The Study on A Real-time Remote Monitoring System for Parkinson's Disease Patients with Deep Brain Stimulators

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Abstract—**The Deep Brain Stimulation (DBS) has become a well-accepted treatment for Parkinson's disease patients around the world. However, postoperative care of the stimulators usually puts a heavy burden on the patients' families, especially in China. To solve the problem, this study developed a real-time remote monitoring system for deep brain stimulators. Based on Internet technologies, the system offers remote adjustment service so that in vivo stimulators could be programmed at patients' home by clinic caregivers. We tested the system on an experimental condition and the results have proved that this early exploration of remote monitoring deep brain stimulators was successful.**

Keywords— **telemedicine, DBS, remote monitoring, Internet**

I. INTRODUCTION

Deep Brain Stimulation (DBS) has become an established treatment to relieve symptoms of neuro-disorder diseases, such as Parkinson's disease (PD), essential tremor, and depression [1-3]. Today, one hundred thousand PD patients are equipped with deep brain stimulators in the world and about five thousand of them come from China [4]. It was reported that in 2005, the amount of PD patients in China was two million and this number would keep growing year by year [5]. DBS has been proved to be quite effective in the act and an increasing number of Chinese PD patients start to take this treatment. However, postoperative care puts a heavy burden on DBS patients according to Francesc Valldeoriola's and Judith Dams' researches [6-7]. DBS patients usually have to come back to hospitals or clinics several times for ensuring that the implanted devices are working at appropriate parameters [8].

Telemedicine has been introduced into the healthcare of PD patients since several years ago. In 1993, Jean P. Hubble and his team concluded that PD patients could be examined and scored (UPDRS) via interactive video conference [9]. Ali Samii and his team also gained the same conclusion based on 100 remote follow-up visits of 34 PD patients [10]. As the rapid popularity of Internet technologies, web-based application was integrated to realize the home monitoring of PD patients [11-12]. Mobile terminals, such as personal computers, Personal Digital Assistants (PDAs) or mobile phones, were selected as patient or physician clients in many studies [13-15].

Although there were a large amount of successful researches and applications focusing on the remote healthcare of PD patients, rare were designed for those who were implanted deep brain stimulators. What's more, limitation lies in the delay of information transmission and the lack of caregivers' direct intervention. To solve this problem, we developed a real-time home monitoring system for DBS patients. The platform provides real-time remote control service which allows caregivers to directly implement remote programming and check the adjustment history records. Video interaction is integrated during the communication between caregivers and patients.

II. SYSTEM DESCRIPTION

A. System Overview

In the present study, the real-time remote monitoring system mainly consisted of four modules: a Physician Client, a Patient Client, a Server Station and a Video Communication System. Providing web service interfaces on the Internet, the Server Station established a virtual link between the Physician and the Patient Client. Via the communication link, the Physician Client assisted caregivers in viewing sufficient information about the patients and sending adjustment instructions to the Patient Client. The Patient Client transmitted adjustment parameters through a wireless link to a programmer. The programmer was set to be the near field communicator with the implanted stimulators. After executing instructions, the Patient Client uploaded results and follow-up history records to the Server Station. The entire remote monitoring and controlling progress was accompanied by synchronistical visual communication provided by the Video Communication System. Fig.1 shows the general architecture of the real-time remote monitoring system.

B. Physician Client

The Physician Client was designed to be located at caregivers' offices, such as hospitals or clinics. For the sake of a strong operability and mobility, we used a common Personal Computer (PC) or a laptop as the terminal hardware. Caregivers could visit the Server Station through a web browser and get detailed information of their patients and

