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Semantic ambient media: From ambient advertising to ambient-assisted living

Bogdan Pogorelc · Radu-Daniel Vatavu · Artur Lugmayr · Björn Stockleben · Thomas Risse · Juha Kaario · Estefania Constanza Lomonaco · Matjaž Gams

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Abstract The term *ambient media* was in its beginning used only for ambient advertising. Nowadays it denotes the media environment and the communication of information in ubiquitous and pervasive environments. With the addition of intelligence, the new field of *semantic ambient media* was established. In recent years, the field of semantic ambient media has spread its span from only a few sub-areas, such as ambient advertising, to new ones, such as *ambient-assisted living (AAL)* and *health-monitoring media*, significantly

B. Pogorelc (✉) · M. Gams
Jožef Stefan Institute, Department of Intelligent Systems, Ljubljana, Slovenia
e-mail: bogdan.pogorelc@ijs.si

M. Gams
e-mail: matjaz.gams@ijs.si

B. Pogorelc · M. Gams
Špica International d. o. o, Ljubljana, Slovenia

R.-D. Vatavu
Research Center in Computer Science, University "Stefan cel Mare" of Suceava, Suceava, Romania
e-mail: vatavu@eed.usv.ro

A. Lugmayr
EMMi Lab, Tampere University of Technology (TUT), Tampere, Finland
e-mail: lartur@acm.org

B. Stockleben
University of Applied Sciences Magdeburg, Magdeburg, Germany
e-mail: bjoern.stockleben@gmx.de

T. Risse
L3S Research Center, Hannover, Germany
e-mail: risse@l3s.de

J. Kaario
Varaani Works Oy, Tampere, Finland
e-mail: Juha.kaario@varaani.com

E. C. Lomonaco
University of Nova Gorica, Graduate School, Nova Gorica, Slovenia
e-mail: estefanialomonaco@gmail.com

supported by intelligence. The study presented in this paper provides an advanced introduction to the field of semantic ambient media including the solutions for threat issues and illustration of success stories of the field. It conducts a survey of the related work and presents a thorough discussion of it. The related work is grouped according to the coverage of the principles of semantic ambient media. Based on the state-of-the-art research, the future possibilities of the field are demonstrated, especially for the ambient-assisted living, audio-visual rendering of media objects, user design principles and the society impact of the field. The paper provides ideas for impacting ambient media and directions and questions for further research. It also discusses the potential of the combination of several research studies.

Keywords Ambient media · Ubiquitous media · Pervasive computation · Ubiquitous computation · Ambient computation · Artificial intelligence · Machine learning · Data mining · Context awareness · Semantics · Ambient-assisted living · Art

1 Introduction

The term *ambient media* started to appear in British media jargon around 1999 and was later established as a standard term within the advertising industry. It is the name given to a new breed of out-of-home products and services described by some as non-traditional or alternative media. The key to a successful ambient media advertising is to choose the best media format available and combine it with an effective message, i.e., content [3].

On a larger scale, the field of ambient media defines the media environment and the communication of information in ubiquitous and pervasive environments (e.g., between the environment and people through reasoning from sensors, and through the interaction between people and machines). The concept of ambient media relates to *ambient media form, content, and technology* [21].

As the communication and sensing technologies become increasingly miniaturized (even wearable), more and more complex sensor networks are being built. With added intelligence, sensory data can be turned into valuable context information and combined in a new kind of media: *semantic ambient media*.

In recent years, semantic ambient media have spread their span from only a few sub-areas, such as ambient advertising, to totally new ones, such as *ambient-assisted living (AAL)* [1, 8, 24, 26]. The AAL Joint Programme is funded by the European Union in order to enhance the quality of life of the elderly, release the burden on the supporting population, and strengthen the industrial base in Europe through the use of Information and Communication Technologies (ICTs). The motivation of the new funding activity is related to demographic changes, in particular the aging of the European population, which implies not only challenges, but also opportunities for the citizens, the social and healthcare systems as well as industry and the European market. Thus, AAL has become an important part of semantic ambient media.

Ambient-assisted living can be combined with intelligent systems into a new sub-area of semantic ambient media - *health-monitoring media*. In line with the definition of media, the health-monitoring medium is a transmission tool used to deliver information (content) from a physical world to a digital world and vice versa. It uses sensors to capture data from the environment (e.g., body movement, physiological signals, sound or temperature). Then, the machine learning [13] can be used to model the underlying processes that have generated

the collected data. The models explain the data and they can be used, e.g., to recognize activities or health problems of elderly, which is an information delivered to a digital world. This information can be transmitted back to a physical world through its representation to a user, e.g., explanation of the diagnosis to a medical expert [8, 26] or through a feedback of the quality of the performed exercises to a user in the rehabilitation process.

Another newer sub-area of the semantic ambient media is e-learning. An example of it, a design, development and evaluation of a hypermedia e-learning tool for university students, can be found in [23]. In contrast to the traditional video files, hypervideos are multimedia files, which can be navigated by using links that are embedded in them. Students can therefore easily access content that explains and clarifies certain points of the lectures that are difficult to understand, while at the same time not interrupting the flow of the original video presentation.

As postulated in [15, 21], the principles of semantic ambient media are: manifestation, morphing, intelligence and collaboration. Several of these principles describe consumer perception, thus the fifth principle is experience. To discuss these principles and to revise the vision of semantic ambient media, we are conducting a qualitative literature study by extending the results of [17–22] by additional research works in the field of semantic ambient media.

The paper is organized as follows. The following part of Section 1 is used to present solutions for threat issues, illustrate success stories of the field and explain the role of semantics and intelligence in semantic ambient media. Section 2 presents a survey of the research studies, classified into groups according to the coverage of principles of semantic ambient media. Section 3 predicts research beyond the state of the art, and Section 4 presents the combination of ideas of several research studies. The paper is concluded with Section 5.

1.1 Solutions for threat issues and success stories

Based on investigation of the related literature, we can extend the understanding of semantic ambient media by contributing to its global vision in various ways. Many of the global threat issues, which were identified in [21], have been partially solved and solutions together with success stories for semantic ambient media are given here.

1.1.1 Solutions for threat issues for semantic ambient media

Five threat issues (information overflow, physical information overflow, social disconnectivity, acceptance, and scalability) have been identified in [21]. In the following paragraphs, these threat issues are discussed and potential solutions provided:

- Information overflow: It is difficult to filter the noise from data and to get access to knowledge in the information jungle. However, in [26] it was proved that this is possible. The paper demonstrated the recognition of health problems even from 2160 coordinates per second.
- Physical information overflow: This concerns whether the available resources in terms of storage space, network capacity, natural resources, and energy are sufficient to deploy ambient media systems. A large storage space and network capacity is not necessary for [26], because it reasons using models with a small memory footprint and in real-time. It is also energy sufficient.
- Social disconnectivity: There is a generally prevailing opinion that digitalization leads to social disconnectivity, where people's communication is performed via digital environments and mediators, rather than in real-life settings. However, the following contributions

have demonstrated the opposite: for instance, [28] helps to enhance human–human interactions through emotional responsive ambient media, and [26] tends to prolong and enrich the autonomous living of the elderly and their social activities.

- Acceptance: Will consumers and professionals accept the new way of creating and consuming content? Because of increasing numbers of elderly people and not enough younger people to take care of the elderly, AAL systems to support the independent living of elderly like [26] are not only acceptable, but necessary. This was confirmed by interviews with consumers. Due to increasing popularity of smartphones, using QR codes as analog portal to digital world is more and more present [2].
- Scalability: This issue reveals that the constantly increasing amount of information regularly raises new scalability matters of their processing. The study [26] describes a system scalable to various numbers of sensors and a large amount of noise without causing processing problems. A core ontology on events for representing occurrences in the real world [27] is also a good example of scalability.

