Context-Aware Medical Content Adaptation through Semantic Representation and Rules Evaluation

Charalampos Doukas[1], Ilias Maglogiannis[1,2], Kostas Karpouzis[3]
[1]University of the Aegean Dept. Of Information & Communication Systems Engineering, Greece
[2]University of Central Greece, Department of Biomedical Informatics Lamia, Greece
[3]Image, Video and Multimedia Systems Lab, National Technical University of Athens, Greece
{doukas, imaglo}@aegean.gr; kkarpou@cs.ntua.gr

Abstract

Proper coding and transmission of medical and physiological data is a crucial issue for the effective deployment and performance of telemedicine services. The paper presents a platform for performing proper medical content adaptation based on context awareness. Sensors are used in order to determine the status of a patient being monitored through a medical network. Additional contextual information regarding the patient's environment (e.g., location, data transmission device and underlying network conditions, etc.) are represented through an ontological knowledge base model. Rule-based evaluation determines proper content (i.e., biosignals, medical video and audio) coding and transmission of medical data, in order to optimize the telemedicine process. The paper discusses the design of the ontological model and provides an initial assessment.

1. Introduction

A number of telemedicine applications exist nowadays, providing remote medical action systems (e.g., remote surgery systems), patient remote telemonitoring facilities (e.g., homecare of chronic disease patients), and transmission of medical content for remote assessment ([1]-[5]). Such platforms have been proved significant tools for the optimization of patient treatment offering better possibilities for managing chronic care, controlling health delivery costs and increasing quality of life and quality of health services in underserved populations. Collaborative applications that allow the exchange of medical content (e.g., a patient health record) between medical experts for educational purposes or for assessment assistance are also considered of great significance ([6]-[8]). Due to the remote locations of the involved actuators, a network infrastructure (wired and/or wireless) is needed to enable the transmission of the medical data. The majority of the latter data is usually medical images and/or medical video related to the patient. Thus, telemedicine systems cannot always perform in a successful and efficient manner; Issues, like large data volumes (e.g., video sequences or high quality medical images), unnecessary data transmission occurrence and limited network resources can cause inefficient usage of such systems ([9], [10]). In addition, wired and/or wireless network infrastructures often fail to deliver the required quality of service (e.g., bandwidth requirements, minimum delay and jitter requirements) due to network congestion and/or limited network resources. Appropriate content coding techniques (e.g., video and image compression) have been introduced in order to assess such issues ([11]-[13]), however the latter are highly associated to specific content type and cannot be applied in general. Additionally, they do not consider the underlying network status for appropriate coding and still cannot resolve the case of unnecessary data transmission.

Scalable coding and context-aware medical networks can overcome the aforementioned issues, through performing appropriate content adaptation. This paper presents a context aware medical content adaptation platform that utilizes semantic representation of the content and the context. Using proper reasoning techniques, content adaptation is performed; medical image and video transmission only when determined necessary and encode the transmitted data properly according to the network availability and quality, the user preferences and the patient status. The framework's architecture is open and does not depend on the monitoring applications used, the underlying networks or any other issues regarding the telemedicine system used. The rest of the paper is organized as

978-0-7695-3444-2/08 $25.00 © 2008 IEEE
DOI 10.1109/SMAP.2008.37

follows: Section 2 discusses the notion of context awareness in telemedicine platforms and Section 3 presents the semantic representation of the context. Section 4 describes content adaptation techniques and Section 5 provides information regarding the reasoning scheme based on semantic rules for the content adaptation decision. Section 6 presents the proposed platform architecture and Section 7 concludes the paper.

2. Enabling Context Awareness

Context awareness refers to the ability of systems to react based on their environment. Devices and computer systems may have information about the circumstances under which they are able to operate and based on rules, or an intelligent stimulus, react accordingly. The term context-awareness in ubiquitous computing was introduced by Schilit [14], [15]. Context aware devices may also try to make assumptions about the user's current situation. Dey (2001) define context as "any information that can be used to characterize the situation of entities." [16].
In the domain of patient remote care context awareness refers to detection of patient status and appropriate adaptation of the medical services according to the latter status and environmental conditions.

2.1 Patient Status Awareness

Patient status awareness can be achieved by continuously monitoring the patient state through collecting information either directly related to the individual's health (e.g., biosignals like heart rate, temperature, blood oximetry, etc.) or information that can be processed and indicate emergency cases (e.g., detection of fall events, call for help, etc.). The latter information is usually collected by equipment installed on the patient or on his/her surrounding environment and is transmitted to monitoring units. Proper processing and classification follows in order to detect the patient status from the data.

