DISTRIBUTED MULTIAGENT APPROACH FOR HYDROCEPHALUS TREATMENT AND MANAGEMENT USING ELECTRONIC SHUNTING

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Abstract: Hydrocephalus is a common chronic condition that results in excessive accumulation of cerebrospinal fluid (CSF) inside the skull, often leading to brain damage. The treatment and management of hydrocephalus remain a challenging issue, especially for diagnosis, improving current shunt treatment, and predicting shunt success. Current diagnosis procedure depends mainly on the surgeons' observation of the clinical symptoms, neuroimages and instantaneous of intracranial pressure recording. These lack accuracy in diagnosis and predicting the outcome. Dominant treatment relies on passive mechanical shunts; these also exhibit virous problems. Adding to that, the lack of communication between the community surgeons and a limited understanding of the hydrodynamics of this disease have limited the effectiveness of hydrocephalus treatment.

This paper proposes a new approach to improve the treatment and management of hydrocephalus through a multiagent cognitive system over a distributed network of hydrocephalus patients with intelligent shunting system. This approach will not only develop autonomous treatment method for hydrocephalus, but also it defines a method for information acquiring and analysis to better understanding hydrocephalus and assess shunt functionality.

1 INTRODUCTION

Hydrocephalus is an excessive accumulation of cerebrospinal fluid (CSF) inside the skull due to imbalance of the production and absorbtion of the CSF, and without treatment has a 50-60% death rate (A.D.A.M., 2002). Even though there is no acceptable statistical information of hydrocephalus patients, estimates show that approximately 1 in every 500 children are affected by hydrocephalus and this rate is increasing rapidly (NINDS, 2008).

Despite more than 40 years of shunt development, hydrocephalus remains a challenging issue particulary in the three critical aspects of diagnosis, treatment and management. This paper seeks to allow the unification of these aspects by facilitating communication at all levels.

Nowadays, hydrocephalus is characterised and diagnosed by clinical symptoms, like dementia, urinary incontinence, and gait disturbance, and analysis of neuroimaging either by computed tomography (CT) or magnetic resonance imaging (MRI) coupled with mean value of intracranial pressure (ICP) (W. Pfisterer, 2007). However, these methods failed to achieve accuracy in diagnosing hydrocephalus and selecting patients that would benefit form shunting (A. Marmarou, 2005a). In addition to that, there is no acceptable standard for diagnosis and treatment of hydrocephalus (A. Marmarou, 2005b).

Currently, the dominant treatment for hydrocephalus is to divert the CSF from the ventricles in the brain to another part of the body by means of an implanted shunt. The currently used shunts are differential pressure shunts that depend on mechanical valves for operation. Even with the latests advances in shunt technology allowing non-invasive adjustment of the pressure setting, the resulting treatment is far from elegant, lacking responsiveness and autonomy, and unable to communicate. Several studies have verified serious problems and shortcomings relating to current shunting techniques, such as mechanical problems and shunt blockage, excessive and insufficient CSF draining (over-drainage and under-draining), and others. Shunt failure rate currently stands at 35-40% (Metzemaekers, 1998). These problems have been exacerbated by the lack of a viable and meaning-

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ful communication channel between practicing neurosurgeons, and the lack of a detailed understanding of the hydrodynamics of the disease.

The increaseing number of patients suffering from this disease, and the associated costs of their treatment, have together highlighted the deficiencies of the current modes of treatment, and has stimulated research towards the next generation of hydrocephalus shunts. What is beginning to emerge is a totally new approach towards the treatment and management of the disease. This approach responds to the needs of individual patients in an autonomous way, and forms a network among those patients to establish a management and learning protocols to better understand aspects of hydrocephalus diagnosis and treatment.

In order to achieve this goal, the ”old fashioned” mechanical shunt valve must first be upgraded to an electromechanical valve, controlled by software. This type of shunt will have sensory inputs to allow it to process and analyse the patient ICP directly, and base the patients’ treatement regime on the values of selected parameters derived therefrom. It has been demonstrated that certain parameters extracted from the ICP signal are more meaningful than the mean or instantaneous ICP in terms of providing information for diagnosis and predicting clinical outcome (M. Czosnyka, 2007). Such a system would be responsive to patient feedback, provind the shunt with a means of evaluate its own performance, coupled with other derived numeric performance indicators. This can be achieved through communication between the implanted shunt and a hand-held device, which could be a normal mobile phone.

This framework of communication, with the ability of the hand-held device connecting to the internet, gives the ability to connect these shunts in a distributed network of agents, which could enable shunts to share their information and disseminate successful treatment regimes. Moreover, this approach will provide a platform for classification of ICP signals, hydrocephalus patients, and treatment regimes.

