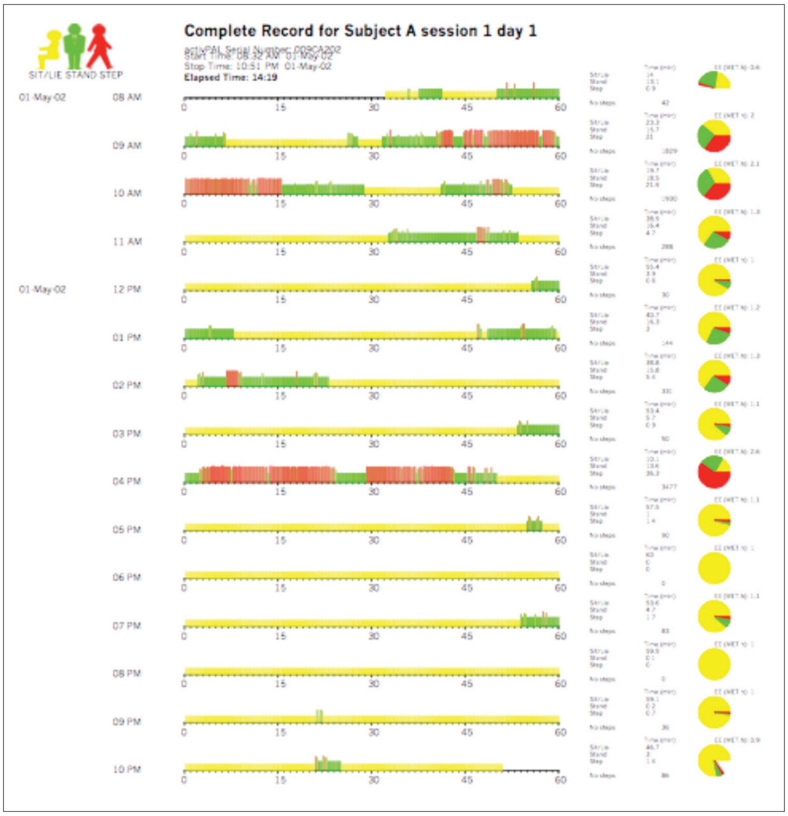

Figure 1. *Illustration of one-day activity profile recorded from a 72 year-old subject using ActivPal wearable sensor (PAL technologies, 2010). The recording covers his walking day of just over 14 hours.*

service provision. Each of these classes of users has a role or roles to play in AAL service provision and its use (Table 1).

AAL services have evolved from relatively simple telecare services such as emergency fall alarm provision into more sophisticated telehealth services supporting people with long-term chronic health conditions such as Alzheimer's disease, in the assessment of their symptoms. In this evolution, the data generated has increased in volume and complexity. The task of interpreting the meaning in the data relating to the well-being and health of the care recipient has also become increasingly more complex and the diverse range of types of user and their overlapping roles in AAL service provision and efficacy has increased markedly.

In determining appropriate AAL services, understanding the behaviour of the care recipients in terms of their Activities of Daily Living (ADL) is of particular value. For example, probabilistic models have been used to manage uncertainty and incompleteness of data as the ADLs are undertaken. ADLs comprise common activities such as making tea, using the telephone, etc. Conveying the information through visualization of such activities is much easier for a carer to interpret and comprehend compared to data-rich, lower-level data about movement within a room, for example. However, incorrect ADL identification has the potential to introduce more significant errors which could be harmful or even life threatening for the care recipient.

There is a need for the AAL services to communicate vitally important information in an easy-to-understand manner to all users while maintaining the privacy of the care recipient and their informal carers. The manner in which these AAL services communicate information draws heavily on visualization techniques. The most important user, the recipient of AAL care services, is more likely to be someone who is not familiar with ICT or computers in general and this is a major complicating factor in the successful provision of visualization of data and information in AAL services.

Data collected in AAL services can include movement information, used to:

- Alert an emergency incident such as a fall
- Alert for unexpected behaviors, such as an older person going out late at night
- Remind and assist daily living activities, such as doing physical activities and taking medications

The AAL services store personal activity profiles over periods of time. The trend of user behavior and the pattern of user activity events provide rich information in the analysis of care recipients' behavior patterns.

