Automated Pegboard Utilizing RFID System with Multiple Reader Antennas

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Abstract

This study proposes an automated pegboard utilizing the RFID system with multiple reader antennas for the rehabilitation services and the occupational therapy. The system automates the scoring by detecting the plugging correctness as well as the plugging status. It also aims to increase the patient's interest and the functional intelligence. The system was prototyped and tested for the automatic capability of the scoring the session time and success rate. The proposed system will be served as the typical example for the ubiquitous rehabilitation devices.

Key words : peg board, RFID, telerehabilitation

Ⅰ. INTRODUCTION

Pegboard test is usually used in rehabilitation services to assess manual dexterity [1-5]. It also can be used as occupational therapy to improve space perception function [6-9]. Especially, the Nine-Hole Peg Test has been known to provide excellent psychometric properties of measurement in upper-extremity motor function for people following a stroke [3]. Furthermore, there are several variations of pegboard in their shape and color. For an example, the pegs shown in Fig. 1 have 4 different types, various colors, and differentiated heights, challenging higher level of space perception and decision.

However, patients, especially the grownups often feel the pegboard session monotonous. In addition, it is a labor-intensive task for the experienced therapists to guide and monitor the pegboard session. The intelligent electric pegboard will be one of the solutions to provide more interest to the patients and reduce the therapist's tasks [10-11]. For example, various melodies can attract the patients and the automatic presentation of the evaluated scores encourage the patients by showing their improvement.

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To automate the pegboard scoring, it is necessary to analyze the pegboard session. When all the pegs are plugged into the their corresponding holes, the session is completed as shown in the left-hand side picture of Fig. 1. In general, we cannot exclude the cases that any peg is plugged into incorrect hole as shown the right-hand side picture of Fig. 1. In the picture, two pegs on the lower-right corner are plugged incorrectly, because they are not placed according to the proper order of height. Therefore, the correctness should also be detected together with the plugging status itself. This requirement can be satisfied by employing the RFID (Radio Frequency Identification) technique.

The RFID technique has various applications including industrial automation, access control, and emergency medicine [12-15]. Typical RFID system consists of reader, reader antenna, tag, and host system. The identification or any additional information in the tag is read out with coupling between the reader antenna and transponder antenna in the tag.

In the RFID system, the reader usually has a single antenna to transfer information from the multiple tags to the host system. By applying a unique tag for each object, multiple objects can be identified. However, our application needs to

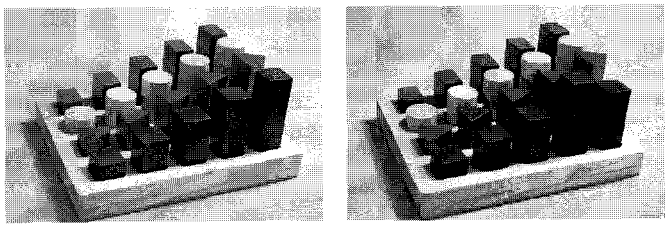

Fig. 1. Conventional pegboard. All pegs are plugged correctly in the left figure. In the right figure, two pegs on the lower-right corner are plugged incorrectly. They have to exchange their positions.

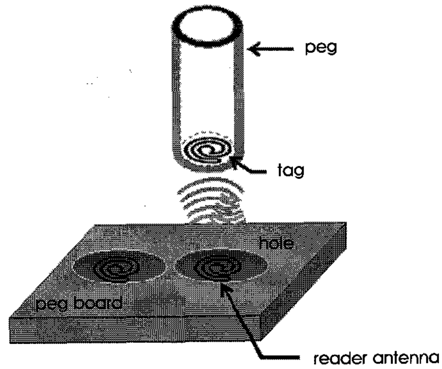

Fig. 2. Electric pegboard with RFID system. RFID reader antenna is placed under hole, and tag is inserted inside peg.

localize the objects in addition to their differentiation because the pegs should be matched to their corresponding holes in the pegboard. In this case, a single reader with multiple reader antennas can save the cost and space, and eliminate the multi-channel communication issues to the host system.

