Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 35 (2014) 822 – 831

Procedia Computer Science

18th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems - KES2014

An infrastructure for individualised and intelligent decision-making and negotiation in cyber-physical systems

Anne Håkansson[a]*, Ronald Hartung[b]

[a] *KTH Royal Institute of Technology, Software and Computer Systems, Forum 100, 164 40, Kista*

[b] *Franklin University, Columbus, and The Design Knowledge Company, Fairborn, Ohio, USA*

Abstract

Cyber-physical systems are often developed with an emphasis on the network of computational elements and the linkage between the computational and physical elements. The physical elements are different kinds of Internet of Things devices that carry out desirable and valid tasks from instructions. However, due to the limitations of current individual-based secure products and delivery of services, the requisites of these products and services have started to increase and, hence, the requirements for intelligent automated, networked and mobile devices arise. The current state of communication between the elements in Internet of Things is data exchange and needs step up to next level to improve the interaction with the surrounding devices to augmenting human capabilities. This paper presents an infrastructure for individualised intelligent decision-making and negotiation in cyber-physical systems with smart Internet of Things devices. The decision-making and negotiation is based on individual preferences to provide the best individual-based solutions. The solution is applied to health care, which will permeate throughout the paper.

Keywords: Cyber-Physical Systems; Internet of Things devices, Intelligent reasoning; Decision-making; Negotiation

1. Introduction

With the growth of population, the requisites of individual-based secure service deliveries with requirements for intelligent automated, networked and mobile devices will increase. Current reports present increasing need for

* Corresponding author. Tel.: 46-8-790-4041.
E-mail address: annehak@kth.se

doi:10.1016/j.procs.2014.08.248

improved infrastructure of intelligent devices that supports people in their daily life. For health care, for example, there are a lot of people that cannot get treatment and medicine and, hence, medical systems must support these services and products by becoming more intelligent in the ways they interact with human users and each other. To provide more individualised intelligent health care, multi-disciplinary research is needed to make possible comprehensive lifelong multi-source health records for individuals. Hence, the requirement is to have things that act, intelligently, and accordingly to pre-defined characteristics and requisites. Thus, the need of intelligent behaviour has arisen and with it, research in an advanced Cyber-physical systems using Internet of Things with devices supporting augmented reality. Necessary and essential individual-based data and information can be retrieved and decision-making can support the exchange of data and information between the different devices in the system.

Augmented reality with smart products and services has started to influence our lives, providing an abundance of advanced and useful research in Internet of Things (IoT)[1,2,3]. This research has been successfully carried out to provide digital support. IoT is a network of things with tagged identifiers that carry out tasks when objects approach the devices. The tasks are based on immediate and present needs and should give applicable support according to data communicated between the end user and the IoT. Currently, the communication between the elements is a simple data exchange, which needs to step up to next level to improve the interaction with surrounding IoT devices to augment human capabilities.

Internet of things can be reckoned as a distributed cyber-physical system with loosely coupled interacting components, or devices. Cyber-physical systems (CPS) are often developed as a network of computational elements with linkage between the computational and physical elements[4]. The physical elements often use different kinds of IoT devices to handle significant data and information, which are needed to carry out desirable and valid tasks[4-10]. CPS can handle an exchange of the required data, information, knowledge and experiences between the devices. However, different devices require various input-output technologies.

Augmented reality[1] using Cyber-physical systems with the smart IoT devices that provide products and services can assist people in especially dangerous environments. This can enable monitoring and delivering healthcare, operation in dangerous and inaccessible environments, coordinating traffic and efficient use of energy in buildings. In particular, the devices can effectuate automatically opening doors for disabled people in the surrounding environment, and providing necessary and adaptive interfaces for visual impaired and/or hearing-impaired people. Moreover, these devices can provide individualised information for different situations, such as, obtaining individual-based information by receiving patient records with earlier diseases, current and earlier treatments and medications, thus providing fast and instant help for unexpected illness and so on. Hence, providing information is not just to provide any information, it must provide user-requested and user-adapted information.

