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Development of the Control System of a Voice-Operated Wheelchair with Multi-posture Characteristics

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***Abstract*—At present, an electrical wheelchair cannot meet the needs of patients, like paralyzed patients, who spend most of their time on beds. This paper presents the control system of a voice-operated wheelchair, which can transform to a sitting, lying and standing posture. We designed the control system including software and hardware. Voice controlled posture change and driving was realized, the hardware circuit and software program are tested and debugged, the recognition rates of voice control of the wheelchair for the same person are acceptable.**

Keywords-control system; voice-operated; wheelchair; multi-posture

I. Introduction

As an assistive means of transportation, both elderly and disabled people need wheelchairs urgently. Manually operated and electrical wheelchairs with simple functions have become gradually unable to the needs of users. To provide elderly and disabled people with means of transportation with superior performance, and to help them improve their freedom of mobility and reintegration, wheelchair now tend to be more intelligent [1].

In the last two decades, most wheelchair studies focused on diversified control modes and additional functions such as standing and elevating etc.

Proposed aspects of control include voice [2]-[4], direction of the face [5], eye gaze [6], electromyography (EMG) signal from the neck and the arm muscles [7], EMG signal from the face muscles [8], wireless tongue-palate contact pressure sensor [9], eye-control method based on electrooculography (EOG) [10], electroencephalography (EEG) [11] are proposed. Using these methods, it becomes easy for elderly and disabled people, to operate a wheelchair.

Some previous studies have shown the efficiency of additional functions. Of course, some previous studies attempted to develop a multifunction wheelchair, which integrated one or more functions including standing, lying and other control modes [12]-[17].

Many multifunction wheelchairs, such as those mentioned previously, improved quality of life to some extent. However, they actually have only several limited capabilities, e.g. they meet at the same time the conditions “effective control modes” and “different additional functions” only very occasionally. In addition, if patients want to get on to the bed from the wheelchair, or do some rehabilitation exercises, they need help from others. It is not only a waste of human resource but it also brings mental pressure to patients. They will gradually lose confidence. Therefore, it will be necessary to develop a versatile wheelchair with good performance and which will be easy to use. Based on the existing mechanical structure of a multi-posture wheelchair this paper presents the control system design which includes a voice control module and a closed-loop and fuzzy PID (Proportion Integration Differentiation).

II. Method

A. Intrduction of the Existing Mechanical Structure Design

Figure 1. Different posture between sitting and standing.

The mechanical structure of the wheelchair, wheelchair frame, seat, backrest, leg support and footrest are simplified as linkages, which are connected as hinges. The actuators for lying and for standing can achieve posture change from sitting to lying and standing respectively. This not only simplifies the structure, but also is beneficial for the design of the control system. In addition, when considering safety in posture change, two anti-sway wheels are added under the footrest to make sure the center of gravity will not shift too much. The anti-sway wheels will not touch the ground in the sitting posture and will not affect obstacles encountered by the wheelchair. Front driving wheels and universal wheels at the back also improve stability and safety in the lying posture. An actuator is added to expand leg support making patients comfortable when lying on it.

The Three-dimensional modeling of the multi-posture electrical wheelchair is shown in Figure 1 and 2. As can be seen in repeating the movement process, wheelchair model achieved posture between sitting and standing (Figure 1), as well as sitting and lying (Figure 2)

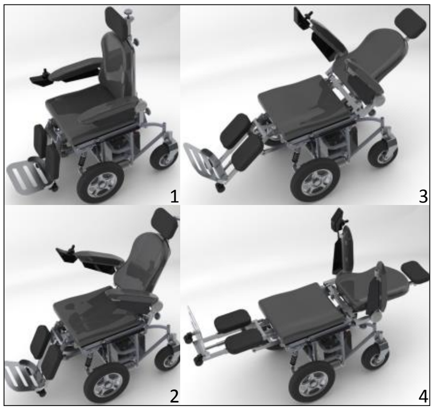

Figure 2. Different posture between sitting and lying.

B. Control System

1) Overall

The implementation structure of the multifunction wheelchair is a mechanical structure, and the core part is the control system. The control system bears all the transformations of the wheelchair, including driving and posture change.

