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A Novel Economical Embedded Multi-Mode Intelligent Control System for Powered Wheelchair

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***Abstract*—In order to assist different kinds of disabled persons and senior citizens, to lower the cost and improve the effectiveness and convenience of human-machine interaction, a novel economical embedded multi-mode intelligent control system for powered wheelchair is developed. The system is based on a high-performance 16-bit compact single chip system. It has "Manual", "Speech", "Vision", and "Autonomous" four modes that are fulfilled by four modules. The mode and the corresponding module can be customized according to the needs of different users and situations and that makes a further lower cost. In addition, fusion of multi-mode and other security measures are discussed. The hardware, software, control mechanism, and some experimental results are elaborated in the paper.**

Keywords- embedded control system; multi-mode human-machine interaction; intelligent wheelchair

I. INTRODUCTION

With the worldwide tendency of aging population and the increase of disabled persons due to diseases and accidents, there is an increasing demand for safe and economical vehicles with high performance and convenient communications, and this is becoming one of the mostly concerned social problems [1]. The economical intelligent wheelchair is an important vehicle for such application and is widely used, especially in developing countries. Usually the price of an electric wheelchair ranges from $1,000 to $2,000. The intelligent control system should not cost too much so that normal people can afford to purchase it. Many different approaches have been proposed to improve the intelligence of human-machine interaction for powered wheelchairs[1-8]. Qadri and Ahmed [2] and Simpson and Levine [3] carried out researches on voice interactive control of powered wheelchairs based on DSP and laptop PC systems. Ko et al.[1] developed an experimental platform based on a laptop, it can enable the user to control the wheelchair using mouth shape and face movement. Based on a personal computer, Ivanchenko et al.[4] proposed an intelligent control system for visual navigation of wheelchairs. In paper[5], the intelligent wheelchair power assistance and visual navigation control systems were proposed. Fattouh and Nader[6] reported a wheelchair control system for obstacle avoidance based on the PC in a simulated environment. Some other system were proposed based on the laser sensors[7] and single-chip system with ultrasonic sensors[8]. Most of these systems are primarily aimed at a certain group of consumers, and they are too expensive to normal people.

In this study, we try to build an inexpensive intelligent wheelchair for people with limited budget. We propose a novel multi-mode embedded control system based on a 16-bit single chip system. Compared with the laptop or personal PC based systems, the proposed system has lower cost and more compact size. Fusion of multi-mode guarantees a safer running condition of wheelchairs and a more friendly interaction of human-machine. The multi-mode interactive control strategy is suitable for different users and different situations. The mode and the corresponding module can be customized according to the specific requirements of certain users or situations to further lower the cost of the entire system. The total increased cost of our system is about $80. In contrast, the increased costs of other intelligent systems are usually over several hundreds.

II. STRUCTURE OF CONTROL SYSTEM

The prototype of the multi-mode interactive intelligent wheelchair (MiiChair) is based on a Foshan electric wheelchair of FS110A. As shown in Figure 1, the MiiChair control system consists of the following parts: (1) a multi-mode embedded control system (MECS), (2) a former controller, (3) sensors of ultrasonic, visual and speech. The MECS system is based on a high performance 16-bit single chip system (SPCE061A), together with some peripheral functional modules that are the foundation of smooth communication between users and the chair. The structure of MECS is shown in Figure 2, where EI stands for Environment Information, RSI for Running Status Information, and CI for Control Information. A vision navigation module is adopted to realize the visual interactive mode (VM). Under this mode, the wheelchair can track along a marked line, stop with stopping identifiers and complete the planed route. This mode is designed for the special situations such as airports, stations, hospitals, museums, and exhibition halls, etc. Speech control module is used to realize the speech interactive mode (SM). Under this mode, users can communicate with the wheelchair through a microphone and earphone or sound-box. Currently the embedded system is trained based on the host of the chair. For a new user, the commands can be trained again and stored in the system. The training process can be easily performed by pressing the "Command Training" button on the controller panel. This module is designed for patients with spinal injuries and persons who can not use joysticks. The MiiChair can run freely with automatic obstacle avoidance under the autonomous mode (AM) in some environments, such as indoors, squares and yards of home and hospitals. The detection function of the autonomous mode can also act as safe security when the chair is running under other modes. Furthermore, the intelligent interactive modes can provide additional funs to normal elder users, and enrich their daily life. Manual operation mode (MM) is the basic control mode of the intelligent wheelchair. The wheelchair is controlled by a joystick under this mode, which is the natural control mode of a powered wheelchair. Thus it is reserved and has the first priority to control. You can control the wheelchair whenever you move the joystick, even it is running under other modes. For a further security concern, an “emergency switch” is designed to cut off the power supply in emergency situations. The brake will engage when the power supply is off.