Data Collection

The data acquisition is usually performed either through sensor devices placed on user's body or monitoring devices at the user's environment. The first collect biosignals, sounds, and/or movement related data, whereas the latter capture and process audiovisual content and generate estimation for events like patient falling, abnormal movement, distress situations like fire, etc. [17], [18], [19]. Previous works [20], [21] present overviews of such system and a prototype platform for detecting fall incidents and distress situation based on user motion and sound data. Sensor devices illustrated in Figure 1. have been used for data collection and transmission to the monitoring unit.

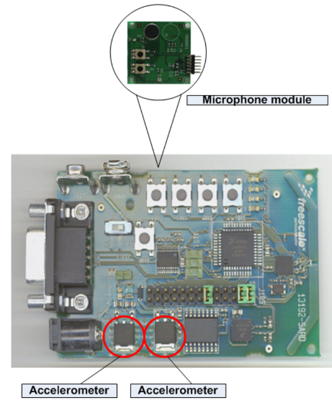

Figure 1. On-body sensor node for collection sound and movement data from the user. It can be utilized for detecting fall events and other distress situations [20], [21].

Data Processing and Classification

The collected data contain information regarding the user's physiological status (in case of biosignals), potential distress situations (e.g., falls in case of movement data) and general information that can be correlated with the patient state. The data need further processing upon collection until the latter information can be acquired. Proper filtering might be required in order to remove irrelevant data like noise (e.g., in case of movement or sound data). In some cases patient state can be determined by applying simple value thresholds (e.g., in case of body temperature or heart rate) but in cases motion detection and interpretation advanced data classification techniques might be required. In [22] an overview of classification algorithms is presented that can be applied on movement and sound data collected by on-body sensors for patient fall event detection.

2.2 User Environment Context Awareness

Apart from determining the patient status, context aware medical treatment and monitoring systems must incorporate information related to user's environment. More specifically:

User's indoor or outdoor location can be determined by external devices (i.e. GPS, mobile or WLAN phones) and facilitate the process of ambulatory dispatching in case of emergency events. Based on location, proper proactive or reactive data transmission

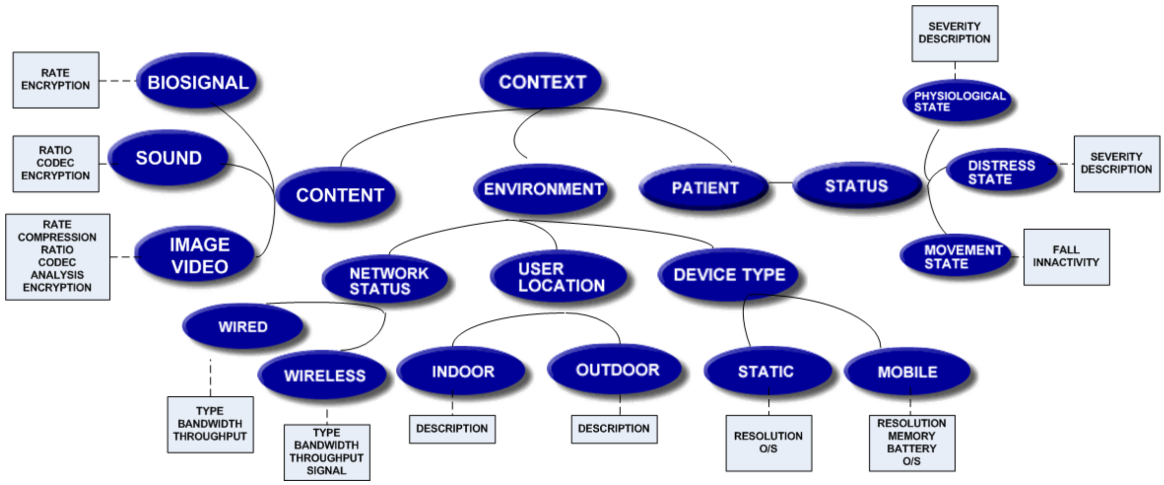

Figure 2. Illustration of the semantic representation of the context aware data adaptation system using an ontological structure. Major component and actuator classes are illustrated among with most important features for each class.

may also be performed. Information regarding the communication equipment used (e.g., laptop computer, mobile phone or PDA) can facilitate the content adaptation in case of video communication.