To get the best possible solution, governed by user needs, the control of the CPS, with near field sensors and other IoT devices, must include individualised, intelligent interactions between humans and CPS. The interaction requires decision-making and negotiation with smart IoT devices to improve the interaction with surrounding devices to augment human capabilities. Strategies for decision-making and negotiations[11], using event-driven algorithms[12,13], are necessary to support individuals by making intelligent conclusions from the data sets. These conclusions must be based on the needs of commonalties and requirements of particular outcomes using individualised, secure and intelligent IoT devices. This paper presents an infrastructure for individualised, intelligent decision-making and negotiation in CPS creating a need-adjusted environment with individual-based performing IoT devices. Research in CPS is, commonly, carried out for the utility network and not for a holistic view of the problem and improved situation for the individuals, as in this paper. The focus moves from 'what can you do in the environment' to 'what the environment can do for you'. As an example of the research, CPS is applied to health care handling required, individual and necessary patient data obtained from monitoring and measuring the current general status of the patient's health, including earlier health issues, and drawing conclusions about medicine usage and side-affects, which is then presented to medical doctors and other users.

2. Infrastructure centered around a personal IoT device, MINi-Me

There are several different operating environments that can occur in the CPS, which is viewed as infrastructure for the CPS system. The emphasis of the infrastructure lies in designing modules in the environments. An infrastructure organizes the components to permit their reuse over a wide range of tasks, were the module interfaces must be expressive and well documented to be used by IoT devices.

Since the individuals are in the focus for individualised, intelligent decision-making and negotiation, the personal data and preferences must be stored and utilised. For this, a personal IoT device is used, so called, a mimicking individualised and intelligent decision-maker, MINi-Me. MINi-Me interacts with the environment in an intelligent comportment by using a smart card that keeps and carries all individual data and information needed to make the performing IoT devices act according to the individuals' preferences and needs.

MINi-Me is a virtual copy of the individual user and is stored on a personal smart IoT device. This device is more than a simple avatar since it is not only a visualisation or an electronic representation of the person. Rather it contains real facts about the individual, information about known problems and current needs, earlier and current status, as well as products and services usage. These facts are collected on a daily bases and updated on an instant, real-time basis. The smart IoT device is updated with diseases and illnesses, medical treatments stored in patient's records, and earlier and current usage of medicines with known side-effects of the medicines, as well as requisites of medicines for the known diseases and illnesses. Facts about current status are also needed. For example, information about a person's diabetic problems, medicine and current blood sugar level can be useful if the person has fallen into a diabetic coma. Also, special needs are stored, for example, disabilities requiring particular products and services.

2.1. Infrastructure with different operating environments for MINi-Me

The personal MINi-Me device is a part of a network of IoT devices in the Cyber-Physical System, where it participates by communicating and collaborating with the surrounding IoT devices and computer systems. The MINi-Me cooperates with the environment, automatically, by establishing contacts with the devices, using near field communication, and exchanges data and information required by IoT devices and computer systems. Depending on the IoT devices or systems, the MINi-Me device uploads and receives the data and information that is needed by the specific device or system to communicate in a correct manner.

To use a personal MINi-Me device, the device must first be programmed with personal data and encrypted using a stationary IoT device with support from external mobile IoT devices, and computer systems containing data and information about the individual. Then, the MINi-Me device can be used together with other smart IoT devices and systems in different situations, as illustrated in the figure below, see Fig 1.

Left in the figure, Fig.1, A) Home IoT Device, mobile IoT device and Internet are used for updating the smart MINi-Me device with individualized, personal context-based data, as well as security keys. The data can be enriched by collecting additional data from external sources where text, pictures, and sounds can be used to receive complementary context-based data, information, knowledge and experiences from the Internet. Security and automatic decision-making and negotiation are necessary to receive meaningful results. The result can, for example, be used for self-treatment and handle in-house convalescence but it can also be used to update information in mobile IoT devices, which are, then, used for communication with other external devices.

