How Are You Doing? Enabling Older Adults to Enrich Sensor Data with Subjective Input

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Abstract. Technology designed to sense behavior, often neglects to directly incorporate subjective input from (elderly) users. This paper presents experiences in deploying technology that considers the elderly user and their subjective input as a way to enrich sensor data systems and empower the user. For this purpose, the paper draws on: (1) Observations of shortcomings in terms of capturing objective data from sensors as experienced in long-term deployments in the homes of older adults; (2) The design and evaluation of a wide range of applications especially designed to enable older adults to give subjective input on how they are doing, including an interactive television quiz, a talking picture frame and a tangible mood board, and (3) The development and field study of one application, the 'Mood button' in particular, that was tested in real-world sensing settings to work with a commercial sensing system. In doing this, this work aims to contribute towards successful sensing deployments and tools that give more control to the (elderly) end-user.

Keywords: Ubiquitous computing · Sensor monitoring · Ambient assisted living (AAL) · Real-world deployment · Autonomy and control · Invisible computing · Affective computing

1 Introduction

Recent funding initiatives, technological improvements, such as small inexpensive sensors and advances in the field of sensor-based activity recognition [1], have stimulated a renewed interest in real-world approaches (e.g. [2]) to the deployment of ubiquitous sensing applications (e.g. [3–5]) to understand, augment and infer people's activities and behavior in their everyday life. These sensing technologies are offering a new generation of applications that are enabling innovative human-machine interactions that are characterized by pervasive, unobtrusive, and anticipatory communications.

Real-world sensing deployments such as smart homes that support Ambient Assisted Living (AAL) (e.g. [6]) have received particular interest from the research community. Ambient monitoring systems (also referred as residential monitoring) typically involve monitoring the Activities of Daily Living (ADLs) and safety of residents to detect changes in their daily routines. Most often, the advantages of sensor (monitoring) technology –such as the opportunities for helping people to live longer independently in their home and more effective care– are highlighted. However, the

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ubiquitous sensing of people's activities and behavior also raises issues which merit more attention [7, 8]. Particularly important are issues regarding the (elderly) user and ways that are enabling them to truly participate, control and behave autonomously.

Since Weiser's vision of ubiquitous computing [9], many have embraced and celebrated the perceived invisibility and seamlessness of sensing devices. However, the shift to ubiquitous computing, resulting in many people dealing with many computers, together with the increasing invisibility of ubiquitous, sensing technology also poses a threat to people's autonomy and control. Some have noted that 'invisible' computing and the implicit disappearance of user interfaces [10–12] indeed come with complications that need more attention, particularly when it comes to including the elderly user. Already, studies [13, 14] have shown that existing technology often does not cater for the needs and abilities of elderly people. Invisible sensing devices with no visible clues or user interfaces for direct control make it even more difficult to engage and participate in human sensing interactions. Therefore, tools are needed that enable older adults to actively participate and contribute to sensing outcomes. Addressing these concerns, this paper presents the design of user-centered solutions for enabling older adults to complement 'invisible' data derived from sensor networks with their own affective input. This paper starts with describing our experiences with deploying residential sensing systems and difficulties in terms of obtaining, understanding and engaging with objective sensor data, as in consciously, willingly and actively contributing to the intent and output of sensor monitoring. Seeing the shortcomings of objective information captured with these sensors, a study was conducted to investigate the design and use of devices that enable the users to give *subjective* feedback with regards to their affective status. The contribution of this paper is a number of design exemplifications that particularly consider the affective input of the (elderly) end-user, of which one (the *Mood button*) was tested in commercial real-world sensing settings and described in more detail.

2 Living Labs: Experiences from the Field

In developing ubiquitous (monitoring) technology and applications, it has been recognized that a potential 'technology push' should be abandoned in favor of working from the perspective of its actual users [8, 15]. Despite major efforts in human-centered fields such as HCI, in the development and uptake of sensor (monitoring) technology, the engagement of users is still often identified as a major barrier [15]. On top of this, technological opportunities offered are frequently not taken-up in everyday practice [8]. With that in mind, the Living Lab approach was chosen, which gives great importance to users' physical and realistic surroundings and the users themselves. Through adopting the Living Lab approach, the relevant stakeholders and users could be involved in technology development at an early stage and play an active role in the research trajectory.

