Journal of Information, Communication and Ethics in Society

Human-driven design of micro- and nanotechnology based future sensor systems

Veikko Ikonen Eija Kaasinen Päivi Heikkilä Marketta Niemelä

Human-driven design of micro- and nanotechnology based future sensor systems

Veikko Ikonen, Eija Kaasinen, Päivi Heikkilä and Marketta Niemelä
VTT Technical Research Centre of Finland, Tampere, Finland

Received 14 November 2013
Revised 19 June 2014
16 November 2014
26 November 2014
Accepted 26 November 2014

Abstract

Purpose – This paper aims to present an overview of the various ethical, societal and critical issues that micro- and nanotechnology-based small, energy self-sufficient sensor systems raise in different selected application fields. An ethical approach on the development of these technologies was taken in a very large international, multitechnological European project. The authors approach and methodology are presented in the paper and, based on this review, the authors propose general principles for this kind of work.

Design/methodology/approach – The authors' approach is based on a great amount of experience working together in multi-disciplinary teams. Ethical issues have usually been handled in the authors' work to some degree. In this project, the authors had the opportunity to emphasise the human view in technological development, utilise the authors' experience from previous work and customise the authors' approach to this particular case. In short, the authors created a wide set of application scenarios with technical and application field experts in the authors' research project. The scenarios were evaluated with external application field experts, potential consumer users and ethics experts.

Findings – Based on the authors' experiences in this project and in previous work, the authors suggest a preliminary model for construction activity within technology development projects. The authors call this model the Human-Driven Design approach, and Ethics by Design as a more focussed sub-set of this approach. As all enabling technologies have both positive and negative usage possibilities, and so-called ethical assessment tends to focus on negative consequences, there are doubts from some stakeholders about including ethical perspectives in a technology development project.

Research limitations/implications – The authors argue that the ethical perspective would be more influential if it were to provide a more positive and constructive contribution to the development of technology. The main findings related to the ethical challenges based on the actual work done in this project were the following: the main user concerns were in relation to access to information, digital division and the necessity of all the proposed measurements; the ethics experts highlighted the main ethical issues as privacy, autonomy, user control, freedom, medicalisation and human existence.

The work presented in this paper has employed numerous people and the work has been mainly team work. So though there are only the four named authors of this text we owe huge thanks to all the colleagues whom with we have been working in these projects. Furthermore, we would like to present our gratefulness of the valuable participation in all the people who have been involved in our projects as potential users of planned solutions. Naturally, we send big thanks also to people who participated actively and pro bono in the Ethical Advisory Board work of the project. EU and the Guardian Angels project partners funded this research, so last thanks belong to them to for making this work possible. Last parts of these research has been done in Great – project which has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 321480.

Journal of Information, Communication and Ethics in Society
Vol. 13 No. 2, 2015
pp. 110-129

1477-996X
DOI 10.1108/JICES-10-2013-0039

Practical implications – Various technology assessment models and ethical approaches for technological development have been developed and performed for a long time, and recently, a new approach called Responsible Research and Innovation has been introduced. The authors' intention is to give a concrete example for further development as a part of the development of this approach.

Social implications – The authors' study in this particular case covers various consumer application possibilities for small sensor systems. The application fields studied include health, well-being, safety, sustainability and empathic user interfaces. The authors believe that the ethical challenges identified are valuable to other researchers and practitioners who are studying and developing sensor-based solutions in similar fields.

Originality/value – The authors' study covers various consumer application possibilities of small sensor systems. The studied application fields include health, well-being, safety, sustainability and empathic user interfaces. The findings are valuable to other researchers and practitioners who are studying and developing sensor-based solutions to similar fields.

Keywords Ethics, Communication technologies, Sensors, Nanotechnology, Ambient intelligence, Ethical assessment

Paper type Research paper

Introduction

Micro- and nanotechnology will enable very small sensors that can monitor our environment and us. This creates possibilities for many kinds of services. In this paper, we analyse future usage possibilities and the related ethical issues concerning small energy-efficient nanotechnology-based sensor systems. The study was carried out as a part of a European research project called Guardian Angels (GA). The project was aiming far into the future with the following vision: GA technology will enable very small sensors and computing units to monitor, provide feedback and actively involve us in understanding and acting on our own well-being and our environment. The GA units will be self-sufficient in terms of energy and, thus, suitable for the long-term use without maintenance. Several usage possibilities are foreseen in health, well-being, safety, sustainability and empathic user interfaces. GA sensor systems can be classified into three classes (Guardian Angels, 2012):

(1) Physical GA facilitate long-term monitoring of health parameters to predict and prevent health problems, and to involve users/patients in actively taking responsibility for their own health and well-being through sustained interactions over longer time periods.

(2) Environmental GA monitor the natural environment, buildings and traffic, for increased safety.

(3) GA technology will enable empathic user interfaces that involve users in experiences where they express themselves and get feedback from the system, which creates even stronger involvement. These systems will offer users "emotional mirrors" that will allow them to reflect and even act on their own bodily signs and signals that indicate different emotional processes.

Ethical challenges of future technologies are multifaceted, and almost infinite when considering different possible contexts and stakeholders. They are also in many cases quite hard to predict and vision concretely. The basic technology should be safe and secure as such, applications should be safe and secure and human values such as privacy, autonomy, trust should not be violated by the technology or the applications.

These ethical issues have frequently been raised as important factors in the user requirement definition process. (Kosta *et al.*, 2008; Rotter, 2008) But ethics has also gained much more visibility as a more important general view in terms of research and innovation (Stahl *et al.*, 2010; Wakunuma *et al.*, 2011). Recently, ethical and societal issues have been emphasised in the European research program Horizon 2020, and a new Responsible Research and Innovation (RRI) approach is proposed for both academia and industry. Engagement, open access, gender equality, ethics, science education and governance are presented as critical dimensions for RRI (European Commission, 2013). But it is not yet clear how this approach would work in real life in particular cases. We intend to give some idea of the implementation of RRI, putting emphasis mainly on the ethics and governance dimensions. We have discussed and gathered feedback on the visions and scenarios with experts and potential users of the identified application fields to further improve our vision of the future possibilities of GA technology. This paper shares the outcomes of those studies.

