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A Tele-rehabilitation System with an Automated Pegboard Utilizing Radio Frequency Identification

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ABSTRACT

Due to the expense of health care and the need to contain costs, many stroke patients are discharged from hospitals while still in an impaired condition. Using Tele-rehabilitation, these patients can receive rehabilitation services remotely. A pegboard is a conventional rehabilitation therapeutic device that integrates cognition, sensation and hand motor function. This study proposes a Tele-rehabilitation content with automated pegboard and shows its functional feasibility. The evaluation of the pegboard session was automated with RFID (radio frequency identification), and a 16-hole pegboard was rapid-prototyped. After a pegboard session is completed, the session result is uploaded to a server automatically for viewing on a web browser by a remote therapist. The therapist can also send messages to remote patients to encourage them or to manage the rehabilitation process.

Keywords*: Tele-rehabilitation, Pegboard, RFID, Rehabilitation Automation.*

1. INTRODUCTION

Due to the expense of health care and the need to contain costs, many stroke patients are discharged from the hospital while still in an impaired condition. Even though they require ongoing rehabilitation therapy, their physical disability hinders them from traveling back to the hospital for frequent therapy visits. Tele-rehabilitation allows rehabilitation services to be provided to patients in remote locations [1], allowing the patients to benefit from rehabilitation therapy at home.

Most Tele-rehabilitation systems combine a virtual reality technique with special interface devices, and they have shown significant clinical effects [2]-[4]. However, the types of interface devices required for Tele-rehabilitation, such as those that provide mechanical force feedback, are very expensive. A mechanical force feedback device has the potential to interfere with the patient's movement, thus it needs frequent calibration. A simple and low-cost device that provides a comparable effect would increase the accessibility of Tele-rehabilitation to more patients.

Studies have been performed on the automation of the

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rehabilitation process [5],[6]. The goal of these studies is for patients to direct their own rehabilitation, either with or without reduced participation and expense of a therapist. As opposed to virtual reality rehabilitation, automated rehabilitation can provide benefits closer to conventional therapist-guided rehabilitation, since it utilizes tangible and physical rehabilitation devices. Sanchez et al. used an exoskeletal robot with a grip sensor to restore a patient's upper limb functionality [6]. Lum et al. automated twelve types of rehabilitation exercises for constraint-induced movement therapy, in which the patient's healthy upper limb is constrained, enabling the rehabilitation of the disabled upper limb [7]. Lum et al. also applied their system to Tele-rehabilitation.

A pegboard is a conventional rehabilitation device used to train and evaluate hand function [8]-[12]. In occupational therapy, it is used to integrate cognition, sensation and motor function [13]-[15]. A pegboard consists of a board with holes and pegs. A session with the pegboard is completed when all of the pegs are plugged into their corresponding holes. The individual session times and the accumulated success rate are important measures. Because the pegboard is a low-cost, simple and effective rehabilitation device, its application to Tele-rehabilitation would be greatly beneficial.

This study proposed a Tele-rehabilitation content with automated pegboard and showed its functional feasibility. The authors had proposed an automated pegboard [16], with radio frequency identification (RFID) [17]-[19]. To test the feasibility of the pegboard as a Tele-rehabilitation content, a simple Tele-rehabilitation server was implemented. At the end of a pegboard session, the session time is uploaded to the Tele-rehabilitation server automatically and the remote therapist views the result history via a web browser. The therapist is also able to send messages to remote patients for encouragement and to manage the rehabilitation process.

2. SYSTEM DESIGN

2.1 Pegboard Automation with RFID

As mentioned in the previous section, the authors had proposed an automated pegboard. For the reader's convenience, the automation method is briefed as follows.

The RFID technique was applied to the pegboard by inserting a tag inside each peg and placing RFID reader antennas at the bottom of the holes (Fig. 1). Each tag's ID (identification) was registered for the corresponding hole. The reading distance of the RFID reader was adjusted so that the tag could be read only when it was inserted into the hole completely.

