International Journal of Medical and Health Sciences Research
2016 Vol.3, No.12, pp.117-125
ISSN(e): 2313-2752
ISSN(p): 2313-7746
DOI: 10.18488/journal.9/2016.3.12/9.12.117.125

EMPIRICAL AND PRACTICAL IMPLEMENTATION METHODOLOGY FOR CLINICAL INTEGRATION OF E-HEALTH IOT TECHNOLOGY

Ábel Garai[1]
[1]*Department of Information Technology, Faculty of Informatics, University of Debrecen, Debrecen, Hungary*

ABSTRACT
This paper structures empirical and practical implementation methodologies for clinical integration of eHealth IoT smart device technology embedded in Cloud service architecture. The results and findings of this two-year research program are summarized from mathematical, system architectural and software engineering perspective. The research takes place in the European Union, in Hungary. The program is the manifestation of the trilateral industry-university collaboration of the University of Debrecen Faculty of Informatics, T-Systems Healthcare Competence Center Central and Eastern Europe and Semmelweis University 2nd Pediatric Clinic Department of Pulmonology. The paper presents the mathematical model for the system architecture optimization. Selected system-architectural solution plans are mapped into directed graphs and converted into adjacency and availability matrices for optimization. Adequate technologies are collected and identified for the research based on industry megatrends. The experiment establishes multidirectional interoperability among eHealth smart devices, telemedicine instruments and clinical information systems. The Open Telemedicine Interoperability Hub, interoperability core module, was developed and embedded into Cloud service architecture. This module transposes and transmits the captured bio-sensory data stream from the eHealth IoT smart-devices and from the telemedicine instrument into the clinical information system. Dominant international healthcare interoperability standards are reviewed and selected for the research. The research program defined different interoperability levels and mapped these against the open systems interconnection model layers. The international interoperability standard, Health Level Seven, was selected for the research. The research explicitly tested interoperability among eHealth consumer electronic sensor-enabled smart-device, spirometer telemedicine instrument and cloud-based hospital information test system. The research proved that universal interoperability between IoT eHealth smart devices and clinical information system technology is from technical perspective absolutely possible. The paper describes the lessons learned, drawbacks and achievements of this research program. An insight is also given into the forthcoming research phase.

Keywords: Biosensor technology, eHealth, Telemedicine, Hospital information system, HL7, Internet of things.

Received: 10 November 2016/ **Revised:** 5 December 2016/ **Accepted:** 18 December 2016/ **Published:** 27 December 2016

Contribution/ Originality

The paper contributes the first logical analysis for clinical integration of the eHealth IoT technology. This study uses new determination method for mathematically optimized healthcare service architecture. The research originates new mathematic formula for healthcare systems integration. The paper's primary contribution is validating the empirical results in real clinical environment.

1. INTRODUCTION

The research is the manifestation of the trilateral cooperation of a university information technology faculty, a university clinical department and a healthcare industry partner. The information technology discipline is

† Corresponding author

represented by the University of Debrecen, Faculty of Informatics, Department of Information Technology. The Semmelweis University 2nd Pediatric Clinic Department of Pulmonology provided the medical background for the program. T-Systems Healthcare Competence Center Central and Eastern Europe delivered the hospital information system for the experiment.

University of Debrecen's predecessor college was founded in 1538. Debrecen is situated two hundred kilometers east from the capital city. The University offers tuition for 29000 students per annum in fourteen faculties. These faculties cover inter alia information technology, engineering, natural sciences, general medicine, pharmacy, dentistry, economics and law.

Semmelweis University, specialized in medicine, was founded in 1769. It is located in the capital city, Budapest. It carries out two and a half million cases and fourteen thousand one-day surgery per year, which represents a five percent domestic medical coverage. It maintains 2200 hospital beds and 10000 students enroll yearly. The faculties and departments cover all medical disciplines: internal medicine, surgery, pathology, dentistry, dermatology, immunobiology, neurology, radiology, cardiology, etc.

T-Systems Healthcare Competence Center Central and Eastern Europe Headquarters is situated in Budapest. T-Systems provides the hospital information system Medsolution. It operates in sixty hospitals in Europe and serves forty thousand users. Medsolution is fully deployed both in Semmelweis University and in the University of Debrecen. Medsolution covers inter alia full patient administration, medication, laboratory, pharmacy, catering, finance and accounting.

This experimental research takes place in Hungary. Hungary is located in Europe, and is the member of the European Union. Hungary has a population of ten million and an area of ninety three square kilometers. The country is divided into nineteen counties and the capital city, Budapest.