In the middle of the figure, Fig. 1, B) External devices, shows a personal MINi-Me device interacting with the external devices that, in turn, act according the individual needs. The external devices act with near field communication (NFC), where the mobile IoT devices communicate, in a secure manner, with the smart devices. As a result of using these devices it can be, for example, possible to deliver necessary health care for acute conditions. This can enable professionals and/or the public to obtain and act on health knowledge from diverse and varied sources. The knowledge includes the current health issues and possible arisen problem and information about how to handle the actual situation.

The right side of the figure, Fig.1, C) Databases and external IoT Device, presents an environment where another external IoT device is used to deliver data and information from the smart personal MINi-Me device. The external stationary IoT device has some connections, either to computers or to other IoT devices. The computer can be connected to databases for retrieval of records or registers of the person. An example of this operating environment is the medical doctors' offices. The smart personal MINi-Me device delivers individual-based information, with earlier treatment, and medicine usage to provide contexts-based information, which can also be used for retrieving data and information about other medicine or complications of medicine usage.

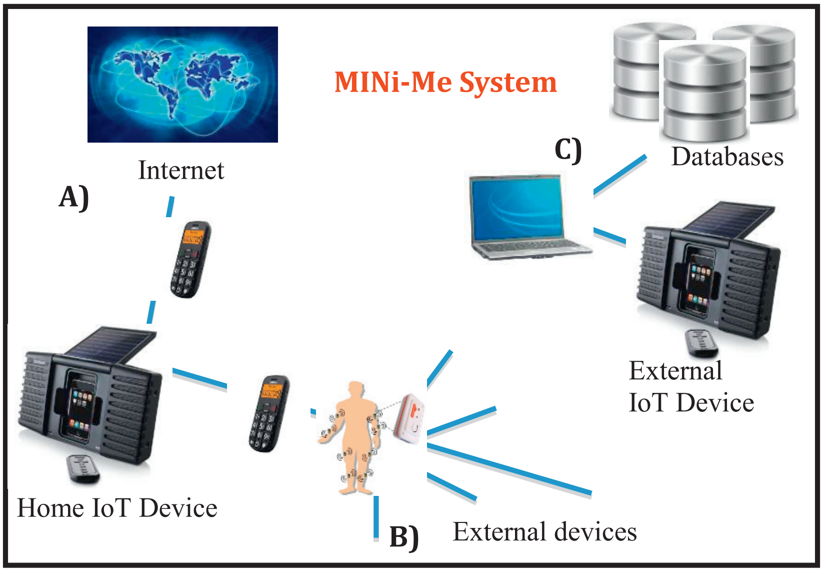

Fig. 1. Operating environments of the MINi-Me system

In order to make the MINi-Me effective, the devices need to interact, and not just receive a pre-defined set of information. The users' MINi-Me IoT devices need to present a profile of needs. The nearby devices need to examine the profile and respond in useful ways. This is the kind of area where ontologies are often proposed. However, this can be a trap in that the ontologies need to be kept in sync. Also, the expectation is that services will blossom and grow faster than ontologies can be rationalized. Instead, event-driven systems with time frames are needed to control the devices and receive feedback. The events must apply to task hierarchies involving asynchronous dynamics, which incorporate geographic scope, as well as different time scales and real-time control handling everything from instant manipulations of opening doors to slower reactions of interactive parts.

3. Individualised, intelligent decision-making and negotiation in CPS

Individual data and information is accessed and communicated by carrying the smart personal MINi-Me device around in the environment. To handle the situations in the operating environments shown in Fig. 1, the following decision-making and negotiations are needed:

A) *Contextual-based decision-making with individualised and mobile IoT devices*. Personal MINi-Me devices use individualised data and mobile IoT devices to store and access personal information. For this situation, personal data and context-based decision-making technology are used to provide individualised support. The personal data are combined with data about current situation and data from external sources to provide conclusions. The combination of data from several IoT devices, i.e., the personal and individualised MINi-Me device, with other mobile IoT devices, provides trustworthy environment with secure communication by containing pieces of data that must be combined to be readable.