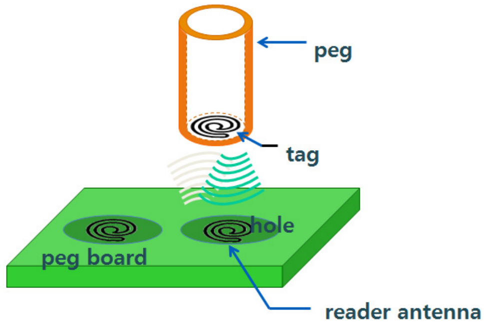

Fig. 1. Pegboard automation with RFID. The RFID reader antennas were placed under the hole, and the tag was inserted inside the peg.

The RFID reader was configured with multiple antennas. Because a peg could be inserted in a wrong hole, for example, their color, shape or size of the peg could not match, the location of the hole should be also indentified. In this case, a single reader with multiple reader antenna can save cost and space, and avoid multi-channel communication issues. Each reader antenna was selected by analog switch.

Each RFID reader antenna was turned on and read one by one as shown in Fig. 2. A hole was marked as 'empty' if no ID was read by the corresponding reader antenna. If any ID was read, it was verified to be the correct registered ID for that tag. If so, the hole was marked as 'match', otherwise it was marked as 'mismatch'. These steps were repeated for all of the reader antennas.

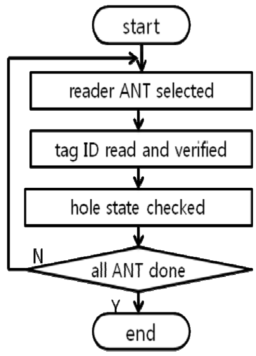

Fig. 2. Flowchart for hole's state detection by reading antennas (ANT). Each RFID reader antenna (ANT) is read one by one, and the corresponding hole's state is detected.

If all the holes were detected to be 'match', then the pegboard session ended, the session was considered to be a 'success', and its session time was recorded. If the session was not completed within a given time or it was cancelled by the patient, the session was considered to be a 'failure'. The accumulated success rate of the sessions was also recorded.

A prototype system was configured as shown in Fig. 3. It consisted of a microprocessor, an LCD (liquid crystal display), a buzzer, a wireless data transmission module, an RFID reader and multiple reader antennas. The microprocessor module (ATmega128L, 8 MHz, Atmel, CA) controlled the RFID reader to score the pegboard session and display the results on the LCD. The microprocessor also played various sound effects with the buzzer to attract the patient's attention. The USART

(Universal Synchronous Asynchronous Receiver and Transmitter) included in the microprocessor and the wireless transmission module provided wireless communication with the host system.

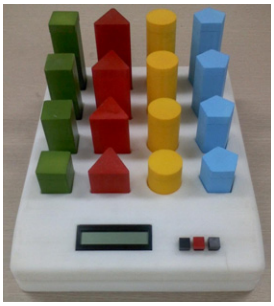

Fig. 3. Rapid-prototyped pegboard. It contained a microprocessor, LCD, buzzer, wireless data transmission module, RFID reader and multiple reader antennas.

The RFID reader module (TRF7960, Texas Instruments, Dallas, TX) drived the ISO 15693 protocol with one sub-carrier, one out of four modulation, and a high bit rate (26 Kbps). It reads ten bytes of ID and sends them to the microprocessor.

The reader antenna was made with a printed circuit board. Each antenna was 30 x 30 mm, with windings up to 5 turns. A commercial inlay 24 mm circular tag (Tag-It^{TM}, HF-I, Texas Instruments, Dallas, TX) was used for the tags.

2.2 Tele-rehabilitation System

The Tele-rehabilitation system consisted of the automated pegboard, a patient's PC, a Tele-rehabilitation server and a therapist's PC (Fig. 4). When the patient finished a pegboard session, the pegboard calculated the session time and sent it to the patient's PC using wireless communication. The patient's PC received the session time from the pegboard and uploaded it to the database on the server. A therapist can view the uploaded data on the therapist's PC using the web browser. The therapist also can send messages to the pegboard to encourage the patient's accomplishment or to manage the rehabilitation process. These messages are displayed on the LCD of the pegboard.

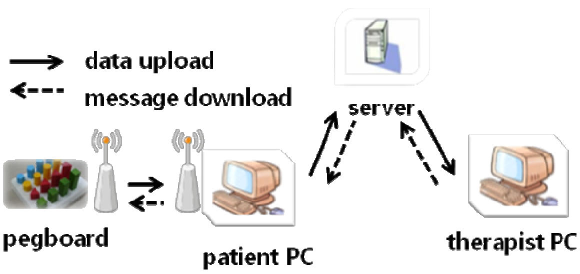

Fig. 4. Overview of the Tele-rehabilitation system. It consisted of the automated pegboard, patient's PC, Tele-rehabilitation server and therapist PC.

