RESEARCH HIGHLIGHTS 7
TECHNOLOGY • SCIENCE • VISIONS

Uniting the physical and virtual

ICT solutions for open smart spaces

VTT RESEARCH HIGHLIGHTS 7

Uniting the physical and virtual

ICT solutions for open smart spaces

ISBN 978-951-38-7970-9 (Soft back ed.)
ISBN 978-951-38-7971-6 (URL: http://www.vtt.fi/publications/index.jsp)

VTT Research Highlights 7

ISSN-L 2242-1173
ISSN 2242-1173 (Print)
ISSN 2242-1181 (Online)

PUBLISHER
VTT Technical Research Centre of Finland
P.O. Box 1000 (Tekniikantie 4 A, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax +358 20 722 7001

EDITORS: Heikki Ailisto and Kaisa Belloni
TECHNICAL EDITING: Anni Repo
GRAPHIC DESIGN: Tuija Soininen

Printed in Kopijyvä Oy, Kuopio 2013

Uniting the physical and virtual — ICT solutions for open smart spaces
Espoo 2013. VTT Research Highlights 7, 58 p.

Foreword

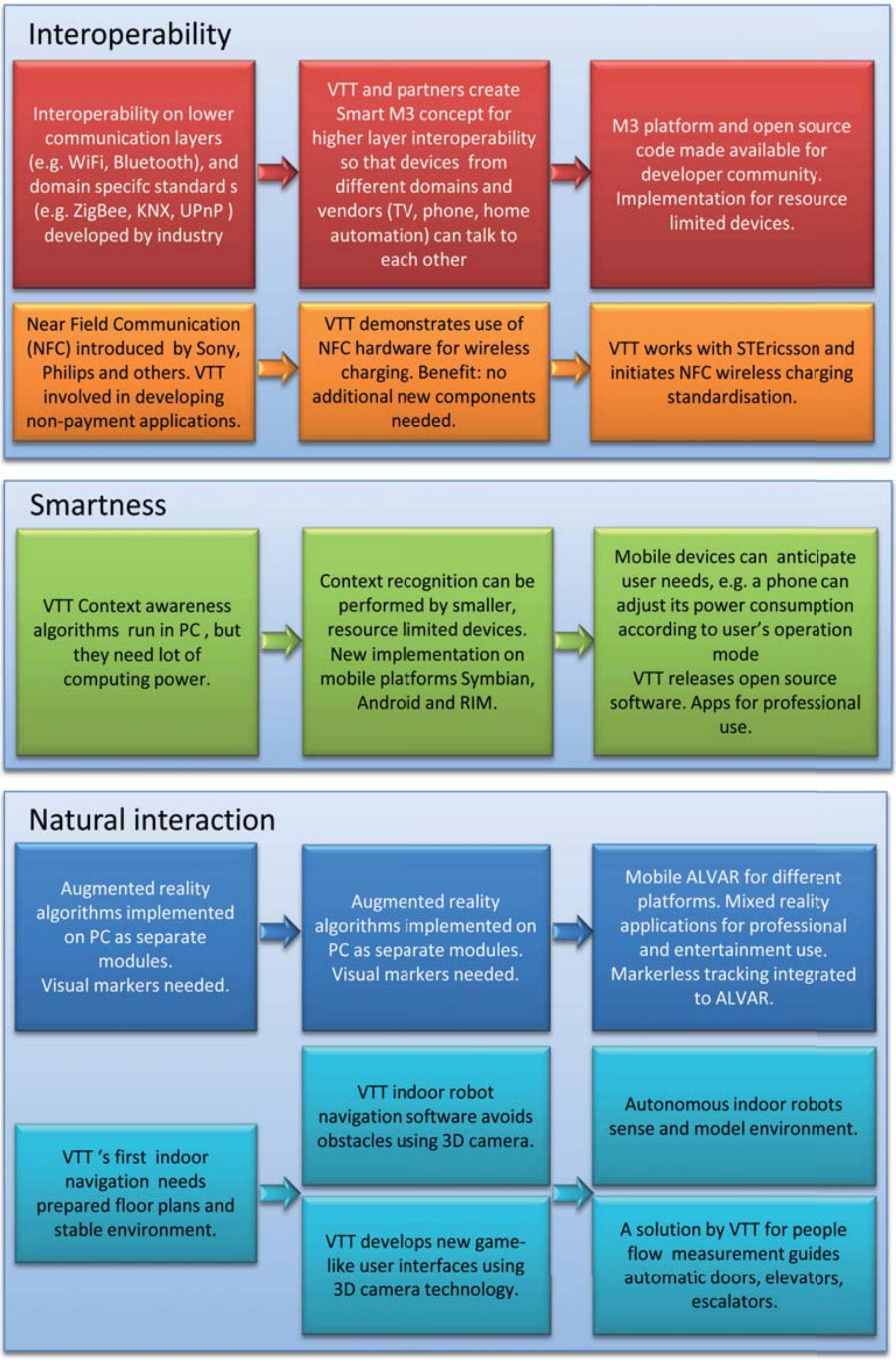
In 2008, VTT Technical Research Centre of Finland saw two major reasons for preparing and starting a four-year spearhead programme in the ICT area. The first reason was technology related, while the second was industry and business related.

A major change in the way electronic and digital technologies influence our everyday lives was anticipated. While the web revolution headed by Google and social media applications was going on, an even more profound trend was seen in emerging ubiquitous computing. It means literally computing everywhere; processing, communicating, sensing, and human computer interaction capabilities, not only in conventional computers but also in cars, houses, appliances, mechanical machines, and even in every-day objects. Scientists and visionaries used words such as calm computing, pervasive computing, ambient intelligence, and, of course, ubiquitous computing to describe the possibilities created by the advances in technology and the pro-tech attitudes of the public. The expectations were crystallised in the Global Trends 2025 report, a document prepared by the U.S. National Intelligence Council every four years. In this report, *ubiquitous computing was named as the most probable and important technology trend to be expected before 2025.*

The mobile communications industry, the Nokia cluster, dominated the Finnish ICT industry in sovereign terms for almost twenty years. It had become the largest exporter, the innovation engine, and even the source of national pride and identity. In 2008, that was about to change. Another company was taking the role of trendsetter in high-end phones, while Korean and Chinese competitors were pressing the profit margins in low and mid-range phones, and new players entered the mobile network and base station business.

These two developments led *us to think that new openings are needed to ensure the future of the Finnish ICT industry*. Openness and smartness in our every-day environment were seen as the cornerstones of ubiquitous computing, and hence the “Open Smart Spaces” spearhead programme (OPENS) was launched to strengthen VTT’s competencies and offering in the field. VTT already had a good scientific and technological base in ubiquitous computing developed in preceding programmes and projects since the turn of the millennium. Only by mastering the technology and applications of ubiquitous computing can VTT help Finnish industry and society to benefit from the opportunities opened by the new technology trend and to be prepared for the radical changes in the mobile industry cluster. The OPENS programme was launched in January 2009 with the following three major topics: interoperability, smartness, and natural interaction.

The OPENS programme ran from the beginning of 2009 until the end of 2012. The programme comprised more than one hundred projects, most of them funded by competitive public sources (EU, Tekes – the Finnish Funding Agency for Technology and



The three major topic of the OPENS spearhead programme and examples of steps taken.

Innovation) and companies. The volume of the programme was about 38 million euros, and it incorporated some 300 person years. Its results include solutions, applications, and concepts developed for customer companies; three spin-offs, namely Adfore, Hookie, and SixStarz; initiation of NFC wireless charging standardisation; development of a powerful sensing and computing device, the VTT Node; more than one hundred inventions and two-hundred and seventy scientific and technical publications (see the information box at the end of this publication for more details).

The world around us changed a lot during the four-year life span of the programme. Ubiquitous computing technologies made big steps in areas like location-based services, situation-aware applications, smart homes, natural user interaction, and mixed reality – think about the new games based on 3D cameras. The disruption to the Finnish mobile communications industry has been even more profound and faster than we expected in 2008. *The results of the OPENS programme were directly used by companies in various fields of industry and services*. Solutions developed for context awareness, mixed reality, and sensor-based 3D modelling of our surroundings opened novel application fields and helped companies to create new businesses. Intelligent sensors and interoperability solutions are used by companies to enhance their processes and productivity.

Now, we are looking towards digitalisation of the world, and the concept of the Internet of Things is bringing physical and digital tightly together. The Internet of Things will be a technology disruption like the telegraph, telephone, automatic data processing, and web. It will change our world and offer opportunities for new business, while at the same time challenging and making redundant old practices and business models. VTT sees IoT technology as a means to increase productivity and thus tackle the big challenges facing Europe. We seek industrial and research partners who share our will to embrace the opportunity.

Acknowledgements

During the programme, we got involved in co-operation with many of the best research and development people around the world through European co-operation projects, contract R&D, and collaboration with Japanese and Korean partners. This co-operation has been inspiring and productive. In some cases, co-operation has evolved into long-term partnerships. Co-operation has also shown that VTT and Finnish companies and universities belong to the top class in the world. I would like to take this opportunity to acknowledge the importance of the contribution of our research and development partners in Finland, Europe, and globally, as well as to thank the funding organisations Tekes – the Finnish Funding Agency for Technology and Innovation, Academy of Finland, and the EU, and the public private partnership organisations ARTEMIS, ITEA, FIMECC, and Tivit for making it possible for us to stay in the technology frontline and to bring this knowledge into everyday operations of Finnish companies.

Heikki Ailisto
Programme Manager, Research Professor
heikki.ailisto@vtt.fi

Global Trends 2025: A Transformed World. Edited by C. Thomas Fingar. NIC 2008-003, U.S. National Intelligence Council, Washington DC, USA, 2008. ISBN 978-0-16-081834-9. http://www.dni.gov.

Ubiquitous technologies in business and everyday life. A VTT brochure about the OPENS programme. VTT, Espoo, Finland, 2012. http://issuu.com/vttfinland.

Contents

This publication describes some of the research highlights achieved in the focus areas of the programme: interoperability, smartness, and natural interaction.

Interoperability between devices, software, and other resources is essential for the emergence of smart spaces. Our work on this challenge is described in two articles. The first article discusses the different levels of interoperability and emphasises how important it is that the devices in smart spaces can communicate using a common language, that is, on a semantic level. The second article addresses semantic interoperability in resource limited devices and gives an implementation example. It also introduces the universal identification system that makes it possible to assign a digital identity to every single object or thing one can imagine.

Context recognition has taken significant technical steps and has matured from laboratory to real world applications during the last couple of years. This development from recognising a user's physical activity – sitting, walking, running – to more elaborate life pattern analysis is described in the article *Context recognition methods bring awareness to mobile devices.*

Development of the VTT Node, a wireless sensing and processing device that brings distributed intelligence to industrial condition monitoring, is explained in *Reforming industrial condition monitoring by high performance wireless sensing and data processing.*

An overview of how near-field communication antennas and circuits, today used, for example, in touch-free payment applications, can double for the purpose of wireless charging is given in the next article.

Finally, a group of articles introduce us to the interesting possibilities given by augmented and mixed reality and 3D cameras. The applications are not limited to natural human computer interfaces, but include 3D awareness for robots and other digitally controlled systems.

More examples of the results of the OPENS programme can be found in *Ubiquitous technologies in business and everyday life*, a link to which can be found at the end of the foreword.

Smart spaces arise from interoperation

Eila Ovaska
Research Professor
eila.ovaska@vtt.fi

Other contributing authors:
Antti Evesti, Pasi Hyttinen, Artem Katasonov, Jarkko Kuusijärvi, Marko Palviainen, Susanna Pantsar-Syväniemi, Jani Suomalainen

In the future, smart spaces like smart homes will provide a seamless way of connecting entities, sharing semantic data, and adapting services and applications in dynamically changing environments. For example, a user's authentication to smart house services depends on his role and intent and the internal digital state of the space.

Moreover, applications and services of smart spaces can be created at run-time, when all factors that influence the service creation are known or can be anticipated. Predictive behaviour based on semantic information provides many opportunities for improving user experience. This kind of predictive capability makes smart space applications able to serve users in a personalised way, without their active demand to be served.

The opening of the data on the public environment encourages ordinary citizens to participate in the development of innovative services for public spaces such as smart cities and schools. These kinds of public spaces provide an opportunity and facilities for ordinary people to act as service creators. More often, this is happening through social communities where volunteers are committed to service co-creation for expressing their values and intents.

Motivations for smart spaces are to support context-based prediction and ultimately provide the right information when and where needed, even if not explicitly requested, with a content and format optimally adapted to the user's situation and profile. Sharing information and its meaning is required for making applications able to proactively adapt their behaviour according to the context of the smart space and its users.

Smart spaces are built around uniquely identifiable objects that can interoperate and that are virtually represented in a semantic-web-like structure. Primarily, the research on smart environments was focused on interconnecting physical objects, but thereafter the focus has been enlarged to cover logical entities. Thus, the object in the semantic web can mean any entity that can have a unique identifier, such as a person, device, system, or data.

What makes smart spaces interoperate?

Over the past few years, interoperability research at VTT has focused on smart homes, smart cities, and smart personal spaces. Design principles, such as context management, simplicity, evolvability, and scalability, guide what kind of architecture and software make devices and systems interoperate. Information is used as a means of integrating separately developed devices, services, and applications. Thus, the exchanged information shares the same meaning and leads to the shared goal of operation.

Alignment of shared information is achieved by standard semantics defined by ontologies, for example, the context ontology for smart spaces. The core part of the development of interoperable smart spaces is semantic information brokers that store and interpret the exchanged data and activate the relevant actions of software agents according to the rules available in the same storage.

Due to the dynamic nature of smart spaces, applications need to be adaptive. Adaptation is made automatically by the inherent reasoning agents that interpret the data collected from different sources (sensors, devices, and systems) within the smart space. Adaptation can also be made semi-automatically, as an end-user creates a new application by merging semantic information from different smart spaces via a specific end-user programming tool. For example, the user mashes up information on a personal space and a car space and configures the created application for the purpose in hand.

In order to create a smart space, the following solutions are required:

- design principles for interoperable ubiquitous devices and systems
- alignment of shared information by ontologies, for defining generic and domain-specific concepts of smart spaces
- service broker architecture for sharing semantic information
- tooling for developing cross-domain smart space applications.

Figure 1. Each interoperability level has a specific purpose.

Interoperability model and design principles for smart spaces

Interoperability appears at all levels in smart spaces (Figure 1) [1]. *Connection interoperability* makes objects exchange signals, for example by means of cable, Bluetooth, and wi-fi. Thus, connection interoperability is a prerequisite for *communication interoperability* that enables to exchange data by providing low level interaction capabilities of hardware and software entities. Data formats, SOAP, XML and NFC tagging are examples of the means used on the communication interoperability level. The next level called *semantic interoperability* aims at understanding the meaning of data and using information as an object of integration without knowledge what for the information is used. RDF Schema, semantic web technologies and ontologies are used as means of achieving semantic interoperability. These three interoperability levels create infrastructure services exploited on the two upper levels that are responsible for providing means for *dynamic and behavioural interoperation* of smart spaces. Therefore, dynamic interoperability deals with context changes and uses events as objects of integration. Typical technologies used are modelling and ontology languages such as OWL and UML. Behavioural interoperability uses domain specific frameworks as means of integrat-

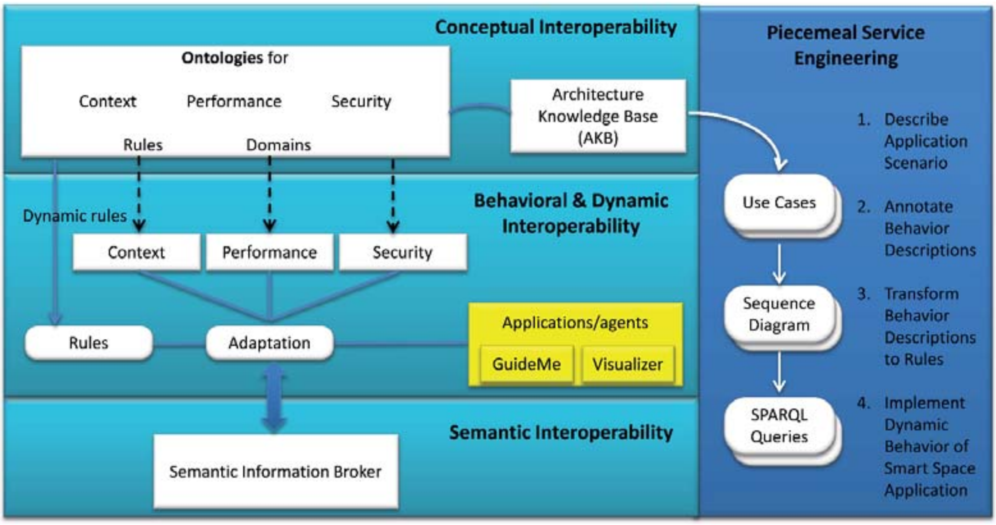


Figure 2. Smartness is achieved by situation-based adaptation of applications.

ing actions and processes together in a way that fulfils the goal of a smart space application. Thus, dynamic interoperability defines and aligns the situation of an application and the behavioural interoperability level completes the actions of the applications with its dependences on other applications and processes. *Conceptual interoperability* focuses on abstracting and modelling concepts and their relationships by scoping, generalization and transformation. Architectural styles and patterns are examples of the means of achieving conceptual interoperability. Moreover, architectural models are enhanced by foundational ontologies and ontological models with a specific focus, such as information security.

Besides the interoperability model, the development of the interoperability platform and smart spaces requires a set of design principles that primarily define the architectural style to be followed in the development of the building blocks for smart spaces. Some of the design principles define the basic concept; some others are related to functions, quality, or commonly accepted development practices. An example of the concept-related principles is the shared information principle: "The interoperability platform (IOP) manages a shared information search domain called Smart Space, which is accessible and understood by all the authorized applications. This information is about the things existing in the environment or about the environment itself. The information is represented in a uniform and use case independent way. Information interoperability and semantics are based on common ontologies that model information." [1]

The context principle is an example of a function that defines context management as an extension of the IOP, and the ontology is to define the context semantics. Security is also defined as an extension, handled both at the service level and at the information level. Moreover, legacy devices and systems shall also interoperate through smart spaces. Therefore, information is modelled by domain ontologies that legacy devices use for providing information to the smart space and subscribing to information from it. The design principles of smart spaces are elaborated in more detail in [1].