1.1.2 Success stories for semantic ambient media

Four success factors (information filtering and analysis, personalization, common infrastructure, and a critical mass of consumers) have been identified in [21]. Success stories based on these factors are presented in the following paragraphs:

- Information filtering and analysis: Many tools have already been developed based on the Semantic Web and data-mining technologies that allow the efficient filtering of information and the analysis of, e.g., sensor data streams [26, 27].
- Personalization in information provisioning: More and more studies of ambient media are based on individual needs for information [26, 28].
- Common technical infrastructures: They allow faster development and consequently a greater number of new quality products. An example of using a common technical infrastructure is given by [2].
- Critical mass of consumers: For example, [26] deals with prolonging the autonomous living of the elderly and as such should not have problems with the critical mass of consumers. The same should be true for [14], which presents the development of a conventional domestic infrastructure for central heating into the ambient media.

1.2 Semantics and intelligence in ambient media

As the name suggests, the field of semantic ambient media needs to include semantics. Semantic models can help us understand and assemble the underlying content according to the respective context. As defined in [21], the key challenge of semantic ambient media is: “Which experience does the perception of a content entity evoke in relation to the individual user, the environment and in collaboration with other content entities?”.

The perception of content has changed from a single entity to a plethora of information sources, such as sensor networks, data streams, multimedia content and services. Therefore, any realization of ambient media requires a good understanding of the semantics of the underlying content, e.g., knowing that a series of values represents heart-rate recordings or distinguishing an audio recording as being music or speech. The better the understanding of the underlying semantics, the better will be the presentation of the content afterwards.

Humans find it much easier to understand the semantics of information, but compared to computers they are limited in many ways. As a result the field of semantic ambient media focuses on the machine processing of content and data.

In order to extract the semantics of the issue, i.e., to model the problem, machine learning (ML) or data-mining (DM) techniques are frequently used. The basic principle of ML and DM is the automatic modeling of the underlying processes that have generated the collected data, e.g., sensor recordings. Learning from data leads to rules, functions, relations, equation systems, probability distributions and other knowledge representations. The models explain the data and they can be used to support decisions concerning the same underlying process (e.g., forecasting, diagnostics, control, validation and simulations) [13]. An important subfield of machine learning is classification. In [26], classification is used to recognize the movement of elderly people, described by motion-capture recordings, into five classes that represent common medical diagnoses.

When the semantics are extracted from documents, the ontologies are frequently used in order to model the world or part of it. It is essential that ontologies specify the concepts and relationships that are necessary to model a domain. Furthermore, they provide the representational vocabulary as a link to the real world. One of the key advantages of ontologies is that they are both man and machine readable [11]. A theoretic approach towards semantic and intelligent ambient media is presented in [16].

2 Semantic ambient media experience

In this section, several considered studies are classified into one of the six groups according to the coverage of the principles of the semantic ambient media. Therefore, the groups are:

- manifestation,
- morphing,
- intelligence,
- collaboration,
- experience and
- contributions covering more than one principle.

Moreover, a comprehensive discussion is provided together with each contribution. The contributions also answer the following challenges:

1. How can high-level and low-level events between media objects be exchanged?
2. How can data mining be used to support ambient-assisted living (AAL)?
3. How can user experience be defined and conventional media be transformed to ambient media?
4. How can affective data be applied in new forms of digital artwork within ambient media?
5. What methods can be used for integrating emotional responses and for evaluating the efficacy of this integration and the success of the artwork itself in terms of the artist's intent?
6. How to select and present the content for ambient displays in the natural human environment?
7. Can human–human interactions be enhanced through emotional responsive ambient media and how?
8. Which methods, techniques, and codes exist to bridge the analogue and digital worlds?

The survey of the related literature is presented in the following six subsections corresponding to the principles of semantic ambient media. The principles with the key ideas from the survey are illustrated in Fig. 1.

2.1 Manifestation—rendering audio-visual content

From the researched literature, two solutions for the manifestation of ambient content were provided. The first research work focuses on a visual information presentation [9] and the second one on audio information presentation [6].

2.1.1 Designing information presentation for ambient displays

The "removal" of the user interface is frequently discussed in ambient media; however, information still needs to be rendered throughout the natural environment. How can an

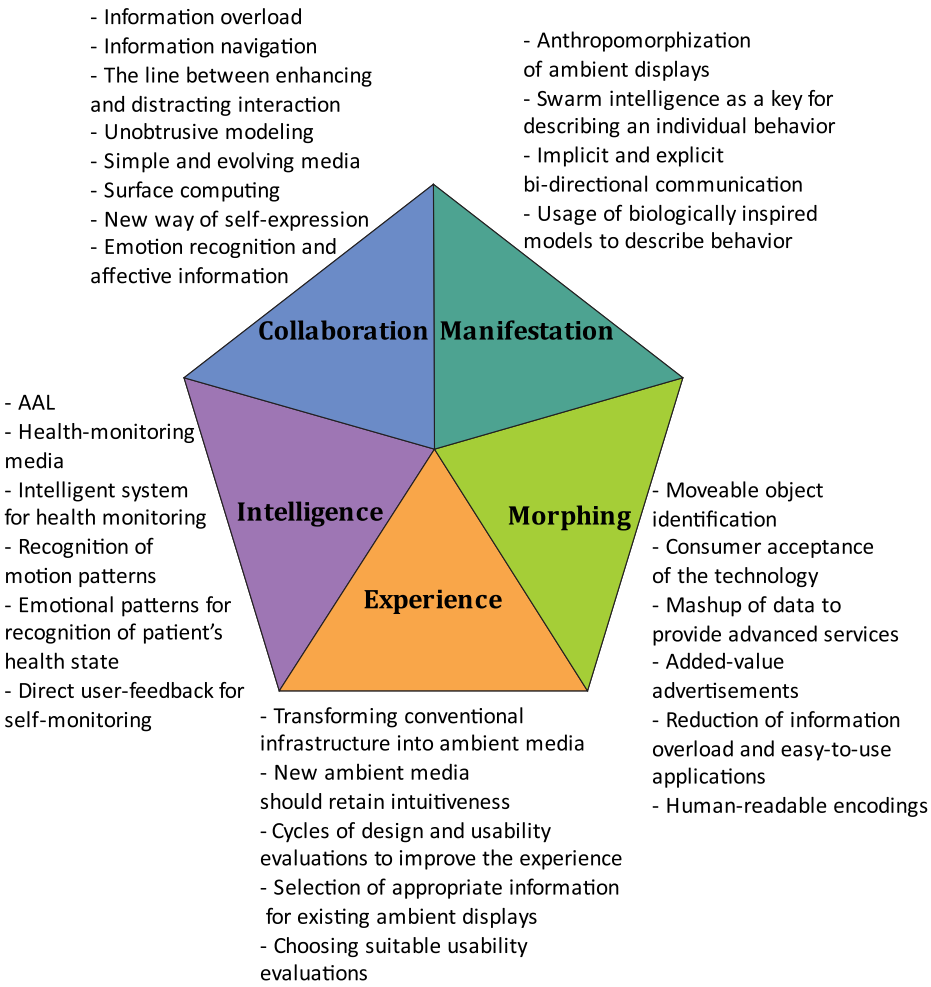

Fig. 1 Visualizing the key ideas from the survey related to the principles of semantic ambient media

information system allow content to "manifest" itself has been evaluated by the Florian Förster contribution entitled "How to Select and Design Adequate Pieces of Information for an Existing Ambient Display" [9]. The paper introduces a user-centered approach for the optimal design of the user interface for ambient displays. It evaluates state-of-the-art research in order to propose several design guidelines, which were tested with the help of the Nabaztag public display installation.