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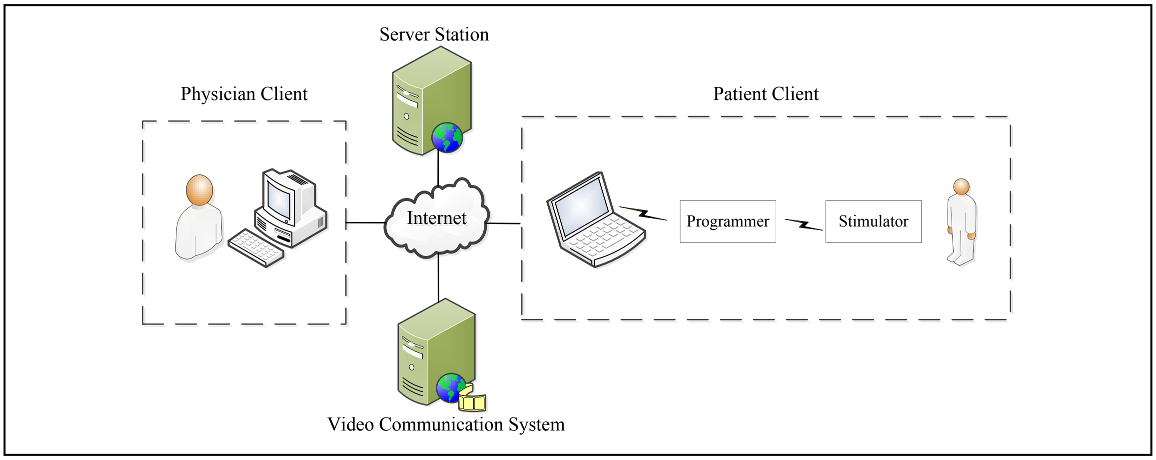

Figure 1. The general architecture of the real-time remote monitoring system.

stimulators. The main functionalities of the Physician Client are as follows.

- Provide a caregiver with an interface to log on or off the system with specified username and secured password authentication.
- Present a caregiver with his personal information and a regularly updated on-line patients list.
- Inform the Server Station of a caregiver's choice of patients and redirection the browser to the programming page.
- Receive a caregiver's input and lodge adjustment parameters to the Server Station
- Display executing results and follow-up history.

To ensure the security of the data transmission, the Physician Client was equipped with a client certificate as an identity authentication which would be examined by the Server Station before the browser gets data.

C. Patient Client

The Patient Client was designed as a home terminal aiming at assisting patients in setting new adjustment parameters and uploading follow-up history records. The entire client hardware consists of four parts: a PC, a Bluetooth dongle, a programmer and an in vivo deep brain stimulator.

The Bluetooth dongle is a custom-built hardware interface based on an off-the-shelf solution. It adopts the latest Bluetooth 4.0 communication protocols and connects the PC via a USB interface.

The programmer consists of RF coils to communicate with the in vivo stimulators [16]. It was also equipped with a Bluetooth slave unit to exchange data with the Bluetooth dongle. The hardware communication link of the Patient Client is shown in Fig.2.

The PC is a common commercial computer or a laptop but equipped with a special patient client software. The software was developed under Winform .NET framework. It helped patients to connect with their caregivers and receive adjustment parameters. The main functionalities of the application are as follows.

- Provide a patient with an interface to log on to the Server Station with specified username and secured password authentication.
- Send a connect request to the caregiver and inform the patient of the reply.
- Receive adjustment instructions and transform them to a stimulator.
- Read executing results and send them to the Server Station.

Communication link between the Patient Client and the Server Station used SSL protocol and certificate identity authentication.

D. Server Station

The Server Station has three servers: (1) the Windows Communication Foundation (WCF) server; (2) the website server; and (3) the database server. The WCF server and the website server were published by Internet Information Service (IIS) 8.0 on the operating system Windows Server 2012 R2.

The foundation of communication service is the WCF server. WCF is a Microsoft .NET framework for building Service-oriented Architecture (SOA) applications. With this framework, we developed the WCF server and the interfaces were divided into three parts: patient service, physician

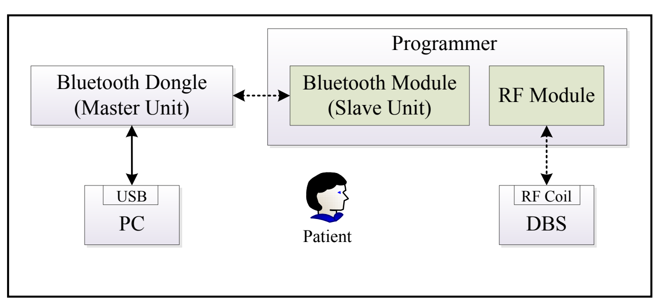

Figure 2. The hardware communication link of the Patient Client.