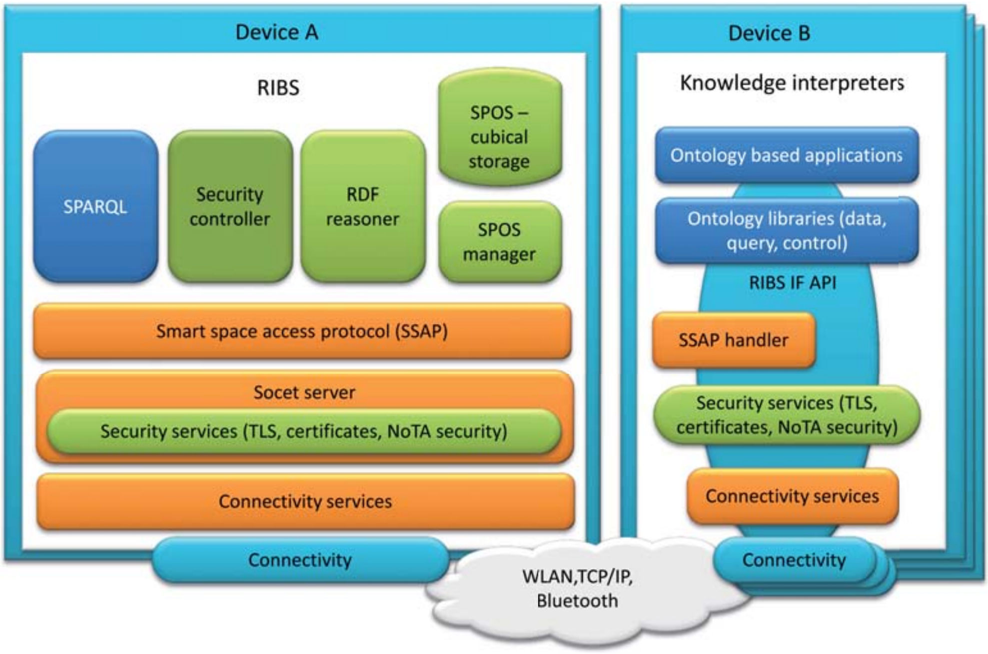


Figure 3. Secure semantic information broker.

Ontologies as a means of achieving interoperation

Ontologies can be used for different purposes and in different ways. For example, a lack of notation constructs for representing quality capabilities in a modelling language can be solved by extending it with specific ontologies via the profile construct. In this way, the architecture modelling language is enhanced with a quality profile to define the security and reliability concepts in the software architecture [2].

First of all, in order to manage quality properties in an adaptable way, the quality properties must be measured at run-time. Therefore, the quality ontologies, such as the information security ontology, were developed by mapping the concepts from the measurement ontology to the concepts of information security. In this way, all the concepts related to run-time information security management could be defined in one model that all applications use, and therefore, information security is interpreted by each application in the same way during operation [3].

Another way is to develop a modelling tool based on a set of interrelated ontologies that support different model abstraction levels and enhance the domain-specific language with the concepts of software artefacts, domain, interaction, and query patterns used for retrieving information from smart spaces [4]. This approach supports model-based smart space application development and is used when run-time adaptation is unnecessary.

Thirdly, ontologies can be used for describing how the application has to behave in a certain situation. In this case, the context ontology plays the key role in context identification, reasoning, and application adaptation. The ontology is an interchangeable part of the running system and intended for use in defining the behaviour of the application. Although all these approaches can be applied to smart space development, only adaptive systems can create real smartness. The smart spaces

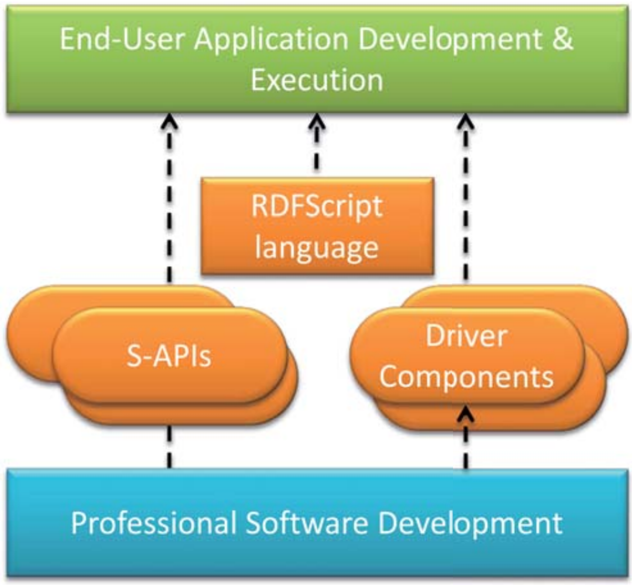


Figure 4. Tool support for software developers and end-users.

are highly dynamic, and thus, the architecture of the IOP and smart space applications has to be dynamic, too. Therefore, we created an adaptation framework based on a reference micro-architecture that exploits ontologies as ready-made building blocks [5].

As depicted in Figure 2, the architecture knowledge base provides concepts as ontologies and reusable models and patterns. Applications are constructed by using these assets for defining their dynamic behaviours, based on the dynamic rules and semantic information retrieved from the semantic information brokers that form the interoperability platform of the smart space. The steps of the piecemeal service engineering define the approach to how the applications are developed by exploiting these reusable assets.

Secure semantic information sharing

One of the reusable building blocks developed for the semantic interoperability level is the RDF Information Broker Service (RIBS) (Figure 3) [6] that follows the Smart-M3 concept (multi-vendor, multi-device, multi-domain) (http://en.wikipedia.org/wiki/Smart-M3). However, the implementation is enhanced for specific usage. First, the RIBS is intended for resource-scarce networked systems. It is efficient for storing and retrieving a relatively small amount of data. Second, the RIBS supports the standard query language, SPARQL. Moreover, it provides efficient access control policies and security control over resources. Performance costs are minimised by requiring that each policy is presented with a single information triple. The security control model is based on context and security measurement concepts, which are used to authorise actions. Hence, the model can be applied in various dynamic security control situations [6].

Cross-domain application development

VTT has also developed a modelling tool, called Smart Modeller [4, 7]. The tool combines model-driven development, domain-specific language, and ontology-oriented design. The tool uses the open source tool platform

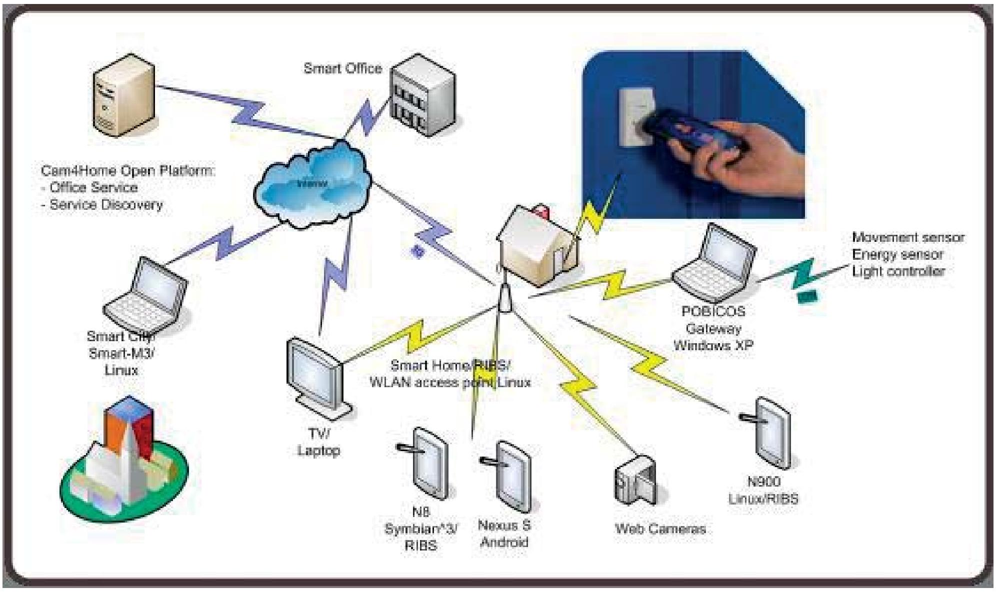


Figure 5. Cross-domain applications combine information from different spaces and the cloud.

Eclipse (http://www.eclipse.org/) and provides an extension point for the plug-ins that perform processing related to the application models. In our experiments, we observed that the Smart Modeller is too complicated for end-user programmers. Therefore, we also developed a simple tool for end-user programmers.

In the future, end-users will be able to automate information service creation, for example by combining energy consumption information with a person's activities. To this end, the end-user programming tool has two levels (Figure 4). The software professional's level supports modelling of S-APIs (semantic end-user application interfaces) and the development of driver components. S-APIs support creation of the execution flows and data flows of applications. Driver components are ready-made building blocks that facilitate the easy creation of cross-domain applications. These driver components are developed by the Smart Modeller. When both driver components and S-APIs are ready, the end user can define the behaviour of the application by configuring inputs and connecting them to the outputs of the previous commands in the command sequence. The command sequence can be visualised via the Smart Modeller. Moreover, the RDF Script Simulator is available for testing applications and driver components in a desktop environment.

Figure 5 represents our piloting environment, where cross-domain applications were developed for smart personal spaces, smart home, smart office, and smart city. The cross-domain applications could also exploit the entertainment services provided through the content delivery platform Cam4Home (http://openplatform.cam4home.fi), also developed by VTT.

Some steps taken, some more ahead

As smart space development follows the interoperability model and the defined design principles, smart spaces have inherent capabilities to proactively anticipate the intentions, activities, and preferences of smart space users, and to adapt the behaviour of applications in a way that best fits the situations of individual users by taking into account the state of the smart environment as a whole. Everything depends on semantics – semantics of information, context, behaviour, and concepts – defined in a machine-readable format that is understandable to all objects participating in smart spaces. These commonly understood models are ontologies that are shared among persons, organisations, systems, devices, and all kinds of things. This enables the creation of smart applications that, without intervention, proactively serve the users in a way that can be called intelligent.

End-user programming tools, together with ontology-oriented service engineering, open new possibilities for ordinary people to participate in service creation and service business. However, it requires that more and more public organisations, and possibly also private ones, make their data freely available for all people whenever no secrecy is required. This will make smart spaces global, and smart communities will be more socially oriented than technology oriented. However, there are still some technical issues to be solved: models and practices for managing the huge amount of heterogeneous data, real-time reasoning for the meaning of the data, and making decisions based on it. They are prerequisites for achieving intelligence in actions and behaviour.

References

[1] Ovaska, E., Salmon Cinotti, T. & Toninelli, A. The design principles and practices of interoperable smart spaces. In: Liu, X. & Li, Y. (Eds.): Advanced design approaches to emerging software systems: principles, methodologies, and tools. Hershey, PA: Information Science Reference (2012), pp. 18–47. ISBN 978-1-60960-735-7.

[2] Ovaska, E., Evesti, A., Henttonen, K., Palviainen, M. & Aho, P. Knowledge based quality-driven architecture design and evaluation. Information and Software Technology, Vol. 52 (2010), No. 6, pp. 577–601. doi: 10.1016/j.infsof.2009.11.008.

[3] Evesti, A., Savola, R., Ovaska, E. & Kuusijärvi, J. The design, instantiation, and usage of information security measuring ontology. Proceedings of the 2nd International Conference on Models and Ontology-based Design of Protocols, Architectures and Services (MOPAS 2011). Budapest, Hungary, 17–22 April 2011. Pp. 1–9.

[4] Katasonov, A. Ontology-Driven Software Engineering: Beyond Model Checking and Transformations. International Journal of Semantic Computing, Vol. 6 (2012), No. 2, pp. 205–242.

[5] Pantsar-Syväniemi, S., Purhonen, A., Ovaska, E. & Kuusijärvi, J. Situation-based and self-adaptive applications for the smart environment. Journal of Ambient Intelligence and Smart Environments, Vol. 4 (2012), No. 6, pp. 491–516. doi: 10.3233/AIS-2012-0179.

[6] Suomalainen, J. & Hyttinen, P. Security Solutions for Smart Spaces. Proceedings of the 11th International Symposium on Applications and the Internet (SAINT). Munich, Germany, 18–21 July 2011. Pp. 297–302.

[7] Palviainen, M., Kuusijärvi, J. & Ovaska, E. Framework for End-User Programming of Cross-Smart Space Applications. Sensors, Vol. 12 (2012), No. 12, pp. 1–25.

Related publications

Evesti, A. & Ovaska, E. Ontology-Based Security Adaptation at Run-Time. Proceedings of the 4th International Conference on Self-Adaptive and Self-Organizing Systems. IEEE. Budapest, Hungary, 27 September – 1 October 2010. Pp. 204–212.

Evesti, A., Suomalainen, J. & Ovaska, E. Self-adaptation Approach for Smart Space Security. To appear in Computers, MDPI, 31 p.

Katasonov, A. & Palviainen, M. Towards ontology-driven development of applications for smart environments. Proceedings of the 8th IEEE International Conference on Pervasive Computing and Communications Workshops. Mannheim, Germany, 29 March – 2 April 2010. Piscataway, NJ, USA: IEEE. Pp. 696–701. doi: 1 0.1109/PERCOMW.2010.5470523.

Palviainen, M., Kuusijärvi, J. & Ovaska, E. Architecture for end-user programming of cross-smart space applications. Proceedings of the 2012 IEEE International Conference on Pervasive Computing and Communications. IEEE Xplore digital library. Lugano, Switzerland, 19–23 Mar 2012. Pp. 829–834.

Pantsar-Syväniemi, S. 2012. Architecting embedded software for context-aware systems. In: Tanaka, K. (Ed.): Embedded Systems; theory and design methodology. Intechopen, pp. 123–142.

Smart Door video https://www.youtube.com/watch?v=anRW0y2r1Q0

Smart Modeller http://code.google.com/p/sofia-application-development-kit/source/browse/

New smart systems by extending semantic web to low capacity devices

Juha-Pekka Soininen
Research Professor
juha-pekka.soininen@vtt.fi

Other contributing authors:
Janne Takalo-Mattila, Esa Viljamaa, Pasi Hyttinen, Jussi Kiljander, Matti Eteläperä, Arto Ylisaukko-oja

Today, digital electronics and computation can be embedded into almost all things and infrastructures. Computer technology has reached a level where low-cost and computationally capable devices can be created in very small dimensions and with very low energy consumption. The concept of ubiquitous computing has become a reality and machine-to-machine (M2M) communication technologies are spreading and changing the ways in which automation and information systems are developed. Computation, storage, and intelligence are being distributed into more autonomous units, and wireless communication and networking technologies allow us to create dynamic and reconfigurable collections of those units of intelligence, providing services for the users and systems in the environment. Opening data on the Internet has revolutionised the creation of applications and services. The next phase will be the so called semantic web, which makes information understandable and usable for digital applications and systems across device, application, and domain boundaries.

The research question in this work is how to bridge the gap between the real world and the digital world. In the real world, we live and exist as physical objects together with other concrete things. In the digital world, we can collect information about physical objects in the real world, and produce virtual representations of those. These virtual objects can then be used in digital processes that automate routines, create welfare, or otherwise help us humans in our everyday lives. The challenge of ubiquitous systems is how to handle complexity and maintain operational capabilities during changes in the environment and in the system itself. The system should be always on and serving human and machine clients. Technically, the question is how to connect all physical objects into digital domain, and further, to the semantic web. How do we design and develop ubiquitous systems? What are the main requirements and building blocks of such a system? How do we arrange constant and meaningful operation of the system for all users? When these questions are answered, it will allow us to mash up, that is, to combine information and services from various providers for far more advanced systems and purposes that we can only dream of.

In order to answer the above question, we need to think of the wholeness and the systemic aspects, since heterogeneous, distributed, and complex systems start to resemble ecosystems, for example in their organisational ability and dynamics. In ecosystems, organisms interact with each other by exchanging energy and material in various nutrient cycles. There is a constant energy and material flow through each individual organism. That flow enables individuals to maintain their processes and thus keep the ecosystem operational. In ubiquitous systems, the individual applications in devices interact by sending messages to each other. The messages contain information meaningful to the application and to the whole system. The constant information flow through each participating application in the system triggers actions in them, and the ensemble of actions is the behaviour of the ubiquitous system. Thus, in order for any application to be part of the ubiquitous system, it needs the abilities to *exchange information* and to *act on information.*

The research results presented in the following chapters focus on low capacity or resource constrained devices, that is, on the devices and embedded systems that are cost optimised for their own individual purposes, such as a humidity sensor, thermometer, oven, electronic lock, or washing machine. We show how to create semantic web capabilities on them and how to build systems on loosely coupled devices using semantic web principles. Our solution M3 is a semantic interoperability architecture that focuses on opening and sharing the information embedded in devices. The name M3 comes from multi-device, multi-vendor, and multi-domain suitability of the solution, as it implements the semantic web principles for embedded systems.

The concept of a resource-constrained device says that, due to cost optimisation, there is a constant lack of additional information storage, computation, and communication capabilities. This is a major challenge for semantic information processing, as semantic information presentation creates significant memory and processing overheads compared to optimised, predefined format-based presentations of data. In semantic data, we have to give unique identifiers to data elements so that they can be separated from others, we have to provide a link to an ontology model that describes the meaning and possible relations of data elements, and we have to link each data element to other data elements, so that we can understand the relationships between them.

The first chapter describes the basic features of the uID approach, where the uID architecture provides a means to create unique identifiers for all objects and a way to link these objects to digital information. We have created a smartphone application for the creation and management of unique identifiers of objects and have merged the uID architecture with the semantic-information-based interoperability architecture M3.

The second chapter describes the solutions for implementing smart systems using semantic-web-based ubiquitous devices. We present our solution, M3, for sharing semantic information in a local place that is also feasible for resource-constrained devices, and solutions for the creation of a service network that provides connection interoperability across multiple physical communication channels. As a case example, these solutions are applied to the creation of a smart greenhouse system that is incrementally developed and that is composed of loosely coupled semantic information capable devices.