The paper presented a process for selecting and designing information for an existing ambient display following a user-centered approach. It consists of four parts: (1) classify the ambient information system, (2) identify users' wishes and select the information, (3) design the information presentation and (4) evaluate and redesign according to the results. All the steps were presented based on a case example, i.e., the Nabaztag rabbit used in a semi-public environment. The process proved to be useful when selecting the right pieces of information for the design process, but needs additional efforts to identify users' wishes and needs, and additional methods for investigating the context of use.

2.1.2 Designing sound spaces for ambient environments

Research in sound is often neglected, or simply forgotten, as we are living in a visually predominant world. However, sound plays an important role in ambient systems. The contribution of Philippe Codognet and Olivier Pasquet is devoted to "Ambient sound spaces" [6]. Ambient sound spaces represent a media installation in a 3D immersive space. The paper is an example of content manifestation of the digital overlay in natural surroundings. Sound is generated by agents who are self-organized and act autonomously.

The ambient media installation presented in the paper "Ambient sound spaces" aims at creating ambient electronic music from a multi-agent simulation in real-time, associating agents with sounds. More specifically, various sound parameters are associated with the internal state of an agent at a given time (position, orientation, internal variables, etc.). The *Sound Agent* generative music installation uses nature-inspired simulations to drive the musical processes, and in particular the swarm intelligence metaphor.

2.1.3 Discussion

Key ideas for impacting ambient media, and directions and questions for further research are provided here.

Key ideas for impacting ambient media:

- Anthropomorphization of ambient displays: the attribution of human characteristics to ambient information helps to perceive it and allows a clear understanding.
- Natural mappings—learn preferences through habits, recognize states and let the users choose the output representation.
- Standardization of human expressions and emotions to harmonize systems in the digital interpretation of human expressions.
- Analogue 'ambient portals' will be the counterpart to 'today's digital portals'.
- Cultural and media usage shift of the modality how to retrieve and access digital information.
- Usage of biologically inspired models (e.g., swarm intelligence) as, e.g., in multi-agent systems with simple rules for describing the individual behavior for mapping the digital world with the analogue world.

- Bi-directional communication and interaction, where the system can track the locations of spectators in the real-world to evolve sound spaces as an implicit interaction model.

Directions and questions for further research:

- Consumer data collection and consumer studies to identify the needs and wishes about the type of ambient display.
- Do ambient displays better integrate with social situations than video screens (e.g., video screens tend to disturb a conversation)?
- Where will ambient displays and sounds be rendered throughout the natural environment? In which spaces will they be placed?
- How is it possible to create ambient information contexts?
- How could ambient displays be used for ambient-assisted living?

2.2 Morphing

The morphing principle maps the digital overlay with the underlying natural environment. Two related papers are discussed. The paper "A core ontology on events for representing occurrences in the real world" contributed by Ansgar Scherp et al. [27] describes the notion of events in multimedia and provides an approach to modeling the relation between the natural world and digital overlay via an "event ontology". The paper entitled "Rethinking QR Code: Analog Portal to Digital World" by Seongbok Baik [2] introduces the QR codes as an analog portal—an ambient media gate to the digital world.

2.2.1 Modeling the relation between the natural world and digital overlay via an event ontology

In the paper of Ansgar Scherp et al. [27], events are described as a natural abstraction of happenings in the real world and objects as participating in events. Computer-science research is evolving from object-based approaches to event-based approaches. Numerous solutions and approaches for modeling, detecting and processing events have been found recently. Moreover, various applications that are based on events and make use of events are developed.

Most of the currently available literature deals with the capturing, processing and management of low-level events, where an event is considered as the existence or non-existence of a signal within some computerized system. As opposed to this, the paper [27] provides an efficient execution of the applications built on the top of such approaches. On the domain-level, there are high-level events, which are understood as the occurrences in which humans participate. Such high-level (domain-level) events can capture and represent human experience. They may be very complex, thus a variety of aspects such as time and space, objects and persons participating, as well as mereological, causal and correlative relationships between events need to be considered.

The paper proposes a formal ontology of domain-level events called Event-Model-F, which is based on the DOLCE + DnS Ultralight foundational ontology and follows a pattern-oriented design approach for ontologies. It uses specializations of the *Descriptions and Situations* (DnS) ontology pattern, which allows formally precise representations of different contextualized views on events. With respect to the aspects of events, specialized instantiations of the DnS ontology pattern have been introduced. They consist of:

- **Participation pattern**, which implements the participation of objects in events and models their absolute time and location.

- **Mereology, causality and the correlation patterns** that implement the structural relationships between events. The mereology pattern also allows modeling of the relative temporal and spatial relations between events and objects. Expressing such a temporal relation between events can be facilitated by the means of DOLCE, such as the formalization of Allen's time calculus.
- **Documentation pattern**, which provides annotating events.
- **Composition pattern** that models the composition of multiple events.
- **Interpretation pattern**, which supports the different event interpretations.

The goal for future work should be to understand the different notions of events in computer science. In addition, research on the low-level and high-level events should be brought together, which can be achieved with the collaboration of researchers from different communities dealing with events.

2.2.2 QR code as an analog portal to digital world

The paper entitled "Rethinking QR Code: Analog Portal to Digital World" by Seongbok Baik [2] introduces a new view of accessing the applications and the activities using QR codes, the information for the objects existing in the everyday human environment. This view emphasizes the possibility of the QR codes as an analog portal—an ambient media gate to the digital world, because it shows a new way of obtaining access to the internet and may be able to change the culture of retrieving information when the QR code infrastructure becomes mature.

In order to realize the plan of connecting the two worlds by the QR code technology, two major infrastructures should be prepared. First, plenty of the printed QR codes should be distributed in the everyday human-life environment. Second, the scanner should be popularized among the general population. Putting the QR codes to real-world objects is more and more common and since there exist scanning applications for many mobile phones with cameras, a second infrastructure is also prepared.

The author of the paper developed two applications. In the first one users access the web page through scanning the QR code with a camera on the mobile phone. The second application makes a call to the preset telephone number, coded with the QR code. They both offer advantages to the user in by-passing internet search engines to find the web page or telephone number connected with some object.

2.2.3 Discussion

Key ideas for impacting ambient media:

- Identification modalities for identifying moveable objects in contrast to location-based services identifying fixed objects (e.g., QR codes).
- An example of the crossover of the digital and analog world.
- Ambient media require a consumer acceptance of novel services and new technologies.
- Combination and mashup of data to provide advanced services (e.g., mashup of the location data with shopping information to compare prices).
- Added-value advertisements, possibilities to draw attention, and consumer-behavior measurements (e.g., increased shopping experience).

- Reduction of information overload and easy-to-use applications.
- Human intelligible encodings (e.g., QR codes vs. conventional media covers).

Directions and questions for further research:

- Can we predict events if we collect sufficient information (e.g., a traffic-prediction system)?
- How can the network of events be handled, smartly interpreted, and how do they differ from existing information-processing systems?
- How do emergency centers currently cooperate with each other?
- Can we use hierarchical modeling of events?
- How to use personal events to enhance communication and collaboration—social presence?
- Can ambient media be applied in ambient assisted living and specific application areas (e.g., event hotspots for journalists)?
- How can ambient media have a meaning and the methods and approaches be used as a tool to model the meaning of ambient environments?
- Who performs the tagging of semantic media? Can information be extracted automatically?
- How can data be verified and conflicting information be resolved?
- Who would be the users of mobile semantic data?