Ethical assessment of future technologies

Technology assessment has been a part of management studies for several decades (Tran and Daim, 2008). Technology assessment originated in public decision-making in the late 1960s, but it has been widely adopted in other sectors as well (ibid). The original aim was to look at the widest possible set of impacts on a society where a new technology is being introduced, giving the decision-makers an analysed set of options, alternatives and consequences (Coates, 1976). Technology assessment was soon adopted in industry too, but as "inverted technology assessment" (Coates and Fabian, 1982). Coates and Fabian coined the term to reflect the industrial aim of anticipating the effects of the outside world on the company's activities, rather than the other way round. The industrial viewpoint was focussed on assessing the readiness of new technologies: is the technology ready to meet organisational, manufacturing or application goals. Tran and Daim (2008) analysed technology assessment literature published 1970-2007, and they concluded that technology assessment studies can still be divided into these two main areas: original technology assessment for public decision-making and inverted technology assessment for business and non-governmental use. Both areas have several sub approaches.

Our aim has been to foresee early usage possibilities and related ethical issues of GA technology. For policymakers, we wanted to give information allowing them to foresee future needs for political action and legislation. At the same time, our aim has been to support the industry in finding ethically acceptable ways to use the technology. When ethical concerns are identified early, the industry can focus on ethically safe areas, and for the less safe areas, they can try to find ethically sustainable applications. Some ethical concerns may require special features in the technology, such as data protection for privacy. As the problems are identified early, the solutions can be built into the technology, rather than building external protection systems afterwards.

Our approach has links to several earlier approaches both in the original technology assessment and inverted assessment. Impact analysis is at the core of the original technology assessment. Ethical technology assessment by Palm and Hansson (2006) focusses on the ethical implications of new technologies. Their check list of nine crucial ethical aspects is used to assess new technology. In our case, the application possibilities are so wide that we need to first analyse the possible applications, and only after that we can assess the ethical implications. This scenario work is close to the scenario-based assessment model (SBAM) proposed by Banuls and Salmeron (2007). However, their approach is not focussed on ethics but on building scenarios and calculating probabilities. Similar to SBAM, in industrial technology assessment approaches, the focus on scenario work has also been on building scenarios and assessing their probability (Thomas, 1996; Tichy, 2004). The scenarios have been defined by experts using techniques such as Delphi (Thomas, 1996). Tichy (2004) proposed that, rather than top experts, a mix of experts should be used to build the scenarios. Our approach has been to involve a multidisciplinary and multicultural project group to build the scenarios, utilising the fact that people who develop technology have their own visions of usage possibilities. The project group also included experts in key application fields. The scenario evaluation with additional application field experts and potential end users was utilised to further develop the scenarios.

Fleischer *et al.* (2005) claim that technology assessment in the area of nanotechnology and its implications is confronted with the problem that most scientific endeavours in nanotechnology can be classed as basic research, while most of the technological visions related to nanotechnology are far (> 10 years) into the future. As technology assessment has to integrate the socio-economic context of a technical product to be comprehensive, in the case of nanotechnology a preparatory step is necessary to connect the ongoing basic research with the visions communicated, either by the scientist themselves or by the media. Fleischer *et al.* (2005) propose roadmapping as one such additional step. Their concept involves structuring the research field, linking research activities with visions of products and applications and supporting more reliable judgements on the realism of or hurdles for innovations discussed. Our approach is not as wide as Fleischer *et al.* (2005) propose, as our focus is within a single project, but is otherwise very similar.

Coates and Coates (2003) have identified opportunities for expanding and improving current tools and introducing new tools into the assessment process. They propose the Internet and information technology as powerful tools for broadening public participation in technology assessment. Coates and Coates also stress that scenarios in connection with assessment have tended to be dry and uninteresting. This is why richer scenarios have great promise. The understanding how specific people will respond to new institutional, social and technological capabilities are virtual void in public policy discussion, and new tools for making that clear could be of enormous value. In our approach, we have been able to utilise all these opportunities.

Over the past decade, our organisation has been participating in a considerable amount of research focussing on the social implications and acceptability of emerging technologies. One of the key elements of our design approach is to take into account ethical issues in our project, as far as it is possible. We have built up ethical guidelines and ethics by design (ED) approach for designing various applications and services in our daily project work. (Topo *et al.*, 2004; Ikonen *et al.*, 2006; Stahl *et al.*, 2010; Kaasinen *et al.*, 2013) We have contributed to the identification of ethical issues in emerging technologies. We have worked in close collaboration with technology developers and other project stakeholders, as well as ethical experts (usually external to a project) and policymakers to ensure ethically sound applications of the technology developed. (Stahl *et al.*, 2010; Stahl, 2011) In this work, we have noticed a need for thinking and practices that aim to provide a positive ethical contribution to system design. Ethical principles and questions should work as sources of innovation for designing ethically sound concepts. This thinking can be called ED, extending from Ann Cavoukian and colleagues' model of privacy by design (Cavoukian, 2009; Lieshout *et al.*, 2011).

In ED, ethical considerations are involved from the very beginning of the development process and embedded through the process. All stakeholders, including technology developers, direct users and indirect users are involved in ethical deliberation through representatives, e.g. in focus groups. In addition to this, to ensure deep enough understanding of ethical issues, ethical experts can work for the project either as internal project workers or as part of an external expert board. Ethics work should cover the user viewpoint, so that the user experience of the ethicality of the design outcomes is studied.

Nanotechnology has raised a lot of ethical discussion over the years. Currently, there is even a journal devoted to Nanoethics (Springer, since 2007). Holm (2014) analyses what makes nanoethics so unique, claiming that one set of potentially unique issues arise from the vision that nanotechnology may be such a powerful technology that it will fundamentally change everything. It may converge with bio-, cogno-, info- and other technologies to allow us to enhance ourselves and perhaps later transform ourselves into a trans- or posthuman state. As nanotechnology is predicted to be so influential, it can be anticipated that nanotechnology will raise new ethical issues, which we cannot yet predict (Holm, 2014). The threats of nanotechnology are related to its small size, which makes manufacturing on the molecular level possible. The first nanotechnology scenarios were focussed on self-replicative materials that, due to a malfunction, could turn all materials around them into replications of themselves (Drexler, 1986). Today, these scenarios are not viewed as realistic, and nanotechnology is proceeding in making small size components such as nanotubes, nanoparticles or molecular motors (Gordjin and Cutter, 2013). Shew (2013) is worried about the current linear narrative for nanotechnology, as it neglects dispute and discourages wider conversation. The things that are possible with nanotechnology – better coatings, targeted materials, improved drug delivery systems – can be very good. Scrutiny and ethical reflection are still necessary, as some applications of nanotechnology may present technological pathways that we should be cautious about pursuing, e.g. due to concerns about toxicity and downstream effects (Shew, 2013).