In the third chapter, we show how a low capacity semantic device can be designed and implemented. The device is an active tag technology-based plant stick that is capable of communicating with the M3 solution, producing its moisture measurements as semantic information in M3, and reacting based on shared information in M3.

These results form the basis for the creation of smart environments. They show how real-world entities can be integrated as extensions to a semantic web, and how their information and capabilities can be used for creating a smarter world.

Giving digital identities to physical objects

Having digital information associated to real-world things that do not have embedded computers in them requires that we have identifiers for things and a computing infrastructure for keeping and sharing the information that we want to link to them. Typical solutions for this are barcodes, QR codes, and RFID/NFC tags, which have product identifiers or web-page addresses linked to things that can be accessed by scanning or touching them. Ubiquitous Identification (uID) architecture is a technology that goes beyond this. It consists of a 128-bit extendable code space called ucodes for identifiers of any kinds of things or objects, and a server infrastructure for allocating the unique identifiers for objects, and for storing and accessing the associated digital information.

uID architecture is different because it focuses on unique digital identities for every unique thing. It is completely independent on physical tag media, and it offers a global server infrastructure for accessing the information through the Internet. Thus, uID bridges the gap between the physical and digital worlds and makes it possible to connect even the simplest things to digital systems. The uID technology is developed by YPR Ubiquitous Networking Laboratory (YPR UNL) from the University of Tokyo. uID server architecture is three tiered and maintained by a uID centre in Japan. VTT hosts the first uID server in Europe, which means that we can allocate ucode subspaces to other organisations and we are also able to use uID technology in our own research [1].

The way in which the ucode is used always depends on the application, and the uID architecture itself is agnostic to applications. Typical examples can be, for example, providing tourist information on a specific place by reading the ucode attached to it, downloading a user manual of a tool, or verifying the identity of the thing. When information on a specific thing or object is needed, the ucode is first read by a mobile device using NFC or QR readers, for example, and then sent to the uID resolution server. The resolution server replies with the information server address from where the actual information related to ucode can be retrieved [2].

The currently available version of the uID architecture provides globally unique identifiers for objects and also a way to fetch information related to the identified object. YRP UNL is also developing a ucode relation model, which extends the current ucode architecture by adding the meanings and attributes for object

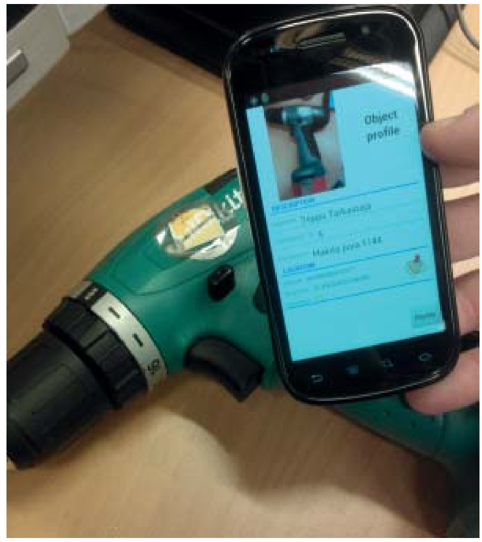


Figure 1. uEasy is a mobile application for the creation and management of ubiquitous identities and related information for things. The application is based on ucodes and uID servers. For example, a user can modify and retrieve information related to the drill simply by touching the drill with the phone.

identifiers. Using ucode, the relation model objects and the relationships between different objects can be described. We have also been using M3 technology together with uID, in order to extend the possibilities for describing the physical objects. M3 provides a way to describe the objects using semantic web technologies, and uID technology provides the object with a unique identifier that can be used as a unique resource identifier (URI) in the information graph that describes the object. That is how we can describe the physical world using semantic web technologies and link the physical world to the digital world by using uID technology without being device or application dependent [3].

We have developed an application called u-Easy, which creates a unique identity using uID and ucodes for any kinds of items. The main purpose of this application is to demonstrate the possibilities of uID technology, and the u-Easy application can also be used as a basis for other applications that are targeted for other use cases. With this application, it is possible to fetch any kind of data about a tagged item (NFC or QR code) just by touching the object or reading the QR code with a smartphone. It is also possible to touch the tagged item and attach text, pictures, and location data to the item and publish all this information on the web.

For example, tools and equipment in a construction company can be tagged either with a QR code or an NFC tag. When an employee takes a tool such as a drill for their own use, they touch the tagged drill with their smartphone, and that is how the current user and the location of the tool are updated automatically on the website. Other employees of the construction company can check the current holder of the drill and their recent location from the web site. Possible faults can also be reported using the u-Easy application, for example by taking a picture of a tagged tool. The user interface for the u-Easy application is shown in the figure (Figure 1).

M3 information sharing solution for interoperability-based systems

The interoperability architecture M3 is a system-level whiteboard for exchanging information in RDF (resource description framework) form, which is a W3C standard model for information exchange in the semantic web. Information exchange between applications happens via a semantic information broker (SIB) that is both an RDF knowledge base and an RDF triplet broker. Applications are knowledge processors (KPs) that consume and provide information for a ubiquitous system. A SIB or set of SIBs is the memory of the ubiquitous system, and KPs are the brain and action mechanisms of it.

The M3 model describes the information-level interoperability in a form of information format (RDF) and information access and exchange operations (SSAP). The model does not mention how to implement interoperability at other levels. This allows M3 to be implemented in various computing environments, enabling a potentially wide adoption of M3 technology among different vendors and their devices – this is the spirit and aim of M3; being a multi-vendor, multi-device, and multi-domain approach. While the abstract model of M3 favours interoperability, it does not put it into practice. The implementation of M3 needs to solve interoperability at all levels.

Our solution aims for wide coverage and use of the M3 technologies in different devices. In addition to devices, our aim is to support a wide set of different programming environments and run-time execution environments. With this in mind, we have developed the M3 Interoperability Framework, which is a set of software modules and practices that support different communication technologies, programming languages, operating systems, and SIB implementations.

Figure 2 illustrates in colour how interoperability layers incrementally solve interoperability issues and hide those from the application designer. ADIOS (Advanced Device Interoperability Solution) is an OSI (open systems interconnection) session-level communication as a service implementation. Libsskp is a presentation-level (OSI 6) library that solves SIB syntax and data format issues. On top of libsskp, there are thin wrappers that solve specific programming language and programming model issues. This enables a developer to choose their favourite programming environment.

The arrow in Figure 2 illustrates information transfer between applications. The Windows application knowledge processors (KP) on the right side send information to an Android application knowledge processor on the left side. The RDF graphs in both applications represent their local knowledge of the whole system knowledge. The system knowledge resides in the M3 SIB, whose whiteboard

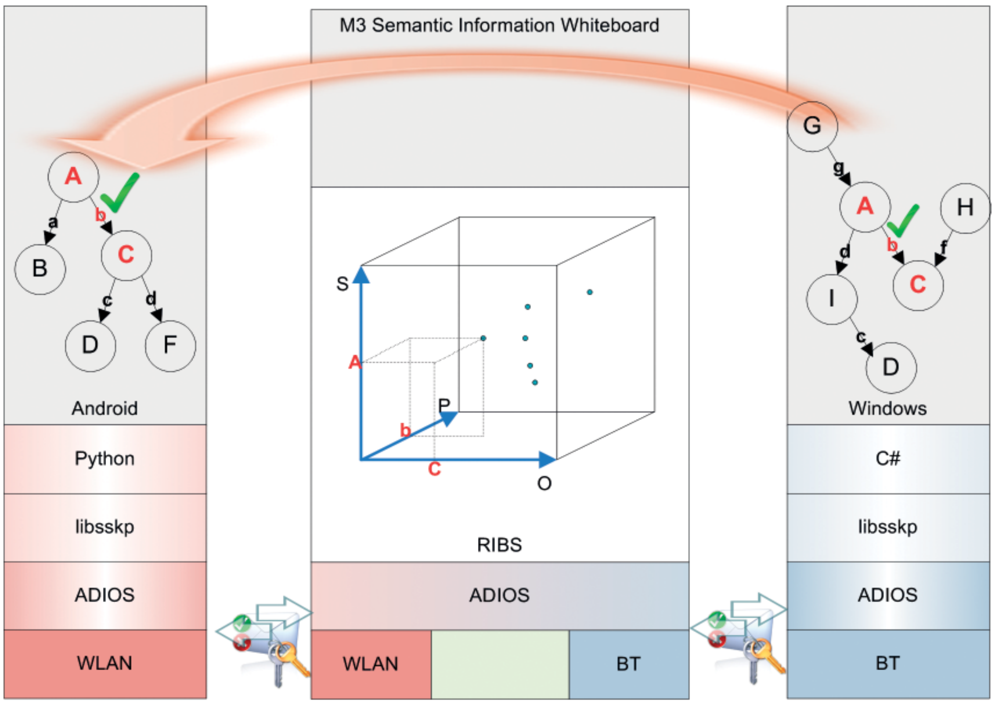


Figure 2. M3-based interoperability layers solve the interoperability issues between two devices. The approach uses RIBS implementation as a common information-sharing solution in a gateway device. The arrow describes how information from Device 1 flows to Device 2 via a gateway device and M3, and how M3 shares the information so that communication and collaboration between the two devices becomes possible.

is used for sharing the information, such as the RDF triplet <A,b,C> in this case. So in practice, KP on the right side first communicates with SIB in the middle, and then KP on the left side communicates with SIB.

The RIBS is an RDF information base solution and M3 SIB implementation for resource-constrained devices. It is compact, portable, and its hardware and operating system dependencies are minimised, making it ubiquitously deployable. Unlike most RDF storage, RIBS does not have a database back-end for storing triples. The URIs of the triple are mapped into numbers, and the numbers are used for addressing the triple information in a 3D memory structure, bit cube. Thus, each triple is a bit 1 in a cube. The figure shows how triple <A,b,C> became a point in a 3D subject, predicate, and object space.

Extendable and incremental approach for developing ubiquitous systems

An example of semantic-technology-empowered ubiquitous computing systems is the Smart Greenhouse [4]. The Smart Greenhouse, illustrated in Figure 3, is a miniature version of a greenhouse where autonomous agents assist a gardener in his daily routines. The Smart Greenhouse demonstrates how semantic technologies can be utilised to build ubiquitous computing systems where semantic-level interoperability is based on the RDF

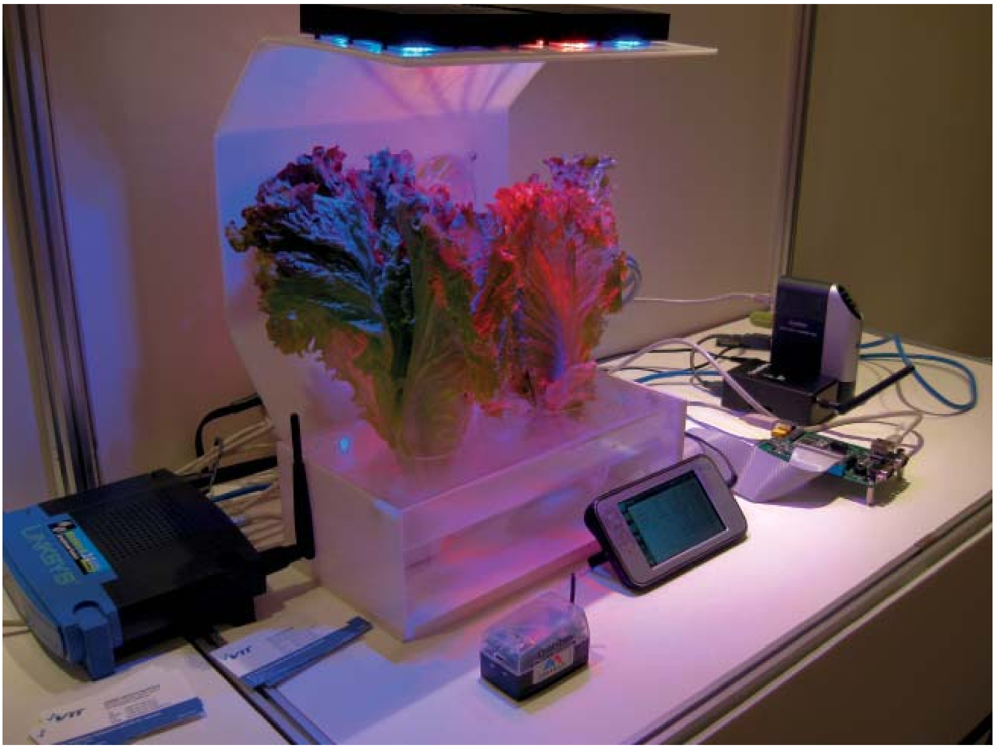


Figure 3. The Smart Greenhouse demonstrator is an example of an incrementally developed system consisting of autonomous devices and shared information-based interoperability.

data model, RDFS vocabulary, and common ontologies. Additionally, it shows how semantic technologies provide flexibility and enable incremental development of ubiquitous computing systems.

The Smart Greenhouse has been built incrementally in four stages by adding new devices and features at each stage. It is noteworthy that no modifications to the existing systems were needed when new features and devices were added, especially when applying the technology to larger applications. The first version of the Smart Greenhouse consisted of three knowledge processors or "modules": the Actuator, Sensor, and Gardener user interfaces. To allow other KPs to modify the state of the physical actuators, the Actuator KP creates virtual representations of them by publishing information about them on the SIB. Then it subscribes to the information on the state of the actuators, so that it is notified when the physical state of the actuators needs to be changed. The role of the Sensor KP is to measure the temperature, luminosity, and humidity in the greenhouse and to publish that information on the SIB. The Gardener UI provides the actual gardener with possibilities to 1) browse available actuators and sensors, 2) view information related to sensor measurements and actuator states, and 3) modify the state of the actuators.

In the second phase, a new autonomous control device, called Autocontrol KP, was added to the system. A new feature in the Gardener UI was also implemented that allowed the gardener to add information about plants to the SIB. The plant data and existing sensor information is utilised by the Autocontrol KP to autonomously modify the physical actuators via the SIB. For example, the autocontrol

KP updates a new state for the virtual representation of LED lights when the luminosity in the greenhouse is not suitable for the plants. Because the Actuator KP has subscribed to the actuator status information, the SIB will notify it about the new LED light status and the Actuator KP will modify the physical LEDs accordingly.

The third generation of the Smart Greenhouse expanded the previous versions with item-level object tagging. The sensors, actuators, and plants where tagged with ucode-based RFID tags, which provided unique identifiers for the physical objects. The same ucodes were also used as the IDs (i.e. URIs) for the virtual representations in the SIB. Since the unique ID of the virtual object can be acquired by reading a tag, this made it possible to both fetch information related to tagged objects and interact with them just by touching the physical object.

In the fourth phase, a smart environment configuration tool (ECSE) enabling the gardener to automate functions in the greenhouse was introduced. The goal of the ECSE tool was to enable users (i.e. the gardener in this case) to see the possible functions provided by a given smart space and to create simple rules that change the behaviour of the smart space depending on the given situation in the smart space; for example, if the temperature inside the greenhouse exceeds 25 degrees, the ventilation will automatically start. The core idea in the ECSE tool was to model the functions in a smart space as events and actions. For the user, the events and actions are represented with a short human-readable description. In the SIB, on the other hand, they are represented as RDF update and query language patterns. The dual presentation makes it easy both for the user to create rules and for the rule handler to execute them.

It is noteworthy that the Smart Greenhouse does not require any system integrator, and that the different KPs do not directly communicate with each other. All the devices are autonomous and independent, and the overall system function or interoperability between devices is achieved by sharing information represented with RDF and ontologies via a common SIB, and by making the devices responsive to this available information.

Figure 4. The battery-operated prototype of an intelligent plant stick measures the moisture of the soil and communicates with the M3 SIB through radio and a semantic information interface. The user can access the measurement results, for example, via a phone.

Connecting low capacity devices to the semantic web

Wireless sensors are often low capacity devices in terms of energy resources, processing power, communication capabilities, physical size, and cost. They typically use one of the standard or proprietary short-range radio communication technologies, such as IEEE 802.15.4 or Bluetooth Low Energy. Such radio technologies have low power consumption and battery-based operation as one of the most important design criteria. They define short message payloads that are preferably sent infrequently, to keep the energy consumption low. The target is naturally to conserve battery life and thereby achieve long operation times before the battery needs to be replaced. Low energy consumption may also enable alternative powering technologies, such as power harvesting, resulting in potentially maintenance-free wireless devices.

Using semantic interfaces with low capacity devices can provide most benefits when the devices are not only able to provide their own information as semantic data, but are also capable of utilising semantic information provided by other devices and adapting their behaviour based on that data. Such devices can be, for example, actuators or combinations of sensors and actuators in any semantic-information-based system.

It is a challenge to apply semantic interfaces to resource-constrained devices, since memory, processing time, and message length overheads easily increase, potentially leading to more expensive and power-hungry devices. The challenge is mainly related to the resulting larger amount of data, due to overheads caused by semantic messages. Previously, processing such messages may also have required resource-hungry programs, such as an XML parser. However, in our solution, the semantic data was designed to use a more compact format created by VTT, called Word Aligned XML (WAX). This enables more efficient wireless communications and remarkably more efficient processing of the messages, with fewer memory resources [5]. Using WAX, the semantic interface increased the size of the microcontroller program by approximately 25%, and the requirement for RAM memory was 80% larger compared to using simpler, application-specific binary data representation. Using traditional semantic representation, the overheads would be significantly larger.

To demonstrate the solution, a wireless, battery-powered moisture-sensing plant stick was developed (refer to Figure 4). The sensor is able to notify the user if the moisture level

Figure 5. The gardener uses a smartphone that reports the moisture values and gives alarms if needed. The phone also provides the moisture threshold values and gardener presence information for the plant sticks via the M3 SIB.

of the soil is not within set limits. The alarm can be given in two different ways: 1) by blinking a bright LED within the plant stick, to be easily noticed, 2) indicating the alarm on a smartphone gardening application targeted at normal consumers (refer to Figure 5).

The plant stick provides the measurement data in a semantic form to the semantic information broker (SIB). This is where the smartphone application gets the data from. But the sensor also reads data from the SIB and adapts its behaviour based on that data: 1) the threshold for minimum and maximum moisture level for the plant, and 2) the presence of the "gardener", to eliminate the power consumption of blinking the bright LED when there is no relevant person present that could see it. The threshold and presence data are provided to the SIB by the actual gardener using the smartphone application.