This experimental research program was started in 2015. The tested theoretical hypothesis is, that does such information technology solution exist, which enables the interoperation between *any* bio-sensor enabled eHealth smart device and *any* hospital information system. We specify three technology sub-domains in the program: eHealth smart device technology, telemedicine instruments technology and healthcare information system technology. If the initial hypothesis is proven to be correct, it means, that theoretically there is no unsolvable technological obstacle blocking the interconnection of all eHealth smart devices, telemedicine instruments and hospital information systems. The extension of this statement would be that theoretically all eHealth smart devices, telemedicine instruments and healthcare information systems can interoperate on a global scale. We can find similar contemporary industry megatrends, like Internet of Things. The fundamental question behind this experimental program is: can we build a global healthcare ecosystem based on the Internet of Things scheme?

2. VISION, MISSION AND GOALS

The vision of the research is that all body-sensor enabled eHealth smart devices and hospital information systems are interconnected, so they build and constitute a global healthcare ecosystem [1].

The mission statement of the research is to prove, that there is a generally applicable information technology solution for healthcare interoperability including eHealth consumer device technology [2].

The direct goal of the experiment is the successful interconnection of the eHealth smart devices, telemedicine instruments and hospital information system through a cloud-based interoperability hub.

3. METHODOLOGY

The applied methodologies are classified into three different abstraction levels [3]: mathematical, system architectural and software technology. A mathematical model was developed for optimizing the underlying service architecture. Subsequently the system architecture was built up. Then, the software solution was developed, tested and embedded in Cloud service infrastructure.

3.1. Mathematical Model for Cloud-Based Service Architecture Optimization

The following demonstration illustrates a simplified example of the application of the developed mathematical model for service architecture optimization [4]. We draft a potential service architecture candidate. Then, we number the elements [5]. The demonstrated system architecture plan (Fig. 1) illustrates a simplified extract of the research architecture. This shows that eHealth smart device is connected to a smartphone via Bluetooth connection, and the smartphone emitted the sensory data to the Open Telemedicine Interoperability Hub (OTI-Hub). Meanwhile, the telemedicine instrument transmitted the captured biosensor-information through USB to the PC-based telemedicine client, and this client forwarded this to the OTI-Hub [6]. Then, the OTI-Hub, after transformation, transmitted this information to the hospital information system (HIS) through landline Internet-connection. The results were sent from the HIS to the HIS Graphical User Interface (GUI) through WLan connection [7]. All these functions mentioned are scanned into the system architectural design displayed in Fig. 1.

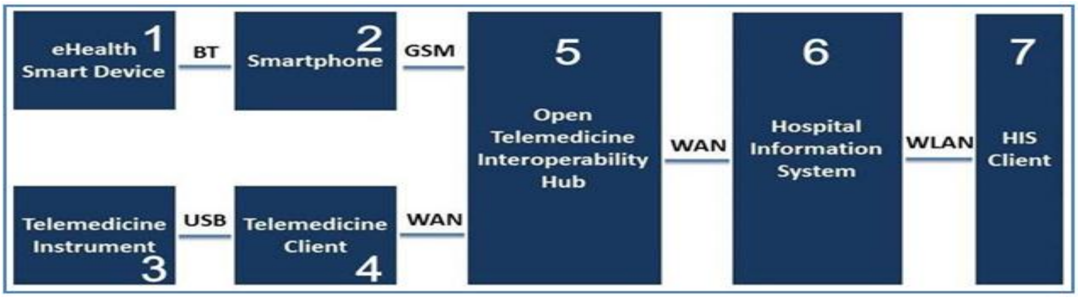

Figure-1. Simplified healthcare interoperability service architecture landscape

Source: Ábel Garai

Then, these system elements are mapped into a directed graph, as illustrated in Fig. 2:

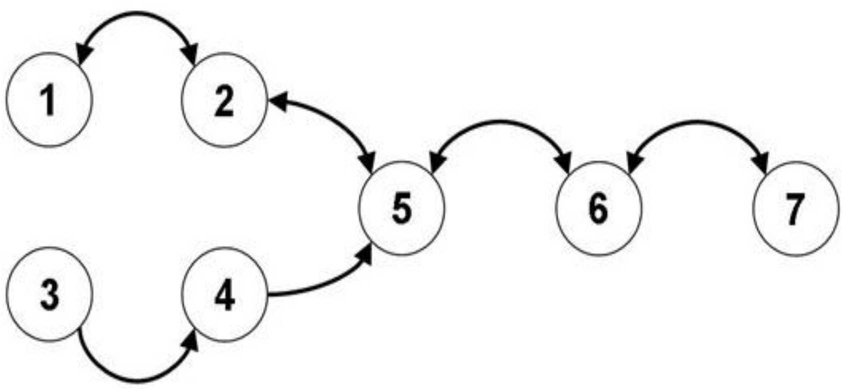

Figure-2. Directed graph describing healthcare interoperability service architecture