In our case, the uniqueness of micro- and nanotechnology is related to the small size and the self-sufficiency in terms of energy. These characteristics make it possible to embed sensor units into our environment and into our bodies, so that they can function on their own for years, communicating sensor measures to whoever is able and allowed to receive the information. One example of our previous studies is the definition of concrete guidance on ethical issues for the Micro–Nano integrated platform for transverse Ambient Intelligence applications (MINAmI) project. There our focus was to take into account ethical perspectives when designing applications and services that utilise the MINAmI platform. The MINAmI platform was designed to facilitate various mobile phone-based Ambient Intelligence applications. The guidelines also covered issues related to implementing the MINAmI platform itself. The aim of the guidelines was to motivate and influence all who are involved in the design and utilisation of mobile-centric ambient intelligence technologies, applications and services. Those guidelines were based on earlier research, the ethical assessment of MINAmI scenarios, user evaluation of the scenarios, feedback from two workshops with ethics experts and comments and contributions from the Ethical Advisory Board of the MINAmI project. (Ikonen *et al.*, 2009).

The MINAmI guidelines are divided into impact on design solutions: what kinds of solutions are ethically acceptable, and impact on the design process: how to design ethically acceptable solutions. The impact of ethical principles on design solutions is analysed on two levels:

(1) general technical features of mobile AmI and impact of ethical principles on them; and
(2) the impact of ethical principles on application field-specific features of mobile AmI.

In the latter, the focus is on MINAmI-specific application fields: health care, assistive technology, housing and everyday life. During different phases of the technology design process, the ethical considerations required are different. The perspectives of different stakeholders should also be taken into account. A holistic perspective is required to consider the challenges, threats and opportunities in advance, when designing new technologies for our future everyday environments. (Ikonen *et al.*, 2009).

The ethical guidelines for mobile-centric Ambient Intelligence were built on six ethical principles selected based on the ethical assessment of MINAmI scenarios (Ikonen *et al.*, 2009):

(1) *Privacy*: An individual shall be able to control access to his/her personal information and to protect his/her own space.
(2) *Autonomy*: An individual has the right to decide how and for what purposes (s)he is using the technology.
(3) *Integrity and dignity*: Individuals shall be respected and technical solutions shall not violate their dignity as human beings.
(4) *Reliability*: Technical solutions shall be sufficiently reliable for the purposes to that they are being used for. Technology shall not threaten users' physical or mental health.
(5) *E-inclusion*: Services should be accessible to all user groups, regardless of physical or intellectual/developmental disabilities.
(6) *Benefit society*: Society shall make use of the technology, so that it increases quality of life and does not cause harm to anyone.

A very thorough work for building up the governance model, and new guidelines for integrating ethics into technical development projects have been established by the EGAIS project. The aim of the EGAIS project was to elaborate on a new perspective on the ethical governance of research projects in Europe, mainly in the technical field. The EGAIS approach was not as concerned with the ethics of technology in the shape of a code or an ethics committee, which are common approaches in Europe. Instead, EGAIS was mainly concerned with the governance of ethics, and with the institutional and organisational conditions that the procedures of assessment must fulfil, so that ethical questions can be addressed. (Rainey and Goujon, 2011; Masclet and Goujon, 2013).

What we have tried to accomplish in our work is very much related to the following (Masclet and Goujon, 2012) citation. The task is, however, not easy and needs further development of the approach in the future.

Taking part in the process of norm construction is a good first step for information systems' professionals to open up their framing and gain awareness of their own presuppositions and of others' points of view. It is not because we agree with the norms that we comply with them. There is a need for constant reflexive thinking about the technologies developed and the systems created. Ethical thinking cannot be assumed to be something in the minds of the people, coming from general principle they agreed on explicitly or implicitly. That is why the gap between the ethical community and the scientific community is so tragic. As a society, we need to reduce that gap; we need to find common ground on which to collaborate.

The GA scenarios

The GA scenarios were based on our common vision within the project group.

GA technology will enable very small sensor and computing units to monitor, provide feedback and involve us actively in understanding and acting on our own well-being and our environment. The GA units will be self-sufficient in terms of energy, and, thus, suitable for the long-term use without maintenance. Several usage possibilities are foreseen in health, well-being, safety, sustainability and empathic user interfaces. (Guardian Angels, 2012).

Essentially, the promises of GA technology are based on the following transitions:

- from signal capturing to decision support;
- from signal capturing to feedback and back: creating sustained interactions with end-users;
- from one to many sensors;
- from controlled environments to mobility (GA systems can be used anywhere);
- from one day battery to fully self-sufficient energy solutions; and
- from reusable to disposable (size and prize).

We created the initial scenarios by gathering different application and service ideas from project partners who were focussed on developing technologies or applications. The ideas were then refined and presented as a selected set of futuristic, scientifically valid scenarios. We intentionally included "dark" scenarios that illustrated usage possibilities with ethical and critical issues. The scenario set included 51 scenarios from eight application fields. The scenarios were presented as written stories, equipped with illustrative photos. The scenarios were evaluated by potential users, application field experts and ethics experts. The ethics experts assessed full, long versions of the stories. Slightly shortened versions of the stories with illustrations were presented for the application field experts. For the potential users, the scenarios were slightly modified to present possibilities in selected application fields (Figure 1).

In the following paragraphs, we describe the core application fields for GA technology, as well as some scenario examples.

GA technology has various application possibilities in health care. Physical GA can measure different physical signals, process the measurements and analyse them to provide instant feedback for the patient or medical professionals. As GA systems are

Source: Guardian Angels (2012)

Figure 1.
GA are smart, autonomous systems that are beyond wireless sensor networks in terms of functionality and power, and feature greater complexity than the simple sensor nodes foreseen today for the Internet of things

extremely small and self-sufficient in terms of power, GA technology facilitates long-term monitoring without disturbing the patients. Measurements that previously required a hospital environment can be carried out at home. Beyond monitoring, this will allow end-users to keep track of their own illnesses over longer time periods, actively influencing their own well-being. This is particularly beneficial for people who have chronic illnesses like diabetes, rheumatism, etc. Such illnesses require patients to keep track of their life styles and behaviour, in order to learn to cope with the illness. Depending on the measurement need, GA sensor units can be implanted or they can be disposable, "smart plaster" devices that are used when needed. Sensors can also be embedded in clothing. GA health applications can be divided into three main groups:

(1) monitoring medication and its effects;

(2) monitoring early symptoms; and

(5) empowering users to take control over their own well-being, in particular, for chronic diseases.

In addition to health care, GA technology can be used for well-being applications, with which people can themselves monitor their physical signals or behaviour. When people can monitor their behaviour and the consequences of it, they may become motivated to change their behaviour towards healthier or enjoyable habits. An important part of well-being is to protect people from harmful substances in their environment. People can receive warning about allergens in the air, in the food or clothes.