B) *Decision-making and Negotiation with individualised and context-aware external mobile IoT devices*. Individualised and context-aware mobile IoT devices access all near field IoT devices and systems in the environment to get individualised services and products. These mobile IoT devices require intelligent and contextual decision-making and negotiation to provide an individualised, complex and supportive environment with high confidence. These constituents are used to communicate and reason with physical devices to make them act accordingly to individual needs and provide services and products, as well as prevent threats using protection mechanisms.

C) *Intelligent reasoning using IoT devices and computer systems allowing human interventions.* Intelligent and contextual reasoning are applied in a CPS using individualised IoT devices and mobile IoT devices, in order to connect databases and make individual-based decisions. This situation includes human involvement to provide individualised services and products and intelligent reasoning is to provide valid and individual-based conclusions from MINi-ME, IoT devices and computer systems. The conclusions must be trustworthy and the intelligent reasoning using the IoT devices and systems must provide and maintain privacy, and security with data and information protection.

3.1. Contextual-based decision-making using individualised MINi-Me device and mobile IoT devices

The MINi-Me and the mobile IoT devices are used as communication links that can connect to Internet and other external computer systems to collect data and information to draw conclusions, as shown in Fig.1, A) Home IoT Devices. To collect and upload the data to MINi-Me, a simple text system is used. Also, user-taken pictures and voice recording are important features of the system. Pictures can be photographs of prescriptions or other necessity information; voice recording can add important information. These input techniques are especially essential for elderly and people with disabilities. The ambition of the research in this paper, is to support all kinds of people allowing alternative input devices. Commonly, augmented reality includes speech recognition systems that translate a user's spoken words into computer instructions and gesture recognition systems that can interpret a user's body movements by visual detection or from sensors embedded in a peripheral device[14]. Here wands, stylus, pointers, gloves and other body wear devices can be useful to support people with disabilities.

Individual and contextual-based decision-making is used to provide individual-based services and products. The individual-based data are stored as concepts in the MINi-Me. These concepts are categorized using pre-determined contexts with a pre-defined list or with a user-defined category, which is applied on the individual's personal data. The concepts and categorizations are utilised to externally search and find important and relevant data and information concerning a particular situation where the concepts correspond to objects and the categorizations are similar to a classes for several objects.

To get a better insight, with a more holistic view of the problem and improved understanding of the situation, complementary data and information is fetched from the Internet. Via the external mobile IoT device, the personal data in MINi-Me is used as concepts to search on the Internet and collect additional data about the concept. In this paper, the system uses a general-purpose vocabulary, called ConceptNet. This allows the MINi-Me to rely on synonym and antonymyns style relations between terms to enable the negotiation. ConceptNet provides a set of 50 relations over a large set of concepts and words, which can be used for a basis of mediating the needs and offers between IoT systems. The result using concepts and categorizations as search terms is a vast set of data and information.

ConceptNet is used to locate concepts and track relevant terms by both synonym and antonymyns. It also is used to identify concept domains. A concept domain can distinguish the medical domain from the restaurant or the home domains. This can be done by several methods the simplest one is to maintain a list of key sets of terms for a domain. This is also used to reject data that may not fit the problem domain, at hand.

From the result of locating concepts and providing holistic view of the problem, decision-making is applied to get only the relevant data that are pertinent to the personal data. The decision-making uses production rules, in a knowledge base, that corresponds to the incoming data[15]. The decision-making can discern the relevant data by comparing the concepts and categories stored on the MINi-Me device with the incoming data and information using context comparison[16] with deductive and inductive reasoning. If the data corresponds to the concepts and categories, it will be stored in the MINi-Me device. Otherwise, it will be discharged. As a result of the decision-making, the concepts are enriched with more data and information relevant to the individual and the situation.

The data and information, provided by MINi-Me system, must be correct and trustworthy and, hence, data security and information security are essential issues. As mentioned above, security is provided by several IoT devices containing pieces of data that must be combined to be readable. Hence, to protect the data, the personal MINi-Me device contains parts of security code and the mobile smart IoT device contains the other parts. Those two devices must be put together to provide the security code that enforces protection when communicating with other external devices.

