e-Health – For Continuity of Care
C. Lovis et al. (Eds.)

doi:10.3233/978-1-61499-432-9-206

A perspective of adaptation in healthcare

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Abstract. Emerging new technologies in healthcare has proven great promises for managing patient care. In recent years, the evolution of Information and Communication Technologies pushes many research studies to think about treatment plan adaptation in this area. The main goal is to accelerate the decision making by dynamically generating new treatment due to unexpected situations. This paper portrays the treatment adaptation from a new perspective inspired from the human nervous system named autonomic computing. Thus, the selected potential studies are classified according to the maturity levels of this paradigm. To guarantee optimal and accurate treatment adaptation, challenges related to medical knowledge and data are identified and future directions to be explored in healthcare systems are discussed.

Keywords. Treatment adaptation, personalized decision, autonomic computing, challenges

Introduction

Clinical Decision Support Systems (CDSS) [1] have shown great efficiency in managing patients' health and providing personalized treatment based on Information and Communication Technologies (ICT). The main goal of CDSS is to assess clinical staff to take the right decision by providing relevant information about patients and clinical knowledge to enhance patient care. The development of CDSS [2] may focus on monitoring (provide what is true about a patient including the treatment history and patient profile), diagnosing patient health (decide which disease the patient has), and generating clinical recommendations (define the appropriate treatment based on patient profile). However, generating personalized treatment requires taking into consideration both patient conditions and environment factors that influence response to therapy. To provide the appropriate treatment plan and to avoid health complications, new mechanisms that dynamically monitor, detect unexpected situations and adapt the current treatment are required.

In this paper, we analyse the different approaches dealing with treatment adaptation and personalization in medicine. We classify existing approaches relative to the autonomic computing maturity levels [3,4]. The autonomic computing (AC) is a paradigm introduced by IBM in 2001. Inspired by the human nervous system, an autonomic system is able to continuously monitor and control the managed elements in order to handle events that may be analysed as requirements for adaptation. Thus, by

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mapping this definition in the healthcare domain, the patient treatment adaptation refers to the ability to dynamically predict and/or detect unexpected situations (e.g. treatment execution failure, environment changes, etc.) and to adjust or modify the current personalized treatment plan (managed element) according to the patient profile.

Following that, we detail the classification based on the autonomic computing. Then, we outline the trends and challenges of patient treatment adaptation. Finally, we discuss how our research directions can cope with some of these challenges.

1. Methods

We reviewed studies published between 2005 and 2013 by addressing the fields of treatment adaptation and clinical decision support. We searched scientific publications in *Pubmed*, *IEEE*, *ACM*, *ScienceDirect* and *Springer* libraries using different combinations of the following keywords: *"context aware, treatment personalization/adaptation, clinical pathway, decision making, automated recommendations, knowledge-based clinical decision support system, and challenges in CDSS"*. We selected publications from a restricted number of journals from the biomedical domain such as *Journal of Biomedical Informatics*, *IEEE Transactions on Information Technology in Biomedicine*, *Artificial Intelligence in Medicine, British Medical Journal, Journal of Medical Systems,* and *Decision Support Systems.*Moreover, we systematically analysed the reference list of the selected publications in order to identify relevant references. We made a first investigation to compile a first list of the pre-selected papers searching for those dealing with "*automating*", "*adaptation*" or "*personalization*" of treatment plan in order to improve the patient care. We excluded studies focusing on diagnostic and those that were too generic or lacking the description of decision support content and adaptation. Finally, the selected papers were classified according to the autonomic computing maturity levels and components.