Source: Ábel Garai

As a third step, this directed graph is transposed into an adjacency matrix, as shown in Fig. 3:

$$C = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

Figure-3. Adjacency matrix representing healthcare interoperability service architecture

Source: Ábel Garai

As a fourth step, we apply matrix multiplication, summa and signum functions to generate the availability matrix for the system architecture, displayed in Fig. 4:

$$z = sign \sum_{n-1}^{k} C^n = \begin{pmatrix} 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 \end{pmatrix}$$

Figure-4. Availability matrix for healthcare interoperability service architecture
Source: Ábel Garai

The availability matrix shows, which service architecture elements can reach each other. This resulting availability matrix under Fig. 4. illustrates, that information from the telemedicine instrument is reachable by all other system components, through the OTI-Hub until the HIS Client. However, this matrix also shows, that data emitted from the eHealth smart device can be captured by inter alia the OTI-Hub, however it is not available for the telemedicine instrument [8]; [9]. The reason for that is, that the telemedicine instrument has only the capability of transmitting information, but it is not prepared for receiving it. The value of this methodology is that different service architecture plans can be compared to each other and the optimum can be selected among them. This method transposes the design elements into mathematically calculable matrices, so the optimal system architecture design selection is based upon numerically represented optimum.

3.2. System Architecture Development

The corner stone of the system is the central OTI-Hub (Fig. 5). This is responsible for the receipt, transformation and forward of the captured bio-sensory information. This Hub is interconnected with the eHealth smart device, telemedicine instrument and hospital information system. This is the crucial part of the overall interoperability [10]. This part should be able to receive, interpret, transform and transmit the healthcare information from and to various formats [11].

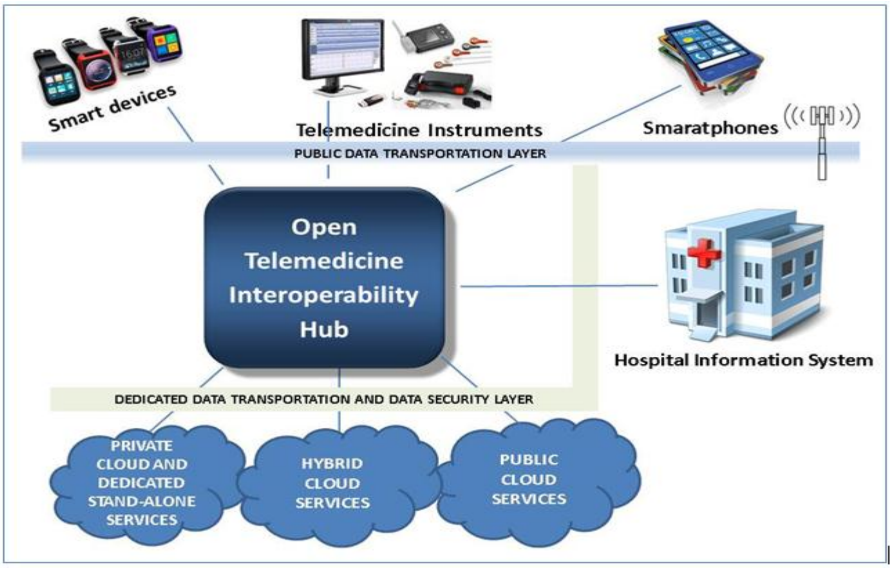

Figure-5. Open Telemedicine Interoperability Hub and system landscape
Source: Ábel Garai

The OTI-Hub interconnects the different technologies and domains: the smart device technology, the telemedicine instruments and the hospital information systems [12]; [13]. The OTI-Hub is embedded in hybrid cloud service infrastructure. As it relies upon the Cloud technology, the Hub can be theoretically hosted without geographical limitations [14]. Patient data is stored in private Cloud for the sake of data protection. Measurement data is processed by system elements embedded in public Cloud service architecture. Therefore, the OTI-Hub relies upon hybrid Cloud architecture.