Transmission capabilities of the underlying networking infrastructures (e.g., network interface type used, allocated bandwidth, real time network traffic information, etc.) can affect the communication and thus facilitate the determination of proper content adaptation like application of compression schemes.

More information regarding context-aware medical networks and telemedicine services can be found at [23].

3. Context Semantic Representation

In order to semantically represent the context aware system and the content adaptation the ontology illustrated in Figure 2 has been developed. Both the patient-related context and content have been modeled. More specifically: regarding the medical content, a representative class with three subclasses has been created. Each subclass represents image and video medical data, audio data and biosignals respectively. Most important features for the proper content adaptation are the transmission data rate, type of encryption used (e.g., PKI [24], simple symmetric, or none), compression ratio (in case of scalable compression), codec used (e.g., H.264 for video, JPEG2000 for images and ITU G.723 for audio), and analysis (specifically for images and video according to the network status and the presentation device). The patient status is characterized according to physiological state, distress state (i.e. more generic from the latter containing status indications based on vocal and sound analysis), and movement state (e.g., detection of falls or long periods of inactivity). The basic attributes for the aforementioned states are the severity of the status (e.g., numerical representation of the emergency severity level), description of the incident and indication of fall or long inactivity status. A patient environment-related class has also been developed for representing the status of the underlying network infrastructures, the user location and the device types that are used for data collection, transmission. Concerning the network status, wired or wireless interfaces can be used. For both interfaces, the type of the medium, the total available bandwidth and the current throughput can affect the data transmission and thus content adaptation, whereas in the case of wireless interface the received signal strength might also be an important factor for the content adaptation. User location has been categorized into indoor and outdoor with a simple description as a respective attribute. Finally, the class “Device Type” refers to the transmission device the patient/user operates for communicating with the treatment/monitoring units. In case of static devices (e.g. PCs) the operating system and the screen resolution might determine content like the video analysis, and frame rate, whereas in case of mobile devices (e.g, mobile phones, PDAs, etc.) memory and power resources can also affect the transmission and presentation of the medical content respectively.

The ontological model has been developed within the Protégé [29] semantic framework using the Ontology Web Language (OWL). The main advantages of the semantic representation of the context aware adaptive system can be summarized into the following:

- Flexibility to modify and extend the contextual scheme by adding more classes. In case the parameters that define the context of the patient (e.g.., status, environment, location, etc.) need to be modified, the ontological model can be altered without invoking modifications to the implementation modules or the architecture of the platform.
- Better and more flexible evaluation of the context facilitating the decisions for the medical content adaptation. Using advanced semantic rule evaluation techniques (to be discussed in Section 5) content adaptation decisions can be made according to a plethora of contextual parameters. The rules can be updated and extended without any need for system platform software modifications.

Additionally, ontologies are explicit because define the concepts, properties, relationships, functions, axioms and constraints that compose the contextual model. They are formal because they are machine readable and interpreted.

4. Content Adaptation

Content adaptation refers to proper medical data coding and proactive or reactive transmission for achieving better utilization of network and system resources during the monitoring and treatment process. The most demanding data in terms of network and system resources for transmission and processing are the medical and audiovisual data. Additionally, content adaptation can also include different data encryption schemes that can be applied according to data sensitivity and severity of an emergency incident.

Image and Video/Audio Coding

The coding of medical image and audiovisual data refers to data compression. According to the patient status and underlying network interfaces and conditions, several compression schemes can be applied; for instance, uncompressed data can be transmitted in case of a fast wired network connection, whereas higher compression schemes can be applied when using wireless connections with lower data rate availability. In case of visual assessment it might be important to maintain particular parts of the image/video of visual context at higher quality and increase the compression on less diagnostic important regions. Examples of special region of interest (ROI) coding with scalable compression can be found at [25], [26] for both medical image and video data.

Adapted Data encryption

Several data encryption schemes can be applied for providing medical content privacy, confidentiality, non repudiation and encryption. According to the sensitivity of the data and the severity of the case, simple symmetrical encryption schemes [27] to more complex public key infrastructures can be applied [28]. The platform decides according to specific context parameters, which data encryption methodology will be utilized prior to transmission. For instance in case of an emergency incident in an area where only low-bandwidth networks are available, the platform skips the encryption process.

Reactive Data Transmission

Unnecessary transmission of medical data or monitoring data (e.g., video from user's environment) can be avoided by using reactive data transmission. In case of normal patient state, data related to the patient context and status (e.g., visual data and biosignals) can be transmitted to monitoring units proactively in specified time intervals. In case of a detected distress situation, reactive transmission can begin. More information on data transmission based on context awareness can be found in [23].