Visualization of information for AAL systems needs adaptive interfaces that target specific needs and preferences of the recipients of care services. We may refer to this as user-awareness, but overall this type of knowledge that the system uses to deliver a more useful service can be considered part of the most widely standard term of context-awareness. For example, for the person being cared for different reminders may be suitable in the morning (e.g., "time to take your medicine," "you did not have breakfast yet") than in the afternoon (e.g., "you did not have lunch yet"). Day and night require different types of content given that the person it is delivered to may have different level of consciousness and alertness. It is also expected that the messages to be delivered during the night will be focused on sustaining a healthy sleeping pattern whilst during the day it could refer to many other daily activities. The place of the house where a reminder has to be delivered can make a difference as well (e.g., kitchen or living room displays may be assumed to be used with normal levels of lighting whilst those in the bedroom which may be mostly used with low lighting or darkness).

Commercial Examples

There are several commercial products providing AAL services that include a visual element through text-based, colored tables and charts. Each vendor tends to differ in terms of how it visually represents data. While some systems are able to push pre-structured alerts to carers when certain events are triggered, the majority of visual representation of data is provided in response to user-driven queries from the carers rather than automatically being streamed to carers in real time.

An example of an advanced system is the use of the ActivPal[1] system in ambulatory monitoring, which has proved successful, in many respects due to powerful visualization software. This provides a concise easy-to-interpret graphi-

[1] *http://www.paltechnologies.com/*

[2] *http://www.tunstall.co.uk/*

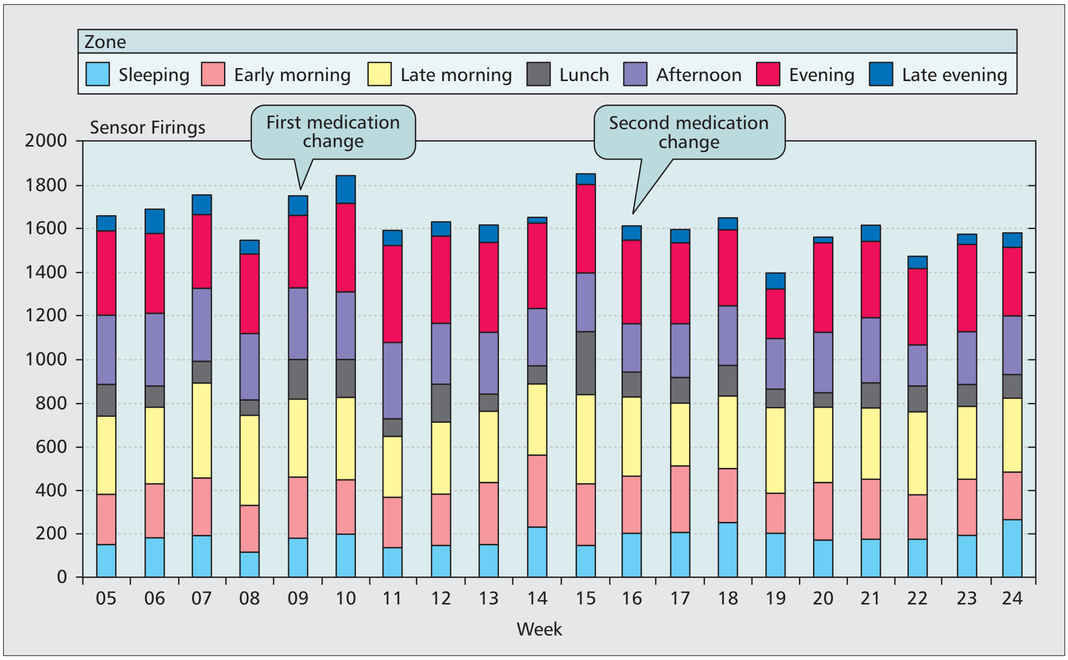

Figure 2. *Illustrating sensor activations per day split into time interval [6].*

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cal representation of the motion activity of a person for a day classified as sitting, standing or walking. Meaningful feedback of the user profiles has proven to be an important tool in assessing users' behavior. Figure 1 illustrates a recording of a user's 14 hours activity using an ActivPal sensor. The profile displays the activity pattern during a day. It shows that the user was inactive most of the time and was only active at 9 am, 10 am, and 4 pm. Using this daily profile, carers would be able to spot the periods where the care recipient can improve their activity level. Comparing the daily profile to the user's weekly profile, many questions can be answered or explored, for example, if the user had increased/decreased his activity level compared to the previous days? Did the user change their life style this day (for example, the user didn't get up for lunch)? If yes, can we infer the reason?