3.2. Decision-making and negotiation with Individualised and context-aware external mobile IoT devices

Once, the individualised, and context-aware, MINi-Me device contains personal important information, it can be used in the external environment, communicating with several other IoT devices, as mentioned in Fig. 1, B) External devices. MINi-Me can interact with the environment applying personal data and getting information when communicating with external smart IoT devices via near field communication. The external IoT devices must be prepared to accept requests and act upon these, accordingly. For people with disabilities, the environment should be able to act by opening doors, giving individual-based information and decision-making by tracking objects or persons without actually physically moving around in the environment or have objects moving when needed. However, the IoT devices in the external environment must support adding individual data and information and expand the content of the MINi-Me device, like measuring blood pressure and glucose, testing urine, mouth, throat and ears, i.e., everything that can be tested without invasive tests like tests that require needles.

Currently, this kind of environment is rather limited and needs to be extended with tags and sensors, as well as becoming mobile. Nonetheless, near field communication has become more common and tags are used on different IoT devices. Several sensor applications have been developed for smart environments, smart cities, logistics, security and emergency and e-health[17], and can be utilised, especially for smartphone detection for CPS. Also, external devices, like self-tests exist, which can be digitalised for example, the self-testing urine tests or aperture tests. Instructions to and the results from these tests can be digitalised and stored by using, e.g., a chip-based urine test device, where a chip can receive instructions, from an external testing application, about the test to be carried out. Then, the test device can measure the urine, accordingly to the instructions and send the results to the testing application and the MINi-Me device, which in turn can upload it and send the results to other IoT devices. The testing application is an intelligent knowledge-based system application that can draw conclusions from results of the tests and from known facts.

Hence, to make use of the CPS environment with sensors and measurements, the MINi-Me and the mobile IoT devices use intelligent decision-making to provide a complex and supportive environment. The personal needs are different and the MINi-Me devices communicate with all the external IoT devices, but do not give commands to every IoT device. Only the devices that can give support will act on the command of the MINi-Me device. To know which devices are interesting to use and should act on commands, decision-making is applied.

Moreover, to act on instructions for different IoT devices, such as the test devices, decision-making is needed to draw conclusions. From a number of facts, like symptoms rules with deductive reasoning can conclude a possible disease, but to confirm the conclusion, data from other surrounding IoT devices may be needed. If so, inductive reasoning can be used to collect the data by instructing the IoT devices about the needed data and aggregate the data to confirm the disease. Additionally, with the use of abductive reasoning it is possible to search and confirm several known symptoms, as well as collect and enrich the set of commonly known symptoms with unknown symptoms for the disease.

Negotiation takes place between the MINI-Me and the IoT devices to select the relevant information by examining offers from the devices and by asking for information of interest. This negotiation is bi-directional as the MINI-Me will not know what may be available for the current devices and the current devices will not know what the MINI-Me may want.

Negotiation is needed when several MINi-Me devices communicate with the same external IoT device. The external IoT device needs to act in an intelligent logical manner, doing the right thing, in the right order and at the right time. Negotiation can take several commands and calculate which order will be the best for all the MINi-Me devices that have contacted the external IoT device. For the negotiation, the event-driven algorithm[12] is applied. From a solicit event, the algorithm supports sending and receiving, collecting, and negotiating data from the MINi-Me device to the external IoT devices. The event can involve several IoT devices interacting with the environment in an intelligent manner. Moreover, the algorithm can also support storing data as hierarchies, which can be utilised when communicating with the same IoT devices again or with other IoT devices with similar structure as well as negotiating the best solution for the person.

A significant issue is to interpret the result of using the devices. Augmented reality can visualize data in its context by working as an immediate and visual medium and display a lot of data, clearly and quickly[18]. With various sort of interfaces, information and services, based on objects can be perceived and understood by users. Using augmented reality as an interface for the Internet of Things has many advantages. As an immediate and visual medium, it can display a lot of data, effectively[18]. For example, temperature readings can be displayed by changing coloured patches on an image. It can allow a MINi-Me to engage much more deeply with what's around in the environment.