2.3 Intelligence

2.3.1 Health-monitoring media

An example of combining ambient-assisted living with intelligent systems into health-monitoring media has been contributed with the paper entitled "Automatic recognition of gait-related health problems in the elderly using machine learning" [26] by Bogdan Pogorelc *et al*. The paper proposes a semantic ambient media system for the automatic recognition of health problems that manifest themselves in the form of gait. The purpose of the system is to prolong the autonomous living of the elderly at home. In the event that the system was to recognize a health problem, it would automatically notify a physician with an included explanation of the automatic diagnosis.

The gait of the elderly user is captured using a motion-capture system, which consists of tags attached to the body and sensors situated in the apartment. The positions of the tags are acquired by the sensors and the resulting time series of position coordinates are analyzed with machine-learning algorithms in order to recognize a specific health problem. The authors propose novel semantic features for training a machine-learning classifier that classifies the user's gait into: a) normal, b) with hemiplegia, c) with Parkinson's disease, d) with pain in the back and e) with pain in the leg.

The studies of a) the feasibility of automatic recognition and b) the impact of tag placement and noise level on the accuracy of the recognition of health problems are presented. The experimental results of the first study (12 tags, no noise) showed that the k-nearest neighbors and neural network algorithms achieved classification accuracies of 100%. The experimental results of the second study showed that by using several machine-learning algorithms a classification accuracy of over 99% is achievable using 8 or more tags with up to 15 mm standard deviation of noise.

The results show that the proposed approach based on semantic descriptions is very accurate and can be used as a guide for future studies in the increasingly important area of ambient-assisted living. Since the system is embedded in the domestic environment of the elderly person, it uses an artificial intelligence approach to semantically interpret the health

state and provides a natural explanation of the hypothesis; it is an example of the semantic ambient media for ambient-assisted living. The paper contributes to a vision for the future of ambient media as it provides a sophisticated algorithm for detecting health problems based on semantic descriptions.

2.3.2 Discussion

Key ideas for impacting ambient media:

- The system is robust (small number of false negatives and false positives).
- What does a realistic environment for the elderly look like?
- What is an adequate approach for a person-independent evaluation of gathered data?

Directions and questions for further research:

- Integration of sensor networks into textiles and clothing.
- Emotional patterns as a tool for recognizing the health state (e.g., unnatural apathy or unexpected excitement).
- QR tags are an additional possible technology for AAL.
- Recognizing motion patterns for other daily-living situations (e.g., rehabilitation or sport analysis).
- Direct user feedback besides feedback to a professional to enable self-monitoring.
- In the final system other indicators of activity such as light and pressure sensors could also be incorporated.

2.4 Collaboration

2.4.1 Enhancing human-human interaction with ambient media

Human–human collaboration and mediated human–human collaboration is already a common part of our daily lives. Where many works focus on the pure technical components of developing audio-video channels for communication, the emotional component is often neglected. The contribution entitled "Presence bubbles: supporting and enhancing human-human interaction with ambient media" by Radu-Daniel Vatavu [28] focuses on this research challenge. The contribution is devoted to the development of new modalities for self-expression and an emotional communication channel. To illustrate the approach, the author developed an application based on interactive surfaces enabling emotional responses and interactions.

Being able to transmit the right message in the right form at the right moment is essential for effective human–human interactions. When messages are correctly transmitted, they enable better understanding or empathizing with the communicator and, consequently, they can better adapt to his/her needs. However, because of the complexity of the factors and means involved during this process, partial transmissions or miscommunications often occur, which sometimes lead to frustration, dissatisfaction and the remaining feeling of an unsuccessful communication. Ambient media appears in this context as an interesting opportunity for locating and using additional means for self-expression: people (i.e., consumers of ambient media) go into their "ambient digital world" and search for the right extra modalities that would enhance (not replace) self-expression beyond current capacities and abilities.

Previous research already tried to use digitally enhanced versions of real-world objects with a known emotional content or potential in order to achieve such desiderates. The goal is to fit such expressive communicators into an ambient media that connects emotionally rather than relies on simple communication. Affection and emotion rather than simple presence communication have been of interest in order to enhance the transmission channels with new dimensions. Picture frames for example have been frequently used for their powerful capacities of generating and transmitting emotions [4], while innovative ambient interfaces such as the lovers' cup [5] have been developed in order to introduce affection in the communication channel. It is worth going even further and looking at ambient media as a form of supporting and enhancing human–human interaction, providing the necessary means at the right location at the right time, transforming thus into a responsive, expressive and emotionally rich media.

Radu-Daniel Vatavu investigates the possibility that ambient media enhance human communication, presence and emotion transmission in order to support a more effective self-expression in the form of the Presence Bubbles [28]. The presence bubbles represent graphical portrayals of one's personal digital content showing information that had already been marked as public on personal blogs or in various social networks. The bubbles are displayed on the nearest available interactive surface or large-screen display, allowing public or private get-togethers to be enhanced by digital content, showing each participant's previous activity in an independent and autonomous fashion. The concept relates to the bubbles being an expression of their owners' personality and recent experiences: they represent their owners, bringing in and showing personal information with the purpose of adding up to currently taking-place interactions. It is interesting how the simple concept of the presence bubbles brings in several advantages with respect to supporting and enhancing human–human interactions: the bubbles provide the means for better self-expression; allow implicit communication; have the ability to trigger new topics in conversation and implicitly new interactions; and act as external memory support, thus generating or enriching communication.

Ambient media become complements and enhancers of human–human interaction, expressing what would have been intended, but words or gestures momentarily failed to express.

2.4.2 Discussion

Key ideas for impacting ambient media:

- Information overload—with how much information can the consumer be confronted (e.g., one bubble).
- Information navigation through ambient content and the line between enhancing and distracting interaction.
- The collaboration environment should be simple and generic, so that the medium can evolve (evolving ambient media).
- An unobtrusive media environment enabling context-awareness.
- Ambient media as new way of self-expression.
- Emotion recognition and consequent collection of affective information.

Directions and questions for further research:

- It should be ubiquitous, because communication is not limited to one or two places.
- How can unobtrusiveness be modeled for consumer convenience?

- How can a complete human–human interaction shift from today's face-to-face collaboration to ambient collaboration (e.g., bubbles can improve and consequently redefine it)?
- What is the role and connection to surface computing, e.g., [7]?
- How can the infrastructure be created, and where can the ambient surfaces be mounted?
- Can better interaction be achieved with the mediated or non-mediated (natural) sharing of expressions and how interactive can the sharing of expressions be?

2.5 Experience

2.5.1 Developing conventional domestic infrastructures into ambient media

The contribution of Andol X. Li and John V. H. Bonner entitled "Smart Control Panel: Developing Conventional Domestic Infrastructures into Ambient Media" [14] deals with the consumer experience that requires a large amount of knowledge in the field of Human–Computer Interaction. The paper presents the novel development of a domestic central-heating control panel from a conventional control system to ambient media.

The authors performed cycles of design and evaluations in order to refine the understanding of the new media. Based on that they investigated potential methodologies for transforming conventional devices into ambient media.