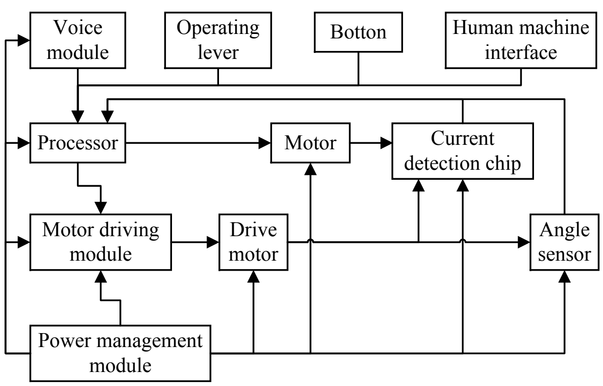

Figure 3. Overall control system structure of multifunction electric wheelchair.

The control system acquires a signal from the control terminal. The master controller of the control system processes the signal, and transmits a control signal to the control circuit of the corresponding execution module in order to control the execution module. As we can see, there are two driving motors and three linear actuators that are controlled by the system. Driving motors drive of the wheelchair. One of the three linear motors drives the lying function, one the standing function, the third the extension of the leg support during posture change between lying and sitting. DC (Direct Current) driving motors need speed control, so a motor driving circuit is added to the control system. Three linear motors need no speed control, so they can be controlled by electronic switch. To improve the control system, a monitoring module is added to it to monitor the status of the wheelchair real-time, and composes a closed loop control. In addition, a voice control module is added to the wheelchair to make it possible for users to control without other people's help. The overall control system structure of multifunction electric wheelchair is as shown in Figure 3.

2) Voice module

In order to enable patients with severe disabilities to control the wheelchair without help of others, voice control is used to operate the wheelchair. Design of the voice module includes hardware design and software design. There is no special requirement for language of voice control and it can be English, mandarin or any native dialect. Pronunciation in use should be as close to the pronunciation when training the system as possible. Volume can be adjusted according to the distance between user and microphone. Volume should be turned down when speaking near microphone.

a) Hardware design of the voice module

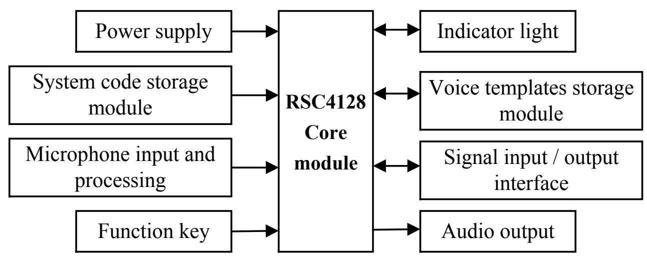

Figure 4. Composition of the voice module.

The composition of the voice module is shown in Figure 4. Accumulator voltage is 24V, and is reduced to 6V by DC-DC (Direct Current to Direct Current) convertor, finally reduced to 2.4-3.6V which is the operating voltage of RSC4128 speech recognition processor. The program code of RSC4128 speech recognition processor is stored in an external flash memory, a flash programmer runs it through the downloading program to the system code memory module. Speech templates of a particular user for recognition are recorded and coded through the execution of a program by RSC4128, and then stored in EEPROM (Electrically Erasable Programmable Read - Only Memory). SST39SF020 is used for the external flash of the system code storage module and 24LC128 is used for EEPROM for speech templates. Speech recognition module pretreats signals collected by the microphone and transmits signals to RSC4128 through an input interface. After processing, RSC4128 communicates with MCU (Micro Controller Unit) module through the output interface, telling MCU module to execute corresponding commands. The speaker acts as an audio output, making a notification sound when training and usage. In addition, I/O (In/Out) port pins are also added to the speech recognition module to debug and reset the circuit.

This enables the module to have the function of reset and communication [18].

In the wheelchair driving control system, differential controls of the two driving wheels are made through the analog voltage of x and y directions from the joystick, enabling the wheelchair to move back and forth or make turns. Output of the speech recognition module is a digital signal. However, output of the joystick is an analog voltage signal. So a DA (Digital to Analog) converter module is added to MCU control module to convert the digital signal into an analog signal. The structure composition of MCU control module is as shown in Figure 5. MSP430f149, designed by Texas Instruments, is used as the processor of MCU control module, and PCF8591 is used in DA module.

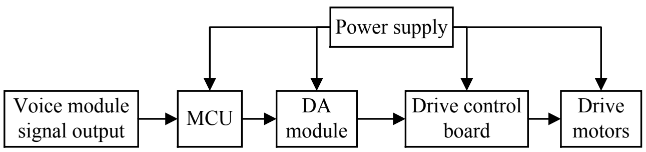

Figure 5. Structure composition of MCU control module.