A visionary application possibility of GA is extending human abilities and senses. This can be used not only to replace lost abilities for disabled or elderly people, but also to increase ordinary sensing abilities. GA technology can be developed to extend all senses: seeing better, hearing better, smelling better, tasting better or a better sense of touch. With GA technology, people could sense, for instance, radiation, toxins or points of the compass.

GA that interact with and encourage human emotions and experiences can be used as the basis for highly involved applications. Usage possibilities are not only seen in games and entertainment, but also in developing empathic computing that adapts smoothly to the user's emotions.

GA in indoor and outdoor environments provides many ways to improve people's safety. Sensor networks in outdoor environments can continuously monitor different hazards such as pollution and hazardous gases, radiation or early signs of natural phenomena. Outdoor safety can also be improved by permanent monitoring of the mechanical condition of key infrastructures such as bridges and roads. In indoor environments, sensor networks can monitor factors such as air quality, allergens or fires. Individuals can be monitored to check if they are carrying explosives or drugs, for example. Safety solutions include monitoring the physical and emotional state of people who are working in safety critical environments, such as traffic or power plants.

GA embedded in everyday items make it possible to monitor and store information on the manufacture, transportation and usage of the items. This enables tracking the whole life cycle, from manufacturing to disposal, as well as monitoring how and how much the item has been used. Maintenance guidance can be provided based on the actual need. With a GA, a unit's condition management can be based on actual wear rather than estimated usage, thus saving resources in maintenance and improving the reliability of machines. Table I presents some examples of the individual scenarios, with slightly shortened texts.

Black box of the body: A black box in a human body can monitor and store long term all the necessary vital signals. In case of a disease, the causes can be tracked. Similar to the black box in a plane, it helps to reconstruct events before the disease. Based on black box data, early warning signals can also be given. The data do not need to be monitored continuously but once a day, for instance, is enough for many signals	*Empathic technology*: Physical signals can indicate emotions such as boredom, anger, joy, fear, excitement and immersion. Empathic technology can adapt to the emotional state of the user. For instance, the emotions may reveal that the user may be about to make an error even before the user actually makes the error, and the technology can be prepared for corrective actions. A bored user may not easily react to warning signs, or may not read through long instructions
Sixth digital sense: GA can enhance human senses in several ways: people can see round the corner, sense allergens, sense electromagnetic radiation, sense UV radiation, sense toxics, sense points of the compass, etc.	*Prediction of hazards*: Big industrial structures such as power plants and means of transportation (trains, ships or airplanes) require permanent monitoring of their mechanical condition. Early detection or prediction of failure of the structure will decrease the cost of repair, but what is more important is that it may help in preventing disasters

Table I.
Examples of guardian angels scenarios

Feedback from application field experts

We gathered feedback on the scenarios from three different technology and application field expert groups. The groups represented expertise in Ambient intelligence (ten experts), well-being technology (four experts) and transport and traffic (two experts). In addition to this, we interviewed two individual experts, one with expertise in sensor networks and another with expertise in ambient-assisted living. All the experts were researchers from the VTT Technical Research Centre of Finland.

In the workshops and individual interviews, we presented appropriate scenarios from our scenario set for the participants as a slide-show presentation with illustrated scenarios. We then discussed the following themes:

- Do you see application areas other than the ones presented?
- Which of the applications presented do you consider credible? Why?
- Which applications are not credible? Why?
- Can you see some other application possibilities?

The application field experts helped us to identify most potential usages, and they also proposed several new application possibilities. They gave feedback about the novelty of the solutions and considered quite a few of the scenarios to be possible even with current technology. However, they emphasised that small energy efficient sensor units would provide additional value to the scenarios and make the applications and services presented in the scenarios easy to adapt to long-term use.

In the Ambient intelligence expert group, health, well-being and life cycle management scenarios were regarded as most credible. The most doubtful scenarios were the black box of the body scenario, as well as all the scenarios focussed on monitoring emotions. Privacy was raised as a crucial issue in terms of monitoring emotions: who can access the measures. Sustainability was also discussed: even if GA solutions are small, they may still have environmental impacts, especially if they will be embedded almost everywhere.

The expert on sensor networks proposed a totally new application area of condition management in industry: continuous monitoring of work machines and vehicles as well as their components. These kinds of wireless solutions are studied very much, as wireless solutions make maintenance easier. Energy self-sufficiency is needed to avoid batteries and related maintenance actions for these wireless solutions.

The well-being experts thought that social issues should be emphasised more in the scenarios: Who else in the environment would have similar GA units? What kind of information could be exchanged? This group gave a lot of detailed ideas of possible applications for specific health conditions. Similarly, the expert on ambient-assisted living proposed specific applications for the elderly, e.g. dehydration monitoring would be very useful for elderly people who often forget to drink enough water.

The experts in traffic and transport pointed out the various possibilities that GA technology would have in military applications: the sensor units would enable monitoring of exact conditions in a wide environment just by scattering the sensors around. This group also discussed monitoring the emotional condition of drivers. Future solutions could not only identify that the driver is about to fall asleep, but also that his/her ability to concentrate is distracted. Current research is debating the roles of automation and driver, e.g. can the car be automatically stopped if the driver seems not to be in a condition to manage the situation him/herself. These kinds of solutions also raise ethical concerns. Special systems could be developed to prevent driving when the person is drunk or has been using drugs. The group proposed that drivers with previous court decisions could be obliged to wear GA sensors to prevent drunk driving. With some experts, we had quite thorough discussions on ethical issues, such as the ethics of monitoring car drivers. Whilst not all the experts raised too many issues regarding ethics, they raised many completely new application possibilities. These possibilities further increased the ethical issues for us to study.

Feedback from consumers

The main purpose of the study was to open a conversation channel where GA visions could be introduced and consumers could give their feedback, as well as express their ideas and opinions regarding the topic in the early phase of the project. The study aimed at gaining an understanding of the users' expectations, concerns and fears regarding GA technology, and getting insight into which application fields seem to be most useful, doubtful or interesting, based on web conversations.

Consumer feedback was gathered in VTT Owela (http://owela.vtt.fi/), which is an open web laboratory for user-driven innovation and co-design. Owela supports active user involvement in the innovation process, from the first ideas to piloting and actual use. Owela has over 1,000 registered users who represent society at large. In this study, Owela was used for gaining user feedback and insights on different GA visions and scenarios. Registered Owela users were invited to discuss and comment on seven GA application fields. The topics were related to GA technology in general, health, well-being, the well-being of loved ones, measuring emotions, safety and consumer products. Besides commenting on the topics, users were asked to evaluate the potential of ideas with a simple poll, and they were encouraged to propose additional usage possibilities for the GA technology. The study was open in the Owela tool for two weeks in January 2012. The content of user comments was analysed qualitatively.