The constituents, used to communicate and reason with IoT devices, must prevent threats using protection mechanisms. The privacy and trust are two major components for these devices. The devices must be protected and cannot and shall not accept any interference of non-valid IoT devices that are fake, fraud or fishing devices or applications. Each IoT device, as well as the combination of several different devices, must handle secure communication to ensure privacy. Also, the IoT devices must act appropriately and accordingly to the MINi-Me's requests.

3.3. Intelligent reasoning using IoT devices and computer systems allowing human interventions

Even with the support of different IoT devices, there are still some tasks and assignments, which must be handled by other humans than the MINi-Me owner, such as surgery and other complicated tasks that require a third part. The collected data and information of the MINi-Me device can support these tasks by providing necessary, fast and valid data and information for a given situation and in a particular context. The MINi-Me device can also support exchanging specific data and information that cannot be communicated, verbally, by transferring important data directly from the MINi-Me device to receivers.

To make use of the content of MINi-Me, individual-based data and information of the IoT device must be made available for other IoT devices and systems using contexts. To start harvesting a MINi-Me device of data, the device must be open for communication. The sensitive contents of the MINi-Me device are accessed by placing it in an IoT device unit and, then, use a mobile IoT device to communicate with the MINi-Me. The combination of MINi-Me device and mobile IoT device is necessary to get the individual-based data and current data in the mobile IoT device. That is, the mobile IoT device has the latest recorded data whereas the individual MINi-Me has the personal data. The data of these devices are used to get more data and information from external computer systems. These computer systems can be closed systems that contain sensitive data and information about particular things, services products that cannot be a part of the Internet, like scans of the persons' brains. These systems are only accessed when really needed, like medical systems in acute situations to get individual-based treatments. Also, important data and information, as well as latest services and products can become available.

Intelligent and contextual reasoning in multi-domains can be used in the CPS system to support individualised mobile IoT devices, in order to connect data from databases and make individual-based decisions and individualized services, as shown in C) in Fig.1. The multi-domains are, for example, illnesses, health care in general, and medicine with contents and side-effects, from which important data can be extracted and combined. Hence, the data in the MINi-Me device can be used for decision-making to quickly reach more solid conclusions based on individual data. The data gives a more complete view of a person, the person's situation and requisite of health care, to support giving the requested services or products, like treatments and combinations of medicines. With the individual-based data, it is possible to avoid making wrong decisions, which may be a problem if decisions are made on incomplete data and information.

Negotiation between the data and information of the computer system and the individual data in the MINi-Me is carried out to suggest individual-based and context-based services and products, such as treatments and medicines. The negotiation will look at the person's indicators on earlier and current problems and compare those with the system's data and information to check whether or not it is the same or similar problems and negotiate a solution to the possible problem.

The result of collecting the new data and information, which have been applied to the person, must be stored on the MINi-Me device to have an up-to-date device. If important pieces are missing, the MINi-Me device will become useless. Most important is that the updating is done by the surrounding IoT devices that collect data using measurements and not by the individuals. These IoT devices should be used as measurements and tests to get the latest data by being attached to the person's body or by testing body substances, like urine, and saliva, but also checking appearances of the body, such as eyes, tongue, throat and ears.

For security, the communication must be secure and include authentication and the data must be trustworthy and protected. An authentication of the MINi-Me device must be used to allow access and communication with external devices, like stationary units or devices and computer systems, the MINi-Me uses the same combination of security keys, that it got when uploading personal data and information in the first situation, A) in Fig. 1, and the same pattern stored in a mobile IoT device. For each time a MINi-Me device is placed in a stationary IoT device, like home IoT device, it will create a new security key. With this kind of authentication, the MINi-Me device is protected from many attacks. The trustworthiness of the data is, as mentioned earlier, that all conclusions and results of the negotiations must be correct and sustainable since it includes people and their daily lives. The protection of sensitive data and information is the same no matter the situation.