The control circuit of linear actuators is an integration of voice control and key control, and the structure is shown in Figure 6. AT89S51 is the microcontroller chosen for MCU control. The DC-DC convertor and LDO (Low Dropout Regulator) provide power to the microcontroller and current detection circuit by reducing the accumulator voltage from 24V to 5V. The current sensor ACS712 is used in the current detection circuit. Motor control will be disconnected when motors are overloaded. Control signal circuit outputs the control information, which processed by the AT89S51 microcontroller and controls the linear actuators. NPN (Negative-Positive-Negative) Darlington transistor matrix ULN2803A is used in output signal control circuit [18].

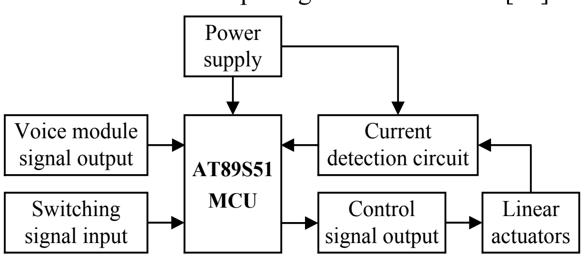

Figure 6. Structure of control circuit of linear actuators.

b) The software design of the voice module

Software design of speech recognition module is written in C language, and assembled using Phyton Project-SE which is provided by Sensory. Software can be divided into a speech training part (Figure 7) and a speech recognition part (Figure 8). Before using it, the user should train the system and store voice command in the storage module of the speech template. After the speech recognition module detects the voice command of the speaker in use, it will compare the command to the templates. If they match closely, recognition will be successful and the result will be transmitted to the control system through the signal output interface. The control system will execute commands corresponding to the identification of results.

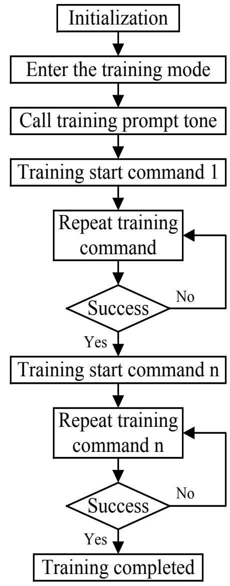

Figure 7. Structure of speech training part.

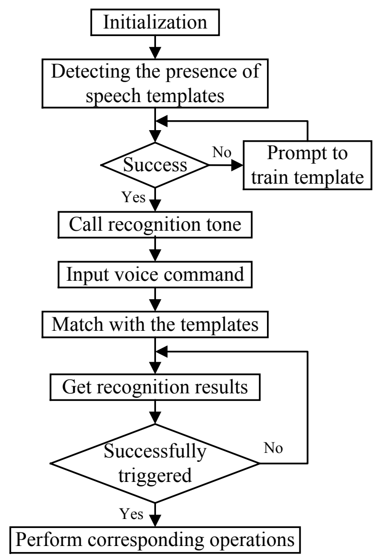

Figure 8. Structure of speech recognition part.

3) Control system experimental test

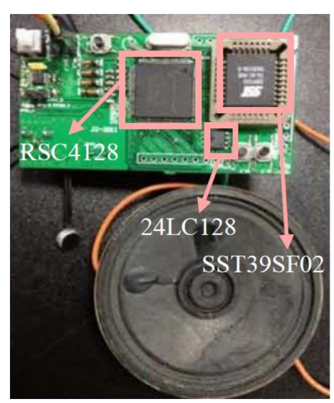

Figure 9. Speech recognition module.

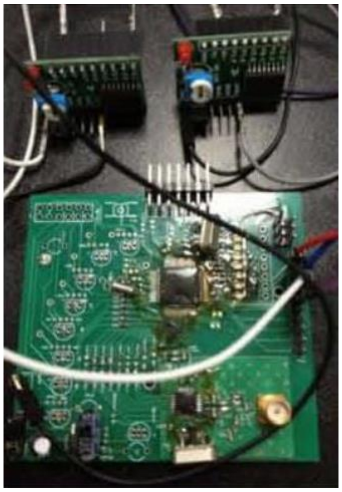

Figure 10. AD module for driving control.

All the movements of the wheelchair including standing, lying down, forward, backward, turning left, turning right and stopping are controlled by voice. Since the processing of the wheelchair prototype is not yet completed, the voice control experiment was done on an experiment platform. Only posture change and wheelchair driving through voice control are tested in this experiment. In the experiment, an ordinary electrical wheelchair is used to conduct driving experiment and linear actuators are used to conduct posture change experiment. The speech recognition module, the AD (Analog to Digital) module for driving control and physical map for voice control linear actuator module are shown in Figure 9, Figure 10 and Figure 11.