The plant stick is essentially based on the Freescale MC13223V System-on-Chip, which includes a short-range 2.4 GHz IEEE 802.15.4 radio and an ARM7 microcontroller. The software runs on top of a Contiki operating system that is optimised for low capacity devices. The microcontroller spends a major part of the time in sleep mode, which consumes only 10 μA @ 3 volts. Depending on the communication interval, the operation time with two AA-size batteries can be up to several years.

Towards a giant global graph

The results shown above originated from research projects that aimed at creation and opening of local embedded data for smart applications in local places. The key targets were the use of open technologies for achieving interoperability between devices and enabling mash-up type applications and services that create smart environments. This idea of openness is ambitious and noble, since it takes the ideas of the Internet and open data to device level. It changes the ways in which devices should interact and how systems should be constructed. It promotes extensive reuse of resources and their information beyond their original purposes and use cases, resulting in overall savings in costs and increased possibilities for new kinds of systems. It calls for a rethinking of business ecosystems towards the models that are used on the Internet, where the keywords are collaboration and interoperability instead of proprietary solutions.

The results above are technology examples that show that open and linked data-based approaches are feasible models for smart environment infrastructure and systems. We are able to integrate real-world devices with very limited or even non-existent computational capabilities to computational systems in the digital world. We have extended the usability of semantic web technologies to low capacity devices and we can use the information from them as a part of larger systems. We have also shown how more complex systems can be incrementally constructed on top of open semantic information, using low capacity devices.

As good research in general, this has also opened our eyes to future challenges. The Internet of Things and cyber–physical systems are buzzwords that have been under active discussion and research recently. The industry and research community is trying to create models and approaches for similar types of problems that we have had in our research. We believe that our open and linked data approach can contribute to these targets. Imagine a future Google Earth on which you can zoom without limits and on which it would be correct in real time, showing the Earth as it truly is all the time. Imagine that you can dive into it, and that you can exploit the information that you see as a part of your system. The current Google Earth is an open data structure that creates a digital image of the world with augmented information. Our vision is to create an open digital image of the world that is based on open and linked data from the things, devices, and systems around us. This data structure or digital counterpart of the real-world could be added to the vision of a giant global graph [6] and then used as a platform for all ICT-based systems.

References

[1] uID center. http://www.uidcenter.org/.

[2] Viljamaa, E., Kiljander, J., Soininen, J.-P., & Ylisaukko-oja, A. A smart control system solution based on semantic web and uID. Proceedings of the UBICOMM2011, the Fifth International Conference on Mobile

Ubiquitous Computing, Systems, Services and Technologies. IARIA, International Academy, Research and Industry Association. Lisbon, Portugal, 20–25 November 2011. Pp. 105–110.

[3] Takalo-Mattila, J., Kiljander, J., Eteläperä, M. & Soininen, J.-P. Ubiquitous Computing by Utilizing Semantic Interoperability with Item-level Object Identification. Proceedings of the Second International ICST Conference on Mobile Networks and Management (MONAMI). Springer LNICST (2010). Santander, Spain, 22–24 September 2010.

[4] Kiljander, J., Ylisaukko-oja, A., Takalo-Mattila, J., Eteläperä, M. & Soininen, J.-P. Enabling Semantic Technology Empowered Smart Spaces. Journal of Computer Networks and Communication, Vol. 2012 (2012), Article ID 845762, 14 p.

[5] Ylisaukko-Oja, A., Hyttinen, P., Kiljander, J., Soininen, J.-P. & Viljamaa, E. Semantic interface for resource constrained wireless sensors. Proceedings of the International Conference on Knowledge Engineering and Ontology Development, KEOD 2011. 26–29 October 2011. Pp. 505–511.

[6] Berners-Lee, T. Giant global graph. http://dig.csail.mit.edu/breadcrumbs/node/215, 2007.

Related publications

Eteläperä, M., Keinänen, K., Kiljander, J., Hyttinen, P., Pehkonen, V., Väre, J. & Soininen, J.-P. Open-M3: Smart space with COTS devices. UbiComp'10 – Proceedings of the 2010 ACM Conference on Ubiquitous Computing, the 12th International Conference on Ubiquitous Computing. Copenhagen, Denmark, 26–29 Sept. 2010. Pp. 363–364.

Eteläperä, M., Kiljander, J. & Keinänen, K. Feasibility Evaluation of M3 Smart Space Broker Implementations. The 11th IEEE/IPSJ International Symposium on Applications and the Internet Applications and the Internet (SAINT). Munich, Germany, 18–21 July 2011. Pp. 292–296.

Kiljander, J., Eteläperä, M., Takalo-Mattila, J. & Soininen, J.-P. Opening information of low capacity embedded systems for smart spaces. 8th Workshop on Intelligent Solutions in Embedded Systems (WISES 2010). Heraklion, Crete, Greece, 8–9 July 2010. IEEE.

Kiljander, J., Keinänen, K., Eteläperä, M., Takalo-Mattila, J. & Soininen, J.-P. Autonomous file sharing for smart environments. Proceedings of the 1st International Conference on Pervasive and Embedded Computing and Communication Systems, PECCS 2011 (2011). Vilamoura, Algarve, Portugal, 5–7 March 2011. Pp. 191–196.

Kiljander, J., Keinänen, K., Eteläperä, M., Takalo-Mattila, J. & Soininen, J.-P. Enabling End-Users to Configure Smart Environments. The 11th IEEE/IPSJ International Symposium on Applications and the Internet (SAINT). Munich, Germany, 18–21 July 2011. Pp. 303–308.

Patents & software announcements

Hyttinen, P., Suomalainen, J. & Tarvainen, P. Mukautuva saumaton turvallisuusjärjestely. Patent application FI 20105432, filing date 21.4.2010.

Hyttinen, P. Menetelmä ja laitteisto XML-formaatin mukaisen tietorakenteen muodostamiseksi ja käsittelemiseksi. Patent application FI 20105549, filing date 19.5.2010.

Hyttinen, P. Menetelmä ja laitteisto tiedon tallentamiseksi ja käsittelemiseksi. Patent application FI 20105571, filing date 24.5.2010.

Keinänen, K., Kiljander, J., Eteläperä, M., Hyttinen, P., Stenudd, S. & Suomalainen, J. Software announcement OI 11030 "libsskp (Smart Space Knowledge Processor library)".

Context recognition methods bring awareness to portable devices

Ville Könönen
Senior Scientist
ville.kononen@vtt.fi

Other contributing authors:
Miikka Ermes, Jani Mäntyjärvi, Juha Pärkkä

Context sensing aims to give a portable device, such as a smartphone, senses, with which it becomes aware of its surroundings. With the senses, the device is capable of measuring its environment and doing context recognition. With the help of successful context recognition, it becomes context-aware.

VTT has conducted research on context sensing and awareness over ten years and from almost all the angles of the area, including hardware development, methodological research, end-user testing, and transferring the research results to commercial solutions. Specialised solutions for different application areas, such as wellbeing, have been developed, as well as general context recognition services for off-the-shelf products. In particular, the rapid development of smartphones during recent years has provided an interesting low-cost testbed for context recognition methods.

This short introduction follows a loose chronological order of the context awareness research work carried out at VTT. The introduction starts with a discussion on human physical activity recognition, which contains both hardware and methodological research work. Then we proceed with the product-level solution for context recognition in smartphones. Finally, we broaden our view from context recognition to a more general topic of human behavioural analysis, with an example of a service provided by VTT.

Context awareness research originates from activity recognition

The studies on automatic recognition of human physical activities and energy expenditure are commonly based on signals obtained from wearable sensors. One of the goals of automatic recognition of human physical activities and automatic assessment

Figure 1. Combination of sensors used for assessing physical activities and mental load: a) audio recorder, b) 3D acceleration sensor box, c) two ECG electrodes, d) two respiratory inductive plethysmogram (RIP) belts, e) sensor box on the belt (acceleration, compass, light, humidity, and temperature sensors), f) skin temperature sensor.

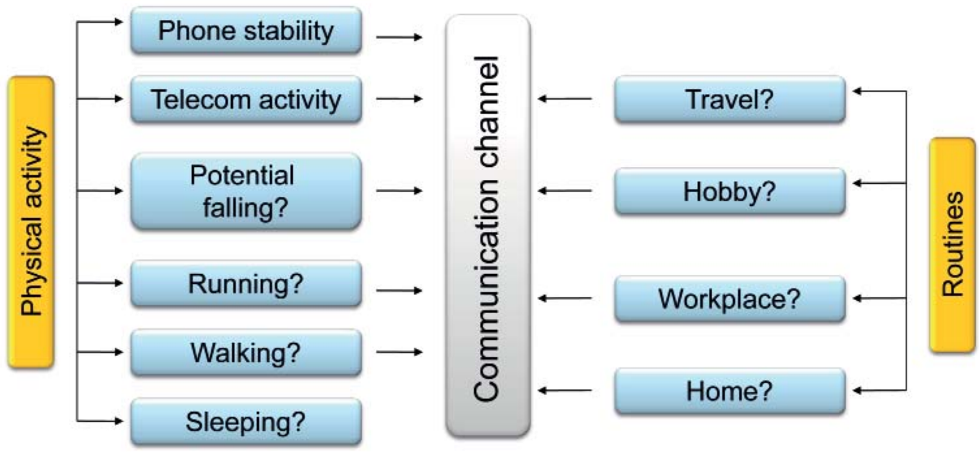


Figure 2. Basic selection of context components in the VTT Context Component Library.

of energy expenditure is to show people the current distribution of their daily activities and the level of their energy expenditure, and to motivate people to a more active lifestyle. The rough estimates of daily energy expenditure provided by simple activity monitors, such as pedometers, can be further improved by using carefully selected sensors and by placing them on well-chosen points on the body, where they can be carried unobtrusively, without disturbing the user. Continuous, automatic monitoring of daily physical activities and energy expenditure could provide more advanced information that can be used to promote a more active lifestyle with a wider spectrum of different exercises.

By definition, physical activity is any bodily movement that results in energy expenditure and that is produced by skeletal muscles. Thus, it covers many types of physical activity, including both natural physical activity and intentional exercise. In order to adequately assess the activity profile of a person, recognition of both the energy expenditure and the types of activities are needed. Energy expenditure gives an overview, indicating whether the person performs enough physical activity. Activity type recognition enables profiling of different categories (aerobic, muscle-strengthening, and bone-strengthening activities).

Using a combination of several wireless sensors and self-assessment tools, new types of data can be collected, which can allow the study of new measures for the objective quantification of health status, unobtrusively and in the long-term. At VTT, algorithms have been developed for activity recognition (e.g., lying, sitting, standing, walking, running, bicycling, rowing, Nordic walking) and combinations of different health parameters, such as assessment of stress levels (see [1–7]). Figure 1 provides an overview of the different sensors and their locations for physical activity recognition.

Context Component Library for smartphones

The rapid development of smartphones during the last few years has enabled the utilisation of the developed context recognition algorithms and methods in off-the-shelf products. The context recognition methods developed by VTT were encapsulated in a library that is available for several smart-phone platforms. The library is highly optimised and it provides a product-level solution for context recognition and human behavioural analysis needs. The

Figure 3. Basic statistics view of the VTT Lifeliner service. The web page shows the prototype day routines worldwide.

core of the library, the VTT context recognition engine, is based on the feather-light context recognition method (see [8–11] for further details), which makes it possible to perform continuous high-quality context recognition as a background process without consuming too much battery power.

Different application domains have different context recognition needs. Therefore, it is impossible to provide a universal solution for the general context recognition task. The library approaches the problem by providing the basic framework into which different context component modules can be plugged. The basic distribution of the library contains the components shown in Figure 2. This basic set of components enables rich services in several business domains such as security, mobile CRM, and marketing. In addition to the basic set of components, VTT has provided customised context components for its customers, for special purposes.

Service offered by VTT: Life-pattern recognition

Life-pattern recognition is a VTT provided service that provides several analyses based on the behaviour of people, their actual lifestyles and habits. It consists of two parts: a smartphone client that is installed on the smartphones of the service users, and the server-side Lifeliner analysis platform. The mobile application utilises the VTT Context Component Library and sends the rich context data on the mobile user's behaviour to the Lifeliner analysis platform. The data communication between the mobile clients and the service is done periodically once per day to save battery power and hence enable long usage times of the smartphones. The context data is aggregated on the server side to find typical behavioural patterns of people in different countries. For example, the service provides answers to the following questions: What is the average sleeping time in Finland? What does the typical day of a Japanese daytime worker look like? An example view of the Lifeliner service is provided in Figure 3.

The Lifeliner service is developed to demonstrate the VTT context recognition and context data analysis solutions. VTT has provided similar commercial solutions for different domains, such as the telecom network domain.

Discussions and a way forward

The examples discussed in this section represent technological foundations of context recognition and are enablers for the novel, context-aware services in different application domains. In the future, the context-aware research will focus on the server-side analysis of the behavioural data. There are several research questions related to the novel kind of data: What business fields can benefit from the data? How can the data be used in an efficient way? What kinds of legal issues are related to the data, and what kinds of consequences do they have to the related services? These are just a few, and in addition to answering these, there remains a constant requirement to enable context recognition services for different application domains.

References

[1] Pärkkä, J., Ermes, M., Antila, K., van Gils, M., Mänttäri, A. & Nieminen, H. Estimating Intensity of Physical Activity: A Comparison of Wearable Accelerometer and Gyro Sensors and 3 Sensor Locations. Proceedings of the 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS'07. Lyon, France, 23–26 August 2007. IEEE. Pp. 1511–1514.

[2] Pärkkä, J., Ermes, M. & van Gils, M. Automatic Feature Selection and Classification of Physical and Mental Load using Data from Wearable Sensors. Proceedings of the 10th International Conference on Information Technology and Applications on Biomedicine, ITAB 2010. Corfu, Greece, 2–5 November 2010. Pp. 1–5.

[3] Pärkkä, J. Analysis of Personal Health Monitoring Data for Physical Activity Recognition and Assessment of Energy Expenditure, Mental Load and Stress. Dissertation. Espoo, VTT, 2011. 103 p. + app. 54 p. VTT Publications 765. ISBN 978-951-38-7740-8 (soft back ed.); 978-951-38-7741-5, URL: http://www.vtt.fi/inf/pdf/publications/2011/P765.pdf.

[4] Pärkkä, J., Ermes, M., Korpipää, P., Mäntyjärvi, J., Peltola, J. & Korhonen, I. Activity Classification Using Realistic Data from Wearable Sensors. IEEE Transactions on Information Technology in Biomedicine, 2006. Vol. 10, pp. 119–128.

[5] Ermes, M., Pärkkä, J., Mäntyjärvi, J. & Korhonen, I. Detection of Daily Activities and Sports with Wearable Sensors in Controlled and Uncontrolled Conditions. IEEE Transactions on Information Technology in Biomedicine, 2008. Vol. 12, pp. 20–26.

[6] Pärkkä, J., Cluitman, L. & Ermes, M. Personalization Algorithm for Real-Time Activity Recognition using PDA, Wireless Motion Bands and Binary Decision Tree. IEEE Transactions on Information Technology in Biomedicine, 2010. Vol. 14, pp. 1211–1215.

[7] Pärkkä, J., Merilahti, J., Mattila, E., Malm, E., Antila, K., Tuomisto, M., Saarinen, A., van Gils, M. & Korhonen, I. Relationship of Psychological and Physiological Variables in Long-term Self-monitored Data during Work Ability Rehabilitation Program. IEEE Transactions on Information Technology in Biomedicine, 2009. Vol. 13, pp. 141–151.

[8] Könönen, V., Mäntyjärvi, J., Similä, H., Pärkkä, J. & Ermer, M. Automatic feature selection for context recognition in mobile devices. Pervasive and Mobile Computing, 2010. Vol. 6, pp. 181–197.

[9] Huuskonen, P., Mäntyjärvi, J. & Könönen, V. Collaborative context recognition. Handbook of Ambient Intelligence and Smart Environments. Springer, 2012.

[10] Könönen, V., Mäntyjärvi, J., Similä, H., Pärkkä, J. & Ermes, M. A computationally light classification method for mobile wellness platforms. Proceedings of the 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS'08 – "Personalized Healthcare through Technology". Vancouver, BC, Canada. 20–25 August 2008. IEEE. Pp. 1167–1170.

[11] Könönen, V. & Mäntyjärvi, J. Decision making strategies for mobile collaborative context recognition. Proceedings of the 4th International Mobile Multimedia Communications Conference, MobiMedia 2008. Oulu, Finland, 7–9 July 2008.

Reforming industrial condition monitoring by high performance wireless sensing and data processing

Pirkka Tukeva
Key Account Manager
pirkka.tukeva@vtt.fi

Other contributing authors:
Esko Strömmer, Marina Eskola

Securing optimum up-time of machinery is of key importance in the global maintenance service business. But what will happen when industrial machines, vehicles, and process equipment are incorporated in their millions to form global maintenance services and produce a massive amount of real-time information?

The machines and vehicles sector is nowadays going through the same kind of revolution that took place in the telecom industry a couple of years ago, when various mobile-based services entered the market. Services and service ecosystems bringing added-value and commercial benefit to mobile operators and manufacturers have, since then, become increasingly important factors in several fields of technology, alongside top quality products. A similar trend can be seen entering the machines and vehicles sector.

There are still a couple of questions blocking the vision of distributing intelligence across all industrial machinery through Internet of Things technologies. First, the amount of the data measured from all the machinery in operation will be enormous and should be both processed and reduced before transferring it over wireless media. Second, systems should be easily configurable for different targets, even in small shipments. Third, in the end, technology should be reliable, even if used in very harsh conditions. The research presented in the following chapters has focused on finding solutions to these challenges.

Introducing the results as a whole

Some significant steps have been taken on the way towards the vision of distributed intelligence within the Open Smart Spaces programme. The timing for this kind of research has been just right, based on two main reasons. The quality and performance of technology components commercially available has increased and the price has been descending due to higher manufacturing volumes. On the other hand, industrial companies have started to develop service-based offerings in addition to component or machine manufacturing. The industry will need more and more ICT-related technology to maintain the global machinery in the future.