2. Results

We found that the automation of the personalized treatment is evolving towards the implementation of adaptive treatment plan. Figure 1 portrays the classification of the selected papers based on the autonomic computing maturity levels, the autonomic manager components and the managed elements. From our vision, the managed elements can be either the patient treatment or the healthcare resources and business process. Thus, the adaptation of patient-specific treatment refers to changing their life style [8] and advises about patient behaviour [7] or/and adjusting the pharmacological plan as presented in [5, 6, 8, 9, 10, 11, 13, 14]. The approaches presented in [5, 10, 12] are interested in the adaptation of the healthcare business process which mainly concerns the definition of tasks to be executed in the patient treatment workflow such as laboratory tests, ECG test, etc. The autonomic computing includes the autonomic manager involving four components: *Monitoring*, *Analysis*, *Planning* and *Execution*. These components have access to a common knowledge which contains medical policies and rules, symptoms, treatments etc.

The *Monitoring* captures the data about the managed elements and stores it in the knowledge. We noted that in healthcare, the *Monitoring* can be achieved manually via physicians or automatically through medical sensors. The *Analysis*, which refers to diagnostic in medicine, detects or predicts possible unexpected situations and identifies the cause based on symptoms. If detected, it sends alarms to the *Planning* which implements methods for selecting the personalized treatment according to the defined policies. Finally, the *Execution* performs the new treatment plan and stores the enactment of the treatment in the knowledge. Also, the *Execution* can either be automatically done or needs the physician's approval for enacting the treatment.

Automating these functions might demonstrate five maturity levels- *basic*, *managed*, *predictive*, *adaptive* and *autonomic* - depending on the business requirements [3]. The *basic* level refers to manually managing the patient treatment. Collecting patient data, analyzing and taking decisions about the treatment plan are done by the physicians. On the *managed* level, new technologies such as sensors are introduced to collect disparate data, but it is the role of the physicians to diagnose and foresee any new treatment for the patient. On the *predictive* level, the system can automatically analyze the data and provide general recommendations about the patient treatment. In this case, the physician's approval is required. On the *adaptive* level, the system is not limited to generating general recommendations but it also provides specific to-do actions. If the treatment is patient-specific, the physician approval is crucial for an automatic execution. And finally, the highest maturity level is the *autonomic*. Based on medical goals and requirements, the system is able to take the right decision and learn to create new policies to adapt the treatment plan.

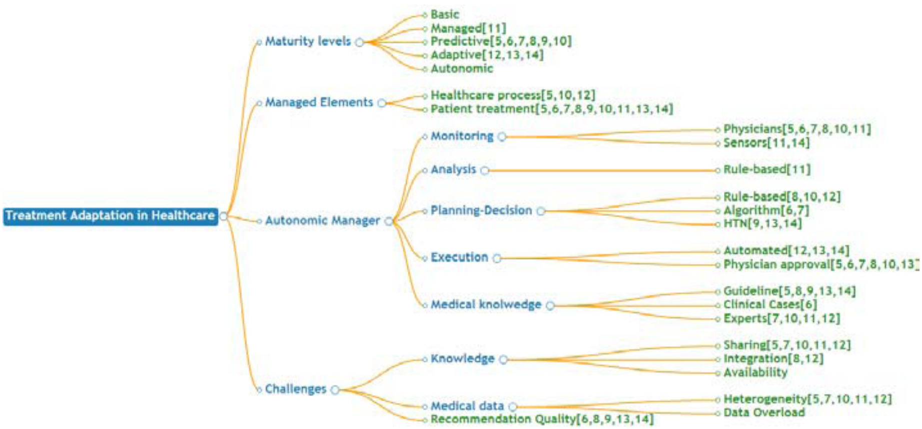

Figure 1.A classification of treatment plan adaptation according to autonomic computing