4. The health care section

As an example for the CPS systems with IoT devices, the health care section is used because it has several problems, which will become severe in the future. Beside difficulties with accessibility, it is expensive, lacks data availability, and the reliance on medicine is high. Health care needs sufficient technology, providing portability and supporting data availability, as well as informing about the side-effects of the medicines.

For specialized domains, medicine for one, using standard medical terms will be the norm. To handle medical terms, an ontology can be useful. A complex example of the medical domain would be a user device that monitors the person and can be interrogated by diagnostic systems. Monitoring and providing conclusions is possible with augmented reality, decision-making, and IoT applications. With augmented reality, devices can check out different temperatures in human bodies, check rashes and use symptoms spoken to the system, and show treatment of the disease. For example, emergency services can use augmented reality and IoT devices to access metadata where augmented reality visors can display schematics for how to treat emergency problems, for example, heart attack with CPR. This can save many lives since, every year, about 10000 people out of 9 million people get heart attacks.

Already, a number of applications for cell phones, like GaitTrack[19], have been developed to measure, e.g., temperature, blood pressure and oxygen, and heart rate but those applications must be enriched with personal health information to get individual health care. When it comes to decision-making using personal IoT device and mobile IoT devices to get information via the Internet, a MINi-me device can help people that suffer from disabilities, i.e., physical and mental problems, to get treatments. By using the health context in the MINi-me, data that concerns personal illness and current usage of medicine can be provided to improve health-care.

Applying decision-making allows the systems to get only the relevant data that are pertinent to the personal situation. The personal data includes earlier and current illness and treatments, medicine usage and known family diseases, which are needed to make valid decisions about current disease, as well as preventing other diseases in the future. By this knowledge, the system can, more easily, determine the disease. Hence, some symptoms can be found in the diseases that the other family members have or have had earlier so by using family history of diseases, some diseases can be confirmed.

Moreover, to make a decision for a particular situation, the data and information from Internet are used to give a complete view of illness, and combinations of medicines, and provide information about the disease and usage of medicine, as well as serious side-effects. Actually, knowing more about the medicines and harmful substances can prevent diseases. With augmented realty, it should be able to show the effects of dangerous combinations of different products, such as a mix of medicine and other drugs like alcohol. Several thousands of people get wrong the medicines every year and many of them die because of their treatments, and as an example, in some industrial countries, this affects up to 46 % of all medicine takers.

By negotiation, a combination of several different medicines can be suggested. Hence, from several different input data, such as earlier known diseases and current medicines, the negotiation can constraint the medicine usage. Some medicines are life-supporting but with a combination of two medicines can be life threating, for example, high blood pressure medicines often requires a combination of medicines but cortisone is not one of them since it raises the blood pressure. Also, some kinds of fruits and hard training can be dangerous.

Providing personal data and information can support doctors in health care situations. For example, in an acute accent, the data and information could actually save a person's life if, for instance, blood type for a person who needs additional blood or diseases, such as bleeding disease. Another example is that the doctor is looking for a particular parameter and too often patients do not know what the doctor is looking for and will give misleading data and information. Having these parameters stored for the individual can be of ultimate help for the doctor.

5. Conclusions and further work

This paper presents an infrastructure for supporting individualised intelligent decision-making and negotiation in cyber-physical systems with smart Internet of Things devices using a MINi-Me system. Enabling intelligent complex systems, and reducing the time and effort required to bring the data, information, knowledge and experiences together are the key driving forces behind this research that, consequently, results in strong research environment, as well as in domestic manufacturing of cyber-physical systems for different domains, like health care and economic growth.

Intelligent data and information exchange and reasoning are based on individual needs and context for the IoT devices. Also, the decision-making and negotiation are made on multi-domain knowledge found in the smart IoT devices in CPS that is exchanged between the IoT devices. This gives arise to many interesting solutions for future problems and can provide high-technology devices. Still, some of the techniques are in an infancy level and need to be developed further. For example, picture and sound reconnaissance on the Internet websites, as well as negotiations among external IoT devices.