The central element in our research and development process has been the development of the VTT Node (Figure 1), a reference architecture and prototype platform similar to a very small-sized re-configurable embedded computer. It has been built for development purposes, as well as for full-scale piloting of distributed signal processing technologies in condition monitoring systems of industrial machinery. The VTT Node has built-in flexibly configurable interfaces for several types of sensors typically used in industrial applications. For example, vibration and stress are very common indicators of failures in structures and bearings. Among others, these could both be measured and analysed in the field by the VTT Node.

Figure 1. The prototype of the VTT Node has been installed in a robust casing and it has been used in several industrial demonstrators for vibration measurement purposes.

The VTT Node has high performance capabilities for comprehensive signal processing, while still being energy efficient and reducing the need for energy storage replacement during operation periods. Robust wireless communication and energy harvesting technologies have had important roles in the development of VTT Node architecture, bringing additional benefits when using the VTT Node both in very harsh and in hardly approachable targets.

During the research and development work, concrete industrial demonstrations have been created to get the industry involved in the development process from the beginning. The commitment of industrial partners has been surprisingly strong, and the contribution from them has been highly valuable, as they are the best information source for the real requirements and challenges.

VTT Node distributing the intelligence

The intelligence of a comprehensive condition monitoring system has to be distributed across several layers. The optimal solution is to integrate the information pre-processing as close to the information source as possible, so that the amount of data before transmission can be reduced, to avoid data overflow during transmission. The challenge here is to have enough signal processing capacity in the pre-processing element while respecting very limited energy resources and an affordable price level. For that purpose, a generic reference architecture of data processing electronics was developed by VTT. The architecture combines the best features of low-power microcontroller technology with energy efficient but still configurable high performance flash-based FPGA (field programmable gate array) technology. The architecture has been designed to meet the fundamental challenges, like periodically high demands for signal processing and data transmission capacity, as well as very low energy states for waiting for the triggering of a new measurement and analysis sequence.

A signal processing algorithm could be programmed into the FPGA using VHDL (Very High Speed Integrated Circuit Hardware Description Language) and algorithms may have highly parallel functions that will be valuable especially when a signal is sampled from several channels in parallel. As VHDL requires special knowledge, some higher level tools are also available for FPGA programming. For example, tool chains to generate hardware descriptions from a Matlab Simulink environment are commercially available, although they not very optimised yet. One promising technology bringing FPGA design closer to traditional programming is TTA (time triggered architecture). This technology has been developed by academic partners of VTT and has

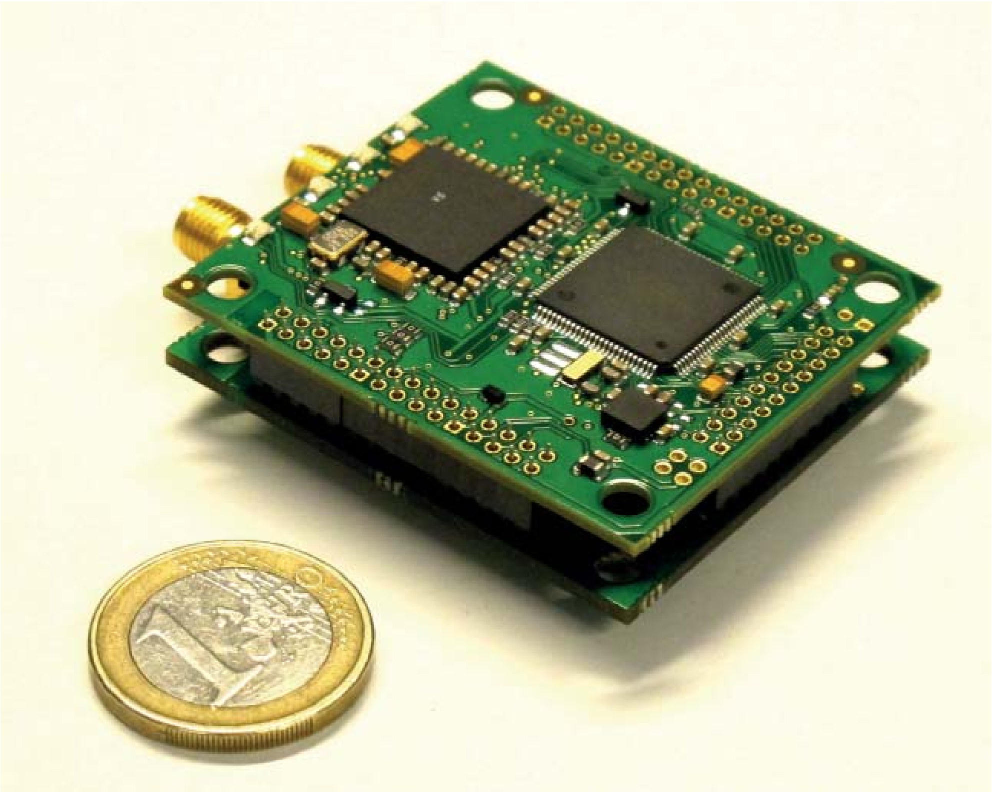


Figure 2. The size of the VTT Node baseboard without external components is similar to a match box.

been successfully demonstrated with VTT Node reference architecture.

VTT Node reference architecture has been designed in a stackable form (Figure 2). The baseboard includes basic functions, including microcontroller, FPGA, memories, digital interfaces, and powering. The other components are placed on the extension boards to achieve a flexible and cost-effective way to modify the configuration. So far, there are extension boards already developed for analogue signal sampling and radio transmission with multiple radio options.

Towards energy-autonomous systems

Wireless connectivity of sensor nodes is important and often even necessary to facilitate mobility of the nodes and easy installation, and to avoid failure-prone cabling in moving objects or unattractive cable retrofitting in a daily living environment. To make the sensor nodes totally wireless, they both have to communicate wirelessly and be energy autonomous, that is, capable of operating without a power supply through external wires. Moreover, operation without external wires must not entail a battery lifetime that is inconvenient from the users' viewpoint.

Energy autonomy of sensor nodes can be implemented in several ways. The sensor node can be fitted with an energy harvester that converts ambient energy flows into electric power for the sensor operation. The exploited ambient energy can be, for example, light, RF fields, mechanical movement, spatial temperature gradients, or temporal temperature changes. To enhance the operation of the energy harvester in the sensor node, a dedicated wireless energy transmitter can be installed close to the sensor node, which is also called wireless energy transfer. The sensor node can be fitted with a battery that lasts its entire lifetime, or at least for long enough so that replacing or recharging the battery can be done conveniently during regular maintenance.

In addition to the development of technologies supporting energy autonomy, VTT has also developed a special power management architecture. The core of the power management architecture in the VTT Node is a low energy consumption microcontroller that has control over all other components by switching the power on and off when necessary. That guarantees the efficient usage of the energy resources available. The most power consuming parts, like the radio transceiver and FPGA-based signal processing unit, are powered off when the system is set to the idle state. The FPGA technology is based on an Actel IGLOO circuit that wakes up from low-power idle mode to fully operational mode within a few microseconds.

The VTT Node has been used in developing and piloting energy autonomous sensor nodes in several target applications. Examples are a vibration measurement application with a wide-band vibration energy harvester, and sensor nodes with wireless inductive powering.

Reliable wireless connectivity

A system is only as strong as its weakest link, as is said. Communication technology is playing a very important role in such systems. The links between the nodes should be reliable and secure even in extreme conditions, such as an industrial environment. Unlike office networks, the industrial environment for wireless networks is harsher due to unpredictable variations in temperature, pressure, and humidity, as well as strong vibrations, atmospheric precipitation, condensation, and airborne contaminants. The signal propagation in a factory environment is often interfered with by multipath propagation, radio-frequency interference, and noise generated by equipment or heavy machinery. To ensure reliable delivery of data packets, changes in radio connectivity need to be detected and managed.

Building and maintaining reliable communication links need efficient and manageable testing methods and tools. The long-term goal is to develop testing methods and techniques that can be implemented and embedded in all nodes and used for self-diagnosis purposes by the nodes and for optimisation of node performance. This kind of automated testing system will diagnose wireless network problems, and the network management will select the appropriate action to take to correct the problem. The operation of the testing system is divided into four main groups: monitoring, alerting, problem identification, and problem correction. During the monitoring, communication link performance is regularly checked, and if link quality deterioration is noticed, the alarm signal is generated. Problem identification and correction are managed by performing the detailed device tests, and examining the environmental problems by automatically generating test cases and analysing their results.

Discussion

The most crucial technology elements for distributing intelligence in condition monitoring and maintenance systems have been developed to prototype level. In addition, several successful industrial pilots have shown that the technology will soon be ready for commercial applications. There are still a few things to be done before the breakthrough concerning system integration, cost optimisation, and application development. These are important drivers for the big markets.

The most important part of the future work is to create an ecosystem that supports the technology platform by offering applications for signal processing, protocols, and software on the top of the hardware components. This ecosystem will provide users with the latest releases of the analysis and control software modules, in a flexible way via remote access. The ecosystem model will also offer new business possibilities in maintaining the analysis tools and related software.

Related publications

Eskola, M., Heikkilä, T. & Tukeva, P. Deriving test procedures of low-rate wireless personal area networks. International Symposium on Performance Evaluation of Computer and Telecommunication Systems, SPECTS'12 – Part of SummerSim 2012 Multiconference. Genoa, 8–11 July 2012. Proceedings of the SPECTS'12 (2012), Article number 6267023.

Huovila, H., Pursula, P. & Strömmer, E. Miten energiaa langattomille antureille? Automaatioväylä 2011, 3, pp. 18–21.

Korkalainen, M., Tukeva, P., Lindholm, M. & Kaartinen, J. Hybrid localization system for situation awareness applications. 3rd Workshop on Wireless Communication and Applications, WOWCA2012. Vaasa, 25–26 Apr. 2012. University of Vaasa, Vaasa. 6 p.

Koskinen, J., Kilpeläinen, P., Rehu, J., Tukeva, P. & Sallinen, M. Wireless sensor networks for infrastructure and industrial monitoring applications. Proceedings of International Conference on ICT Convergence, ICTC 2010. Jeju Island, 17–19 Nov. 2010. KICS: ETRI. Pp. 250–255.

Pentikäinen, V., Tukeva, P., Hannuksela, J. & Silvén, O. Langatonta kunnonvalvontaa ja ennakoivaa kunnossapitoa vaativiin ympäristöihin. Automaatioväylä 2011, 3, pp. 28–29.

Sibakov, J., Tukeva, P., Antila, J., Mokkila, M. & Lehtinen, P. Uusia välineitä elintarviketeollisuuden mittauksiin ja analytiikkaan. Kehittyvä elintarvike Vol. 22 (2011), No. 1, p. 58.

Novel wireless charging technology utilises existing NFC antennas and circuits

Esko Strömmer
Senior Scientist
esko.strommer@vtt.fi

Other contributing authors:
Marko Jurvansuu, Arto Ylisaukko-oja

Over the last couple of years, wireless charging has evoked rapidly increasing interest among mobile device vendors and technology providers. The motivation for wireless charging has been its usability, which will come to full fruition when wireless chargers are massively embedded in our living environment and interoperable with mobile devices independently of their manufacturers, even when charging several devices simultaneously on the same charging plate, instead of using several plug-in chargers. Besides making charging easier, wireless charging is believed to mitigate the problem of the ever-increasing gap between battery capacity and device power consumption, which is leading to short device use times. Wireless charging will change the entire approach to mobile device charging by enabling users to supplement energy storage just by laying devices on charging plates or in charging slots, found everywhere, without seeking out a separate charging accessory and plugging it into a wall outlet and into the device. These easy-to-use ubiquitous charging facilities, coupled with other advantages of wireless charging, such as the ability to fully enclose the charging connection, are expected to make up for the disadvantages of wireless charging, such as lower efficiency, higher technical complexity, and the resulting higher cost.

The increasing interest in wireless charging has also promoted standardisation activities. The first commercial smartphones with a wireless charging interface based on open specifications, such as the Qi specification of the Wireless Power Consortium (WPC), have already been launched by leading phone manufacturers [1]. A general challenge to the phone manufacturers is currently the increasing number of external interfaces, which also tends to increase the costs and physical size of the products. From this viewpoint, the implementation of wireless charging by technologies that are available currently has become one additional challenge, and in the case of even smaller devices, such as wrist units and mobile phone accessories, this challenge will be further emphasised.

Another new technology gaining ground in mobile devices is Near Field Communication (NFC), the standardisation of which is managed by the NFC Forum [2]. NFC is a key enabling technology for several mobile applications, such as payments, content sharing, and easy-to-use information access and service discovery. Both NFC and wireless charging are based on inductive coupling between loop antennas and could thus basically be integrated into a single implementation with a common antenna. Based on this idea and an associated concept study, VTT launched an initiative to the NFC Forum in autumn 2011 to start activities to include wireless charging in the open NFC specifications. A new Wireless Charging Task Force, under the NFC Forum Devices Work Group promoting this, was started in February 2012.

Wireless charging over NFC can be applied to mobile handsets and especially to smaller devices. The main differentiating features of wireless charging over NFC from the

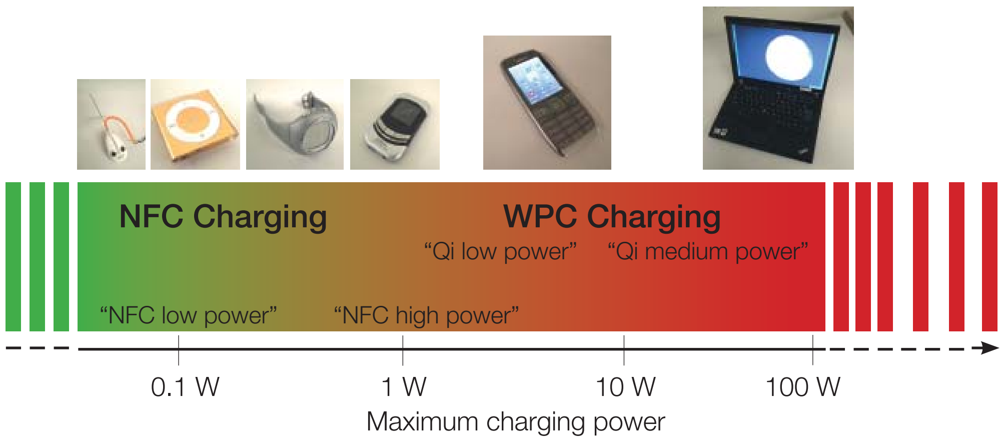


Figure 1. Applicability of wireless charging over NFC vs. Wireless Power Consortium Qi specification. Wireless charging over NFC is most suitable for relatively small devices.

state-of-the-art wireless charging technologies for mobile handsets are a more limited power transfer capability and, as a counterbalance, more compact and cost-efficient implementation that integrates NFC and wireless charging.

The main results of the activities of NFC-based wireless charging at VTT are:

- a concept study of wireless charging over NFC
- contribution to the wireless charging standardisation activities at the NFC Forum
- a reference design of an NFC-compatible wireless power transmitter.

Concept study of wireless charging over NFC

The motivation at VTT for starting research activities in wireless charging over NFC was the fact that, as a technology based on inductive coupling, NFC is inherently capable of transferring power wirelessly. In fact, NFC already exploits this feature when reading passive RFID tags. However, the power transfer capability of current NFC implementations is not enough for convenient charging of devices in general. Thus, some modifications to the existing technical implementations and amendments to the existing NFC standards are required before viable wireless charging over NFC can be offered. The main challenge of the modifications and amendments will be combining efficient and controllable wireless power transfer with NFC communication by using shared antennas and communication channels. This has to be done without sacrificing the performance of either function. In addition, several specific issues, such as safety, EMC compatibility, and cost impact due to the increased power level during charging, have to be addressed.

The goals of the concept study were to get better understanding of the possibilities and most potential use cases, and to evaluate the technical challenges and performance bottlenecks. The concept study was carried out in 2010–2011, and it included technology surveys, theoretical analysis, and a pilot implementation of an NFC-compatible charging system.

The goal to exploit existing NFC resources as much as possible led to preserving the current NFC operating frequency (13.56 MHz) for charging power transfer. Since this is relatively high when compared to the operating frequency of the WPC Qi wireless charging specification, wireless charging


Wireless charging of small NFC-enabled devices


Using NFC-enabled devices (e.g. a laptop) as wireless chargers


Auxiliary charging of mobile handsets

Figure 2. Examples of potential use cases for wireless charging over NFC.

over NFC favours use cases with relatively low charging power levels. Still, charging power levels of up to at least 1 W are possible with close proximity between the antennas, even within the RF field strength limit of the current NFC specification. Thus, wireless charging over NFC is most suitable for relatively small devices. In this respect, wireless charging over NFC is rather a completing than a competing technology to the WPC Qi specification and other existing wireless charging technologies for mobile phones. This is illustrated in Figure 1. The limited power transfer level over NFC is counterbalanced by the compactness and cost-efficiency of the entire implementation, with combined NFC and wireless charging features.

Examples of specific use cases are presented in Figure 2. The main benefits of the integrated NFC and wireless charging solution in the presented use cases are:

- a more compact and cost efficient wireless charging interface for small NFC-enabled portable devices
- a more pervasive charger infrastructure (based on existing NFC devices) with reduced costs (no dedicated chargers)
- the possibility to integrate NFC-based services with charging applications
- benefits due to the relatively high operating frequency of NFC, such as lighter antennas and reduced parasitic heating of nearby stray metallic objects.

Contribution to the wireless charging standardisation activities at the NFC Forum

Based on the concept study, VTT introduced the idea of wireless charging over NFC to the NFC Forum in October 2011. Soon after this, a supporting group of VTT, ST-Ericsson, NEC, and others promoted the idea to leading industrial members of the NFC Forum. An official proposal for a new working item was filed to the NFC Forum Technical Committee by the supporting group on 30th November 2011. The Technical Committee of the NFC Forum accepted the work item as a part of the NFC Forum work on 9th February 2012 at the NFC Forum meeting in Frankfurt.

During the course of 2012, VTT has actively supported the work of the NFC Forum Wireless Charging Task Force in working out the requirements documents for NFC Forum wireless charging. By October 2012, the task force had submitted a draft of the requirements document to the Devices Working Group for review and had also provided resolution ideas for the review output. After some editing, the Devices Working Group reached consensus on the requirement document in October 2012 and submitted the requirement document to the NFC Forum Technical Committee for final resolution. In 2013, the Wireless Charging Task Force will continue its work and start to work out more detailed technical specifications.