In 2006, our first Living Lab for sensor monitoring was set up in Naarderheem, The Netherlands. Subsequently, several care complexes and residences were equipped as Living Lab environments to support the design and development of new care solutions using sensing technology, together with its users and stakeholders. In the residential monitoring project, which experiences are the motivation for this work, 28 apartments were equipped with sensor-monitoring systems for the purpose of investigating the monitoring of daily activity patterns and detecting a decline in daily functioning. Our long-term experiences with residential sensor monitoring deployments provide real-world context in terms of obtaining, understanding and engaging with ambient sensor data.

2.1 Obtaining Sensor Data

In our Living labs, it was not always possible to obtain (sufficient and reliable) data from the installed sensor networks. Insufficient project management, local resident selection criteria and consent issues were one predominant reason. This meant that eight dwellings with sensor networks installed were not considered for subsequent data analysis. Also failing technology and sensors (e.g. false positives from sensors due to incorrect placing, sensors not transmitting data and short battery life) was problematic. Eventually, our sensor data analysis study included 20 participants (from the original $N = 28$) with monitoring systems installed for 11705 days in total. However, 5746 days needed to be removed from that data set. Thus in this instance, almost half of the data (49 %) that could have been used, was lost.

Insight: In explorative real world sensing settings, technological infrastructures are not typically robust. Consequently, the collection of satisfactory amounts of reliable data from residential sensor networks for effective usage can be a problematic process that requires lots of commitment and resources. When information about users' behavior and status is desired, other more robust, but also simpler techniques –for example, less sensors or more input from other (human) sources– might be more effective and should therefore also be considered.

2.2 Understanding Sensor Data

Once data has been collected, interpreting sensor data to acquire relevant information is not an easy and straightforward process. For measuring 'functional health', sensor patterns need to be recognized and classified, such as for emergency situations (e.g. if one has fallen), activities of daily living (e.g. cooking, sleeping), and to predict slow-moving, latent problems. A number of researchers (see [1] for an overview) have dedicated their work towards detracting such meaning from objective sensor data and identifying relevant deviations in patterns. In most cases, machine-learning techniques are used that need annotated sensor data. For example, if a sensor indicates a high frequency of a door being opened, this could be a sign of frequent social or medical visits, or simply something else. In short term lab situations, annotation is often done by a human observer (on-site) looking at the behavior of the participant. For long-term experiments, annotation of activity patterns and achieving true contextual understanding of sensor output in general is much harder to obtain. Especially for older participants, it seemed to be difficult to continuously keep a precise diary of their status and activities. The deployment of cameras in private homes for this purpose is also not an optimal solution, for obvious privacy concerns.

Insight: For meaningful and effective usage of sensor data, annotation and additional interpretation is needed, which can be hard to obtain from older participants for the long-term. To make better sense out of data, durable solutions enabling richer data annotation would be helpful.

2.3 Engaging with Sensor Data

Engaging with sensor data in terms of having a clear understanding of how to actively and willingly control and contribute to the system's output and implications was found to be a concern. Namely, sensor technology can uncomfortably emphasize a person's limitations and so subsequently be confronting and less empowering. For example, some could perceive the technology and its data output as an indication that a person is less independent. In some cases (see also [8, 16]), potential participants did not want to adopt sensor monitoring technology because of the stigmatizing effect. Also, sensor data interpretations, such as minimal sensor activity output from a door sensor could uncomfortably or inaccurately reveal a person's lack of social contact. A way to add personal interpretations to the sensor data would help to empower the user in this process.

A disadvantage of having small, embedded, nearly invisible sensing technology without visible affordances is that it becomes more difficult to understand and actively control the system and its data implications. Consequently, some (potential) users in previous study thought that the sensor networks implied the use of cameras to observe them (in the shower) and control them [8], which can raise concern in terms of what happens to personal data.

Without highly legible systems and interfaces for managing, understanding and actively contributing to 'smart sensing' with its pervasive, unobtrusive, and anticipatory communications, it is likely that people can feel powerless, lost or frustrated. Indeed, as sensing systems record people's personal activity and data, according to Arnall [11], invisibility is exactly the wrong approach. It is important to develop visual cues and user interfaces that show the workings of technology (such as [8]) and enable the user to actively control and contribute to the system (instead of letting the system control them and disappear as user).