Each conversation topic included a short one or two-chapter description of the vision with descriptions of some application possibilities, a couple of open questions to encourage discussion, and a poll with three options to evaluate the topic. In the poll, the users were asked whether they found the topic useful, doubtful or whether they could use the technology in the described way themselves. Figure 2 illustrates how the discussion themes were presented in Owela, with polls and links to discussions.

Study participants were recruited through an invitation email sent to participants in previous Owela studies (for those who have allowed their contact information to be stored in a user register and agreed to be contacted when new studies are starting). After a week's response time, the users were sent a reminder email to encourage them to participate in conversations, create their own ideas and respond to the polls. In total, 110 people registered to participate in the study. A total of 54 people participated in the conversations and around 30 people (27-34 depending on the topic) took part in the polls. The participants represented different age groups and were almost equal numbers of males and females took part.

GA technology raised lively discussion and evoked both enthusiasm and concerns. The most active conversation topic was health, gaining more than 60 comments. All the other application areas raised a lot of discussion as well, gathering 40-49 comments. Participants had a fairly positive attitude towards different application areas. With the

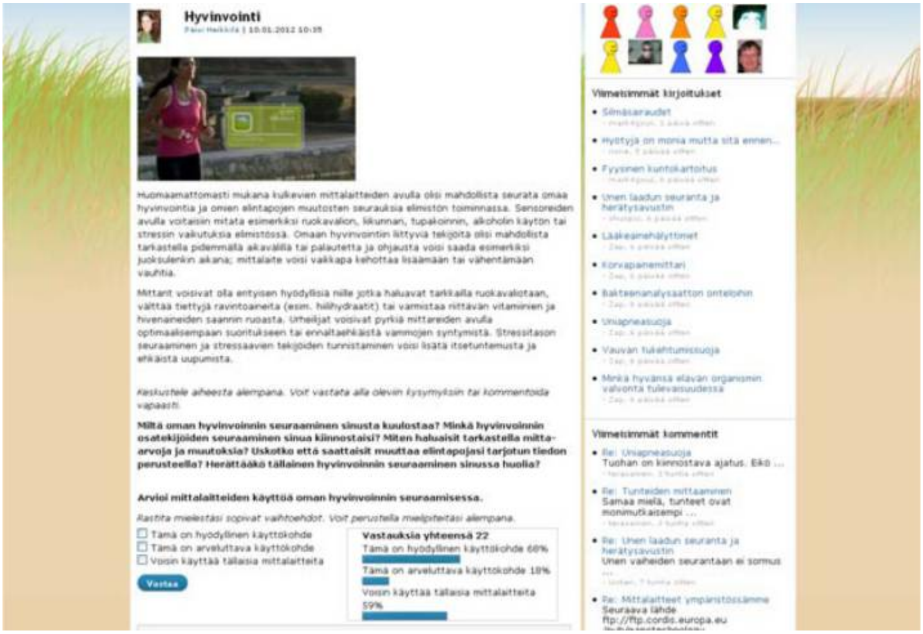

Figure 2.
Presentation of the discussion theme well-being in Owela

exception of one area, all the use cases were seen as useful and not very doubtful. The exception to this was emotions; measuring emotions was an area which had reversed responses. It was not seen very useful, and over 70 per cents of respondents considered it doubtful. Health, well-being and consumer products were the areas in which participants saw most potential for using the devices themselves (Figure 3).

Besides commenting on the proposed usage possibilities, participants proposed new ideas for using the technology. Sixteen ideas were posted in an ideas section, and they also led to discussion between the person who proposed the idea and other participants

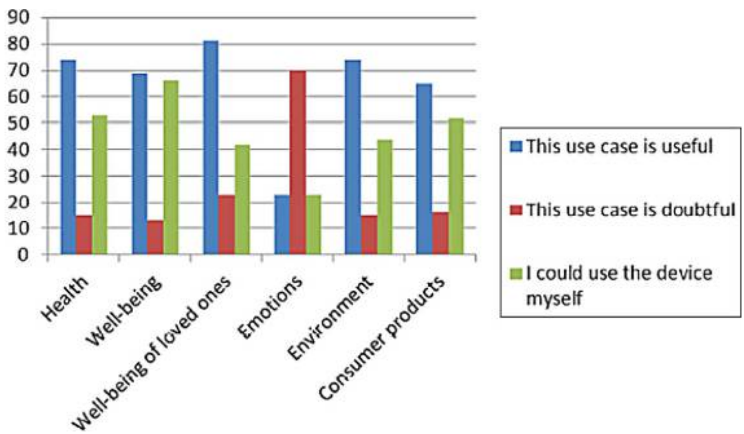

Figure 3.
Poll results

(most of the ideas proposed 5-15 comments or additional ideas). The study seemed to increase participants' interest in nanotechnology in general; they not only got more information about it, but some searched for new information themselves. One participant even posted a link to an international nanotechnology report.

GA technology was regarded as an interesting conversation topic, creating both optimism and concerns. Some of the participants emphasised that these solutions have been expected on the market for years and would provide significant enhancements, especially in health care. On the other hand, many of the participants were doubtful about the technology and were concerned about the technology gaining too much control over our lives. This might reflect in the threat of misuse of information, lack of health-care personnel, lack of social contacts and stress caused by constant measurements. GA technology could be seen as an empowering tool for increasing people's possibilities in terms of monitoring their health, well-being and environment. However, the growing power also creates concerns – whether the power is given to the right people, whether some are excluded against their will, whether some are included against their will and in the end – whether society would work better without so much technology, knowledge and measurements. Even though the GA technology would be beneficial in many cases, the extension into almost all fields of our lives seems to create concerns. (Heikkilä and Kaasinen, 2012).

Feedback from ethics experts

We gathered feedback on the scenarios from 13 experts in different fields of ethics. The experts came from 11 different organisations and from different European countries. They worked on the project on voluntary basis, and commented on the GA white paper, which included our vision and scenarios. The aim of the study was to identify the most crucial ethical issues related to the GA technologies. By identifying those issues early, our target was then taking them into account in planning the activities of the forthcoming implementation projects. Another aim was to familiarise the experts with the GA technology and our ideas regarding usage possibilities.