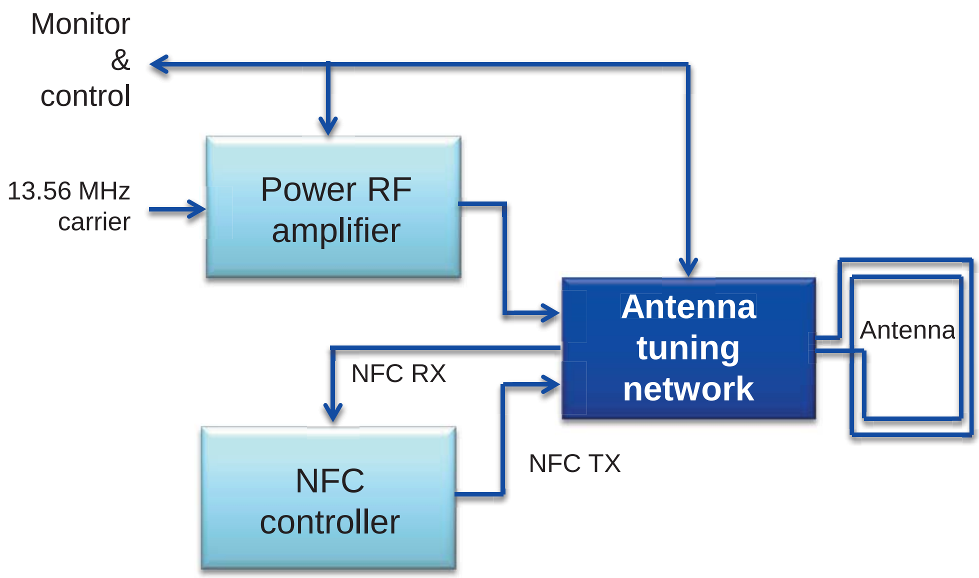


Figure 3. Block diagram of the NFC-compatible wireless power transmitter.

The requirement document includes requirements for both power transfer and the control procedure that is needed to set up and maintain charging. The control procedure (charging management) enables the identification of chargeable devices placed on the charging plate, as well as adjustment of the transmitted power depending on the need of the chargeable device as charging progresses. The power transfer period and charging management will be different in time (time division multiplexing). The power transfer is not allowed to risk human safety or to damage existing NFC devices or tags. In addition, the requirement document gives various examples of possible use cases.

Reference design of an NFC-compatible wireless power transmitter

VTT has developed and demonstrated a solution that integrates controllable wireless power transmission and NFC communication. The solution shares the same antenna circuit between NFC and wireless power transmission functions, and features an NFC-compatible wireless power transmitter reference design with adaptive antenna tuning and a demonstrator prototype based on commercial off-the-shelf components (COTS) on a printed circuit board (PCB).

Application examples of the developed solution are wireless charging of various devices and wireless powering of battery-free sensors with communication and enhanced power supply via NFC. The block diagram of the reference design is presented in Figure 3 and the demonstrator prototype in Figure 4.

Future challenges and opportunities

We are already witnessing an ever-increasing amount of news and product launches related to devices utilising wireless power. The mass market penetration starts from wireless powered mobile phones, but it is expected to expand to various other devices, such as mobile phone accessories, tab devices, remote controls, laptops, computer LCD screens, TVs, and vehicles. To satisfy

Figure 4. Demonstrator prototype of the NFC-compatible wireless power transmitter.

the needs of the whole range of devices, the technology development is targeting power levels from the few watts of mobile phones to up to several kilowatts. On the other hand, more cost efficient and compact solutions are required, especially for smaller portable devices. The wireless charging activities at the NFC Forum will, in the near future, bring wireless charging and wireless powering features especially to small NFC-enabled devices such as wrist units, headsets, remote controls, mouse devices, and sensors.

In addition to R&D activities, the commercialisation of wireless charging over NFC calls for standardisation activities at the NFC Forum and amendments to the existing NFC standards, so that they support the implementation of open charging interfaces that are interoperable regardless of device vendors. This concerns both NFC devices with a charging power transmission facility and NFC devices with a charging power reception facility. This work is going on in the Wireless Charging Task Force at the NFC Forum. The first commercial NFC devices with integrated wireless charging feature can be expected in 2014–2015.

Standardised wireless charging can also produce added value for NFC-enabled mobile phones by auxiliary charging of the phones via the NFC interface, and wireless charging of accessories using phones as charging plates. Even totally new NFC products and applications with novel business models related to wireless charging can be expected. The wireless charging feature can also increase public interest in NFC and NFC-enabled products in general. All this will boost the penetration of NFC technology to various devices for the benefit of the users and the NFC community.

NFC-based wireless power is a viable technology option, but there are several other wireless power and short-range communication standards and industry alliances that are fighting to ensure their future share in the huge consumer electronics market. Each alliance, with its member companies, promotes its own technology and provides compatible devices, infrastructure, and services to tie users to the ecosystem. Interoperability between standards is not likely to happen for both technical and commercial reasons. Presumably, there will be several overlapping standards in the future, which will emphasise the importance of co-existence issues and comprehensive, cost-efficient, and compact multi-standard solutions.

In the long run, we expect to see wirelessly powered devices throughout our daily home and working environments. It is thus an important opportunity for a research organisation to take part and develop novel technologies and concepts to support a future society built on wireless communication and power.

Acknowledgements

For the research and development results obtained in this field during the Open Smart Spaces Programme, the cooperation with VTT's partners has had a significant role. In particular, the cooperation with ST-Ericsson is acknowledged.

References

[1] http://www.wirelesspowerconsortium.com/

[2] http://www.nfc-forum.org/

Related publications

Strömmer, E., Jurvansuu, M., Tuikka, T., Ylisaukko-Oja, A., Rapakko, H. & Vesterinen, J. NFC-enabled wireless charging. Proceedings of NFC 2012, the 4th International Research Workshop on Near Field Communication, NFC 2012. Helsinki, 13 March 2012. IEEE. Pp. 36–41. doi:10.1109/NFC.2012.17.

Strömmer, E., Jurvansuu, M., Tuikka, T., Ylisaukko-Oja, A., Rapakko, H. & Vesterinen, J. NFC-enabled wireless charging. Presentation in WIMA 2012 NFC Conference. Monaco, 11–13 April 2012.

Advanced depth camera systems produce 3D spatial awareness

Paul Kemppi
Senior Scientist
paul.kemppi@vtt.fi

Other contributing authors:
Otto Korkalo, Matias Elo, Juha Zidbeck

The introduction of low-cost spatial sensors, such as depth cameras, accelerometers, sensors for detection of angular rate and proximity, and GNSS, has had a major impact on the development of user interfaces (smartphones, gaming devices, etc.). At the same time, these sensors have created new opportunities for enabling 3D spatial awareness within living and industrial spaces. For instance, obstacle avoidance and path planning of autonomously operating vehicles (domestic robots, forklifts, etc.) require a means of sensing the surrounding three-dimensional environment in real time. If this spatial awareness can be achieved with low-cost sensors, it will provide new opportunities and markets for robot manufacturers and companies providing autonomously operating vehicles. Moreover, the same sensors and methods can be used in 3D scene reconstruction to, for example, create virtual models of real environments, which can be then used in virtual/augmented reality applications.

Spatial awareness technologies can also be applied in remote monitoring and control systems for intelligent buildings. They enable advanced people counting, consumer behavioural pattern analysis, object detection, and monitoring, which can all be combined to produce, for example, surveillance and security applications for challenging environments.

VTT has strong competence in the field of computer vision. For instance, the knowledge related to visual tracking (estimating the camera pose frame-by-frame using visual features detected in the frames) and scene reconstruction can also be exploited with the new sensing devices, such as depth cameras. Because of the computer vision background, the current work is focused on two main topics, including human tracking and 3D scene reconstruction using depth cameras assisted by other sensors. VTT's main role is to transfer the developed solutions related to these two topics to the domestic industrial sector. The goal is to create new business and revenue for the customers, and therefore increase their competitiveness.

Human tracking based on data from networked depth cameras

Low-cost depth sensors are nowadays widely used in video gaming consoles to capture users' movements and gestures to control the game. Depth-sensing technology offers an intuitive and embodied method of interaction, and it is wireless, unnoticeable, and affordable. As depth sensors capture the 3D information from the sensor's field of view, they significantly improve the human detection and tracking algorithms compared to conventional 2D cameras. Nevertheless, several challenges still exist: the humans may be partially occluded by other humans; external infrared sources may cause problems to the sensors, and so on.

Previously expensive depth sensors have become commodity hardware. The availability and pricing of the technology are attractive and, in addition to the entertainment, it can be applied in other application fields where

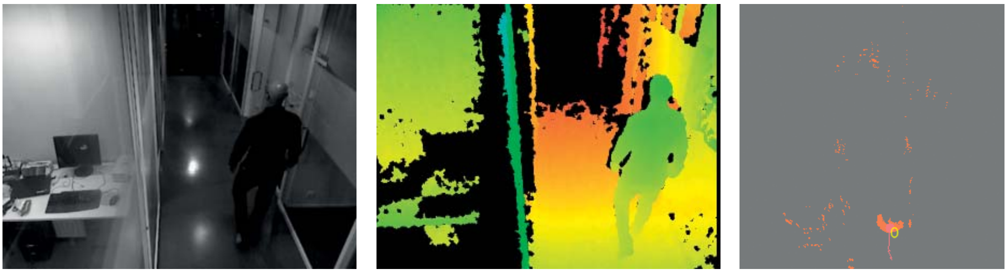


Figure 1. Example of people tracking, showing the digital camera view on the left, the corresponding depth camera image in the middle, and the tracked path of the person from a top-down perspective on the right.

the interest is in human detection and tracking. Examples of this are surveillance, people safety, crowd management, and people counting.

VTT has developed methods for detecting and tracking people in indoor environments using multiple low-cost depth sensor nodes. In VTT's solution, depth sensors are connected to low-cost single-board PCs that perform pre-processing of the depth image data. The nodes are networked, and a centralised server implements the sensor fusion and event generation procedures. The use of multiple depth sensors helps to minimise the occlusion problems and to increase the tracking area. The solution is based on freely available open source image processing and robotics libraries, as well as custom algorithms. An example of a people tracking result with one depth camera module is shown in Figure 1.

VTT's research results are currently being used in, for example, the Finnish Nature Centre Haltia, where the visitors are shown changing digital content depending on where and how they move in the exhibition area. Other real-life applications include people counting applications in smart buildings, and detecting events like an elderly person falling, in people safety applications. VTT's research is conducted in close co-operation with the European computer vision industry.

Accurate 3D scene reconstruction of complex indoor spaces

The recent developments in depth sensor technology enable new possibilities in the field of 3D reconstruction. Nowadays, it is even possible to reconstruct geometrically precise, 3D models of a physical scene in real time, using additional sensors [1]. A few examples of such reconstructions are shown in Figure 2 and Figure 3. The major challenge in the 3D reconstruction is to be able to track the pose of the depth sensor accurately in all six degrees of freedom as it moves in the scene. To estimate the depth sensor movement, additional information sources can also be utilised. For instance, a mobile robot equipped with a depth sensor often also has wheel encoders to estimate the travelled distance and angular rate sensors to track changes in orientation. These additional sources can be used to provide a prior estimate of the camera pose change from one depth image frame to another, which is then used in the process of aligning the 3D point clouds created from the raw depth image frames. The process of aligning these point clouds into a globally consistent model is called registration. A wide variety of registration methods can be used, including several variants of the Iterative Closed Point (ICP) and the Normal Distributions Transform algorithms to name a few. As a result of this registration process, the prior camera pose estimate can also be refined. The refined pose

Figure 2. 3D reconstruction of a sleeping baby, based on depth camera data recorded in a dark room.

Figure 3. 3D reconstruction of an office room, based on depth sensor data. The aligned RGB image frames are used to combine the colour information in the scene.

estimate can be further fed back to the assisting sensors to, for example, estimate zero bias in the angular rate measurements or to detect wheel slippage in the case of wheel encoders.

After the pairwise registration of the input point clouds, the resulting concatenated point cloud can be refined further by performing global optimization and loop closure detection. Additional steps may also include the creation of a multi-resolution map structure that represents the data as a 3D occupancy grid describing the environment as free, occupied, and unknown areas [2]. Many methods have also been developed to create a regular and continuous (triangular) mesh representation from the point cloud.

VTT has developed methods for reconstructing 3D models of indoor spaces to be renovated. The reconstructed 3D model is used to estimate the physical dimensions and limitations of the space when choosing new machinery in technical facilities. The low-cost depth sensors and registration methods can also be used to create geometry-aware augmented reality applications and physics-based interactions. 3D scene reconstruction is also an important prerequisite for autonomous machines to be able to operate safely in complex indoor environments (to avoid collisions with furniture, humans, and to tackle uneven surfaces etc.).

Towards everyday situational and spatial awareness

Despite the wide range of opportunities offered by the new low-cost spatial sensors, the commercial use cases still concentrate mainly on applications developed by the gaming and entertainment industry. However, this situation is likely to change in the near future, and the new innovations will affect the way humans and machines interact in everyday life.

Already now, remarkable efforts have been carried out in this field to create common knowledge bases with state-of-the-art algorithms available for free for commercial and research use. These knowledge bases include PCL [3], ROS [4], and OpenCV [5], to name just a few. The open source projects are being developed by a large number of engineers and scientists from many different organisations, geographically distributed all around the world. VTT represents Finland in this global community of excellence. Our role is both to contribute to these open source knowledge bases and to commercialise the innovations built on top of them.

References

[1] Newcombe, R., Izadi, S., Hilliges, O., Molyneaux, D., Kim, D., Davison, A., Kohli, P., Shotton, J., Hodges, S. & Fitzgibbon, A. Real-Time Dense Surface Mapping and Tracking with Kinect. Proceedings of the IEEE International Symposium on Mixed and Augmented Reality (ISMAR 2011). Basel, Switzerland, 26–29 Oct 2011. Pp. 127–136.

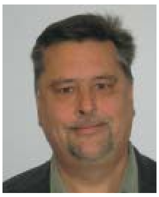
[2] Wurm, K. M., Hornung, A., Bennewitz, M., Stachniss, C. & Burgard, W. OctoMap: A probabilistic, flexible, and compact 3D map representation for robotic systems. Proceedings of the ICRA Workshop on Best Practice in 3D Perception and Modeling for Mobile Manipulation, 2010.

[3] Point Cloud Library (PCL), www.pointclouds.org.

[4] Robot Operating System (ROS), www.ros.org.

[5] Open Source Computer Vision Library (OpenCV), www.opencv.org.

Mixing realities for work and fun



Charles Woodward
Research Professor
charles.woodward@vtt.fi

Other contributing authors:
Seppo Valli, Petri Honkamaa

Augmented reality (AR) involves superimposing virtual objects on the user's view of the real world, providing novel ways of visualisation for a wide range of application areas. In augmented reality, camera-captured views from real-world environments are enriched (augmented) with digital 3D objects and effects in real time. The challenges for the speed, accuracy, and quality of the augmentation can be understood when comparing the effort needed for producing special effects for movies.

Augmented reality has been predicted to be one of the most likely areas of innovation to alter research, fields of industry, and even the way we live our lives. Many of today's AR applications have been known for more than 15 years, but the technology (processing power, camera and display technologies, etc.) has just recently matured to a level that makes it feasible for practical use.

Taking advantage of today's low-cost mobile devices and networks, together with advances in the required camera tracking software, augmented reality has started to show commercial success in the last couple of years. VTT has contributed to the AR research among the frontrunners in the world, over the years developing various first-of-a-kind AR solutions and software technology, for consumers and industry alike.

A basis for augmenting reality – tracking and rendering

Augmenting real-world scenes with 3D objects requires tracking the camera's position and view direction relative to the scene. Using only sensors (e.g. gyro-compass) and some positioning methods (e.g. WLAN) for camera tracking is too inaccurate in practice. An often used method to reach good tracking accuracy is to detect the 3D positions of graphical "markers" from the camera view. However, this presumes that the markers can be placed a priori in the environment, and that their visibility does not unduly disturb the user.

Instead of markers, a more elegant – and demanding – solution is offered by feature-based tracking. This is based on the detection of distinctive natural features of the scene from various viewpoints, which – after various filtering and matching processes – results in a set of representative feature points in three dimensions (a so-called point cloud). These 3D feature points are then used for rendering the augmented information without the need for artificial markers.

Further technical challenges for augmented reality are found in the rendering of 3D objects. Compared to traditional computer graphics applications, such as games, speed requirements in AR are even harder, as the rendering has to run in parallel with camera tracking, and on mobile devices as well. In addition, to make the rendering look natural, the lighting properties of the 3D objects should be adjusted to real-world conditions, as light direction, intensity, and so on.

An open source library for creation of Augmented Reality applications – ALVAR

In the OPENS programme, VTT has developed the above-mentioned technical enablers for augmented reality. Many of them are now included in the ALVAR (A Library for Virtual and Augmented Reality) toolkit and its mobile versions. The ALVAR software library offers high-level tools and methods for creating basic augmented reality applications with just a few lines of code. As the library also includes user interfaces for all of the tools and methods, it is possible for the user to develop their own solutions using alternative approaches or completely new algorithms; see http://virtual.vtt.fi/virtual/proj2/multimedia/alvar.

As the main result in the OPENS programme, the desktop version of ALVAR was developed to a level that enabled its publication as open source in spring 2012, thus promoting the wider acceptance of augmented reality solutions among developers and end-users. Today, ALVAR has over a thousand users worldwide, including, for example, the game developer community around Columbia University's Goblin XNA. Among commercial companies, the world's largest data glass manufacturer, Vuzix Inc., has integrated ALVAR into its products.

ALVAR Desktop is currently provided for Windows and Linux operating systems. Furthermore, the ALVAR Mobile SDK for iOS, Android, Symbian, Maemo, Flash, and Silverlight platforms, as well as the ALVAR Render engine, is available for VTT's project work, and for adoption by commercial partners.