The paper discusses two studies: in the first, consumer groups were interviewed in order to discover behavior patterns that would inform the design of an interface for room-temperature control. The behavior patterns were firstly observed on the existing devices for the temperature control. A new interface for the conventional temperature-control device was designed by adding novel features such as the room's temperature setting, energy supplying switcher and real-time energy-consumption display. The most advanced feature was the prediction of consumption costs, which was shown intuitively. To transform the physical device into a form of ambient media, the authors used a ceiling-mounted projector and a camera; the interface was projected to the coffee table and all manipulations were achieved by the camera overhead. The evaluation of the new ambient media was achieved using scenario settings, questionnaires and teach-backs. The results of the evaluation revealed that participants paid more attention to the ambient environments, such as the respective rooms' temperature and real-time consuming. However, the participants got confused in the way of the control as they did not know which components were clickable, and how to fully understand the crowned information displays.

The second study is based on the evaluation results of the first one and is devoted to the development of a novel user-interface design for visualizing home controls. The evaluation was useful in identifying the usability and helped researchers to improve the next design in visualizing control buttons and grouping display messages. More physical appearances were introduced to simulate the virtual interface in the new design. The authors also evolved an evaluation methodology due to the requirement of a precise understanding of new features. The results of the analysis showed that the new interface provided intuitive information for the participants and all the participants preferred the improved design to the previous one.

2.5.2 Selection and design of adequate pieces of information for an existing ambient display

Ambient media systems are embedded into the environment. Therefore, when talking about presenting ambient media, it is also important to consider a way of displaying it. A great number of ambient information systems exist; some of them built for a special purpose, other for various purposes. The paper "How to Select and Design Adequate Pieces of Information for an Existing

Ambient Display" by Florian Förster [9] is built for various purposes and tries to provide answers to the question of how to select and design information for such an ambient information system. Special attention is paid to the evaluation in a real context. The paper is based on a study comparing two ambient displays: one with an embodiment (namely the "Nabaztag rabbit") and the other one with a screen display. Both systems offered the same kind of information. Since the paper is asking users what they would want to have on an ambient display, it is trying to improve their experience. Moreover, the evaluation of the design is made for the same reason. Furthermore, to make the experience of the users better, the re-design is also made on the basis of a user evaluation.

2.5.3 Discussion

Key ideas for impacting ambient media:

- The paper "Smart Control Panel: Developing Conventional Domestic Infrastructures into Ambient Media" revealed a potential to transform a conventional infrastructure into interactive ambient media.
- The messages provided by the new ambient media should be as intuitive as the original function meanings.
- To improve the experience of the users with the ambient media device, cycles of *design and usability evaluations* are necessary.

Directions and questions for further research:

- How to convert the existing media into ambient media in order to maximize the user experience?
- How to select the appropriate information for existing ambient displays?
- What usability evaluations are the most suitable?

2.6 Contributions covering several ambient media principles

2.6.1 Affective interfaces and ambient artwork

An illustrative example for covering the principles of morphing, intelligence, and manifestation is the contribution by Stephen W. Gilroy *et al*. entitled "Affective Interfaces and Ambient Artwork" [10]. The paper describes a system for digital artwork gathering context information about the environment (morphing) to perform an affective, thus emotional interpretation (intelligence), to display its responses (manifestation).

The authors describe a system for incorporating affective data within digital artworks using a dimensional model of emotion and discuss the approaches for evaluating both the efficacy of such a system and the artistic success of the resulting artworks.

The aim of the paper is to provide a combination of generalized models of emotion and conceptualized interpretations of affective interactions, making use of ambient technologies, which artists can deploy to mediate the relationship between the audience reaction and the evolving aesthetics of the artwork. The ambient aspects of this system lie more in the sensors and the aggregation necessary to derive an affective interpretation than in the conveyance or visualization of user-relevant information.

2.6.2 Discussion

Key ideas for impacting ambient media:

- It serves as an electronic emotional memory.
- Affective interfaces provide an ambient interactive medium that can be utilized in digital artworks embodied in physicality.
- Temporal patterns of affective interaction offer a new model of user experience as part of the semantics of interactive art.
- The presented study is introducing *flow* as a desirable measurement of the pleasure derived from the interaction with engaging, ambient, immersive new media, accessible through ambient affective means.
- Temporal characterizations of affective experience, including flow, can help guiding and evaluating the development of ambient artworks in real time.

Directions and questions for further research:

- What is the actual content that is affecting emotions?
- How can artwork display "mirrored" emotions?
- Does an "element of fun" attract users in ambient systems?
- In the future, semantic links between places, objects and actors can be made.
- Eye-tracking and other sensors can be included.

3 Results and discussion

The aim of this section is to predict research beyond the state of the art in the field of semantic ambient media until the year 2020. As shown in Fig. 2, the state-of-the-art literature can be grouped into three major topics in the following way:

1. Content & art:
   a. How to select and design adequate pieces of information for an existing ambient display
   b. Affective interfaces and ambient artwork
2. Recognition & capture of happenings:
   a. Automatic recognition of gait-related health problems in the elderly using machine learning
   b. How to select and design adequate pieces of information for an existing ambient display
3. Event hot-spots (situations, news, location):
   a. A core ontology on events for representing occurrences in the real world
   b. Presence bubbles: supporting and enhancing human-human interaction with ambient media
   c. Rethinking QR code: analog portal to digital world

3.1 Analysis of literature

The links between them denote they are all connected, i.e., they are all part of the field of semantic ambient media.

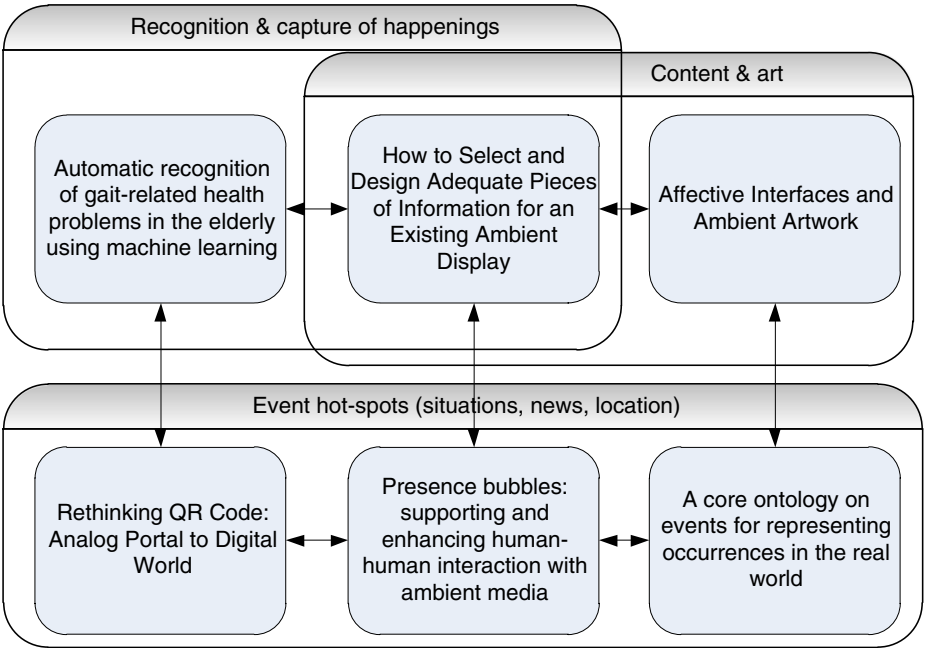

Fig. 2 Links between the analyzed literature

Another possible grouping of the contributions is the following:

1. Modeling and understanding:
   a. A core ontology on events for representing occurrences in the real world
   b. Automatic recognition of gait-related health problems in the elderly using machine learning
   c. Affective interfaces and ambient artwork
2. Interfacing and visualization:
   a. How to select and design adequate pieces of information for an existing ambient display
   b. Presence bubbles: supporting and enhancing human-human interaction with ambient media
   c. Rethinking QR code: analog portal to digital world

Within each of the two groups of papers, discussions with regards to different perspectives of the papers are presented in the following subsection. The differences and similarities in their perspectives were investigated in order to find the common connecting idea. The results of discussions within each group form the vision of semantic ambient media for the year 2020.