Insight: For true autonomy and better engagement with sensor data, the user should be provided with visible, active means to control and contribute to the sensor system.

3 Technology that Asks How You Are Doing

Sensing technology often neglects to directly incorporate input from its users, making users –to some extent– less autonomous. For example, the described sensor monitoring deployments that typically focus on the automatic detection of daily activities and status of older adults, do not directly ask how they are doing. Having observed the shortcomings of sensor monitoring systems in terms of obtaining, understanding and engaging with sensor data, indicate the potential for systems that incorporate users' input. Particularly, input of affective states might add more value to sensed behavior.

Furthermore, although social media, mobile technology (e.g. [17]) and Internet offer opportunities for distilling affective states, as well as expressing oneself, studies on the use of Internet [13] and Twitter [14] show that older adults are en masse not typically included in the process of such communication technology usage. To address this, the ‘How are you doing?’ project is presented, which aim was to develop elderly-centered communication technologies that directly ask the user’s input on their affective status. Adding or enabling affective input from older adults could serve many goals, namely:

- Provide an additional verification when a sensor system detects that something might be wrong or when the technology is failing;
- Empower and enable users to indicate an alarming situation themselves;
- Make the user feel more democratically in control of the technology and connected with the outer world by giving the opportunity to initiate interactions themselves;
- Increase the feeling of wellbeing through expressing how you are doing. Seeing that a large body of research (e.g. [18–20]) has shown that the act of self-expression alone can be beneficial for one’s physical and mental health.

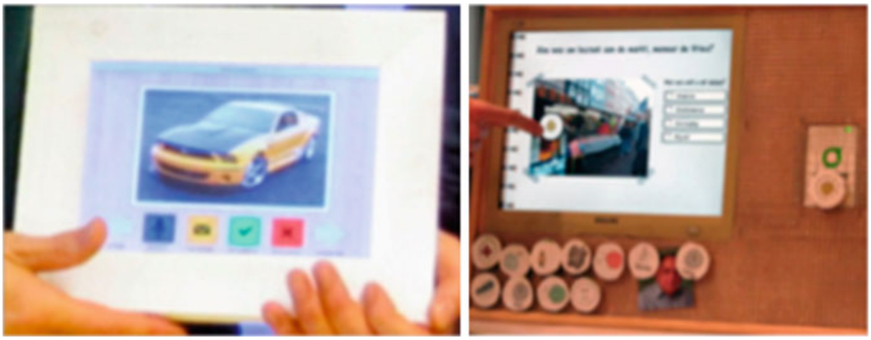

Fig. 1. Prototypes of the ‘How are you doing’ project: Talking picture frame and mood board.

Addressing these goals, groups of Communication & Media Design students were given the assignment to design solutions for enabling elderly users (>65 years old) to communicate their affective status. This resulted in eight different applications that are all able to inquire how the user is doing and are especially designed to relate to the elderly’s world of experience. Students were encouraged to involve elderly participants in the early design stages, and to frequently show them interim results for small-scale user research. For this reason, many of the solutions employ metaphors that might come more naturally to older adults. The resulting applications are described in the following sections.

TV-Friend. The TV-friend is an application that runs on a regular television. The first questions of the interactive TV-quiz are about the users’ status, while the other quiz questions function as a fun reward. The front-end of the TV-friend includes a small media player and a remote. The back-end includes a Content Management System for creating new questions so that specific data on how someone is doing can be obtained from the user. Just like other interactive television applications (such as [21]), the reason for using a television in this concept is that many older adults are more familiar with this device than with computers or tablets.

Going Out. This is a social network application for arranging and making (short) walks. It aims to make older adults less isolated by encouraging them to go out together. The application enables the users to initiate walks or to arrange walking together, such as setting a specific time slot to walk to the grocery store together. Based on their walking activities and behavior, the application asks the user how they are doing.

Mood Board. The tangible mood board is a wooden frame with an embedded screen and real magnets that enable the user to communicate how one is doing (see Fig. 1). The board comes with several questions and magnets representing a certain answer, for example a positive versus negative response to questions relating to one's status. The user is asked to put the magnet into an answer area whereby the board uses RFID technology to identify the answer. This answer is registered on the screen, and the screen provides the option to share this answer with different parties (such as family and formal care givers) through simple touch actions. Inspirations for the tangible mood board were fridge magnets. These were frequently observed to hold notes and reminders in the homes of the elderly participants.