Tunstall's ADLife[2] service provides a user interface for representing client data, which is intended for use by healthcare professionals. The setup provides the user with information on individual care recipients in the form of a table listing the total activations of all the sensory equipment over a day, week and month. Each cell is color coded to represent activity based on a standard deviation from the previous week's pattern, with green showing under use and red over usage. Each cumulative activation number cell and date cell is hyperlinked to the complete data sets for that period, which are returned in the form of bar charts. These indicate periods of activations over time and the total number of activations for each sensor device.

The QuietCare system[3] caters for formal and informal carer needs. The home page is organized around activities rather than specific sensors providing sensor information in a more meaningful structured output. A simple traffic light indicator is used as the status display for each activity. In addition there is meaningful text related to each area. Contact information is also provided for alarm conditions. If the user wants to view specific trend details they can select the view buttons, which provides information for each activity on the last week, along with a textual description. If the user requests more detailed data they can select to view it from a sub-menu. While both these examples provide visual representation of data through imagery or well-structured text, there is variation as to how service data is presented.

Academic Examples

In academia, researchers have focused on lowering the cognitive processing required in order to interpret the data being visualized. For example, [4] developed an ambient facial interface used to provide visual feedback and confirmation to the user in a manner independent of age, language, culture and mental alertness. Their work used animated or actual human faces to display emotional expressions easily recognizable by an elderly person with non-verbal feedback. The facial responses were controlled by measurements or interpreted data on the user's current state or the products and objects with which he or she is interacting. By combining these measurements into a single facial expression, which is displayed to the user it assisted the user to evaluate their task. Reference [5] commentated on the growing area of application development. Their system moved application creation from the developer's perspective whose focus was on devices and their interactions, to end users' interpretation of goals or tasks. Comic scripts scenarios depicting assistive aids were presented to participants to explain the applications in their own words. This study highlighted the separation between the ages and living conditions of the designers and the people using AAL services. To over-

[3] *http://www.quietcaresystems.co.uk*

	Data		Visualization →	Decision support		
User type	**Data capture/ viewing/ analysis**	**Data abstraction**		**Communication of advice**	**Providing information**	**Managing nuances of alarm escalation**
Care recipient	Data captured from sensors using internal infrastructure network; user responses		Graphical (simple, metaphor for day, e.g., traffic lights)	Advice on activities of daily living	Self care	Supply instruction; multimodal; communication (e.g., audible)
Formal carers on-site	Real-time, archive	Abstracted text information on single care recipients	Graphical (summary day chart + weekly/monthly trend)	Support for assessments	Assessment inferences on care recipient	
Formal carers off-site (contact by networks)	Real-time, archive	Abstracted text information on groups of care recipients	Graphical (summary day chart + weekly/monthly trend)		Assessment inferences on care recipient(s)	Contact by mobile networks or broad-band networks
Telecare/Tele-health monitors offsite (contact by networks)	Real-time, archive		Graphical (summary day chart + weekly/monthly trend + statistical metrics)			Abstracted alarm dashboards for single and groups of care recipients; Contact by mobile networks
Informal carers on-site		Non-medical information abstracted for informal carers	Graphical (simple, metaphor for day e.g., traffic lights)			
Informal carers off-site (contact by networks)		Non-medical information abstracted for informal carers	Graphical (simple, metaphor for day e.g., traffic lights)			Contact by mobile networks
Technical mainte-nance (network access for remote monitoring)	Anonymous access to data; time restricted; real-time analysis					Status reports

Table 2. *How visualization supports decision support across different users and roles.*

come the disparity end user could develop applications using a text-based interface. End users would drag and drop scenarios of daily living using a list of predefined words into a window and click a *run* button. The system would then parse the words and develop a specification for an application to meet the needs of clients involved.

Reference [6] modeled ADLs for care recipients, and found that using these life patterns could provide enhanced home-based care (Fig. 2). The study found that changes in a *busyness* metric were visible and detectable even with irregular behavior.

Reference [7] indicated that a graphical user interface significantly improved performance response times, error rates, and satisfaction ratings compared with an existing text based interface for nurses using an information system. The study highlighted that staff found the advent of a more functional, intuitive and user friendly GUI easier to learn to aid navigation through the system and to prioritise management tasks.