Applications from augmented media content to city planning

Augmented reality related projects in the OPENS programme have enabled implementation of AR in real applications, thus gaining visibility and development projects among new customer segments and audiences. The first real applications have mainly been those for hybrid and mobile media using 2D markers,

Figure 1. Dibidogs augmented in TV magazines (image courtesy of Aller Media Oy).

while methods for markerless (feature-based) tracking have also been experimented with and applied, especially for outdoors applications. Below, some example cases are presented.

In co-operation with VTT, Aller Media Oy was the first in Scandinavia to publish AR magazine content in their Katso, Seiska, and Elle magazines in 2010–2011. Aller's augmented promotions for the Dibidogs TV series and Veijarit & Vares movies offered thousands of Finns their first encounters with AR. See Figure 1.

For interior design, the VividAR solution by VividWorks Oy enables consumers to try out virtual 3D furniture within photos of their home interiors. The VividAR application is available for free download on the web pages of various furniture manufacturers and stores, such as Vepsäläinen and Laulumaa in Finland, and many others abroad. See Figure 2.

Supporting mobile users with architectural visualisations outdoors has been one of the most studied areas of augmented reality at VTT. Using markerless tracking technology on mobile phones and tablets, VTT, together with FCG Oy, was the first in the world to bring mobile AR to actual decision-makers in the city planning process, in the Raseborg Billnäs (2011) and Helsinki Jätkäsaari (2012) cases. See Figure 3.

Figure 2. Virtual furniture augmenting a real room/environment (image courtesy of Vivid-Works Oy).

Figure 3. Billnäs city plans, augmented on mobile phones (images courtesy of FCG Oy).

Future applications require new camera tracking solutions

Unobtrusive markerless solutions for the augmentation of real-world scenes with 3D objects will be required more and more in the future, as graphical markers are, in many cases, not desirable (e.g. for artistic reasons) or feasible (e.g. outdoors). On the other hand, feature-based tracking still requires a lot of research on object recognition, classification, and search methods to identify the scene or product reliably, and to create the desired virtual overlay (augmentation).

As one part of the research for tracking methods, OPENS has promoted the take-up of 3D depth sensing methods, and especially the use of Kinect types of sensors, which have meant an abrupt leap in the development of machine-vision-related applications. This is due to the reliability that depth sensing devices have brought to scene analysis. In addition to augmented reality, video image analysis and depth sensing knowledge have also served VTT research in many other application areas, such as in multi-modal user interaction and security surveillance.

Discussion – future research in AR

During the past 12 years, VTT has developed a large number of AR applications, such as virtual furnishing, architectural visualisation, data visualisation for process industries, enhancing of printed media (hybrid media) with digital information, and various entertainment and game applications. Developing the ALVAR toolkit and demonstrating it in new applica-

A new application area enabled by augmented reality technologies is telepresence, which combines virtual and camera-captured images of the users in a shared meeting space (e.g. Second Life, see Figure 4) with various so-called Mirror World applications, where various 3D-modelled images of the real world (e.g. terrain and city models) are enriched by information being captured or measured from the real world. Some examples of VTT research in this area can already be seen at www.vtt.fi/multimedia.

Augmented reality interaction between real people and a Second Life avatar.

tions have strengthened VTT's position in research and business, not only in Finland but internationally as well.

Producing camera tracking solutions for mobile AR has been one of the main objectives in AR-related OPENS projects. More generally, 3D tracking of the features of a scene can be used even for indoor positioning, for example, for building maintenance and industrial facility management applications. The same algorithms can also be used for 3D reconstruction of the environment in urban environments, as well as for object recognition for navigation and game applications, for example.

Related publications

Aittala, M. Inverse lighting and photorealistic rendering for augmented reality. Visual Computer, Vol. 26 (2010), No. 6–8, pp. 669–678.

Kantonen, T., Woodward, C. & Katz, N. Mixed reality in virtual world teleconferencing. Proceedings of IEEE Virtual Reality 2010. Waltham, Massachusetts, USA, 20–24 March 2010. Pp. 179–182.

Kymäläinen, T. & Siltanen, S. Co-designing novel interior design service that utilizes augmented reality, a case study. Proceedings of the Second International Symposium on Communicability, Computer Graphics and Innovative Design for Interactive Systems. CCGIDIS 2012. Italy, 5–6 July 2012.

Olsson, T., Savisalo, A., Hakkarainen, M. & Woodward, C. User evaluation of mobile augmented reality in architectural planning. In: Gudnason, G. & Scherer, R. (Eds.): eWork and eBusiness in Architecture, Engineering and Construction. ECPPM 2012. Reykjavik, Island, 25–27 July 2012. Pp. 733–740.

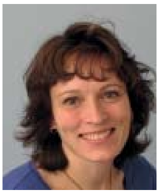
Siltanen, S. & Aikala, M. Augmented reality enriches hybrid media. MindTrek 2012. Tampere, Finland, 3.–5.10.2012.

Siltanen, S. Theory and applications of marker-based augmented reality. VTT Science 3. Espoo, VTT 2012. 199 p. + app. 43 p. http://www.vtt.fi/inf/pdf/science/2012/S3.pdf.

Woodward, C. & Hakkarainen, M. Mobile mixed reality system for architectural and construction site visualization. In: Nee, A. Y. C. (Ed.): Augmented Reality – Some Emerging Application Areas. InTech 2011. ISBN 978-953-307-422-1. Pp. 115–130.

Woodward, C., Hakkarainen, M. & Billinghurst, M. A client/server architecture for augmented reality on mobile phones. In: Alencar, P. & Cowan, D. (Eds.): Handbook of Research on Mobile Software Engineering – Design, Implementation and Emergent Applications, Volume I. Engineering Science Reference 2012. Pp. 1–16.

Capturing movement for interaction



Satu-Marja Mäkelä
Senior Scientist
Satu-Marja.Makela@vtt.fi

Other contributing authors:
Tommi Keränen, Ville Valjus

Interacting with computers in various ways is part of everyday life for most of us. The field has already reached the point where improving and integrating existing technologies, and even more so, the successful mainstream penetration of new products, rely heavily on their ease of use. Human-computer interaction (HCI) is a multidisciplinary field of science that aims to develop natural interaction techniques and methods to enable versatile interaction with technology, using human capabilities and limitations as a starting point.

We have studied depth sensing technologies and HCI systems by developing and using both a gesture-based interface, where users can manipulate virtual objects appearing on a display by moving their hands, and a projected user interface (UI), where users can directly manipulate the projected images by touching them, or use their fingers as mouse-like pointers.

Gesture interaction has been a subject of research for a long time. There are plenty of examples of camera [1], wearable sensor [2], and some other device [3] based gesture interaction systems. The new trend in gesture interfaces is to use affordable depth cameras to provide information on the world in three dimensions and to measure the distance of every world point to the sensor. Depth sensing technologies enable the creation of natural and tangible interactive user interfaces for projected interfaces as well [4, 5].

The pricing of depth sensors, such as *Microsoft Kinect* and *Asus Xtion PRO*, has dropped dramatically in the past couple of years, in many cases near to webcam levels, and this enables their use as interaction enablers in different applications. Application areas can range from consumer-level entertainment solutions at home to larger-scale public displays, smart buildings, and even locations like hospitals, where interaction via physical touch might not be preferred. Utilisation of depth sensors is changing the face of human-computer interaction, but research is required to find the best interaction methodologies and principles of user interface design.

The use of depth sensors in HCI applications has multiple benefits over 2D cameras, to which they are most commonly compared. They work well in a wide range of lighting conditions, even in complete darkness. Object detection is more straight-forward and reliable than with bare colour information, and unlike with 2D cameras, shadows cannot be mistaken for objects. They can also be easily used to handle occlusion – one object partially or completely covering another – which again has traditionally been a severe Achilles' heel for 2D cameras. Depth sensors are unobtrusive, and as they do not provide actual photographic information, any potential privacy issues can be more easily handled. Figure 1 summarises the benefits of depths sensors over 2D cameras.

Depth-sensor-based interaction systems can be used individually or they can be combined, modified, added to, and used in both real and virtual spaces (e.g. for natural use of the body as an interaction element in virtual

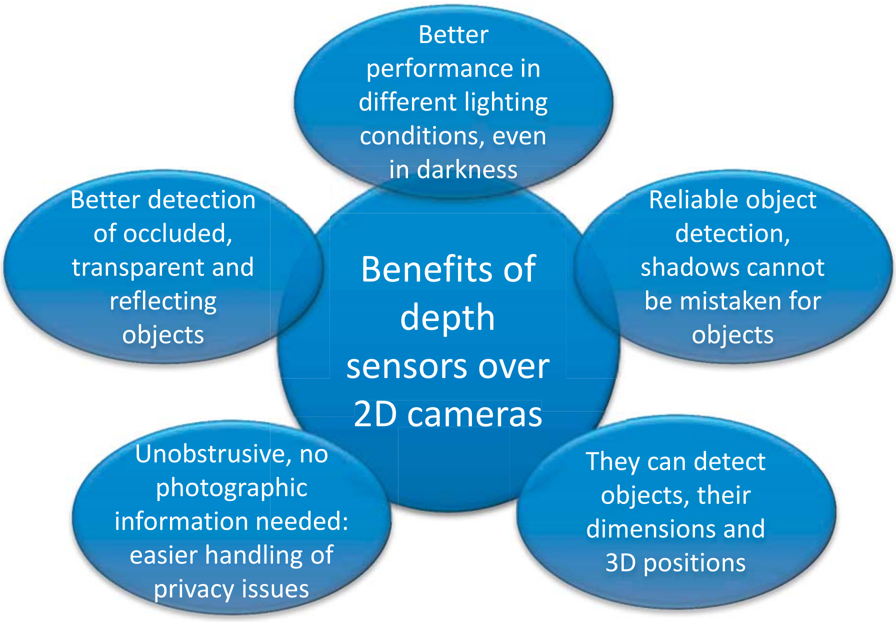


Figure 1. Main benefits of depth sensors over 2D cameras.

reality). The aim of this development is to find computer interaction methods that are not only novel and usable, but also useful and natural – pushing down the learning curve and minimising the initial frustrations of user trial and error.

Using human gestures in a natural user interface to manipulate objects

As camera-based gesture recognition has been widely studied, there are plenty of good reviews on camera-based methods that can be found, for example in [1] and [6]. Some recent advances in depth-sensor-based gesture recognition are reported in [7]. Depth sensing is already used as an input modality in, for example, some virtual reality (VR) environments [8], large public displays [9], and interactive presentation technologies [10]. Gestures for interaction can be performed either with hands and arms or fingers, depending on the purpose of use. Even though gestures are in many ways a very natural method of interaction, the design of hand movements needs to seriously consider ergonomic aspects as well, as over time they can cause serious fatigue to the user [11].

We demonstrated a basic gesture-based control scheme with a gesture-controlled application, in which the user could create, pick up, move, scale, and rotate 3D objects representing pieces of furniture, and arrange them in a virtual space in the manner of their choosing (Figure 2). This demonstration focused on testing how different gestures mapped to different tasks performed by the user in the virtual space, aiming for a public display with little or no guidance to the untrained users. It was developed in cooperation with a Finnish industry partner that works in the field of interior design and decoration.

The gesture interface was implemented using a Microsoft Kinect sensor and Kinect SDK, which includes an API for the depth sensor, as well as a skeleton tracking library for tracking the human skeleton and creating the skeleton model. The skeleton model of a per-

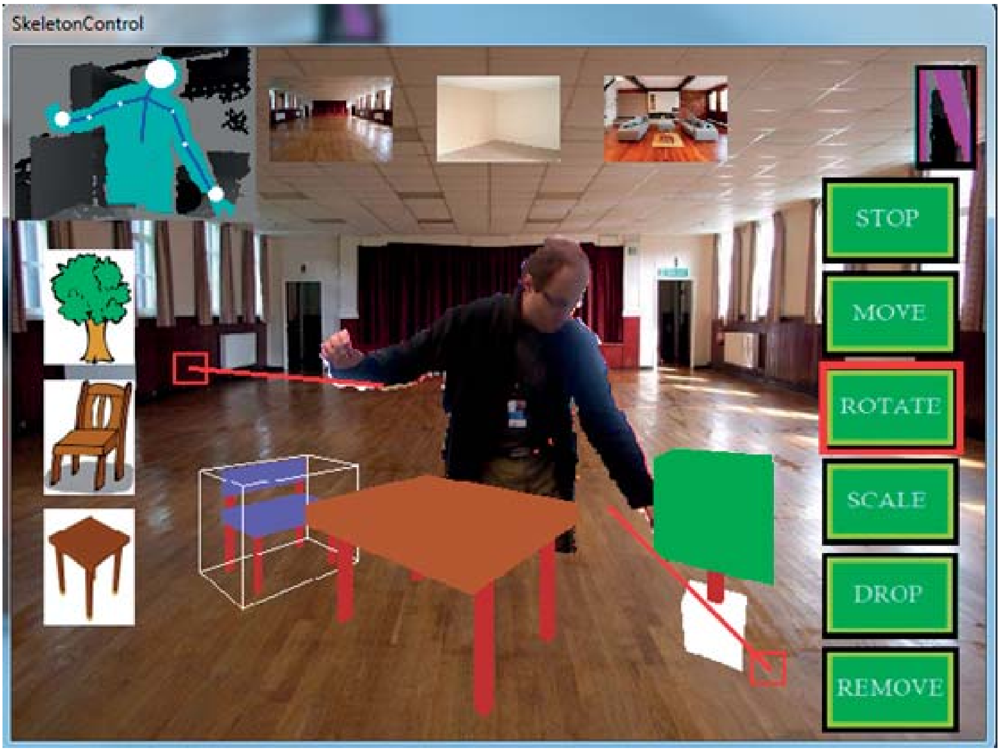


Figure 2. Screenshot of the gesture interface for furnishing a real room virtually.

son contains the major skeletal joints of the human body and their relation to one another, tracked over time and optimally fitted into the 3D volume that the software automatically recognises as a human body (visualised in the upper left corner of Figure 2).

The software that VTT has developed detects and visualises multiple simultaneous users in front of the sensor, but gives control of the scene to only one of them at a time. Different functions and gestures can be mapped to left and right hands simultaneously (e.g. create, pick up, and manipulate items with the left hand using swipes and simulated button pushes, choose a function for the left hand, or change the background by hovering the right hand above a button for a set amount of time, as visualised by a red progress bar). See Figure 2 for a screenshot of the program in use. In the figure, the user is virtually furnishing the real room displayed as background. The object being manipulated is a chair surrounded by a white box, and the selected activity is rotate (outlined by a red box).

The object under manipulation is a chair surrounded by a white box, and the selected activity is rotate (outlined by a red box in the list on the right). The red lines are virtual hand extensions that allow the user to easily reach objects that are located further away in the virtual scene, and to interact with the UI components.

In the screenshot, two red lines can be seen extending from the user's hands. These are called virtual hand extensions, or ray cast lines, which is a technique to enable the user to easily reach objects that are located further away in the virtual scene. Using them, large arm movements, which would otherwise quickly tire the user, are kept to a minimum, even when reaching for the over-head UI components. Scene manipulation happens via the red squares at the end of each hand extension line. The user is rendered in the scene in order to get their attention – they appear in the virtual space as soon as they happen to walk past the sensor – an important aspect for a potential public space installation.

It was quickly noted that allowing full 3-dimensional movement and rotation in this kind of setup requires a lot of concentration from the user and results in less than precise control over the objects, as movements are not mapped 1-to-1 (e.g. sweep-to-rotate vs. actually taking hold of a physical object and rotating it). That is why all the objects are bound to the floor of the virtual scene, and their rotation is only allowed around their y-axis; that is to say, for example, a table cannot be flipped over, it can only be rotated in a "normal" fashion. Scaling works similarly via up/down sweeps, mapped to scale up and down, respectively. Moving the object is only possible over the floor plane of the virtual scene. Here it was found, through user feedback, that it was more "natural" to move the objects along the depth (Z) axis by vertical motion of one's hand (Y).

Only one method of manipulation (rotation, scaling, etc.) can be activated at a time, using the right-hand button interface. This way, a single set of hand gestures could be dedicated for all manipulative functions, both to make the program easier to learn, and to focus on one gesture at a time. Similarly to the restrictions of freedoms of movement, it was discovered through user testing that the use of 3-dimensional hand gestures actually made the program much more difficult to use for the average user. It might seem, for example, that to push a button, the most natural gesture would be to push one's hand towards the UI component to mimic an actual button press. This might be the case, were the button actually right in front of the user, but when manipulating a virtual scene on an image shown or projected away from the user, the direction and accuracy of the button presses suffered greatly. It also led to several false button presses, because as the user is expected to move around when using the program, they would eventually end up gesturing, not exactly towards the scene, but rather at an angle where simple sideways motion could be mistakenly interpreted as a click gesture. Indeed, simply hovering one's hand over the required UI element resulted in the most positive response, when coupled with a visual indication that something was happening (e.g. a bright-coloured progress bar around the button).

Gesture recognition is often performed by using classifiers, for which you have to teach the classifier certain features to correspond to certain gestures. This is very troublesome work and we wanted to avoid using classifiers and created rule-based gestures relying on the skeleton model in order to create a platform where we can quickly prototype the gesture interface.