5. Content Adaptation based on Semantic Rules evaluation

In order to perform the appropriate medical content adaptation that has been discussed in the previous sections, several semantic rules have been defined. These rules concern features of the ontological class that represents the context aware model semantically. By performing proper evaluation of the latter, decision regarding the content adaptation can be made.

The creation of semantic rules required the description of the latter through abstract semantic languages like the Semantic Web Rule Language (SWRL) [30]. Within this context, the SWRL Factory [29] mechanism and an integrated Jess rule engine [31] using the Protégé tool have been utilized. Jess provides both an interactive command line interface and a Java-based API to its rule engine. This engine can be embedded in Java applications and provides a flexible two-way run-time communication between Jess rules and Java. The Jess system consists of a rule base, a fact base, and an execution engine.

Two indicative sample SWRL rules follow that can be used within the presented framework in order to facilitate the decision on the content adaptation based on patient's context parameters:

```
Patient(?x)  ^ PhysiologicalState(?y)  ^
hasSeverity(?x,?y, ?severity) ^
hasDescription(?y,?description)^
Biosignal(?BS) ^ BiosignalRate(?Rate)^
swrlb:otherThan(?severity,?Normal) ->
DefineTransmissionRate(?Rate,"100kbps")
^ StartTransmission("true")
```

```
Patient(?x)  ^  MovementState(?move)  ^
FallDetected(?x,?move) ^
hasDescription(?move,?description)^
UserLocation(?Location)                ^
VideoRate(?Rate)^NetworkStatus(?Wired)^
swrlb:equals(?move,"Fall")^swrlb:equals
(?Location,
"Indoor")^swrlb:equals(?Wired,   "true")
->
DefineVideoRate(?Rate,"300kbps")^
StartTransmission("true")
```

The first rule examines the physiological state of the patient as characterized by the status awareness modules in terms of status severity. If the latter is considered to be other than "Normal" then transmission of the collected biosignals to the monitoring units begins at a specific data rate. The second rule is more advanced and takes into consideration potential indication of a fall event, the location of the user and the network status. According to the rule, video transmission of the patient's premises will begin in case a fall has been detected. High transmission rate will be used if the user is located indoor and a wired network infrastructure is used.

6. Proposed Architecture Scheme

This Section presents the proposed architecture scheme that incorporates modules that feature the discussed aspects of context awareness and medical content adaptation. The interconnection and communication of the different components can be illustrated as five different application layers (see Figure 3). Initial data acquisition from the sensor and monitoring devices is followed by proper processing for feature extraction. The context awareness is performed by classifying the generated features and utilizing semantic evaluation of the latter. Application of semantic rules facilitates the determination of patient status and detection of emergency events.
According to the detected patient status and additional contextual information regarding the patient's environment and underlying network conditions, proper content adaptation to the medical data is performed. The content related to incident is coded (i.e. compressed and encrypted) accordingly and transmitted to the monitoring units.

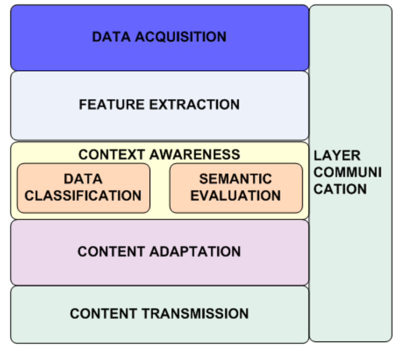

Figure 3. Illustration of the incorporated application layers for context awareness and content adaptation and transmission.