2 APPROACH SPECIFICATION

2.1 Intelligent eShunt System

This approach proposes a software-driven, electronically-controlled shunt replacing the passive mechanical one. This shunt consists of an electronic valve, ICP sensor, microcontroller with software, and a transceiver which provides the shunt two-way to communicate with the outside word. This modification of shunt characteristic by adding autonomy and intelligence allow us to overcome some of the problems in the mechanical shunts, farther enables the system to detect malfunctioning.

2.2 ICP Signal Analysis and Parameters

Depending on symptoms, MRI and mean ICP, for diagnosis of Hydrocephalus achieves low accuracy, add to that cost of treatments and shunt revisions which exceed \$1 Billion in year 2000 (Vacca, 2007). Furthermore, these factors do not reliably predict response to treatment or clinical outcome after shunting (W. Pfisterer, 2007), which leads to emphasis on discovering new trends and parameters in ICP waveform, which carry valuable information about patient state (M. Czosnyka, 2007).

This approach, by extracting a set of representative parameters from the ICP signal, enables the electronic shunt to respond to the dynamics of the ICP signal and provide a way of controlling the valve on demand. These parameters, such as Pulse amplitude of the ICP (AMP), RAP index, mean ICP, and mean ICP wave amplitude and latency, (M. Czosnyka, 2007), proves efficiency in treatment.

2.3 Distributed Multi-agent

Intelligent agents are an innovative technology for developing complex and distributed systems. These intelligent agents have, in an autonomous way, a flexibility in performing actions to achieve their goals. This flexibility includes reactivity, pro-activity , and social ability (Weiss, 1999).

Multiagent systems are widely used in healthcare, medicine and other domains (Moreno, 2003), where here several novel aspect need to be highlighted:

1. Clustering technique, for clustering patients into groups.
2. Local and general classification technique for ICP pattern classification.
3. Performance evaluation technique, for evaluating agent’s performance, and assigning successful credit for each case.
4. Using communication language and identification ontology for agents to announce about their self and their experiences.
5. Knowledge sharing and negotiation techniques.

This technology provides a suitable choice in this case, where distributed electronic shunts need to communicate and exchange their successful experiences. These shunts represent a distributed sources of information and decision around multiple patients, where single patient (i.e. electronic shunt) does not have a complete view of the hydrocephalus environment and does not encounter adequate cases of ICP patterns to develop a general classification and management protocol. By sharing data and treatment experience among electronic shunts in different patients, more effective treatment and management system can be developed.

Distributed agents will benefit from the semantic web technology which will be used for exchanging information, and interacting and reasoning about their knowledge (Hendler, 2001), with a defined ontology domain which define a set of terms and messaging vocabulary to be used by agents in the communication language.

While agents are using their knowledge about their cases and their performance in treatment and information from other agents, they will be able to reason about and recommend appropriate treatment scheme for particular case.

3 APPROACH ARCHITECTURE

3.1 Functionality Overview

The functionality of the approach, goes through the following steps:

- ICP sensing, the eShunt agent senses the ICP signal through the pressure sensor and store it in the database of the eShunt.
- Preprocessing, the ICP signal is preprocessed to extract its parameters, like pulse amplitude of the ICP (AMP), RAP index, mean ICP, true ICP, and mean ICP wave amplitude and mean ICP wave latency.
- Formatting form, the extracted parameters, the real ICP and other data related to the patient such as disease history, patient feedback, surgeon advice and diagnosis, are putted down in a common form.
- Processing, then based on the information in the form, the eShunt agent tries to discover new trends like new thresholds and values of the ICP parameters with corresponding clinical cases, such as shunt malfunctioning, patient clinical outcome, ICP production rate state.
- ICP classification, then the eShunt agent, based on different ICP parameters and processed data, classify the ICP signal into categories.
- Testing, these classifiers are tested using appropriate cases from the distributed eShunt agents.
- Patient clustering, including ICP classification, patient history and patient general information, patients are clustered into different categories.

The eShunt agent attempts to diagnose its patient for whom ICP data and other information are available, uses web service to establish a record of the patient case information into the system's blackboard, in anonymous form. The system via different eShunt agents may suggest classification and diagnosis based on their data for similar cases, or the enquiring eShunt may ask via the net whether certain classification and diagnosis are appropriate. Then the performance of the suggested classifications and diagnosis becomes a negotiation process among the system, and when they agreed on a satisfied level of performance of the classifier and diagnosis, the classifier is published.

3.2 Agents Needed

The functionality of the system is fulfilled through the following agents:

- ICP sensing agent to sense the ICP signal and store it in the database of the eShunt.
- Preprocessing agent to extract the specified parameters from the ICP signal.
- Processing agent to discover new trends and thresholds of the parameters with the corresponding clinical cases.
- Classification agent that classifies ICP cases based on different parameters.
- Testing agent that test the locally classified and diagnosed cases through the distributed system.
- Clustering agent that cluster other eShunts in groups based on similarities.
- Communication agent that identify other agents and establish a communication link with them.