The Tele-rehabilitation server managed the patient's information and the pegboard result using a MySQL database (http://www.mysql.com). The server also provides dynamic server pages programmed with JSP and the Tomcat server (http://tomcat.apache.org) for a bidirectional interface between the patient's PC and the therapist's PC. All the development tasks including coding and compiling scripts, interfacing with the database were processed on the NetBeans 5.5 as an integrated development environment (Fig. 5).

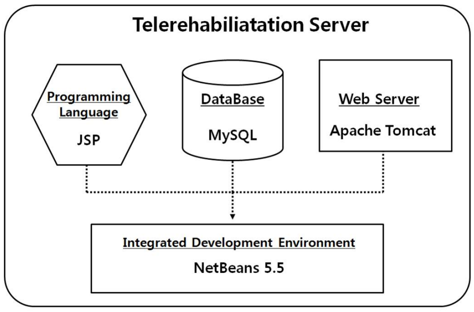

Fig. 5. Development environment of the Tele-rehabilitation server.

The database for Tele-rehabilitation stored the information for the pegboard evaluation results and enabled the bidirectional information exchanges between the patient and the therapist. The tables constituted of 'patient', 'session', 'message' and 'board' according to their attributes (Fig. 6). The patient table contained the patient's basic information such as patient no, id, password name, age and gender. It also contained the patient's pathological recording, including event and status of pathological outbreaks. The session table stored the pegboard session results such as state (failure or success) and the session time. The message table managed the therapist's feedback messages to the patient. The board table provided the web board conventional communication between the patient and the therapist.

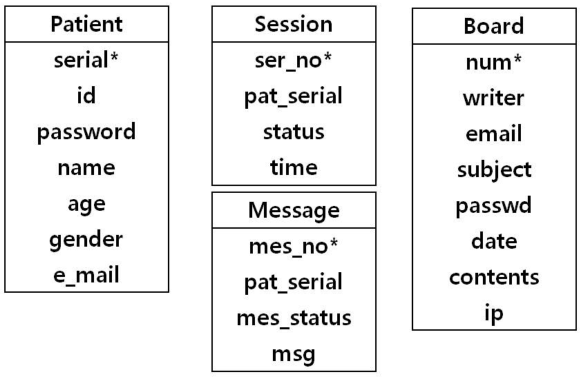

Fig. 6. Database tables for the Tele-rehabilitation server ('*' indicates primary key).

The operation of the patient's PC was hidden so that it does not interrupt the patient while it uploaded the pegboard results to the server and downloaded the therapist's messages. A dialog-based application, programmed with Microsoft Visual C++ 6.0 with MFC (Microsoft Foundation Class), was launched at boot time and resided in a minimized form in the patient's PC. The MFC dialog contained a web browser control. When the application received data from the pegboard, the web browser control navigates a server side page (Fig. 7), entered the data onto the form, and submitted the page automatically.

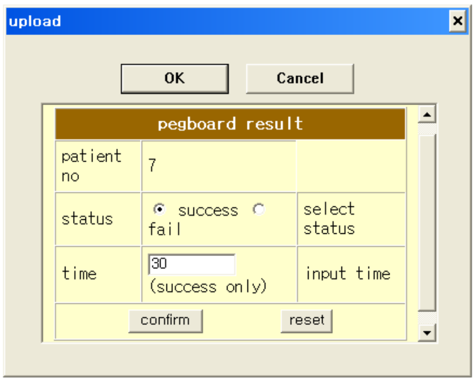

Fig. 7. An MFC dialog containing the web browser control for data uploads. The dialog-based application navigated this page, entered the pegboard session results and submitted them automatically.

Similarly with data upload, another MFC dialog box containing a web browser control, as shown in Fig. 8, was executed periodically (every two minutes in this study). The web browser control navigated a server side page to receive the messages entered by the therapist. Any unsent messages were wirelessly sent to the pegboard and displayed on the LCD. The sent message was marked as such to avoid multiple transmissions.