3.2 Vision of semantic ambient media for the year 2020

Modeling and understanding Within the first group the topic of modeling and understanding is discussed.

Modeling of entities:

- situations,
- data/information/knowledge,

- devices,
- users,
- events and
- tasks

is an important research issue. The overall quantity of these models is sufficient, but there is a lack in their quality. Moreover, the modeling of relations, influences and interactions between the models of different entities is a difficult task to achieve. This is not only for technical reasons, but also because the system needs to understand the interactions between all the entities. For instance, if an *event* happens, how does it influence how the *user* feels in a certain *situation* given a certain *task*.

Understanding as second part of the group discussion topic means to understand how these entities relate to each other, how ambient applications should behave, what kind of content should be displayed, etc. The schema of the modeling and understanding is shown in Fig. 3. Since all the entities need the data/information/knowledge, they are all connected with the block representing it. The entities–devices, users, tasks, events and situation–all interact with the entity data/information/knowledge.

Some additional terms that are connected with the group topic were also identified. The term *narrative structures* is connected with storytelling, one example being interactive games.

Another term is *tutoring system* where the system has explicit *expert knowledge* of how to teach *users* what they should do. The traditional tutoring system consists of:

- user,
- expert and
- tutor model.

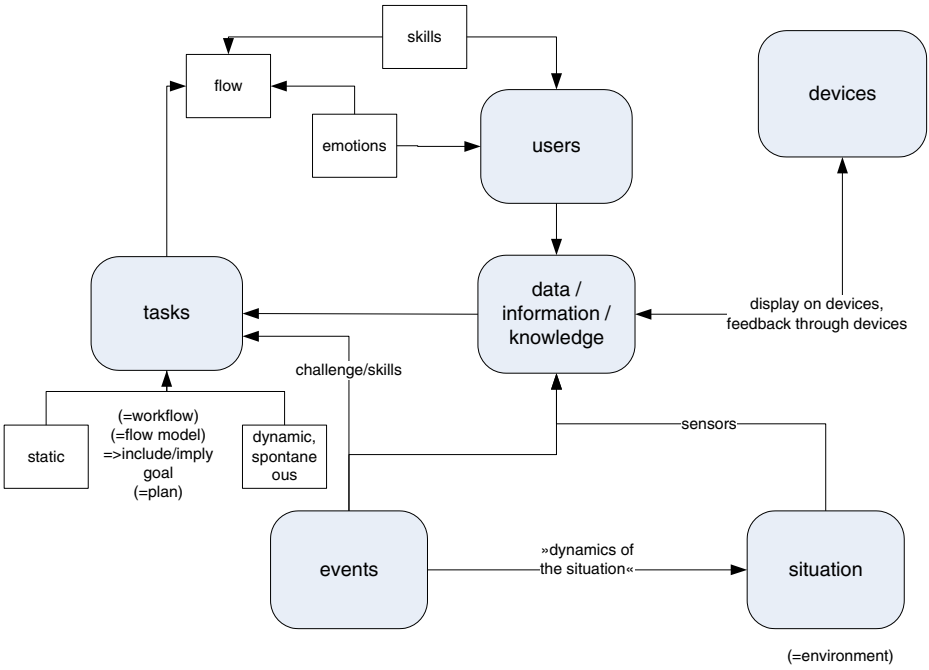

Fig. 3 Modeling and understanding schema

In relation to AAL, an *expert* could mean a *medical knowledge base* that the system uses to provide information to the *users* about what to do in a specific health *situation*. These applications are domain specific and have to be prepared for a specific scenario in advance.

A future tutoring system could be addressing the issues of AAL. An example of using a medical *knowledge base* is health-problems detection, especially required for prolonging the autonomous living of elderly users at home. Currently in [26], the movement is captured using a motion-capture system and the potential health problem is modeled and automatically recognized using data mining algorithms. In the future, such systems could also teach the elderly, their relatives and medical professionals how to react in a certain *situation*. Also, the feedback between elderly *user* and the system should be provided, thus if the user's movement in some situation is erroneously interpreted as a health problem, the user could provide feedback to the system whose model will adapt in order not to repeat the alarm in a similar situation in the future.

Another proposed application using medical *knowledge* is the brain-stroke rehabilitation scenario. After the brain stroke the *user* should repeat exercises (*tasks*) every day, and the tutoring system is teaching him/her how to perform the exercises. If the user feels bad or depressed, the system should slow down the training or adapt it to the user's current needs. Physiological measurements (e.g., galvanic skin response and electromyography) such as in [10] can be used to evaluate the user's emotions in order to adapt the training.

The loop in Fig. 4 denotes that providing content should influence the users' experience/emotion and vice versa. Users normally perceive content through communication with other users or through (digital) media. That causes experiences and emotions in their perception. Thus, the feedback to the system should capture the current status of the users, tasks, events, devices etc. in order to provide the most appropriate content, which is a difficult task. A step in the direction of capturing the user's emotional status was presented in [10]; however, for the future application the current status of other entities should also be considered. Furthermore, there are a lot of possibilities for improvement in providing the appropriate content for the specific context (e.g., experience and emotion), i.e., providing the context-specific content.

The questions that remain for the future are:

- How does the system know what information should be rendered to an environment?
- What kind of interaction and in which way should the system provide?
- etc.

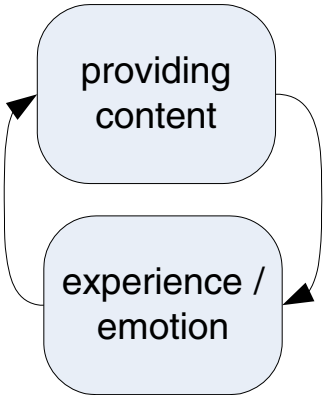

Fig. 4 Content-experience loop

Future applications of the monitoring of elderly people could be improved if the approaches presented in the papers *Automatic recognition of gait-related health problems in the elderly using machine learning* [26], *Affective Interfaces and Ambient Artwork* [10] and *A core ontology on events for representing occurrences in the real world* [27] were to be combined and upgraded.

With the Event-Model-F, sophisticated descriptions of real world events can be created and exchanged. We can model the participation of objects with the *participation pattern*. Objects in this domain are living and non-living objects. Living objects are: the elderly person being monitored, the relatives and the emergency control center being notified in case of the recognized health problem as well as medical doctor helping the old person. The non-living objects are: motion-capture equipment, machine-learning algorithm on the computing device, physiological sensors and system for the interpretation of emotions as well as the communication path and the graphical user interface for the emergency control center. In the case of a particular movement of the elderly, instantiation of the *causality pattern* is also used for a speculation about the health state causing this movement. The causality pattern can be used to speculate about the current emotions of the user causing the change on the physiological sensing devices, such as galvanic skin response and electromyography.

Machine learning provides a description for the causality pattern and also for the *correlation pattern* from Event-Model-F since it correlates a current recording of movement with the recording of different health states to recognize it. Similarly, it correlates the outputs of the physiological sensors with the emotions. A health state may typically be composed of multiple events, which are modeled using instantiations of the *composition pattern*. These events are called symptoms in this particular domain and are recognized with multiple features of a machine-learning algorithm. For describing an event, different instantiations of the Event-Model-F are combined, each providing a specific part of the event description. In the same way, the output of each physiological sensor is a separate feature.