Tell me How You Are Doing. This application makes simple conversations using solely speech. From the answers, the application detects positive or negative feelings. The prototype uses the Google Speech API for determining which words were spoken and compares the first few words with an internal list of words with either positive or negative associated valence. The application comes with a CMS so that, for example, caregivers can monitor how the older adult is doing. This interface has been inspired by the premise that using speech as a way to communicate comes natural to most people.

Talking Picture Frame. This product enables the elder user to show and (digitally) exchange pictures with others via an object that is already rather familiar to them: a picture frame. Other researchers have also considered picture frames as an attractive and inspiring object for digital usage (e.g. [22, 23]). The Talking picture frame has the added ability to attach voice message recordings, so to avoid strenuous keyboard interactions. Furthermore, the system engages family and friends in monitoring the wellbeing of the elderly user.

Social Calendar. This application enables elderly to keep track of their social events. Users can make connections in the real world and catch up on how they are doing. The social calendar is a web-based application, using real-life metaphors, such as post-its for making digital notes. The application enables the planning of social events by means of inviting others to an event or responding to other events. It uses the calendar information on daily routines as contextual source to question the user about his emotional and physical state.

Mood Box. This physical box with embedded (iPad) screen is 'alive' like a Tamagotchi. The Mood box, a web-based iPad-application, asks questions about the user's state. When the user fails to respond regularly, the mood box starts to express a sad face so to call upon the user's need to care.

Mood (dial) Button. The Mood button is a tangible device for the explicit communication of how you are feeling. With the tangible, radial dial button a person can indicate how (s)he feels by turning the switch from left (not feeling well at all) to right (feeling very well), while a smiley face is changing accordingly from very happy to very sad (see Fig. 2). Just like other tools for registering sentiment –such as the AffectButton [24], Funometer and Smileyometer [21] – the Mood button enables the user to explicitly capture one's feelings in a simple and dynamic way. However, instead of being a rating tool, the Mood button is a physical, tangible device for expressive self-report that has particularly been designed with older adults in mind. The primary design phase of the button was informed by iterative design studies with elderly users ($n = 6$), which suggested that colors and smiley's (as opposed to using words and bar charts) for indicating one's mood were best understood by the participants. This is supported by other research [25] which also found that a simple, visual and language-independent tool (using smiley's) was desirable for practical usage with elderly in clinical context. Furthermore, an ordinary dialing mechanism, often used in devices such as room thermostats, inspired the Mood button, so that users can interact in a way familiar to them.

Fig. 2. Prototype of the mood dial button.

Insight: Engaging with elderly's world of experience and using metaphors from daily life can be a true source of inspiration for accessible interfaces and technology. The results show that there are many different possible ways in terms of designing enabling and inclusive technology that consider elderly's status input.

4 User Study

Besides the iterative design sessions for developing each of the systems individually, different small-scale studies were conducted to evaluate the expressive applications from the 'How are you doing?' project. This included the following studies:

- *Feedback and demo event*. All the eight applications were shown and demoed by its different makers in a social meeting hall in an elderly care home. This event was open to all people interested. Custom-made stickers with predefined space for feedback and commenters' details were provided for rating the different applications in terms of most useful, and best technical, creative and overall achievement. The goal of this event was to gauge initial understanding of how the different applications compared and were valued;
- *User group sessions (n = 4) and semi-structured interviews with elderly users* (N = 5, > 65 years old). These were conducted by occupational therapists to evaluate the different expressive applications all together. The aim of this study was to gain a general overview of how the applications were used and valued by *the elderly participants*;
- *Additional user group sessions* (n = 4+3, > 65 years old) *and structured interviews* with *elderly participants* to evaluate and inform the iterative design of the Mood button to work in combination with a commercial sensor system in more detail.

4.1 Findings from the User Studies

The different small-scale studies provided insights with regards to the design and attitudes towards the technology. The initial design sessions affirmed design lessons from other human-centered studies (e.g. [26]). For example, the study stressed that when designing for elderly users, text and buttons could never be large enough. It also stressed the importance of engaging the user from the beginning, as all the eight concepts were improved and very much influenced by the elderly target group. Technology that is based on familiar devices (such as a television or photo frames) and activities (walking or talking) was found to be a good starting point for elderly-centered design.