service and generic service. The first two interfaces were designed as the gate of database and they were called respectively when the Patient Client or the Physician Client needed to exchange data with the database server. The generic service is used for saving temporary sessions during remote monitoring. The functionalities of the WCF server are: 1) Establish duplex communication channels in which session messages and adjustment parameters are transmitted to the clients; 2) Reorganize follow-up results and store the data on the database server.

The website server together with the Physician Client constitutes the Browser/Server (B/S) architecture. The server is a MVC framework application developed under the .Net Framework 4.0. The main functionality of the website is to transmit data between the Physician Client and the WCF server.

The database server is designed to store users' personal information and follow-up history records. It is developed in the MySQL database system and opened only to the WCF server. Data links of the Server Station are shown in Fig.3.

E. *Video Communication System*

The video communication system is also located at the Server Station's computer room, but it works separately on the Internet. As an experiment trial, we chose embedded flash controls as video publisher and displayer. The Flash Media Server4.5 (FMS4.5) established a P2P connection for a couple of flash controls and media stream was directly transmitted between them. The functionalities of flash controls are (programmed by Actionscript 3.0): 1) Call cameras and microphones to capture videos; 2) Connect the FMS and publish its video stream on the Internet; 3) Receive and play the subscriber's video stream.

Portable digital USB cameras and microphones were used to capture videos. The resolution of the video window for each client was 320×240 pixels and the sample rate is 15fps. Video (encoded by the format of FLV) and audio (encoded by the format of SPEEX) would be automatically attached into the media stream and the maximum bandwidth it needed would be smaller than 144kBps.

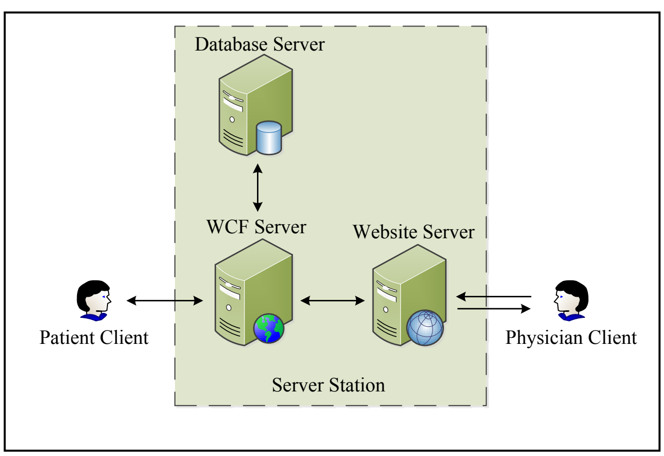

Figure 3. Data links of the Server Station.

III. Perform Approach And Results

A. *Perform Approach*

A typical telemedicine session started with a patient and a caregiver logging in the system. To initiate an adjustment session, the patient clicked a "Connect" button and a request was sent to the Server Station synchronously. On the Physician Client, the caregiver accepted the request by clicking an "Agree" button on the web page. After these steps, a point to point connection between the patient and the caregiver was established. The caregiver then opened a remote control page while the patient was waiting for the remote adjustment.

At the remote control page, the caregiver inputted a group of adjustment parameters and sent them to the Server Station by clicking a "Program" button. The parameters were stored in the database and sent to the Patient Client. The Patient Client reorganized them to an instruction which was identifiable to the programmer. Once the in vivo stimulator received the instruction and finished the execution, the session was completed.

Video Communication began before the caregiver went into the remote control page. Once the patient clicked a "Video Connect" button, the embedded flash control published a video stream on the Internet. The caregiver answered the request and subscribed the patient's video stream. The caregiver's video stream was then re-subscribed by the patient. A remote adjustment process was allowed only if the video communication worked at a normal status.