3.3. Software Development and Testing

The software development was undertaken in Microsoft Visual Studio in C++ programming language [15]. The developed OTI-Hub was embedded in Microsoft Azure Cloud service [16]. The basis for the development was the Application Programming Interface (API) of the healthcare smart device, Microsoft Band 2. A software component of the OTI-Hub was deployed on a Windows cell phone. The component integration tests ran separately for the eHealth smart device, telemedicine instrument and for the hospital information system. No overall system integration test was carried out, as the research phases were separated in time.

The internal design of the OTI-Hub is demonstrated in Fig. 6. There are different input and output interfaces enabling the flawless communication of the interconnected system landscapes [17]; [18]. The Hub is connected to the eHealth smart devices (and telemedicine instruments), external hospital information systems, other external systems and web clients. Internally the Hub consists of relational database management systems, application server, web- and communication-servers. The application server is responsible for the program logic. The web-server delivers the output screens for the web clients. The communicational server controls the data-exchange with all other systems. The relational database management systems (RDBMS) store patient and measurement data.

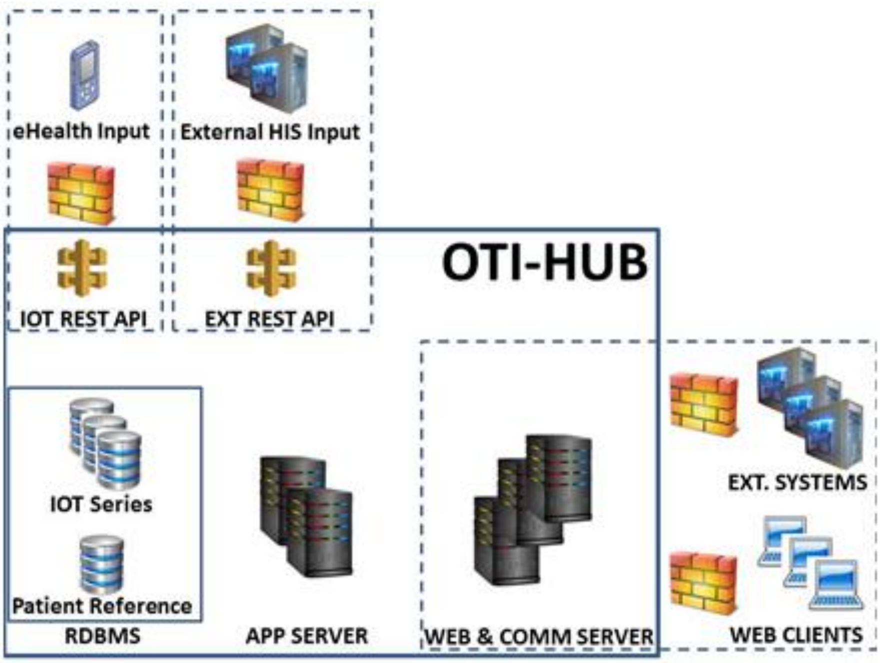

Figure-6. Open Telemedicine Interoperability Hub internal design
Source: Ábel Garai

4. DISCUSSION

Beside the technical factors we also considered the logical basis for the tested healthcare interoperability. The Health Level Seven (HL7) international healthcare interoperability standard was selected for the research [19]; [20]. It represents the most widely available interoperability standard by the healthcare institutions. Within the HL7 standard family the HL7 v2 was selected for the research, because it is the most widely spread version of this standard family [21]. A representative sample of leading scientific journals was reviewed for the selection of the HL7 v2 standard. This standard applies comma separated values files (CSV files) [22]. Each field is delimited by the special pipe character, as seen in Fig. 7. This is the technical representation of healthcare patient information.

```
MSH|^~\&|PXP||||20160802095510||ORU^R01|20160802095510|P|2.3.1|||NE|AL|HUN|
PID||65488965|18||Patient^Anonymised^^^Mr.||19870513|F||||||||||||||||
OBR|1||20160802094856^PXP|94011|||20160802094856||||||||||||||2016080209485
OBX|1|ST|0^FVC^99MKW||3,29|1|3,75||||F
OBX|2|ST|2^FEV*0.5^99MKW||1,04|1|||||F
OBX|3|ST|3^FEV*1.0^99MKW||1,57|1|3,27||||F
OBX|4|ST|5^FEV*0.5/FVC^99MKW||31,70|%|||||F
```

Figure-7. HL7 medical interface file

Source: Ábel Garai

During the research program clinical spirometer, as telemedicine instrument, was calibrated and connected to the factory software on its dedicated test laptop (Fig. 8). Spirometer is applied inter alia for asthma diagnosis [23]. The sensory information from the spirometer was transmitted to the factory-program and transformed to HL7 v2.3 interface file. Then, this file was sent to the OTI-Hub. The OTI-Hub transferred it to the hospital information system. The result was checked by the hospital information graphical user interface.