3.3 Layered Framework

Since the system should be both reactive and proactive, reactive to instantaneous ICP changing and doing simple action based on that, and proactive to support in a timely fashion ICP parameter extraction and analysis, and negotiation of appropriate case diagnosis and corresponding proper treatment, and in addition that this system is wrapping the eShunt system which locally control the valve, the system adopts multi-layer framework. It is composed of the following layers:

- Inner control layer, represents the eShunt behavior locally which is limited to controlling the valve in an instantaneous manner.

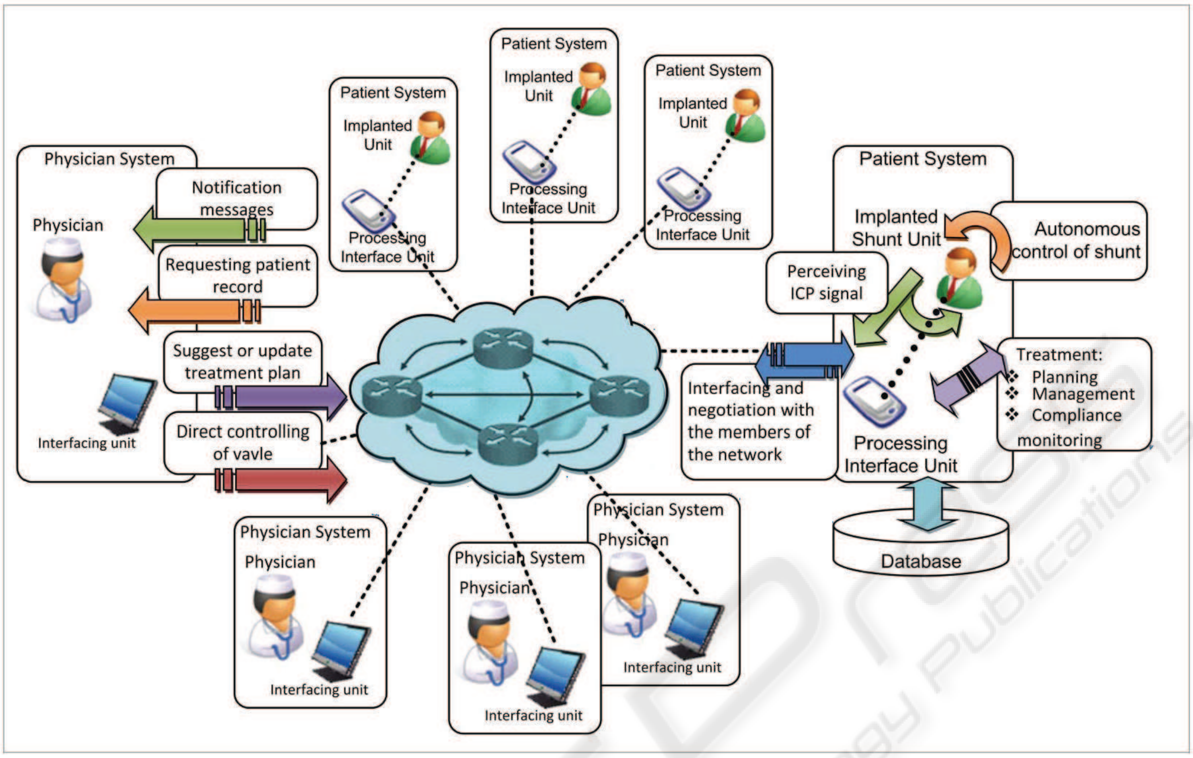

Figure 1: System high-level overview.

- Processing layer, where ICP analysis is happened.
- Database interface layer, it locally logs ICP data, treatment regimes and stores patient information in the database.
- Processing layer, which mines the data providing the main functionality of the approach such as ICP classification, ICP thresholds findings, and patients clusterings.
- Testing layer, where evaluation process occurred and cases verified through the system.
- Communication layer, which provide environment for agent communication via the web.

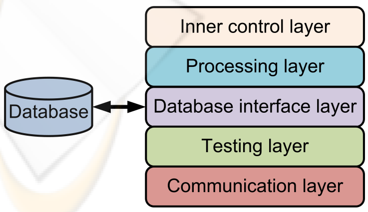

Figure 2: Framework layers.

4 CONCLUSIONS

This paper has presented a new methodology for the integration of hydrocephalus biomedical data and applying knowledge discovery techniques. It specifically addresses the use of the valuable information in the ICP signal coupled with patient feedback and surgeon examination and enforced by the eShunt agent, to improve understanding and management of hydrocephalus.

A requirement of a considerable amount of ICP analysis and treatment data is necessary to build a self-learning and robust classification system for ICP waveforms and hydrocephalus patients. This approach will tackle challenges in analysing, collecting and managing ICP data, by providing a distributed system of eShunt agents that manage patients autonomously, and share information between them. It is envisaged that such an approach will typify the next generation of hydrocephalus management and treatment; it will undoubtedly reduce treatment costs dramatically, and can potentially save lives.

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