The ethics experts gave us thorough feedback on the vision of the project and the predicted application possibilities. In general, they considered Environmental GA to be the least sensitive solutions and Emotional GA to be the most sensitive solutions. The most obvious ethical issue was privacy, as GA will enable continuous monitoring of personal data. Once data have been generated, issues related to access rights, protection against misuse and user control of his/her own data are raised. It is crucial that the user can turn off the monitoring whenever (s)he wants. Regarding health and well-being applications, an important ethical issue is whether knowledge, e.g. about early symptoms of diseases, really improves quality of life. People may get addicted to monitoring well-being parameters, and this can cause stress for some people. Implanted devices, however small or invisible, are a very sensitive issue. These solutions will require informed consent, and the dignity and autonomy of the user must be protected. Hence, it is crucial that the users themselves are involved in the design of the systems, as early as in the very initial stages, and that the opinions and concerns of potential users are taken into account. Physical GA can be used to extend human performance beyond what is normal. Is that acceptable and under what conditions? Empathic technology that adapts to the user's emotions may hinder young people from learning from the potentially negative impact that failing to control their emotions may have. Empathic technology can be used as a persuasive tool in marketing, and this raises several ethical concerns. With security systems, a common ethical issue is that when security is increased, privacy and autonomy may be decreased. In security solutions, there are risks that complex management tasks may be delegated to technology alone. The following comments illustrate examples of the feedback from the experts:

> I think Guardian Angels has promising application fields with the purpose of making users' lives better, especially regarding detection of early symptoms of cancer. However, we may need to rethink when we say that technologies can learn to adapt to human beings: perhaps technologies should adapt to serving humans. Technologies do certainly get better at processing data in a more meaningful way to function better and for the "right" purpose; but they do not learn to my understanding. Their purpose and use should be defined together with possible users (and non-users) right from the beginning; users should not be treated solely as feedback mechanisms for the scenarios created by the experts who are involved in producing these technologies

> Most of the ethical implications of the envisioned application areas of very small sensors and computing units lie in the wider environment of the applications, including the organisational and social environment, the policies and regulations, as well as the written and unwritten ethical codes affecting the use of such technologies. Nevertheless, technology is not neutral, especially when it is embedded in other technologies and application areas, therefore not only solution architects but developers of very small size sensors and computing units, too, may have the task of facilitating the ethical application of such technologies and preventing their unethical use.

> Pervasive fields of application raise serious issues regarding the normal presumptions people can reliably make about their environments as arenas in which their decisions make a difference, plus feedback. In scenarios with invisible and ubiquitous technologies carrying out various processes, this idea of a scene as a backdrop changes into an adaptive context. There are therefore implications for decisions, autonomy and perception that affect not just 'users', as far as they can be identified, but the very general idea of context of action as it affects anyone in the scene.

The ethics experts stressed that there is already a good selection of research, recommendations and public opinions that could be utilised in ethical assessment. The *European Group on Ethics in Science and New Technologies* has published opinions on implants and ICT in general. (i.e. Opinion no. 20; 16/03/2005: Ethical aspects of ICT Implants in the Human Body, and Opinion no. 26; 22/02/2012: Ethics of information and communication technologies). Research projects also have interesting results that can be applied in this field (the ethics of ICT). However, as the world in general, people and especially technology and its applications change quite rapidly, there must be continuous debate on these issues (i.e. impact on society) at all levels of society.

On a research project level, this means a strong emphasis on discussing ethical issues and building up tools for empowering different stakeholders to be involved in this discussion by various means. Governance of societal issues in this kind of project has to be prioritised internally, but ideally deliberation also needs to be enabled and accomplished through the project for the wider audience. GA technology and applications have been introduced in the scenarios in a very positive way, and inevitably they have the potential to benefit society at a global level too. However, there are lots of threats and weaknesses that should be taken into account from the very beginning when designing these technologies. The ethics experts identified numerous issues that should be studied in more detail before proceeding with real-life experiments: privacy issues are of course the most obvious, but issues related to autonomy, user control, freedom, medicalisation and human existence were also raised. Some less obvious issues are accessibility, affordability and accountability: Will these solutions be available for those who need them? Who will be responsible if these solutions do not work? The technology can lead to infantilising and patronising people, and medicalisation is not always a good thing. Trade-offs need to be considered for security solutions, as security often limits liberty. Once an information resource exists, there are multiple interest groups that may have interest in exploiting the data. Thus, the measurement and storage of data must be assessed on a wide scale. The following comments illustrate examples of the overall feedback from the experts:

> In summary, most applications in the White paper may violate the person's privacy. That is especially the case if the application collects personal data, and even more so if it transfers data to be processed elsewhere. The most severe situations appear in the applications which process sensitive health data. The processing of personal data is usually acceptable if the person has given consent. However, many of the applications are designed to be used in situations where it may be difficult or even impossible to get consent. In such cases, when using the application even if it violates the person's privacy, there should be another strong reason that outweighs privacy issues and justifies the use of private data.

> It is also necessary to guarantee that the use of such applications is in no way compulsory for the human subjects, and people's right to live in an "unhealthy way" should be respected. Even the existence of very small devices should be detectable by others than the persons concerned, e.g. the doctor and the patient (or the automated systems concerned), only on the basis of the informed consent of the subject. This is already a practical problem with airport body scanners. A further general requirement is to ensure that it is possible for a human to override automated decisions, and to detect human and system errors (also establishing responsibility), and correct these errors if necessary.

The ethics experts thought that the descriptions of technologies and their usage in the scenarios were on too general a level. As technology as such is not good, bad or neutral, it must always be studied in context: the same technology can be used in a good way or in a bad way depending on who is defining good or bad. Different frameworks are needed to enable the assessment of the impacts of GA in different application fields and in different contexts. More detailed scenarios are needed to study different perspectives: the same application may benefit one person or a group and have negative impacts on the other ones. Besides more detailed scenarios and scenario analysis, detailed experiments and real-life studies should be conducted. Developers, designers, users and all other possible stakeholders should be involved and informed about the potential of these technologies – good or bad. Potential users need to be involved in the studies, but technology developers should also participate in considering the ethical application of the new technologies.

Human-driven design and ethics by design

As a term, human-driven design (HDD) was introduced earlier by Braund and Schwittay (2006) and Ikonen (2008). Ikonen presents HDD as an approach to the design of future smart environments and emerging ICT, and describes HDD as an "approach which broadens the perspective from a focussed product or service development process model to the more holistic design perspective". Ikonen (2008) also describes stakeholder-based design that "furthermore broadens the scope and role of involved participant groups in the actual design process". In addition to this, he calls for ethical assessment to continue throughout the design process. Ikonen (2008) calls the resulting combination empowering design. Based on our review, we agree that HDD should integrate the three perspectives endorsed in (2008):

(1) it should be holistic;

(2) strive for collaboration with different stakeholder groups; and

(3) be ethically reflective.