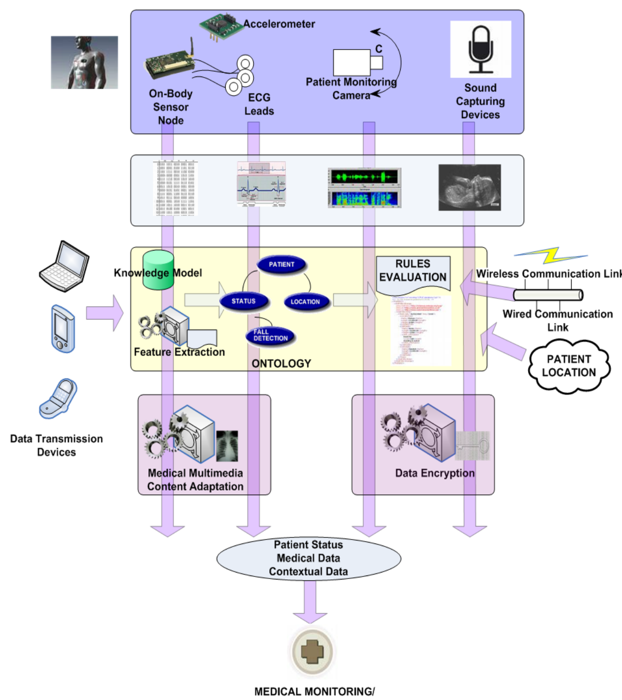

Figure 4. The proposed architecture that incorporates modules and components for proper medical content adaptation based on context awareness.

Figure 4 illustrates a proposed architecture scheme for interconnected all the involved components for enabling context awareness and proper content coding.

7. Conclusions

A context-aware medical content adaptation platform has been presented. The platform utilizes sensor data for determining the patient status and takes into account additional contextual information like underlying network conditions, and data transmission devices. A semantic representation for the patient context has been developed and appropriate rule-based system is used in order to perform proper medical content adaptation according to the context, facilitating and improving the diagnosis and treatment process.
Future work might include the deployment of the proposed platform in a real remote treatment and monitoring environment for assessing the actual contribution of context awareness and content adaptation to the remote medical care process.

Acknowledgement: This work has been partly funded by the EU via the CALLAS Integrated Project (contract number 034800, www.callas-newmedia.eu).

8. References

[1] Lin J. C., "Applying telecommunication technology to health care delivery", *IEEE Engineering in Medicine and Biology Magazine*, vol. 4, pp. 28-31, 1999

[2] Pavlopoulos, S., Kyriacou, E., Berler, A., Dembeyiotis, S., Koutsouris, D, "A novel emergency telemedicine system based on wireless communication technology-AMBULANCE", *IEEE Transactions on Information Technology in Biomedicine*, vol. 4, pp. 261-267, 1998

[3] Deb, S., Ghoshal, S., Malepati, V.N., Kleinman, D.L., "Tele-diagnosis: remote monitoring of large-scale systems", in Proc. of *IEEE Aerospace Conference*, 2000, pp: 31-42.

[4] Choi, Y.B.; Krause, J.S.,H. Seo, C., K.E., K. Chung,, "Telemedicine in the USA: standardization through information management and technical applications", *IEEE Communications Magazine*, vol. 44, pp. 41-18, April 2006

[5] Pattichis, C.S., Kyriacou, E., Voskarides, S., Pattichis, M.S., Istepanian, R., Schizas, C.N., "Wireless telemedicine systems: an overview", *IEEE Antennas and Propagation Magazine*, vol. 44, pp. 143-153, April 2002

[6] Aakay M., Marsic I., Medl, A., Guangming Bu , "A system for medical consultation and education using multimodal human/machine communication", *IEEE Transactions on Information Technology in Biomedicine*, vol.2, (4), pp. 282-291, Dec. 1998.

[7] Zhou J., Shen, X., Georganas N.D., "Haptic tele-surgery simulation", in Proc. of the 3rd *IEEE International Workshop on Haptic, Audio and Visual Environments and their Applications*, pp. 99-104, Oct. 2004.

[8] Fontelo P., DiNino E., Johansen K., Khan A., Ackerman M., "Virtual Microscopy: Potential Applications in Medical Education and Telemedicine in Countries with Developing Economies" , in Proc. of the *38th Annual Hawaii International Conference on System Sciences*, pp. 153, Jan. 2005.

[9] Lage A.-L., Martins J., Oliveira J., Cunha, W., "A quality of service approach for managing tele-medicine multimedia applications requirements", in Proc. *of IEEE Workshop on IP Operations and Management*, 2004, pp. 186-190.

[10] LeRouge C., Garfield M.J. Hevner, A.R., "Quality attributes in telemedicine video conferencing", In Proc. of *35th Annual Hawaii International Conference on System Sciences*, 2002, pp. 2050-2059.

[11] Hongtao Yu, Zhiping Lin, Feng Pan, "Applications and improvement of H.264 in medical video compression", *IEEE Transactions on Circuits and Systems*, vol. 52, (12), pp. 2707-2716, Dec. 2005.