Case Study: Nocturnal AAL Services for People with Dementia

The University of Ulster and the Fold Housing Group collaborate in the NOCTURNAL project on issues including data visualization for AAL services. The goal is to develop a solution that supports older people with mild dementia in their homes, specifically during the hours of darkness. This is a relatively new area of research and was identified as a key area of need for care recipients with dementia. It is also of interest

Figure 3. *Chart illustration of sensor data: a single sensor cell (left), location vs. time display and previous 28 days cell (right).*

because of the negative impact that lack of sleep and consequent anxiety causes for the informal carer in the home of the person with dementia. In their literature review on night-time care of people with dementia using AAL services, [8] found in that only 7 percent of papers addressed night-time specific issues with a further 26 percent focusing on night and day activities together. Of the night-time specific papers, only half involved any form of visual data representation, indicating that there is need for research in this area.

The focus on night-time AAL services centers around lighting and guidance, motion monitoring, and intervention decision-support. In the case study, the intention is for the AAL services to provide reassurance, aid and guidance for the general behavior of the care recipient and to support a stable circadian rhythm. This case study is appropriate to illustrate the issues in communication between AAL services and the different user types and roles — as identified in Table 1 — who all are potential actors. It also provides a clear example of the need for converged communication networks, as it uses a broad range of sensors, processors and actuators. In this case, the following communication networks and protocols are used:

- Body sensor and personal area networks, relying on protocols such as Bluetooth, Zigbee, and Ant+
- Home networks, providing either wired and wireless connectivity with specialist protocols such as x10 used to supplement standard 802.x networks
- Wider connectivity to remote stakeholders (cares, monitors and healthcare professionals) via secure broadband services
- Enhanced cellular services (GPRS, 3G, UMTS, Long Term Evolution and beyond) facilitating a sort of *virtual presence* for family members and occasional carers.

The visual representation of the data is a key component of the work, and visualization is designed based on the needs of the different users and their roles. Table 2 shows the results of an analysis of the users and their roles from the perspective of the translation of data to a mode where it supports decision-making and how visualization plays a part in that process.

The visualization of AAL data is accessible on computer interfaces after authenticated access, but as Table 2 shows, different modalities of access are also possible. For example, alerts can be *pushed* to mobile clients as the alerts are triggered. Table 2 illustrates how the AAL services generate data, which is then abstracted before being made available for visualization in support of decision support. The three main decision support modes are: communication of advice, provision of information, and management of (nuances of) alarm escalation. Figure 3 shows the Tunstall-based interface for a *technical maintenance* user at single sensor level as well as multi-sensor over a 28-day period.

The need to visualize information temporally is clear in each illustration in Fig. 3 as is the requirement to show activities in different locations of the home of the care recipient. This type of visualization of activities across space and time displayed on two dimensions of the interface, as used in our project, is becoming the most common manner of displaying the wellbeing of the care recipient in many AAL services. However, this interface is not appropri-

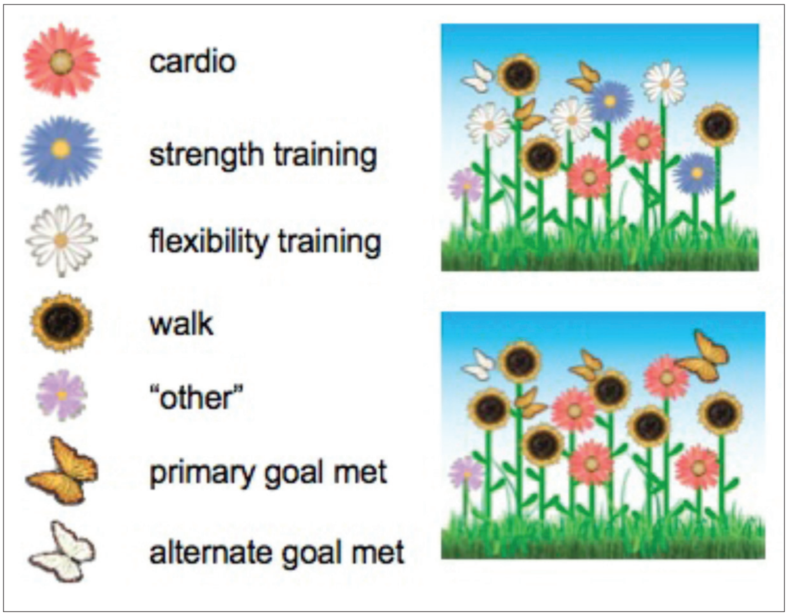

Figure 4. *Garden mappings and two sample gardens [9].*

ate for the care recipient or carers using AAL services.