What we have done in this particular project (i.e. in the preparation phase of the actual technology development project) follows our ambitions and the ideas of HDD quite well. We had a strong ethical perspective in this project, but we could not be as reflexive as we would like to be within the project. We had good collaboration with different stakeholder groups, but we should have done more in this area, both in terms of quantity and quality, if we evaluate our stakeholder participation. Relating to the previous point, we aim to have a holistic view of the development of technology: we looked at and discussed technologies in different phases with many kinds of stakeholders. We were only at the very beginning and in the very early phases of this project and were just aiming at having a holistic approach. We were (and are) aiming for stronger implementation in the next phases of the project, when we should have more resources available and a common understanding of the subject.

The heart of ED is positive, forward-looking and proactive ethical thinking. Ethical points of view are considered in the early project phases, with the aim of creating a positive, ethical-solution-oriented mindset among project partners. The ethical approach should not just identify current or future problems, but actively design for and be inspired by achieving ethically sustainable solutions. The ethical perspective is brought by ethical experts, for instance, in the form of an ethical advisory board that participates in the development from the very beginning of the project. In our project, where we were in fact developing this approach, we indeed could identify the preliminary list of critical and ethical issues in relation to the development of these technologies. In the ED "style", we were already aiming to implement the next steps of the project: building up a true governance model of societal and ethical issues within the project, including a strong ethical advisory board with authority, emphasising a wide, multidisciplinary and trans-methodological view on stakeholder involvement and amongst these activities, aiming to have strong reflexivity within the project.

In reflexivity, we understand that one of the key dimensions both of HDD and of ED is the inclusion or involvement of stakeholders. Without true implementation of that dimension, other dimensions cannot reach their full potential. In our ED, ethical perspectives are identified, opened and co-constructed with technology developers, domain experts, potential end-users and other relevant stakeholders, and ethical solutions are sought together. ED should produce ethical design solutions, but, perhaps even more importantly, produce or encourage mutual learning by participants about ethical issues surrounding technology development. This aligns well with the goals of RRI: foresight (anticipation), ethical thinking, reflection and deliberation will be part of the mindset of the designer, developer and end-user. Nowhere can we expect fixed, universal ethical solutions; instead they are described as contextual, case-specific, transient and negotiable over and over again (Sengers *et al.*, 2005; Stahl *et al.*, 2010).

Discussion

We have gathered feedback on GA scenarios from application field experts, consumers and ethics experts. The application field experts helped us to identify most potential usage possibilities and they also proposed several new application ideas. Those ideas led us further, to think about ethical issues related to the proposed applications. The initial feedback from potential users towards the GA technology was very positive. GA technology was seen as an empowering tool for increasing the possibilities people have to monitor their health, well-being and environment. People could see usage possibilities in their own lives, especially for health and well-being applications as well as for GA embedded in consumer products. However, concerns were raised, in particular regarding access to information, digital division and overall whether society would work better without so much technology, knowledge and measurement. The potential users of the GA applications raised the question: Would all the information generated with the measures really improve quality of life? On the whole, the feedback from consumers linked our scenarios to the contexts of daily life for different people. This gave us a rich understanding of the various aspects of each individual scenario. Each scenario can manifest differently in different individuals' lives. Potential users' feedback also gave early estimates for the marketing potential of the solutions proposed. If we were to identify solutions with lots of marketing potential but ethical concerns, those application possibilities should be prioritised in the consideration of legal and political actions required to prevent ethical problems. In our case, however, people were not interested in adopting the solutions where they saw ethical concerns.

The ethics experts gave lots of valuable feedback to the GA technology in general, as well as regarding the scenarios. The ethics experts identified numerous issues that should be studied in more details before advancing to real-life experiments: privacy, autonomy, user control, freedom, medicalisation, human existence, accessibility, affordability and accountability. The ethics experts emphasised the point that the scenarios were on a general level and, thus, they were not sufficient to assess all possible ethical issues. Ethical issues should be further studied in various contexts and from the viewpoints of the different actors. Experiments and real-life study may also be needed to gain a deeper understanding of the ethical challenges. The ethics experts also stressed that users, developers and other stakeholders should be involved in ethical design activities. Our scenario set was intentionally designed, so that it presented both positive and negative application possibilities. As ethical assessment is focussed on identifying problems, our findings emphasise all the problems that these kinds of small energy efficient sensor units could create. However, the sensor technology clearly also has positive usage possibilities: it supports the monitoring of health and environmental safety; it supports sustainability, as the measures can indicate wear and prevent having to replace components that are still functional. On the other hand, the sensor measurements can be interpreted as giving early warnings of wearing, preventing hazards with serious consequences.

How should we then react to this kind of technology, which has both promise and danger? How can we guide development towards good path and how can we protect people from potentially threatening scenarios? What is the role of ethics experts in this?

Forthcoming further development of the recently launched RRI approach tries to find answers and solutions for the constructive and positive co-development of future technologies, applications and services. RRI seems to be a promising initiative, aiming to be a cross-cutting, horizontal layer in the development pillar. However, radically changing landscape and power structures of technological development will still bring new challenges. Our suggestion of a strong HDD approach and the ED model as a more focussed approach, focussing on ethical issues, is to offer a more practical view on the development of RRI. One of the basic observations, based on our experiences, is that technological development should have more direct connections with application and service development to facilitate understanding of both the positive and critical views regarding the technologies in various contexts. HDD, ED or RRI should not have a role in technological development projects where acceptance (as a legal process or something similar) of the work done is achieved via a very narrow view of the theme. On the contrary, these humanistic approaches should hold a position comparable to technological development, both in impact and in resource allocation.

References

Banuls, V.A. and Salmeron, J.L. (2007), "A scenario-based assessment model – SBAM", *Technological Forecasting & Social Change*, Vol. 74 No. 6, pp. 750-762.

Braund, P. and Schwittay, A. (2006), "The missing piece: human driven design and research in ICT and development", *Proceedings of the International Conference on Information and Communications Technologies and Development*, *IEEE, Berkeley, CA*, *May 25-26 2006*, pp. 2-10.

Cavoukian, A. (2009), "Privacy by Design", *Information and Privacy Commissioner of Ontario*, Toronto, avialable at: www.ipc.on.ca/images/resources/7foundationalprinciples.pdf (accessed 10 Novermber 2014).

Coates, J.F. (1976), "The role of formal models in technology assessment", *Technological Forecasting and Social Change*, Vol. 9 Nos 1/2, pp. 139-190.