From the first, demo event, in which participants awarded 32 stickers in total, it was found that all the applications were positively valued for different aspects. For example, 'Tell me how you are doing' was awarded with 40 % of the 'best technical achievement' stickers, while the Mood button (21 %) and the Mood board received most sticky votes in total (27 %). Unfortunately, the raters were mostly the younger people present. One explanation was that it was difficult for some older adults (e.g. in wheelchair) to move between the displayed projects. The younger people present made insightful comments such as *"I think my father would like this"* (female, 51) and *"The physical remote and TV will appeal to the experience of elderly people*" (male, 44) when rating the TV-friend. However, a different study approach was clearly needed as to obtain views from the elderly users themselves more directly. For this reason, and to avoid a technology bias, the second study included solely the 65 + years-old target group in fixed settings, and was conducted by occupational therapists (and one HCI-expert as guide and observer), as they have typically more experience with dealing and engaging with older adults [17].

The findings of the user group studies stressed the importance of making the technology as simple, robust, mature and accessible as possible. Interacting with the lower-fidelity prototypes and the touch screens of some applications was particularly observed to be difficult for the elder participants. Tangible buttons and devices might therefore be a better option, but more extensive study is needed to further verify this. The elderly study participants found two-way interaction (as to be heard by another party) one of the key important elements. Interestingly, for the elderly participants, novelty and innovation was not considered important. Being highly aware of their old age (one participant even dramatically proclaimed: "my coffin is already waiting for me!"), important for the participants was how they could instantly use and integrate the technology in their daily lives without a steep learning curve.

5 Field Study with the Mood Button

Closely working together with a commercial sensor installation company, the ideas stemming from the 'How are you doing?' project were further explored for integration with an existing commercial sensor system. The Mood dial button was particularly positively reviewed, because of its perceived low costs, simplistic, attractive and tangible form, and so further developed (Fig. 3). Eventually, the Mood button was further iterated for integration with a commercial sensor system in the home, so that objective sensor data could be enriched with affective input from users.

In this process, it became clear that for an end product to be used in real-settings, production (e.g. screen) costs need to be limited. This meant that some good ideas had to be abandoned, and that the most fruitful ideas that will eventually make it, may not necessarily be the most innovative solutions. However, this approach is more realistic and required for faster uptake and usage of technology in real-world daily practices.

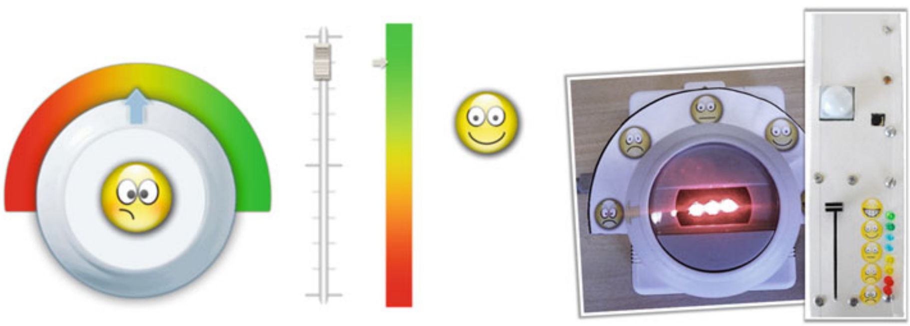

Fig. 3. Dial and slider prototype versions of the mood button.

On the basis of these findings, the mood button was further developed and evaluated in a field study ($n = 2$, > 65 years old) that focused on the use of the Mood button in real context. The Mood button was installed in the homes of two older adults (both widowers) that had already commercial sensor networks installed. Two versions (dial and slider) of the Mood button were tested each for one week in the homes of the elderly. They were requested to use the applications, but not set specific usage totals or set times. Their usage data was recorded and participants were interviewed afterwards.

Figure 4 presents the results of the actual use of the mood buttons (dial and slider) by the two participants. Participant A shared his mood once a day, not at a specific set time. During the final interview, he indicated having sometimes forgotten about the Mood button, despite of its visual presence. Reminder functionality (that could potentially be based on sensor activity) would suit him well. Participant B frequently and regularly shared his mood. He stated that he had never forgotten about the Mood button, because he had linked the action of setting his mood to post-meal time.