This study proposes an electric pegboard which automatically scores its session, using the RFID system with the multiple reader antennas. The system was prototyped and the feasibility was tested for three healthy adults.

II. MATERIALS AND METHODS

A. Design of Automated Pegboard using RFID

RFID technique was applied to the pegboard as shown in Fig. 2. A tag was inserted inside each peg and the RFID reader antennas were placed at the bottom of all the holes. Each tag identification was assigned uniquely for the corresponding hole position. The reading distance of the reader was adjusted so that the tag could be detected only when it was inserted in the hole entirely.

Each antenna was turned on and read one by one at a time, as described in the procedure of Fig. 3. A hole was marked as 'empty' if no identification was read from the corresponding reader antenna. If an identification was read, it was verified for the validity. The tag identification was valid if it had been registered. The following check step for the plugging correctness was skipped for the invalid identification. The valid identification was correct, if it was the same as the identification assigned to the corresponding hole. A hole was marked as 'match', if the correct identification was received from the hole. Otherwise, it was marked as 'mismatch'. These steps were repeated for all of the reader antennas.

When all the holes were marked as 'matched', the pegboard session was finished and the session was considered as 'success'. When the session was succeed, its duration was recorded. If the session was not finished within given time or cancelled by the patient, the session was considered as 'failure'. The success rate of the sessions was also recorded.

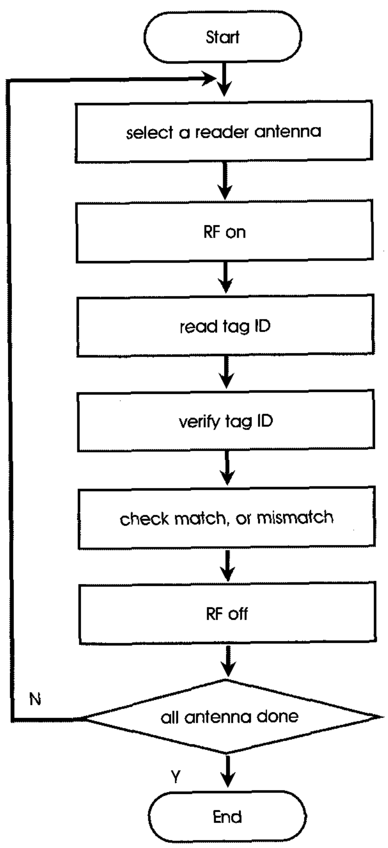

Fig. 3. Flowchart for scanning multiple reader antennas. Each antenna is turned on and read one by one at a time.

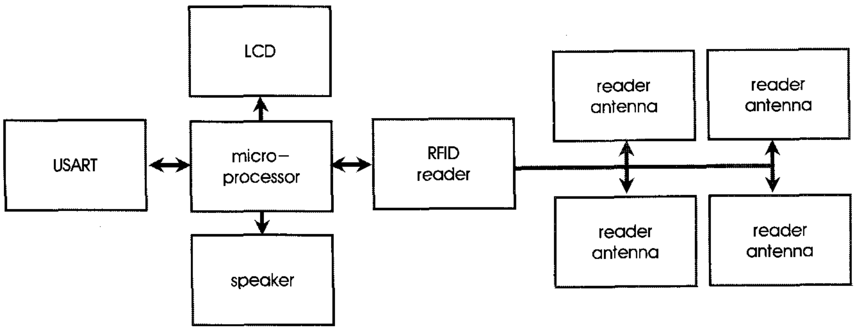

Fig. 4. Configuration of the proposed electric pegboard using RFID with multiple reader antennas. It consists of microprocessor, LCD, speaker, USART, RFID reader, and multiple reader antennas.