Coates, J.F. and Coates, V.T. (2003), "Next stages in technology assessment: topics and tools", *Technological Forecasting and Social Change*, Vol. 70 No. 2, pp. 187-192.

Coates, V.T. and Fabian, T. (1982), "Technology assessment in industry: a counter productive myth?", *Technological Forecasting and Social Change*, Vol. 22 Nos 3/4, pp. 331-341.

Cutter, A.M. and Gordijn, B. (Eds) (2013), *Pursuit of Nanoethics*, Springer, New York, NY.

Drexler, K.E. (1986), *Engines of Creation: The Coming Era of Nanotechnology*, Anchor Books, New York, NY.

European Commission (2013), "Responsible research and innovation leaflet", available at: http://ec.europa.eu/research/science-society/document_library/pdf_06/responsible-research-and-innovation-leaflet_en.pdf (accessed 10 November 2014).

Fleischer, T., Decker, M. and Fiedeleret, U. (2005), "Assessing emerging technologies – methodological challenges and the case of nanotechnologies", *Technological Forecasting and Social Change*, Vol. 72 No. 9, pp. 1112-1121.

Guardian Angels (2012), "FET Flagship Pilot", *Final Report*, April 2012, available at: www.ga-project.eu (accessed 10 November 2014).

Heikkilä, P. and Kaasinen, E. (2012), "Involving users in the fuzzy front-end design of future emerging technologies", Innovation through Social Media, ISM 2012 workshop proceedings, Oslo, 3 December 2012, ISM og Akademika forlag, Trondheim, pp. 70-78.

Holm, S. (2014), *Does Nanotechnology Require a New "Nanoethics"?*, *Pursuit of Nanoethics*, Springer, Netherlands, pp. 31-38.

Ikonen, V. (2008), "Towards empowering design practices", *Proceedings of the Ambient Intelligence Forum 2008*, (*Hradec Králové, CZ, 15-16 October 2008*), pp. 132-139.

Ikonen, V. and Kaasinen, E. (2008), "Ethical assessment of future-oriented design scenarios", *Proceedings of the Tenth International Conference ETHICOMP 2008, Ethicomp 2008, Mantua, IT, 24-26 September 2008*.

Ikonen, V., Niemelä, M. and Kaasinen, E. (2006), "Scenario-based design of ambient intelligence", *Proceedings Third International Symposium, Lecture Notes in Computer Science, Ubiquitous Computing Systems, UCS 2006*, Vol. 4239, pp. 57-72.

Ikonen, V., Kaasinen, E. and Niemelä, M. (2009), "Defining ethical guidelines for ambient intelligence applications on a mobile phone", *Workshops Proceedings of the 5th International Conference on Intelligent Environments, IOS Press, Amsterdam, NL, EDAmI, Barcelona, ES, 19 July 2009*, pp. 261-268.

Kaasinen, E., Kymäläinen, T., Niemelä, M., Olsson, T., Kanerva, M. and [anonymised], V. (2013), "A user-centric view of intelligent environments: user expectations, user experience and user role in building intelligent environments", *Computers*, Vol. 2 No. 1, pp. 1-33.

Kosta, E., Pitkänen, O., Niemelä, M. and Kaasinen, E. (2008), "Ethical-legal challenges in user-centric Ami services", *SLAECE2008 Conference*, June 2008, Athens.

Lieshout, M.V., Kool, L., Schoonhoven, B.V. and Jonge, M.D. (2011), "Privacy by design: an alternative to existing practice in safeguarding privacy", *Info*, Vol. 13 No. 6, pp. 55-68.

Masclet, L. and Goujon, P. (2012), "Implementing ethics in information systems, presuppositions and consequences in ethics and information systems", *Proceedings 10th IFIP TC 9 International Conference on Human Choice and Computers, HCC10 2012, The Netherlands, Amsterdam, 27-28 September*.

Masclet, L. and Goujon, P. (2013), "Governance in perspective: the issue of normativity", in Rainey et al. (Eds), *Ethical Governance of Emerging Technologies Development*, IGI Global, Hershey, pp. 1-14.

Palm, E. and Hansson, S.O. (2006), "The case for ethical technology assessment", *Technological Forecasting and Social Change*, Vol. 73 No. 5, pp. 543-558.

Rainey, S. and Goujon, P. (2011), "Toward a normative ethics for technology development", *Journal of Information Communication and Ethics in Society*, Vol. 9 No. 3, pp. 157-179.

Rotter, P. (2008), "A Framework for assessing RFID system security and privacy risks", *IEEE Pervasive Computing*, Vol. 7 No. 2.

Sengers, P., Boehner, K., David, S. and Kaye, J. (2005), "Reflective design", *Proceeding 4th Decennial Conference on Critical Computing (CC '05): Between Sense and Sensibility*, pp. 49-58.

Shew, A. (2013), "Engines of second creation stories about nanotechnology", *Bulletin of Science, Technology & Society*, Vol. 33 Nos 1/2, pp. 21-27.

Stahl, B. (2011), "IT for a better future: how to integrate ethics, politics and innovation", *Journal of Information Communication and Ethics in Society*, Vol. 9 No. 3, pp. 140-156.

Stahl, B., Heersmink, R., Goujon, P., Flick, C., Hoven, J.Vd., Wakunuma, K., [anonymised], V. and Rader, M. (2010), "Issues, concepts and methods relating to the identification of the ethics of emerging ICTs", *Communications of the IIMA*, Vol. 10 No. 1, pp. 33-34.

Thomas, C.W. (1996), "Strategic technology-assessment, future products and competitive advantage", *International Journal of Technology Management*, Vol. 11 Nos 5/6, pp. 651-666.

Tichy, G. (2004), "The over-optimism among experts in assessment and foresight", *Technological Forecasting and Social Change*, Vol. 71 No. 4, pp. 341-363.

Topo, P., Rauhala, M., Sotamaa, O., Saarikalle, K. and Vainio, T. (2004), "Ethical issues in personal navigation", Deliverable 4 of the project Key Usability and Ethical Issues in NAVI-programme (KEN).

Tran, T.A. and Daim, T. (2008), "A taxonomic review of methods and tools applied in technology assessment", *Technological Forecasting and Social Change*, Vol. 75 No. 9, pp. 1396-1405.

Wakunuma, K., Stahl, B. and Ikonen, V. (2011), "Cloud computing as an emerging technology and its associated ethical issues: experiences that may be shared between Europe and Africa", Paul Cunningham and Miriam Cunningham (Ed.), *IST-Africa 2011 Conference Proceedings, IIMC International Information Management Corporation*.

Corresponding author
Veikko Ikonen can be contacted at: veikko.ikonen@vtt.fi