A metaphor interface, for example, as described by [9], would be more appropriate to the abstraction and appreciation of the on-going AAL supported care. In their research, the interface (Fig. 4) was in a mobile device to monitor wellbeing, and it incorporate images such as flowers and butterflies that change as the person became more active in daily exercise regimes.

Discussion

In developed countries such as the UK, the increasing prevalence of chronic disease in the ageing population provides the context for more pervasive deployment of AAL services. Additionally, government policy such as the citizen's right to high-speed connectivity by 2020 throughout the United Kingdom as published in [10] provides the social and technological climate for such applications to succeed. However, there is a significant risk that due to the large streams of data generated by these AAL services, poor visualization techniques in interfaces, as described, will become a key issue, leading to potential misunderstandings and misinterpretation of information and data generated from AAL services.

This article has described the systems that provide AAL services in support of assisted living. It has examined exemplars in both commercial and academic areas. The NOCTURNAL research project was used to highlight the visualization components required to service the needs of the different user types. The paper highlights that a key requirement for successful AAL service uptake is to address the needs of the different user groups and translate these needs into interface and data visualization components that communicate clearly the wellbeing and health of the care recipient(s).

It is evident that there is currently a gap with regards to the supply of a fully functional, dependable and appropriate visualization of relevant service data, particularly with regards to the different user types and roles of people involved in the delivery of care. There is a need to design applications, which display AAL service data in a meaningful, holistic yet concise manner. Identifying the needs for each user group and how these needs are provided both physically and visually has to be resolved if AAL services are going to be utilized more fully in society. Gil *et al*. [6] suggested that the focus of visual representation should concentrate on living aspects that are regular, e.g., sleeping, eating etc., and have a relationship with wellbeing. A key requirement for AAL services is to minimize the cognitive overhead required to interpret information, by presenting normal behaviors and patterns in the most succinct form possible, and highlighting abnormal behaviors and alarm states tailored to each end user group's needs. The work by Consolvo *et al*. [9] on visual metaphors that requires minimal cognitive processing by the users is promising and indicates possible development pathways that communicate regular behaviors and useful feedback to care recipients and their informal carers.

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References

[1] K. Ducatel *et al*. (Eds.), "Scenarios for Ambient Intelligence in 2010," *IPTS-ISTAG*, EC: Luxembourg, 2001; www.cordis.lu/ist/istag.
[2] D. J. Cook, J. C. Augusto, and V. R. Jakkula, "Ambient Intelligence: Technologies, Applications, and Opportunities," *Pervasive Mobile Comp*., vol. 5, no. 4, 2009, pp. 277–98.
[3] M. Wojciechowski and J. Xiong, "A User Interface Level Context Model for Ambient Assisted Living," *Smart Homes and Health Telematics*, 2008, pp. 105–12.
[4] B. Takacs and D. Hanak, "A Mobile System for Assisted Living with Ambient Facial Interfaces," *Int'l. J. Comp. Sci. Info. Sys*., vol. 2, no. 2, 2007, pp. 33–50.
[5] K. Truong, K., E. Huang, and G. Abowd, "CAMP: A Magnetic Poetry Interface for End-User Programming of Capture Applications for the Home," *Proc. Int'l. Conf. Ubiquitous Comp*., Nottingham, UK, 2004, pp. 143–60.
[6] N. M. Gil *et al*., "Data Visualization and Data Mining Technology for Supporting Care for Older People," *Proc. 9th ACM SIGACCESS Int'l. Conf. Comp. Accessibility*, Tempe, AZ, 2007, pp. 139–46.
[7] N. Staggers and D. Kobus, "Comparing Response Time, Errors, and Satisfaction between Text-Based and Graphical User Interfaces During Nursing Order Tasks," *J. American Medical Info. Assoc*., vol. 7, 2000, pp. 164–76.
[8] W. Carswell *et al*., "A Review of the Role of Assistive Technology for People with Dementia in the Hours of Darkness," *Tech. Healthcare*, vol. 17, no. 4, 2009.
[9] S. Consolvo *et al*., "Flowers or a Robot Army?: Encouraging Awareness & Activity with Personal, Mobile Displays," *Proc. 10th Int'l. Conf. Ubiquitous Comp*., Sept. 21–24, 2008, Seoul, Korea.
[10] Digital Britain, "Final Report, Department for Culture, Media and Sport and Department for Business, Innovation, and Skills," *TSO*, June 2009.

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