Figure-8. Clinical spirometer PDD-30/sh

Source: Ábel Garai

Thanks to the clinical research partner, the transposed and transmitted spirometry information was validated in the clinic's pulmonology department. The spirometry test is applied on a daily basis, and the extended system availability is a critical success factor for delivering this healthcare service for the increasing number of patients. There were dedicated tablets connected into the clinic's Wlan system with the necessary hospital information system licenses, so the doctors and nurses can assess the patient result queries and patient information also in a remote location. The eHealth smart device technology was represented by the Microsoft Band 2 in the research. This device has several body-sensors. One of these sensors measures the owner's heart rate. The device emits this pulse value in every second. This device was connected to a Windows cell phone via Bluetooth connection. Then the cell phone transmitted the captured pulse values to the Cloud-based OTI-Hub. The Hub saved, transformed and calculated hourly average pulse value, and then sent this aggregated information to the hospital information system in HL7 format. There were also other smart devices tested during the experiment. However, there are unfortunately numerous smart eHealth devices on the market with unstructured or undocumented external interface. It means, that they can communicate only with their own smartphone-app, however they do not offer accessibility to the captured sensory data. The result is that such devices cannot be connected to our research system architecture. Having several smart bracelets tested, we found the Microsoft Band fulfilling our research criteria. It offered structured and documented output with the corresponding Application Programming Interface (API) [24]; [25]. This helped the research to represent the eHealth smart device technology through this consumer electronic device (Fig. 9).

Figure-9. Microsoft Band 2

Source: Ábel Garai

5. RESULTS

During the research we tested the data exchange among eHealth consumer electronic technology, telemedicine instrument and hospital information system equipped with standard input through the OTI-Hub. The conducted these test phases separately. First we tested the telemedicine-HIS channel, and then the eHealth device-HIS channel. The test was successful regarding the telemedicine instrument data transmission. However, the eHealth smart device sensory information required stable and continuous internet connection, which is very unlikely in real conditions. Notwithstanding that this test phase was also successful, for real-world deployment the corresponding data transmission module of the OTI-Hub should be adjusted or rebuilt. The applied Cloud service proved to be stable after thorough configuration. Overall, each different test phases was successful, however an overall system test is also required in the future.

6. CONCLUSION AND RECOMMENDATION

This research program concluded that interoperability among eHealth smart device technology, telemedicine instruments and hospital information systems is possible. As the experiment relied upon a software solution embedded in Cloud architecture, this interoperability prototype theoretically can be extended without geographical limitations. All the applied eHealth smart device and telemedicine technology represents internationally standardized technology elements. The research's central interoperability modul (OTI-Hub) also applies standard methodologies and techniques. This module is hosted by internationally available Cloud service. As a result, the demonstrated and tested solution can be deployed wherever these technologies are available.

The research also demonstrated a prototype, where both data sources (eHealth smart devices and telemedicine instruments) and hospital information system graphical user interfaces are operating on mobile devices. Therefore, this interoperability solution can be applied for telemedicine and telecare solutions in general.

Based on the experiences through the research, it is recommended, that eHealth smart device manufacturers develop and apply industry-wide open standard formats. On the other hand, industry-leading healthcare standard development bodies, like Health Level Seven, should extend their standards for the emerging body-sensory devices.

The forthcoming research phase will simulate and test duplex data transmission, for example, when data is sent and received from an eHealth smart device at the same time.

Funding: This study received no specific financial support.

Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

REFERENCES

[1] B. Fong, A. C. M. Fong, and C. K. Li, *Telemedicine technologies: Information technologies in medicine and telehealth*. Chichester: Wiley, 2011.

[2] U. Varshney, "Pervasive healthcare and wireless health monitoring," *Mobile Networks and Applications Springer US, New York*, vol. 12, pp. 113-127, 2007.

[3] R. J. Rossi, *Applied biostatistics for the health sciences*. Hoboken, NJ: Wiley, 2010.

[4] L. Martinez and C. Gomez, *Telemedicine in the 21st century. Applied biostatistics for the health sciences*. New York: Nova Science Publishers, 2008.