B. *Results*

We tested the DBS remote monitoring system under laboratory conditions and our results showed that the design is feasible. Two of our technicians played the role of the patient and the caregiver respectively. They followed the perform approach and realized the remote adjustment of a stimulator in two different rooms. Some captures are shown in the Fig.4.

Both of the technicians had a positive impression about the entire system functionality. They highlighted that the most important benefit was the realization of deep brain stimulators remote monitoring and adjustment. It was quite convenient to perform the program approach and the user experience is well-designed. However, one of the technician suggested to improve the stability of the system because his first login to the system was failed. The latency of video communication stream was within acceptable limits.

IV. Discussion And Conclusion

In summary, this paper came up with a real-time remote monitoring system for deep brain stimulators. We have described the system components and the perform approach. Experimental test results showed that the basic functionality could be achieved. The system is still under development, and we could see the following aspects waiting for improvement.

1) Reliability: more measures should be taken to strengthen the system's robustness. The running software in the Patient and Physician Client should have the ability to deal

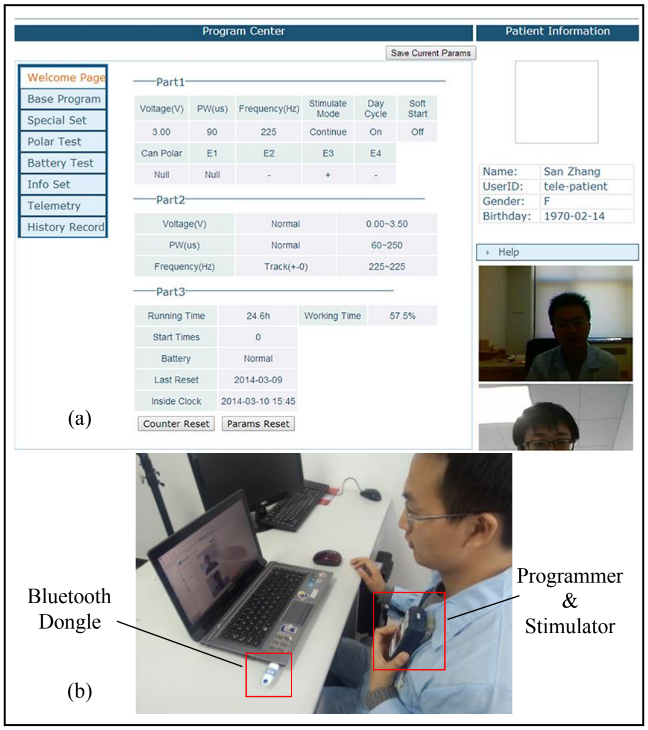

Figure 4. Some captures during the tests. *(picture (a) is the parameters input page of the Physician Client, including the stimulating voltage, pulse width, frequency and other operating parameters; picture (b) is one technician who was playing the role of a patient and receiving remote adjustment service.)*

with some exceptions and errors. The Server Station should be regularly maintained.

2) Higher server performance: the server response time and processing power could be improved by the means of increasing the speed of the CPU, hard drive and network.

3) Video communication quality: some advanced encoding, such as H.263, MPEG-4, could be used in video transmission to get a better picture quality. Digital cameras need higher resolution and a wider range of viewfinder because patients have to show whole body status to caregivers during practice adjustment.

In the future, we plan to invite about 5-10 patients and 1-2 caregivers as volunteers to accomplish a first clinical trial under real conditions to verify the usability and efficiency. Challenges may lie in the cooperation of the patients and the quality of the patients' networks.

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REFERENCES

[1] M. K. Lyons, "Deep brain stimulation: current and future clinical applications", *Mayo Clinic Proceedings*, vol.86, no.7, pp. 662-672, July. 2011.

[2] A. Chopra, B. T. Klassen, M.Stead, "Current clinical application of deep-brain stimulation for essential tremor", *Neuropsychiatric disease and treatment*, vol.9, pp. 1859-1865, Nov. 2013.