As there might be different opinions about the cause of the current recorded movement of the elderly, there can be multiple instantiations of the causality pattern. To manage these multiple instantiations of the causality pattern, the event *interpretation pattern* is used to form different nexuses of the causality pattern instantiations and providing different views of the same event. This is equivalent to the emotion interpretation domain.

In the elderly health-monitoring domain, several entities are involved, such as the elderly person, relatives, emergency control center and a medical doctor, who need to exchange event descriptions. Typically, they use different systems which do not provide an efficient exchange of descriptions. For making efficient communication and thus providing more safety for the elderly people, the proposed approach can be used.

The presented research provides answers to questions of the Semantic Ambient Media Experience (SAME) notion [21]:

- *What is 'content' and how can it be presented in the age of 'ubiquitous' and 'pervasive'? How to present, select, compose and generate ambient content?* In the domain of prolonging independent living of the elderly, a combination of the Event-Model-F ontology and machine learning are proposed. Content is information about the health state of the elderly and is generated with a machine-learning algorithm that provides descriptions for the causality and correlation pattern of the Event-Model-F ontology through a recognition of the cause for the particular movement of the elderly. Content is then composed using instantiations of the composition pattern and finally

presented using Event-Model-F ontology. Content can also be composed through the interpretation of emotions and presented in the form of changing artwork.

- *How can sensor data be interpreted and intelligently mined? How to manage and re-use ambient content in specific application scenarios?* In the elderly monitoring domain, sensor data from the motion-capture system are modeled with machine-learning methods, which provide descriptions for the causality and correlation pattern of the Event-Model-F. The models for the interpretation of the health state (content) are induced from the initial group of the elderly with specific health problems and used on the new elderly users, who are healthy when starting to use the system, for the interpretation of their potential health problems. Thus, the content is re-used. To manage these multiple instantiations of the causality pattern (or other patterns), the event interpretation pattern is used to form different nexuses of the pattern instantiations and provide different views onto the same event. Thus, the interpretation pattern supports reusing parts of the event descriptions on the level of pattern instantiations. In "Affective Interfaces and Ambient Artwork" [10] the system makes use of reusable components, each focused on an affective modality, characterized as sensor data combined with an affective interpretation in terms of a universal formalism of emotion, the Pleasure-Arousal-Dominance (PAD) model. This is a dimensional representation that does not impose emotional categories and is therefore compatible with complex affective experiences, including aesthetic ones, which may not be otherwise represented by standard emotional categories.
- *How can collaborative or audience-participatory content be supported? How can existing media such as TV, home entertainment, cinema be extended by ambient media?* In the elderly care domain, audience-participatory content is supported through the possibility of the physician seeing/hearing the alarm and an explanation of the reasons for the alarm (including a live kinematic visualization of the user's movement) on the augmented existing media, i.e., on the ambient media. Another example of extending existing media into the ambient media is the contribution of Andol X. Li and John V. H. Bonner [14], which presents a novel development of a domestic central-heating control panel from a conventional control system to ambient media.
- *What are the characteristics of ambient media, its content, and its technology?* Ambient media are ubiquitous, pervasive and embedded in the natural environment of the user and they improve the quality of life.

The topic of the first group *Modeling and understanding*, mainly done in the digital world, is closely connected with the topic of the second group, *Interfacing and visualization*, mainly performed in the physical world, through a rendering of information to an environment.

Interfacing and visualization The summary of the second group with the topic *Interfacing and visualization* is presented in the paragraphs below. Interfacing ambient media should be simple, efficient and as natural as possible. The requirements are in agreement with what is envisioned for human–computer interaction in the year 2020 [12]. Systems that allow interaction to take place naturally, comfortably, effortlessly and fluently will be more and more preferred and gain great popularity as technology will allow them. The advantages of such interactions come from the fact that they do not require previous knowledge, skills or long-term practice. The naturalness of interfacing ambient media for performing the desired task will be definitely a plus for all professional or age categories for which previous knowledge or even dexterity during the interaction are not longer required.

With the continuous advances in visualization technology it is likely that ambient displays will become ubiquitous and more and more low-profile and unobtrusive. In the same direction of thought, the visualization of ambient information should take advantage of natural human-oriented perception and should employ and make use of the benefits of anthropomorphism [9]. Questions are being raised with regards to the proper information to be displayed: what to display, when to display, how to display and to whom the information should be directed? Adaptive visualization that takes context into account (in the form of location, time, user and current activity) will become a requirement in the era of terabytes of knowledge. The format in which ambient media is displayed to the always-moving user must be rethought in order to maximize the impact of the message as well as the benefits of the information that is acquired.

Emotion should play an important role when interacting with computing systems, just as it plays an important role in human interactions [25]. Benefits of recording actual emotion in opposition to it being derived from other media are clear, but the question still remains - how to retrieve it correctly, efficiently and at the right moment in order to enhance the users' current experience.

Interfacing and visualization can serve as enhancers for human–human interaction. With respect to this perspective, current every-day interactions and conversations may trigger proper adaptive visualization and, inversely, the visualization of content may trigger new interactions with both ambient media as well as interactions between the concerned human participants (such as the presence bubbles [28]). To put it all in one summarizing form, "ambient media could shift human–media interaction towards human–human interaction".

4 Combining the ideas of several research studies

Ideas from the paper *How to Select and Design Adequate Pieces of Information for an Existing Ambient Display* [9] and from the paper *Affective Interfaces and Ambient Artwork* [10] can in future be incorporated into the system presented by the paper *Automatic recognition of gait-related health problems in the elderly using machine learning* [26] and therefore a health-monitoring system for elderly could be turned into an even more ambient application. In the beginning we would need to evaluate what information is critical and what is non-critical and can be displayed on ambient display, which is on the periphery of the user's attention. Since elderly people should be active and performing enough energy-consuming activities, one example of adequate information for an ambient display would be information about whether an elderly person has done the appropriate activities during the day. Such information could be displayed as an ambient artwork in the form of a painting on the wall.

An example of such artwork could be a tree, which would have a lot of green leaves when the elderly person did a lot of activities. Otherwise, leaves would start falling from the tree. Another idea would be digital painting of a waterfall. In the case of a large amount of activities it would be full of water, otherwise with less and less water. In addition, ambient sound could be incorporated into such an artwork; however, it should not be obtrusive. In the case of enough performed activities, birds would sing, otherwise not. In the case of displaying this information as an ambient artwork, guests would understand this painting only as an art, not knowing the private information behind it. Such a display would be completely incorporated into the wall: the digital world would be morphed with the physical.

Since the elderly often feel lonely and not able to communicate with their relatives, (e.g., because relatives are at work), they could also be interested in expressing their emotions and

presenting their current statuses using emotional responsive ambient media [28]. Therefore, health-monitoring systems would get a useful communication addition. The proposed addition would not have automatic recognition part as the main monitoring system, but would give control to the elderly. By using it, the elderly would gain an important means of self-expression.

The technology presented in the paper *Rethinking QR Code: Analog Portal to Digital World* [2] is suitable for a health-monitoring system for the elderly. For such an application, QR codes would be scanned with mobile phones and would consist of additional data, such as a schedule for taking the medicine or a schedule for doing exercises. In both cases the schedules can be adapted in time by the physician remotely, based on the recognized progress of the observed user. Moreover, since the elderly often have problems with eyesight, QR codes could make their living easier. After scanning the QR code, the system would generate voice instructions for the schedule of taking the drug and also for the way of taking it, e.g., with liquid after a meal. The system would remind the elderly at the time to take the next dose of medicine. Furthermore, after scanning each medicine, the system will check if it can be taken with other medicines that the elderly person is already taking.