[5] R. L. Bashshur and G. W. Shannon, *History of telemedicine: Evolution, context, and transtiormation*. New Rochelle, NY: Mary Ann Liebert, 2009.

[6] H. Eren and J. G. Webster, *The E-medicine, E-health, M-health, telemedicine, and telehealth handbook*. Oakville: CRC Press, 2015.

[7] P. Baranyi, A. Csapo, and G. Sallai, *Cognitive infocommunications (CogInfoCom)* vol. 1. New York: Springer International, 2015.

[8] T. J. Hajdu, Z. Pistar, B. Domokos, and Z. Török, "An ensemble-based collaborative framework to support customized user needs," presented at the 3rd IEEE International Conference on Cognitive Infocommunications (CogInfoCom 2012), Kosice, Slovakia, 2012.

[9] B. Péter and C. Ádám, "Definition and synergies of cognitive infocommunications," *Acta Polytechnica Hungarica*, vol. 9, pp. 67-83, 2012.

[10] S. Gyula, "Chapters of future internet research," presented at the IEEE 4th International Conference on Cognitive Infocommunications (CogInfoCom), Budapest, 2013.

[11] H. Marjo, P. Sakari, D. J. Sikke, and E. Christian, "Experimenting industrial Internet with a mobile robot: Expanding human cognitive functions," presented at the IEEE 6th International Conference on Cognitive Infocommunications (CogInfoCom), Győr, 2015.

[12] H. Toman, L. Kovacs, A. Jonas, L. Hajdu, and A. Hajdu, "Generalized weighted majority voting with an application to algorithms having spatial output," presented at the 7 th Int. Conf. on Hybrid Artificial Intelligence Systems (HAIS 2012), Lecture Notes in Computer Science, 2012.

[13] R. Szabo, K. Farkas, M. Ispány, A. Benczur, L. Kollar, and A. Adamkó, "Framework for smart city applications based on participatory sensing," presented at the Cognitive Infocommunications (CogInfoCom) IEEE 4th International Conference on, IEEE, 2013.

[14] K. Mahmud and J. Lenz, "The personal telemedicine system. A new tool for the delivery of health care," *Journal of Telemedicine and Telecare*, vol. 1, pp. 173–177, 1995.

[15] R. Wootton, "Telemedicine in the national health service," *Journal of the Royal Society of Medicine*, vol. 91, pp. 289–292, 1998.

[16] G. Singh, J. O'Donoghue, and C. K. Soon, "T telemedicine: Issues and implications," *Technology Health Care*, vol. 10, pp. 1-10, 2002.

[17] I. M. Llorente, R. S. Montero, E. Huedo, and K. Leal, "A grid infrastructure for utility computing," in *Proceedings of the 15th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises*, 2006.

[18] H. H. Asada, P. Shaltis, A. Reisner, R. Sokwoo, and R. C. Hutchinson, "Mobile monitoring with wearable photoplethysmographic biosensors," *In Engineering in Medicine and Biology Magazine, IEEE*, 2003.

[19] S. Tr, M. As, and A. Mh, "An ad hoc wireless sensor network for telemedicine applications," *Arabian Journal for Science and Engineering*, vol. 32, pp. 131-143, 2007.

[20] Y. Xiao, Y. Tao, and Q. Li, "A new wireless web access mode based on cloud computing," presented at the Computational Intelligence and Industrial Application, 2008. PACIIA '08. Pacific-Asia Workshop, 2008.

[21] U. Varshney, "Pervasive healthcare and wireless health monitoring," *Mobile Networks and Applications, New York*, vol. 12, pp. 113-127, 2007.

[22] A. Attila, A. Mátyás, F. Gábor, and J. István, "Performance evaluation of large-scale data processing systems," in *Proceedings of the 7th International Conference on Applied Informatics, Eger, Hungary*, 2007, pp. 295–301.

[23] A. Attila and K. Lajos, "MDA-based development of data-driven web applications," in *Proceedings of the Fourth International Conference on Web Information Systems and Technologies, Volume 1, Funchal, Madeira, Portugal*, 2008, pp. 252-255.

[24] A. Attila, G. Ábel, and P. István, "Adaptive services with cloud architecture for telemedicine," presented at the Cognitive Infocommunications (CogInfoCom), 6th IEEE Conference, 2015.

[25] G. Ábel, "Methodology for assessment validation of platform migration of roboust critical IT-systems," presented at the ICAI 2010, 8th International Conference on Applied Informatics, 2010.