[3] H. S. Mayberg, A. M. Lozano, V. Voon, H. E. McNeely, D. Seminowicz, C. Hamani, J. M. Schwalb, S. H. Kennedy, "Deep brain stimulation for treatment-resistant depression", *Neuron*, vol.45, no.5, pp. 651-660, Mar. 2005.

[4] J. Shi. (2013, June. 26). "The Deep Brain Stimulators focus on Parkinson's disease" [Online]. Available: http://xmwb.news365.com.cn/kjw/201306/t20130626_1270224.html

[5] E. R. Dorsey, R. Constantinescu, J. P. Thompson, K. M. Biglan, R. G. Holloway, K. Kieburtz, F. J. Marshall, B. M. Ravina, G. Schifitto, A. Siderowf, C. M. Tanner, "Projected number of people with Parkinson disease in the most populous nations, 2005 through 2030", *Neurology*, vol.68, no.5, pp. 384-386, 2007.

[6] F. Valldeoriola, O. Morsi, E. Tolosa, J. Rumià, M. J. Martí, P. Martínez-Martín, "Prospective comparative study on cost - effectiveness of subthalamic stimulation and best medical treatment in advanced Parkinson's disease", *Movement Disorders*, vol.22, no.15, pp. 2183-2191, Aug. 2007.

[7] J. Dams, U. Siebert, B. Bornschein, J. Volkmann, G. Deuschl, W. H. Oertel, R. Dodel, J. Reese, "Cost - effectiveness of deep brain stimulation in patients with Parkinson's disease", *Movement Disorders*, vol.86, no.6, pp. 763-771, Apr. 2013.

[8] P. Krack, V. Fraix, A. Mendes, A. Benabid, P. Pollak, "Postoperative management of subthalamic nucleus stimulation for Parkinson's disease", *Movement disorders*, vol.17, no.S3, pp. S188-S197, Mar. 2002.

[9] J. P. Hubble, R. Pahwa, D. K. Michalek, C. Thomas, W. C. Koller, "Interactive video conferencing: a means of providing interim care to Parkinson's disease patients", *Movement disorders*, vol.8, no.3, pp. 380-382, 1993.

[10] A. Samii, P. Ryan-Dykes, R. A. Tsukuda, C. Zink, R. Franks, W. P. Nichol, "Telemedicine for delivery of health care in Parkinson's disease", *Journal of telemedicine and telecare*, vol. 12, no. 1, pp. 16-18, 2006.

[11] B. R. Chen, S. Patel, T. Buckley, R. Rednic, D. J. McClure, L. Shih, D. Tarsy, M. Welsh, P. Bonato, "A web-based system for home monitoring of patients with Parkinson's disease using wearable sensors", *IEEE Trans. Biomedical Engineering*, vol.58, no.3, pp. 831-836, Mar. 2011.

[12] M. Memedi, J. Westin, D. Nyholm, M. Dougherty, T. Groth, "A web application for follow-up of results from a mobile device test battery for Parkinson's disease patients", *Computer methods and programs in biomedicine*, vol.104, no.2, pp. 219-226, 2011.

[13] J. Westin, M. Dougherty, D. Nyholm, T. Groth, "A home environment test battery for status assessment in patients with advanced Parkinson's disease", *Computer methods and programs in biomedicine*, vol.98, no.1, pp. 27-35, 2010.

[14] M. C. Barroso, G. P. Esteves, T. P. Nunes, L. M. Silva, A. C. Faria, P. L. Melo, "A telemedicine instrument for remote evaluation of tremor: design and initial applications in fatigue and patients with Parkinson's disease", *Biomedical engineering online*, vol.10, no.1, pp. 10-14, 2011.

[15] D. Surangsrirat, C. Thanawattano, "Android application for spiral analysis in Parkinson's Disease", *2012 Proceedings of IEEE Southeastcon*, pp. 1-6, 2012.

[16] W. Wang, B. Ma, H. Hao, F. Liu, C. Hu, L. Li, "Study of a Transcutaneous Wireless Communication System", *Chinese Journal of Biomedical Engineering*, vol.28, no.3, pp. 408-414, June. 2009.