B. System Prototype

A prototype system was configured as shown in Fig. 4. It consisted of a microprocessor, an LCD, a speaker, an USART (Universal Synchronous Asynchronous Receiver and Transmitter) interface, an RFID reader, and multiple reader antennas. The microprocessor module (ATmega128L, 8 MHz, Atmel, CA) shown in Fig. 5 was interfaced with the RFID reader to score the pegboard session and display the results to the LCD. The microprocessor also played various melodies with speaker for the patient attraction. The USART provided the serial communication with the host system.

The RFID reader module (TRF7960, Texas Instruments, Dallas, TX) was shown in Fig. 5. It drives ISO 15693 protocol with one sub-carrier, 1 out of 4 modulation, and high bit rate (26 Kbps). It reads 10 bytes of identification and sends to the microprocessor.

The reader antenna shown in Fig. 6 was made with printed circuit board. Each antenna had the size of 30 x 30 mm, and the windings up to 5 turns. A commercialized inlay 24 mm circular tag (Tag-It™, HF-I, Texas Instrument, Dallas, TX) was utilized for the tags.

In order to select a reader antenna, a switching board shown in Fig. 7 was employed. It had the single-pole double-throw analog switches (ADG619, Analog Devices, Norwood, MA). These switches were connected to the output ports of microprocessor and turned on one by one as mentioned in the previous section.

The reader circuit included the analog part shown in Fig. 8. The signals OUT_RF and ANT correspond to the analog output of RFID reader module and reader antenna, respectively. The C_1 and L_1 construct a notch filter to pass 13.56 MHz base signal, and the C_2-C_4 and L_2 builds a low pass filter. The C_5-C_8 and L_{ANT} forms a resonant circuit for 13.56 MHz frequency. The resistor R decreases quality factor down to about 50. The signal $RFIN_1$ and $RFIN_2$ feedback the coupling signal from the tag.

C. Experimental Method

First, all the holes were checked for the successful detection of their states such as empty, match, and mismatch. Each peg

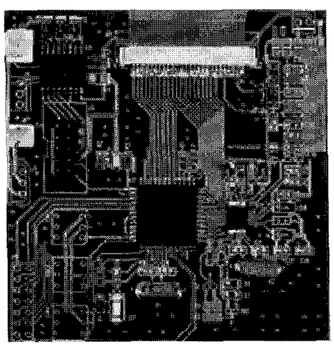

Fig. 5. Microprocessor and RFID reader board. The microprocessor interfaces with the RFID reader to score pegboard session. The RFID reader reads 10 bytes of identification and sends to the microprocessor.

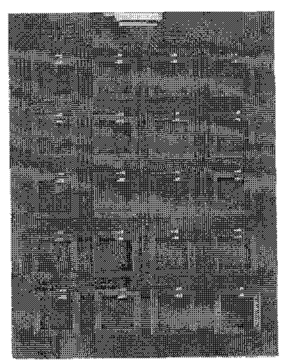

Fig. 6. Reader antenna board made with printed circuit board. Each antenna has the size of 30 x 30 mm, and the winding up to 5 turns.

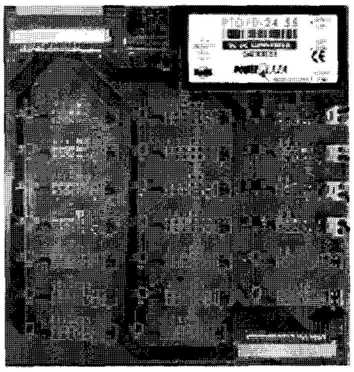

Fig. 7. Analog switch board. Single-pole double-throw analog switches are connected to the output ports of microprocessor.

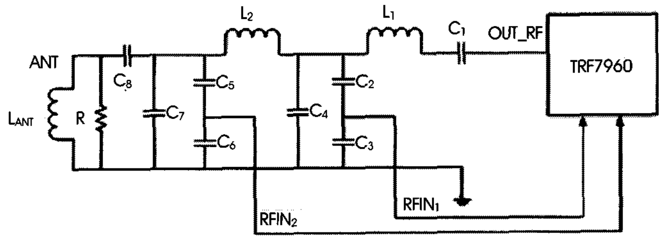

Fig. 8. RFID reader circuit. It consists of notch filter (C_1, L_1), low pass filter (C_2-C_4, L_2), and resonant circuit (C_5-C_8, L_{ANT}) at 13.56 MHz.

was plugged and unplugged in sequence for all the holes. The state change of hole was detected and their new state was notified by different beep sound. The match, mismatch, and empty states were notified with one-beep, two-beep, and three-beep sounds, respectively.