5 Conclusion

This paper provided an advanced introduction to the field of semantic ambient media. In recent years, semantic ambient media have progressed from ambient advertising to one of ever-present areas such as ambient intelligence or pervasive computing. Now, the field has several broadly accepted definitions and principles (manifestation, morphing, collaboration, intelligence and experience). Researchers in the field have established a list of threat issues. The paper gives solutions for the threat issues and illustrates success stories of the field. The study presents a survey of the related work with a thorough discussion of it. Special attention is given to a new sub-area of semantic ambient media - ambient-assisted living with health-monitoring media, significantly supported by intelligence. Important part of the study is discussion of the future possibilities of the field, especially by combining the ideas of the state-of-the-art research.

Despite the evident progress in the field, several problems are still present, such as true semantics and human-cognition-level content. However, the increased number of contributions presented demonstrates the growing dynamics of semantic ambient media.

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Bogdan Pogorelc (http://dis.ijs.si/bogdan/) is a Ph.D. candidate and a Research Assistant at Department of Intelligent Systems at Jožef Stefan Institute (JSI) in Ljubljana, Slovenia. Since 2008 he has been employed at Jožef Stefan Institute and Špica International d.o.o. for which he obtained the *Young Researcher* fellowship.

Bogdan was visiting researcher at University *Rovira i Virgili* in Tarragona (Spain) in 2007, where he performed research on *Fuzzy Artmap neural network for assessment of metabolic syndrome*. He received several awards for his research: e.g., 1st Prize at Slovenian forum of innovations for *Intelligent security system for the surveillance of buildings* in 2009 and awards of 1) National Instruments and 2) University of Maribor for *Mobile electrocardiograph* in 2006. His publication list consists of 30 items, 6 of them in scientific journals. He is a reviewer for several scientific journals and conferences, a member of several scientific societies, e.g., ACM, IEEE and ECCAI, and a Program committee- and Organizational committee member of the series of *Jožef Stefan International Postgraduate School Student's Conferences* and of the series of *International Workshops on Semantic Ambient Media Experience*. His work *Intelligent surveillance system and procedure for detecting unusual activities* is in the patent pending procedure. Bogdan's research interests include artificial intelligence, machine learning, (temporal-/time series-) data mining as well as applications in these areas, especially medical informatics and ambient intelligence. His main research interests are health problem recognition, activity recognition and fall detection.

Radu-Daniel Vatavu is a Lecturer in Computer Science at the University "Stefan cel Mare" of Suceava, Romania. He holds a PhD in Computer Science from the University "Stefan cel Mare" of Suceava and from the University of Sciences and Technologies of Lille, France in the domain of gesture recognition. His research interest is Human-Computer Interaction with focus on novel interactions, gesture-based interfaces and using computer vision for achieving innovative interactions.

Prof. Dr. Artur Lugmayr describes himself as a creative thinker and his scientific work is situated between art and science. Starting from July 2009 he is full-professor for entertainment and media production management at the *Department of Business Information Management and Logistics* at the *Tampere University of Technology (TUT)*: EMMi – Entertainment and Media Production Management (http://webhotel2.tut.fi/emmi/web/). His vision can be expressed as to create media experiences on future emerging media technology platforms. He is the head and founder of the New AMbient MUltimedia (NAMU) research group at the Tampere University of Technology (Finland) which is part of the Finnish Academy Centre of Excellence of Signal Processing from 2006 to 2011 (http://namu.cs.tut.fi). He is holding a Dr.-Techn. degree from the Tampere University of Technology (TUT, Finland), and is currently engaged in Dr.-Arts studies at the School of Motion Pictures, TV and Production Design (UIAH, Helsinki). He chaired the ISO/IEC ad-hoc group "MPEG-21 in broadcasting"; won the NOKIA Award of 2003 with the text book "Digital interactive TV and Metadata" published by Springer-Verlag in 2004; representative of the Swan Lake Moving Image & Music Award (http://www.swan-lake-award.org/); board member of MindTrek (http://www.mindtrek.org), EU project proposal reviewer; invited key-note speaker for conferences; organizer and reviewer of several conferences; and has contributed one book chapter and written over 25 scientific publications. His passion in private life is to be a notorious digital film-maker. He is founder of the production company LugYmedia Inc. (http://www.lugy-media.tv). More about him on http://www.tut.fi/emmi.

Björn Stockleben was awarded his master's degree in Media Sciences, Media Technology and Computer Sciences from Technical University of Brunswick and Brunswick School of Arts in 2003. For Rundfunk-Berlin Brandenburg he has been acting as technical manager in EC- and ESA-funded research projects such as IST-INSTINCT, IST-ENTHRONE and ARTES-COTV. He is an expert in participative media, interactive service authoring and non-linear AV media. Currently he works as scientific coordinator for the new master program "Cross Media", which combines management, journalism and interaction design at University of Applied Sciences Magdeburg-Stendal. He lectures in media theory at University of Applied Sciences Bremen and human-machine interaction at Technical University Brunswick.

Thomas Risse is the deputy managing director of the L3S Research Center in Hanover. He received a PhD in Computer Science from the Darmstadt University of Technology, Germany in 2006. Before he joined the L3S Research Center in 2007 he lead a research group about intelligent information environments at Fraunhofer IPSI, Darmstadt. Currently he is the scientific and technical director of the FP7 ARCOMEM project on Web archiving using social media information. Thomas Risse's research interests are semantic evolution, data management in distributed systems, and self-organizing systems. He serves regularly as program committee member or project reviewer. He published several papers at the relevant international conferences.

Juha Kaario (MSc, MBA) is a Head of Business Development at Varaani Works Oy, a start-up founded in 2010. Previously he was a Senior Business Development Manager at the Nokia Research Center. He joined Nokia Mobile Phones marketing department in 1995 and moved to Nokia Research in 1997. In Nokia Research Center he has worked ten years as a research manager and senior research manager for several teams including Wearable Computing (1998–2002), Personal Content (2002–2003) and Mobile Games (2003–2007). Prior Nokia he has worked in the University of Tampere (1993–94), in the Technical Research Center of Finland (1992–93) and as a co-owner in a small enterprise (1993–1996). His interests are in cross discipline research for sustainable development, pervasive computing, social media and mobile services combined with business innovation. He is currently working in the Varaani Oy as a business developer and is the Chairman of the Board in another start-up, Newelo Oy.

Estefania Constanza Lomonaco is a Ph.D. student at the University of Nova Gorica and at the Slovenian Academy of Sciences and Arts in Ljubljana (Slovenia). She obtained Bachelor of Science in Marketing in 2006 and Bachelor of Science in Business Administration in 2008 from the UADE Business University. The University UADE also awarded her with the honor diploma in 2007.

Prof. Dr. Matjaž Gams (http://dis.ijs.si/Mezi/) is professor of computer science and informatics at the Ljubljana University and senior researcher at the Jozef Stefan Institute, Ljubljana, Slovenia. He teaches several courses in computer sciences at graduate and postgraduate level at Faculties of Computer science and informatics, Economics, etc. His research interests include artificial intelligence, intelligent systems, intelligent agents, machine learning, cognitive sciences, and information society. His publication list includes 500 items, 70 of them in scientific journals. He is an executive contact editor of the Informatica journal and member of editorial boards of several international journals. He is heading the Department of intelligent systems, president of several societies, cofounder of the Engineering Academy of Slovenia and the Artificial Intelligence Society and Cognitive sciences in Slovenia; currently president of ACM Slovenia. He headed several major applications in Slovenia including the major national employment agent on the Internet, the expert system controlling quality of practically all national steel production, and the Slovenian text-to-speech system donated to several thousand users.