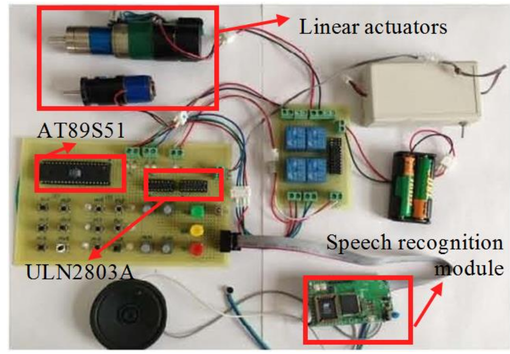

Figure 11. Physical map for voice control linear actuator module.

The voice module is connected to the driving motors and linear actuators in the experiment platform for the voice control test. The results are recorded after the experiment. In the first experiment, the subjects stood behind the wheelchair and did voice command training for ten functions in Mandarin, Cantonese and English. After that, the subjects commanded each function 50 times and execution results were recorded. The results are shown in Table I.

TABLE I. TEST RESULT OF VOICE COMMANDS ACCORDING TO DIFFERENT LANGUAGES

Language	Successful number of times/success rate	Different postures					Drive				
		Stand up	Lie down	Sit down	Stop	Reset	Go	Back	Turn left	Turn right	Stop
Mandarin	Number	50	50	50	50	50	50	50	50	50	50
	Rate (%)	100	100	100	100	100	100	100	100	100	100
Cantonese	Number	49	50	50	50	50	50	49	49	50	50
	Rate (%)	98	100	100	100	100	100	98	98	100	100
English	Number	47	48	48	50	48	50	49	47	47	50
	Rate (%)	94	96	96	100	96	100	98	94	94	100

TABLE II. TEST RESULT OF VOICE COMMANDS ACCORDING TO DIFFERENT PERSON

Subject	Gender	Successful number of times/success rate	Different postures					Drive				
			Stand up	Lie down	Sit down	Stop	Reset	Go	Back	Turn left	Turn right	Stop
A	Female	Number	50	50	49	50	50	50	50	50	50	50
		Rate (%)	100	100	98	100	100	100	100	100	100	100
B		Number	21	19	20	28	25	35	30	18	20	31
		Rate (%)	42	38	40	56	50	70	60	36	40	62
C		Number	18	16	18	25	24	33	34	21	17	30
		Rate (%)	36	32	36	50	48	66	68	42	34	60
D	Male	Number	0	0	0	1	0	2	1	0	0	1
		Rate (%)	0	0	0	2	0	4	2	0	0	2
E		Number	0	0	0	2	1	0	0	0	0	0
		Rate (%)	0	0	0	3	2	0	0	0	0	0

Under the premise of recognition rate guaranteed in the first experiment, we did specific speech recognition tests. First, subject A trained the system, then A, B, C, D and E did the voice command. Execution results were recorded. Among the five subjects, subject A, B and C are female, D, E are male. Finally, the recognition rate of five subjects were calculated, which are shown in Table II.

As can be seen from Table I, no matter what kind of language subjects used to train the system, recognition rates are above 94%. Therefore, the recognition rate of voice system has nothing to do with the language used. Users can select a language to train and control the wheelchair according to their preferences. From Table II we can find out that the system only recognizes well the voice commands of subject A and recognizes commands from subjects B, C occasionally. Voice commands from D, E were completely unidentified. We can conclude that voice system only recognizes voice commands from the trainer. For B, C, the reason for incorrect recognition is that their voices were probably very similar.

III. Discussion

Based on the existing mechanical structure of the multi-posture wheelchair, we designed the control system including hardware and software, which make it possible to control the wheelchair by voice. Performance and success rates of voice control have been verified according to the tests. The voice control tests indicate that the voice module can be applied well to the wheelchair, making it convenient for patients to use. In the following study, the voice recognition rate can be further improved.

IV. Conclusion

The proposed control system design is an important part of the project that we are conducting "development of a voice-operated multi-posture wheelchair". In our previous study the mechanical structure of the wheelchair have been finished. In this paper, the voice module realizes the control of posture transformation and driving. The next research steps will include the implementing of the wheelchair plan, improvement of its mechanical structure based on the prototype and the experience of the voice control system.

Besides, the voice module can be the basis for follow-up research of intelligent wheelchair navigation. Autonomous obstacle avoidance and automatic navigation of intelligent wheelchair can be achieved by installing an ultrasonic distance sensor to measure distance and an image sensor to capture terrain.

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