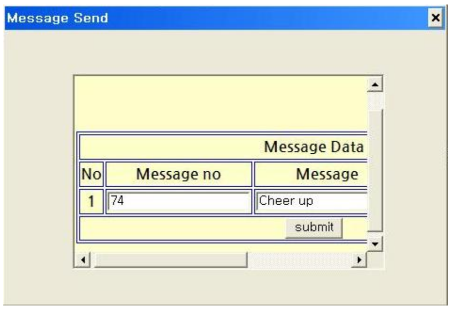

Fig. 8. An MFC dialog containing the web browser control for message downloads. The dialog-based application navigated this page, and displayed the therapist's message to the patient.

3. EXPRIMETAL RESULTS

Each of five pegboard sessions was evaluated for five healthy subjects (three males and two females). The total of 25 sets of session time and their status were logged into the database. All of the results were detected by the pegboard and updated in the server without any difficulty.

Each patient's result history was displayed in both graph (Fig. 9) and table formats (Fig. 10). Fig. 9 was taken from the therapist web page. The graph was generated automatically as a bitmap image using the uploaded results data.

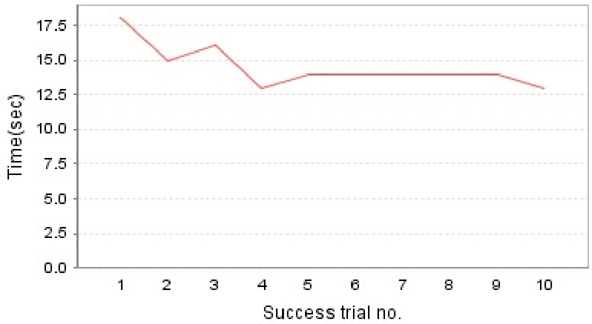

Fig. 9. Graph of a patient's pegboard result history. This is a portion of the clinician's page. The therapist views this page via the web browser.

Trial no	Time[sec]	Status
1	18.0	success
2	15.0	success
3	16.0	success
4	13.0	success
5	14.0	success
6	14.0	success
7	14.0	success
8	14.0	success
9	14.0	success
10	13.0	success

Fig. 10. Table of a patient's pegboard results history. This was a portion of clinician's web page. The therapist sees this page via web browser.

The messages from the clinician's page were displayed on the LCD of the pegboard as shown in Fig. 11. For example, messages such as "EXCELLENT" and "CHEER UP" were used for encouragement and "LET'S TRY" and "ONE MORE TRY" for management were displayed after being sent by the clinician.

Fig.11. Messages sent by the therapist and their display on the LCD.

4. CONCLUSION

This study proposed a Tele-rehabilitation content with the automated pegboard utilizing RFID technique and showed its functional feasibility. The evaluation of the pegboard session, the upload of the results to the server and the download of the therapist's message to the pegboard all executed automatically without interrupting the patient.

In this study, only the feasibility test was conducted using five healthy subjects in their twenties. For the clinical use, we are planning a future clinical study on the targeted population, especially post-stroke patients.

The automation of the pegboard evaluation shows that there is a potential for many other real rehabilitation devices that can be used within Tele-rehabilitation, as opposed to virtual modeling. Physical and tangible devices could be more effective for rehabilitation than virtual representation since they project the reality.

The automated evaluation also demonstrates its feasibility for mass screening and systematic large-scale research in a related field. Because the evaluation of the pegboard is processed automatically without an inspector's intervention, the automated pegboard is a simple and low-cost diagnostic method. The automated device can also be used for a large-scale study involving a large population, because it stores and provides the result data in a convenient form for statistical analysis.

As seen with the pegboard, the application of an RFID technique provides a low-cost solution for behavior detection compared to an expensive motion tracking system. This is a key factor for compact and low-cost Tele-rehabilitation devices. However, the limitation of this system is that the motion can be detected only at predefined positions by the RFID reader antenna. Despite this limitation, the solution can be used for other similar applications.

There have been interesting studies on digital game contents based on tangible user interface based on RFID technique [20]-[23]. In particular, Lee et al. suggested the possibility of RFID technique to detect any subject's spatial arrangement, which could provide strategic game components for educational applications [23]. The application of the RFID technique proposed by the authors could match this requirement in digital game contents.

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