[12] Bernabe G., Gonzalez, J., Garcia J.M., Duato J., "A new lossy 3-D wavelet transform for high-quality compression of medical video", in Proc. of *IEEE EMBS International Conference on Information Technology Applications in Biomedicine*, pp. 226-231, Nov. 2000.

[13] C. N. Doukas, I. Maglogiannis, G. Kormentzas, "Medical Image Compression using Wavelet Transform on Mobile Devices with ROI coding support", In Proc. of the *27th Annual International Conference of the IEEE EMBS*, Shanghai, China, 2005.

[14] B. Schilit, N. Adams, and R. Want. (1994). "Context-aware computing applications". *IEEE Workshop on Mobile Computing Systems and Applications* (WMCSA'94), Santa Cruz, CA, US: 89-101.

[15] Schilit, B.N. and Theimer, M.M. (1994). "Disseminating Active Map Information to Mobile Hosts". *IEEE Network* 8 (5): 22–32.

[16] A. Dey, Anind K. (2001). "Understanding and Using Context". *Personal Ubiquitous Computing* 5 (1): 4–7.

[17] Shuangquan Wang, Jie Yang, Ningjiang Chen, Xin Chen, Qinfeng Zhang, "Human activity recognition with user-free accelerometers in the sensor networks", In Proc. of *International Conference on Neural Networks and Brain*, pp. 1212-1217, Oct. 2005.

[18] S.-G. Miaou, Pei-Hsu Sung, Chia-Yuan Huang, "A Customized Human Fall Detection System Using Omni-Camera Images and Personal Information", In Proc. of *1st Transdisciplinary conference on Distributed Diagnosis and Home Healthcare*, pp. 39-42, 2006.

[19] Istrate D., Castelli E., Vacher M., Besacier L., Serignat J.-F., "Information extraction from sound for medical telemonitoring", *IEEE Transaction on Information Theory in Biomedicine*, vol. 10, 2, pp. 264-274, April 2006.

[20] Charalampos Doukas, Ilias Maglogiannis, "Enabling Human Status Awareness in Assistive Environments based on Advanced Sound and Motion Data Classification", presented at *The 1st ACM International Conference on PErvasive Technologies Related to Assistive Environments* (PETRAE), July 16-19 2008, Athens, Greece.

[21] Charalampos Doukas, Ilias Maglogiannis, "Advanced Patient or Elder Fall Detection based on Movement and Sound Data", presented at *2nd International Conference on Pervasive Computing Technologies for Healthcare* 2008.

[22] Charalampos Doukas, Ilias Maglogiannis, "Human Distress Sound Analysis and Characterization using Advanced Classification Techniques", to be presented at *5th Hellenic Conference on Artificial Intelligence*, 2-4 October 2008, Syros, Greece.

[23] Charalampos Doukas, Ilias Maglogiannis, George Kormentzas, "Advanced Telemedicine Services through Context-aware Medical Networks", In Proceedings of the *IEEE EMBS cosponsored International Special Topic Conference on Information Technology in Biomedicine* (ITAB 2006), Ioannina-Epirus, Greece, October 26-28, 2006

[24] Public Key Infrastructure, online information at http://www.ietf.org/html.charters/pkix-charter.html

[25] I. Maglogiannis, C. Doukas, G. Kormentzas, T. Pliakas, "Optimized Mobile Access to DICOM Images using Wavelet compression with ROI coding support", to appear in *IEEE Transactions on Information Technology in Biomedicine*.

[26] Charalampos Doukas, Ilias Maglogiannis, "Adaptive Transmission of Medical Image and Video using Scalable Coding and Context-aware Wireless Medical Networks", in *EURASIP Journal on Wireless Communications and Networking*, vol. 2008, Article ID 428397, 12 pages, 2008. doi:10.1155/2008/428397.

[27] Lambros Makris, Nikolaos Argiriou, Michael G. Strintzis, "Network and data security design for telemedicine applications", *Informatics for Health and Social Care*, Volume 22, Issue 2 April 1997 , pages 133 – 142

[28] Shu-Di Bao, Lian-Feng Shen, Yuan-Ting Zhang , "A novel key distribution of body area networks for telemedicine", In Proc. of 2004 *IEEE International Workshop on Biomedical Circuits and Systems*, Dec. 2004, pp. 1-17-20a.

[29] Protégé Ontology Editor and Knowledge Base Framework, more information available at http://protege.stanford.edu/

[30] The Semantic Web Rule Language definition, http://www.w3.org/Submission/SWRL/

[31] The Jess Rule Engine, http://www.jessrules.com/jess/index.shtml