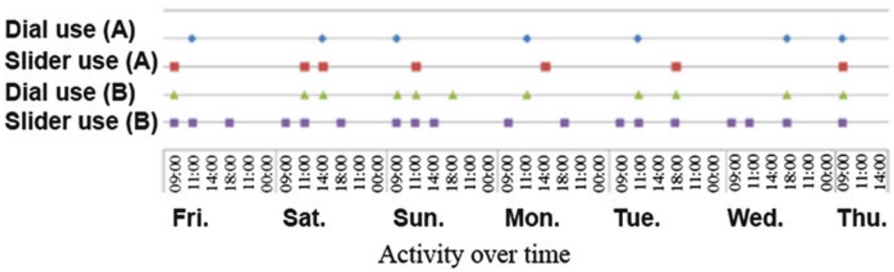

Fig. 4. The use of the Mood buttons throughout the week. The first two rows indicate the use of the prototypes by participant A, and the lower two rows indicate the use of the prototypes by participant B.

Being able to effectively combine and compare the subjective input with objective sensor data is one important aspiring goal of this work. As a proof of concept, a PIR sensor and light sensor were integrated in the mood button slider. Figure 5 displays the mood values, set with the slider throughout the week, for participant A. This figure shows that the participant was able to change and submit his mood status over time. For conducting a meaningful activity analysis that includes the personal affective state, a more advanced sensor system would be needed than now tested. As a proof of concept however, this figure shows that with the technology presented in this paper, the sensor data can be augmented with the affective state from users.

The participants used the expressive system in their daily lives and homes and found the ability to enrich their 'objective' sensor data with their own subjective data a valuable contribution.

Insight: Older adults are able to use a novel, simple tangible interface for sharing their affective state in their daily routines and can so become active participants and contributors in the sensor monitoring process.

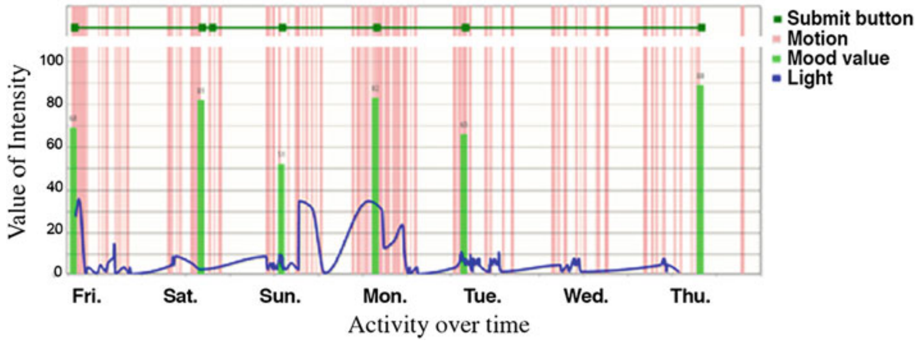

Fig. 5. Usage of the mood button slider by the first participant during the week. The neon green bars indicate the mood rating (on a scale from 0–100), in relation to the sensor output from sensors on the slider. Motion detected in front of the device is indicated by the small salmon red lines, while the blue line shows the intensity values coming from the light sensor. Finally, the dark green squares indicate the active use of the submit button, which is useful in case the mood is constant, but the user wants to set and share the same mood status.

6 Discussion and Conclusion

This paper presented a critical reflection of our experiences and challenges in terms of obtaining, understanding and engaging with objective sensor data when deploying residential sensing systems. To enhance and enrich such sensor data, this paper presented practical solutions and design exemplifications that particularly consider the active input and participation of the (elderly) end-user.

People's autonomy and engagement with technology considerably declines at older age. To respect the autonomy of the elder user, we not only need to engage elder users in the design process, we need data sensing approaches that avoid thinking with a third-person and emphasize realistic integration in daily life. Having observed the difficulties with obtaining, understanding and engaging with data derived from sensor systems, this paper presented a more elderly-focused approach in using sensor technology by presenting a wide range of different enabling applications for affective user input, that connect with the elderly's world of experience. Emphasis was placed on the Mood button as adapted to work in realistic settings in combination with a real-world sensing system. More studies still need to be done, particularly in terms of actually and effectively combining objective data derived from sensors with affective status input from users long-term. This work hopefully sets direction in inspiring the community in the design of ubiquitous technologies that engage with the elderly user and consider their autonomy, real-life practice and their 'subjective' input.

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