Security is an important issue with this system. So far the techniques, mentioned in this paper, are limited and must be further developed before being implemented and become trustworthy in the MINi-Me system. The system must handle a multilevel secure domain. Some information is of common nature and do not need to be protected, e.g., food offers from local restaurant. Although, one could argue for authentication so that one knows the offer is genuine. Medical information has a different need. Personal medical and financial data requires careful protection. This is going to require domains to be established with protection standards for each domain.

References

1. Atzori, L. Iera, A. Morabito A., 2010. The Internet of Things: A survey, The International Journal of Computer and Telecommunications Networking Volume 54 Issue 15, October, pp. 2787-2805.
2. Ashton K. 2009. That Internet of Things' Thing, in the real world of things matter more than ideas. RFID Journal.
3. Magrassi, P. Panarella, A. Deighton, N. Johnson G 2001. Computers to Acquire Control of the Physical World, Gartner research report T-14-0301.
4. Lee, E. A. and Seshia S. A., 2001. Introduction to Embedded Systems, A Cyber-Physical System Approach., http://LeeSeshia.org, ISBN 978-0-557-70857-4, 2011.
5. Lee E. A, 2010. CPS Foundations in Proceedings of Design Automation Conference (DAC), ACM.
6. Lee E. A. 2008. Cyber Physical Systems: Design Challenges," International Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing (ISORC), May, 2008; Invited Paper. Roboswarm.eu.
7. Edward, L., 2008. Cyber-Physical Systems: Design Challenges. University of California, Berkeley Technical Report No. UCB/EECS-2008-8.
8. White, J. Clarke, S., Dougherty, B. Thompson, C. Schmidt, D., 2011. R&D Challenges and Solutions for Mobile Cyber-Physical Applications and Supporting Internt Services. Springer Journal of Internet Services and Applications.
9. Ernst & Young, 2011. Tracking Global trends. How six key developments are shaping the business world,http://www.ey.com/Publication/vwLUAssets/Tracking_global_trends/$FILE/Tracking%20global%20trends.pdf.
10. NITRD, 2011. Winning the Future with Science and Technology for 21st Century Smart Systems, NITRD http://www.nitrd.gov/nitrdgroups/images/1/12/CPS_OSTP_ResponseWinningTheFuture.pdf, white paper,
11. Håkansson, A. 2011. A Multi-Agent System with Negotiation Agents for e-Trading Products and Services. KES (4) 2011: 415-424
12. Anne Håkansson, 2009. An Event-Driven Algorithm for Agents on the Web. Knowledge Processing and Decision Making in Agent-Based Systems. Studies in Computational Intelligence Volume 170, 2009, pp 147-174
13. Håkansson, A. Hartung, R.L. 2008. An Approach to Event-Driven Algorithm for Intelligent Agents in Multi-agent Systems. KES-AMSTA 2008: 411-420
14. Azuma, R., Baillot, Y., Behringer, R. Feiner, S. Julier, S., MacIntyre, B., 2001. Recent Advances in Augmented Reality. IEEE Computer Graphics and Applications 21(6): 34-47
15. Håkansson, A. Hartung, R.L Moradian, E. Wu, D., 2010. Comparing Ontologies Using Multi-agent System and Knowledge Base. KES (4) 2010: 124-134
16. Wu, D. Håkansson, A. 2012. Ontology Integration by Using Context and Ontology Violation Check. KES 2012: 450-459

17. Libelium. 50 Sensor Applications for a Smarter World. http://www.libelium.com/top_50_iot_sensor_applications_ranking/ (2014-05-05)
18. Leach, A. 2010. When augmented reality hits the Internet of Things. Wired.co.uk. http://www.wired.co.uk/news/archive/2010-10/14/augmented-reality-internet-of-things (2014-05-05)
19. Juen J., Cheng, Q., Prieto-Centurion V., Krishnan JA., Schatz, B. 2004. Health Monitors for Chronic Disease by Gait Analysis with Mobile Phones. PubMedgov. US National Library of Medicine National Institutes of Health, 2014-04-02, PMID: 24694291, Telemed J E Health.