An interactive user interface can be projected onto a surface

As projectors and depth sensors get smaller and cheaper, they open new possibilities for interaction by projecting a UI onto a surface and enabling interaction with the depth sensor. Projected UIs can be implemented on any available surface, such as tables, walls, sides of an object, or even a human arm and hand. As depth sensors can see distances in their surroundings, they can also detect when an object is approaching or touching another object, or when it enters a certain volume of space. Using a depth sensor, interaction can take place on any available surface [12] or even just in its immediate vicinity "in the air". The user can either touch a surface/object to elicit an action, or there can be a UI that is projected onto the surface/object that the user can manipulate. One trend has been to study projected interfaces for personal use, as in the Omnitouch project [13], or to enlarge small displays of per-

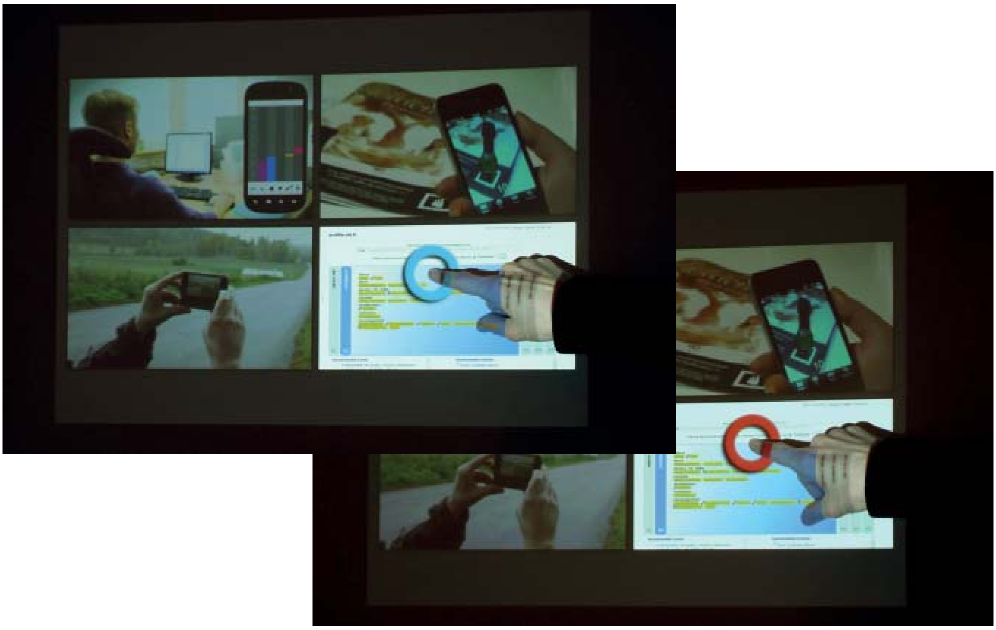


Figure 3. Projected video player. The user can choose to play one of the 4 video clips by clicking it on the UI projected onto the wall. The blue circle in the front image is the cursor that the user moves along with their finger. When the click is detected, the cursor turns red and the video starts to play.

sonal devices via projection, as in the Mozilla Seabird project (http://www.youtube.com/watch?v=oG3tLxEQEdg). It should be kept in mind that the usability of (personal) projected user interfaces might not be that straight-forward in every situation, as especially in public spaces, privacy issues and questions over what is appropriate may arise [14].

To demonstrate a projected user interface, we created a video player with which the user could use their finger as a mouse and click one of the four videos shown in the projection in order to begin its playback (Figure 3). The main idea was to project a user interface onto a flat surface and let the user control the UI with their finger as a mouse. The projection was a front projection and the depth sensor (ASUS Xtion PRO) was placed on top of the projector.

The depth sensor detects the plane (the surface on which the projection UI is) and the user's hand and fingers, and can then estimate the distance between the user's fingers and the control surface. The hand is detected from the depth data simply by clustering all "new" objects over a pre-computed background model. Sufficiently large objects are determined to be hands, and they are scanned for thin, long protrusions that, in turn, are declared fingers. The tip of the finger is chosen as the point furthest away from the centre of mass of the hand object. Later, this algorithm is planned to be adjusted for a portable system, where a static background model is no longer possible. At that point, the finger shapes will be detected directly from a depth gradient image calculated from the depth image (see the Omnitouch system for similar implementation [14]).

A "touch" on the projected UI surface is detected if the distance from the back of the finger is closer than a predefined threshold.

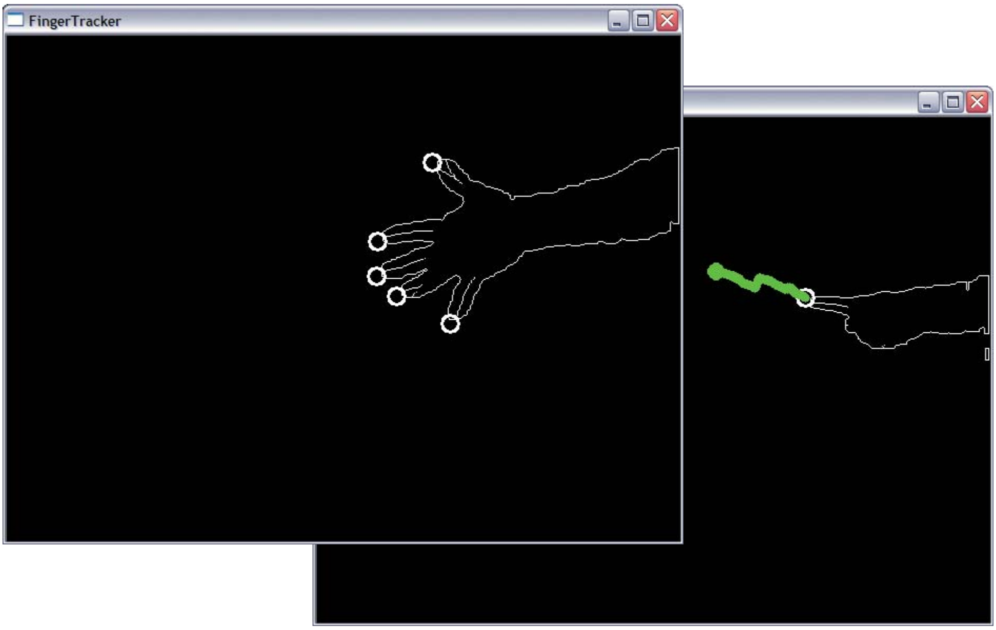


Figure 4. On the screen in the front: illustration of hand and finger detection; on the screen in the back: illustration of surface touch detection. The hand and fingers and the touch detection enable the use of a finger as the mouse cursor over the projected display.

We used 2 cm as a threshold. In Figure 4, the hand/finger recognition result is shown, as well as the touch detection, visualised as a green continuous line drawn to where the finger has slid along the surface.

This approach to detecting fingers also allows the user to use, for example, something like a pen as a "finger", dragging and tapping it just as they would with a mouse (or indeed their finger).

The video player UI application was created to demonstrate the case of a finger replacing a mouse. The default mouse cursor was replaced with a larger one, so that it would not be hidden behind the fingertip and the user could see a visual response to their actions in the UI when touching the wall. The cursor was also modified so that, when the finger was close enough to the surface and thus performing a click, the colour of the cursor changes briefly, indicating that a click has been registered. A click on a video will start playback. Another click outside the video will stop it.

There are a few remarks on using the finger as a mouse on a projected interface. First, the UI has to give some kind of feedback to the user on the performed action – one of the main principles in UI design. That is the reason why the bigger cursor and the colour indication of the click were introduced. If the user taps the wall and does not know whether the action is taken or not, the overall experience is quite poor. Second, although the pointing and tapping is a very natural way to perform interactions, the application and its UI have to be designed so that the items to be interacted with are large enough. The detection of tapping tiny objects, smaller than the fingertip, is not easy.

Ubiquitous digital content requires new methods to manipulate and control

Augmented reality applications and future emerging mobile trends, such as different head-up displays (HUDs) such as Google Glasses and holographic interfaces, require new types of non-touch interaction methods for digital object manipulation, as in many of the cases, there is no possibility to use de facto methods (e.g. a mouse). Depth sensors are one way to provide the natural UIs in an evolving digital environment, as they have proven to be powerful tools for improved natural human-computer interaction, by enabling new ways to operate computer programs and applications.

The research with gestures and depth sensors is advancing fast, and to be in the forefront of development requires research effort now. The focus on research is turning more towards small-sized micro-gestures that are more natural to use and do not require large movements of arms and hands. The number of sensor manufacturers releasing their own hardware is increasing (Asus, SoftKinetic, PCM, Panasonic etc.), and many of them have even seen it wise to follow design guidelines that allow sensors from different manufacturers to be used in the same system with no, or minimal, software changes.

Although many of the sensor manufacturers provide software interfaces for gesture input, it is still necessary to think carefully how to design the interaction and gestures of natural user interfaces. The gestural interfaces are still waiting for their breakthrough in everyday HCI.

Currently, Samsung's Galaxy Beam mobile phone has a small-sized pico projector built in, and with a miniaturised depth sensor, interaction with a projected UI could take place anywhere. The future LED lighting in homes and offices can offer UI projections and interaction via depth sensing anywhere, when required. Miniaturising of depth sensors and falling prices will enable the use of these sensors in variety of places. In the future, they can be built within walls to create potentially interactive objects and walls.

As different technology fields develop fast and integrate information technology deeper into our lives, there will be more cases where natural interaction is required. This will open up new opportunities for depth sensing and gestures.

References

[1] Pavlovic, V. I., Sharma, R. & Huang, T. S. Visual interpretation of hand gestures for human-computer interaction: a review. IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 19, No. 7, pp. 677–695, July 1997.

[2] Han, Y. A low-cost visual motion data glove as an input device to interpret human hand gestures. IEEE Transactions on Consumer Electronics, Vol. 56, No. 2, pp. 501–509, May 2010.

[3] Kela, J., Korpipää, P., Mäntyjärvi, J., Kallio, S., Savino, G., Jozzo, L. & Marca, Di. Accelerometer-based gesture control for a design environment. Personal and Ubiquitous Computing, Vol. 10, No. 5, pp. 285–299, July 2006.

[4] Klompmaker, F., Nebe, K. & Fast, A. dSensingNI: a framework for advanced tangible interaction using a depth camera. In: Spencer, S. N. (Ed.): Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction (TEI '12). ACM, New York, NY, USA, pp. 217–224.

[5] Hardy, J. & Alexander, J. Toolkit Support for Interactive Projected Displays. Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia (MUM '12). Ulm, Germany, 4–6 December 2012.

[6] Mitra, S. & Acharya, T. Gesture Recognition: A Survey. IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews, Vol. 37, No. 3, pp. 311–324, May 2007.

[7] Suarez, J. & Murphy, R. R. Hand gesture recognition with depth images: A review.

RO-MAN, 2012 IEEE. Proceedings of the 21st IEEE International Symposium on Robot and Human Interactive Communication. Paris, France, 9–13 September 2012. Pp. 411–417.

[8] Shiratuddin, M. F. & Wong, K. W. Non-contact multi-hand gestures interaction techniques for architectural design in a virtual environment. Proceedings of the International Conference on Information Technology and Multimedia (ICIM). Kajang, 14–16 Nov. 2011. Pp. 1–6.

[9] Hespanhol, L., Tomitsch, M., Grace, K., Collins, A. & Kay, J. Investigating intuitiveness and effectiveness of gestures for free spatial interaction with large displays. Proceedings of the 2012 International Symposium on Pervasive Displays (PerDis '12). ACM, New York, NY, USA, Article 6, 6 p.

[10] Cuccurullo, S., Francese, R., Murad, S., Passero, I. & Tucci, M. 2012. A gestural approach to presentation exploiting motion capture metaphors. In: Tortora, G., Levialdi, S. & Tucci, M. (Eds.): Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI '12). ACM, New York, NY, USA, pp. 148–155.

[11] Nielsen, M., Störring, M., Moeslund, T. B. & Granum, E. A Procedure for Developing Intuitive and Ergonomic Gesture Interfaces for HCI. Gesture-Based Communication in Human-Computer Interaction Lecture Notes in Computer Science, Vol. 2915, pp. 409–420, 2004.

[12] Wilson, A. D. Using a depth camera as a touch sensor. Proceedings of ACM International Conference on Interactive Tabletops and Surfaces (ITS '10). ACM, New York, NY, USA, pp. 69–72.

[13] Harrison, C., Benko, H. & Wilson, A. D. OmniTouch: wearable multitouch interaction everywhere. Proceedings of the 24th annual ACM symposium on User interface software and technology (UIST '11). ACM, New York, NY, USA, pp. 441–450.

[14] Ko, J.-C., Chan, L.-W. & Hung, Y.-P. Public issues on projected user interface. In: CHI '10 Extended Abstracts on Human Factors in Computing Systems (CHI EA '10). ACM, New York, NY, USA, pp. 2873–2882.

Impacts of OPENS 2009-2012

Inputs	• Volume of the programme 38 million euros, roughly 9.5 M€ per year • Programme incorporated ca. 100 projects • Roughly 300 person years
Outputs	• 112 invention reports, 12 patents and applications • Altogether 276 technical and scientific publications (59 international peer-reviewed scientific journal papers, 206 international conference publications, 13 VTT publications) • Media coverage in national professional and general media, more than 30 news hits, columns and feature articles in major national media • Three start-up companies (Adfore, Hookie and SixStarz) • Solutions and technologies of novel UI and context sensitive functions • The volume of VTT's annual contract work quadrupled from 500 k€ to 2000 k€ during the programme. • OPENS was instrumental in forming the European Internet of Things Alliance (EIoTA), an alliance fostering EU and Japan cooperation
Examples	• Solutions and technologies for companies, including mobile applications, industrial sensor systems, state-of-the-art software implementations of novel user interface and context sensitive functions • Two major software libraries for augmented reality and context awareness • Development of Smart M3 semantic interoperability framework developed with industrial and academic partners • Proof of concept for wireless charging using NFC technology and initiating standardisation of the technology with industrial partners
People & networks	• More than 100 researchers, business development and IPR specialists from VTT and ca. 300 from stakeholders • International cooperation in more than 25 EU, ITEA, Celtic, and ARTEMIS projects • European industry partners include Accenture, Bosch, Daimler Benz, EADS, Ericsson, TU Eindhoven, FhG, Fiat, Philips, SAP, Siemens, STEricsson, Telefonica, Thales, University of Bologna, WUT Warsaw University of Technology • Partnership with University of Tokyo was established • Long term cooperation between VTT and ETRI in Korea • Steering Group: Tatu Koljonen (Chair), Anne Ritschkoff, Jorma Lammasniemi, Jussi Paakkari, Seija Sihvonen, Petteri Alahuhta, Petri Kalliokoski, Caj Södergård • Coreteam: Heikki Ailisto (Programme Manager), Marko Jurvansuu (Customers), Timo Koivumäki (Business plan, IPR)
Award examples	• ARTEMIS Exhibition award at the Artemis Autumn Event Exhibition during the Artemis/ITEA2 Co-Summit 2009 for SOFIA project. • The 2009 gold ITEA Achievement Award went to the SmartTouch project for its outstanding contribution to the programme of ITEA 2 - the EUREKA Cluster for Software-intensive Systems and Services (SiSS). • UseNet project won the ITEA Achievement Silver Award 2011 for the development of M2M Internet thus increasing the size of potential market for M2M deployments. UseNet has delivered an open architecture and has been very active in the new ETSI M2M TC standard.

Series title and number
VTT Research Highlights 7

Title	Uniting the physical and virtual — ICT solutions for open smart spaces
Author(s)	Heikki Ailisto and Kaisa Belloni (Eds.)
Abstract	This publication describes some of the research highlights achieved in the focus areas of the Open Smart Spaces spearhead programme 2009–2012: interoperability, smartness, and natural interaction. Interoperability between devices, software and other resources is essential for the emergence of smart spaces. The different levels of interoperability are discussed together with the importance of a common language for the devices. Semantic interoperability in resource limited devices is also elaborated and an implementation example is given. Context recognition has taken significant technical steps and matured from laboratory to real world applications during last couple of years. This development from recognising user's physical activity – sitting, walking, running – to more elaborate life pattern analysis is discussed. Development of VTT Node, a wireless sensing and processing device bringing distributed intelligence into industrial condition monitoring is explained. An overview of how existing near field communication antennas and circuits can double for the purpose of wireless charging is given. Finally, the interesting possibilities given by augmented and mixed reality and 3D cameras are introduced.
ISBN, ISSN	ISBN 978-951-38-7970-9 (Soft back ed.) ISBN 978-951-38-7971-6 (URL: http://www.vtt.fi/publications/index.jsp) ISSN-L 2242-1173 ISSN 2242-1173 (Print) ISSN 2242-1181 (Online)
Date	April 2013
Language	English
Pages	58 p.
Keywords	Ubiquitous computing, interoperability, context awareness, mixed reality, wireless sensors, indoor positioning, wireless charging, augmented reality
Publisher	VTT Technical Research Centre of Finland P.O. Box 1000 FI-02044 VTT, Finland Tel. +358 20 722 111

VTT Technical Research Centre of Finland is a globally networked multitechnological contract research organization. VTT provides high-end technology solutions, research and innovation services. We enhance our customers' competitiveness, thereby creating prerequisites for society's sustainable development, employment, and wellbeing.

Turnover: EUR 300 million
Personnel: 3,200

VTT publications

VTT employees publish their research results in Finnish and foreign scientific journals, trade periodicals and publication series, in books, in conference papers, in patents and in VTT's own publication series. The VTT publication series are VTT Visions, VTT Science, VTT Technology and VTT Research Highlights. About 100 high-quality scientific and professional publications are released in these series each year. All the publications are released in electronic format and most of them also in print.

VTT Visions

This series contains future visions and foresights on technological, societal and business topics that VTT considers important. It is aimed primarily at decision-makers and experts in companies and in public administration.

VTT Science

This series showcases VTT's scientific expertise and features doctoral dissertations and other peer-reviewed publications. It is aimed primarily at researchers and the scientific community.

VTT Technology

This series features the outcomes of public research projects, technology and market reviews, literature reviews, manuals and papers from conferences organised by VTT. It is aimed at professionals, developers and practical users.

VTT Research Highlights

This series presents summaries of recent research results, solutions and impacts in selected VTT research areas. Its target group consists of customers, decision-makers and collaborators.

Uniting the physical and virtual — ICT solutions for open smart spaces

This publication describes some of the research highlights achieved in the focus areas of the Open Smart Spaces spearhead programme 2009–2012: interoperability, smartness, and natural interaction.

Interoperability between devices, software and other resources is essential for the emergence of smart spaces. The different levels of interoperability are discussed together with the importance of a common language for the devices. Semantic interoperability in resource limited devices is also elaborated and an implementation example is given. Context recognition has taken significant technical steps and matured from laboratory to real world applications during last couple of years. This development from recognising user's physical activity – sitting, walking, running – to more elaborate life pattern analysis is discussed. Development of VTT Node, a wireless sensing and processing device bringing distributed intelligence into industrial condition monitoring is explained. An overview of how existing near field communication antennas and circuits can double for the purpose of wireless charging is given. Finally, the interesting possibilities given by augmented and mixed reality and 3D cameras are introduced.

ISBN 978-951-38-7970-9 (Soft back ed.)
ISBN 978-951-38-7971-6 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN-L 2242-1173
ISSN 2242-1173 (Print)
ISSN 2242-1181 (Online)