After that, the successful detection procedure was tested with six pegs for three healthy adults, and the test time was measured. Finally, the prototype with six pegs was tested for three healthy adults, to confirm the feasibility of proposed system. Five pegboard sessions for each adult were monitored and their session times were recorded.

III. RESULTS AND DISCUSSIONS

Each peg for all the holes was confirmed with the match-mismatched matrix shown in Fig. 9. The column and row correspond to hole and peg numbers, respectively. In each element, the mark 'O' and 'X' denote match and mismatch state, respectively. The actual states according to the match-mismatch matrix were confirmed with beep sounds. This match-mismatch matrix test will be expanded to investigate any error rate for each matrix element.

It took 83, 70, and 84 seconds to confirm the match-mismatch matrix (Fig. 9) for adult 1, 2, and 3, respectively. Even thought the test number is limited, the slight variation in test time for each adult was seen.

Five sessions for each of the three adults were monitored and their session times were recorded as shown in Fig. 10. The session times did not overlap each other, showing the differences among the individuals. The session times also showed decreasing trends as the sessions were repeated. These characteristics showed the feasibility that the proposed system can be used as rehabilitation device.

The microprocessor detected the peg state (unplugged, correctly plugged, or incorrectly plugged) successfully, and scored the session to give session time. It took 20 msec to read

	1	2	3	4	5	6
1	O	×	×	×	×	×
2	×	O	×	×	×	×
3	×	×	O	×	×	×
4	×	×	×	O	×	×
5	×	×	×	×	O	×
6	×	×	×	×	×	O

Fig. 9. Match-mismatch matrix. The column and row correspond to hole and peg numbers, respectively. 'O' and 'X' denote match and mismatch state, respectively.

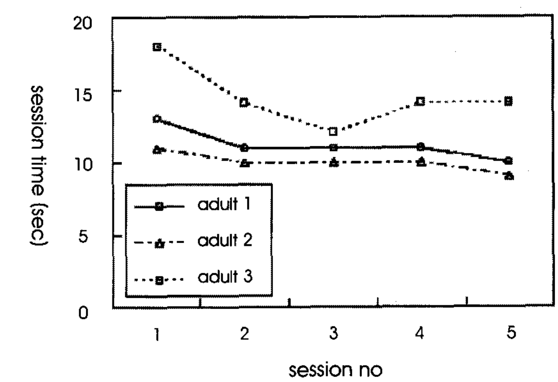

Fig. 10. Session time record. The session times show the difference among individuals and decreasing trend as the sessions are repeated.

one reader antenna. Among them, 10 msec was allocated to select reader antenna considering the switch's stabilization. The other 10 msec was used to read tag with ISO 15693 protocol 26 Kbps rate, considering the RF power stabilization.

Ⅳ. CONCLUSION

This study proposed an electric pegboard with RFID system, and discussed the design issues. The multiple antennas are scanned in sequence to detect not only the plugged or unplugged state, but also match or mismatch state. A prototype was implemented and tested to show that this system can automatically score pegboard session and provide each session time. There was no collision between antennas during they were scanned.

Meanwhile, the automatic scoring of pegboard also has a significant and potential role in telerehabilitation application. The electric pegboard keeps the patients session record inside its memory and this memory is uploaded to a telerehabilitation server and monitored by clinician. The up and down links will be processed by wireless communication such as Bluetooth. Our research group is planning to construct a telerehabilitation server to provide various rehabilitation therapies to patients in remote places. The integration of the ubiquitous technology into rehabilitation devices, like the case of the electric pegboard introduced here, will be a promising application.

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