As presented in Figure 1, automating the AC functions in healthcare can reach the managed level [11], predictive level [5, 6, 7, 8, 9, 10] or adaptive level [12, 13, 14]. Lasierra et al. [11] adopted the medical sensors to remotely monitor patients, detect unexpected situations and alert physicians in order to establish the personalized treatment. In the context of K4CARE project, a Case Profile Ontology (CPO) [5] is provided and used to personalize chronic disease. However, the integration of the generated interventions is manually achieved by physicians. Yao and Kumar [10] proposed a CDSS that automatically generates the recommendation concerning the patient treatment plan based on SWRL-rules. Ontology is used to acquire the patient and resources context. González-Ferrer et al. [9] developed a system based on a planning technique named Hierarchical Task Network (HTN) to automatically generate the best treatment plan. Huang et al. [6] proposed a recommendation service that matches patient status with medical interventions based on mathematical model. Grando et al. [8] proposed a state-based goal framework associated to an aggregation function based on the argument-weight. These proposed solutions mainly differ in the Planning-Decision approach. Both Huang et al. [6] and Emerencia et al. [7] provided sophisticated algorithms to calculate the best recommendation, whereas Grando et al. [8] and Yao and Kumar [10] conceived a rule-based approach to generate recommendations. From our vision, based on the autonomic computing, these systems have reached the predictive maturity level since they are able to generate recommendations. The physician approval is still required.

Fewer works were presented on the adaptation level. Alexandrou et al. [12] proposed an ontology based solution able to automatically observe the execution of each task specific to a patient treatment workflow process and to dynamically adapt the treatment schema concerning the healthcare business process. In contrast to [12], Milla-Millán et al. [13] complemented the approach proposed in [9] and generated the patient-specific treatment plan. They contributed by providing an approach based on PELEA architecture in order to enable the continuous planning and monitoring of the patient state during the treatment enactment. The system provides specific actions related to the patient treatment to be taken. After physician approval, the new treatment is automatically incorporated in the system and the monitoring of the new treatment starts again. The work of Sánchez-Garzón et al. [14] represents a continuity of this work by integrating the monitoring of patients' daily activities in an ambient environment. Based on the Clinical Practise Guidelines, the system is able to repair the current plan and to automatically update the medical record.

To conclude, the highest maturity level reached in these works is the adaptive level. The main goal of the adaptive level is to facilitate and accelerate the decision making process in order to guarantee an optimal patient care by automatically detecting deviations and repairing the treatment plan. The physician approval remains necessary for the treatment enactment.

3. Discussion

Behind managing and adapting the patient treatment plan, a set of challenges need to be considered for improving the efficiency of CDSS. For instance, the work presented in [6, 8, 9, 13, 14] mainly focused on the recommendation quality based on advanced methods such HTN or the mathematical model when generating recommendations. The works presented in [5, 7, 10, 11, 12] pointed out the importance of considering the semantic heterogeneity by providing a common model based on Semantic Web Technology and ontologies when acquiring the information about resources, patient and/or medical knowledge including medical problems. Obviously, Semantic Web is not limited to solve the heterogeneity challenge but also opens the door to share the medical knowledge, which represents one of the main challenges in healthcare. Certainly in such systems, it is not enough to guarantee only the sharing. The knowledge availability, which is not considered in these works, remains a requirement [15] in healthcare knowledge management. Another challenge that has already been mentioned in [16] is knowledge integration and update. This challenge was partially covered in [8, 12], where it was described how experts can add new rules from a user-friendly interface. Moreover, the presented works seldom emphasize the challenges owing to the ICT evolution that may impact the treatment plan accuracy. With the connected medical devices and sensors, the amount of generated data will keep increasing. By 2020, the number of medical mobile connected devices is expected to increase by 100% to nearly 12 billion [17]. Big data remains a challenge to be considered in future works.

To address these challenges, we aim at providing a multi-layer management architecture dealing with medical data, knowledge and services with different maturity levels based on the autonomic computing paradigm. Our first challenge will focus on providing a big data solution that deals with medical data velocity and variety which systematically impact the medical decision, and on implementing mechanisms that identify high quality of data and extract useful knowledge from the generated data. Since knowledge is the main basis for adaptation and decision making, our second challenge will mainly concentrate on providing knowledge that is shareable, and that also is accessible anytime by participants from anywhere who are involved in patient care. Thus, the Knowledge as a Service (KaaS) approach coupled with the semantic web is envisaged in our work to take the advantages of availability, accessibility and sharing the medical knowledge.

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