Figure 1. Multi-mode interactive intelligent wheelchair

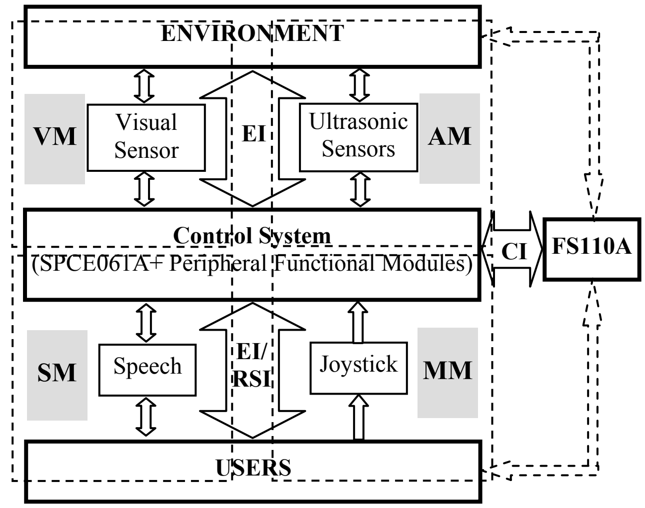

Figure 2. Structure of multi-mode embedded control system

III. FUNCTIONAL MODULES

A. Speech Control Mode and Module

The structure of speech control module is shown in figure 3, which includes earphones/sound-box, microphone, speech processing module, and the public hardware platform (PHP). The PHP platform consists of SPCE061A, D/A module, and FS electric wheelchair platform, which is shared with other modules. The speech processing module consists of both hardware and software, which functions as data acquisition of voice, data processing, command recognition, and result output. A complete speech command process, as shown in

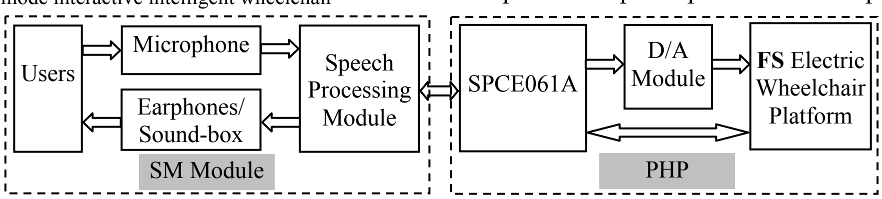

Figure 3. Structure of speech interactive module

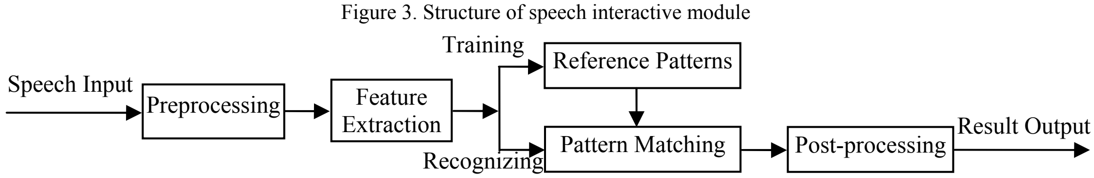

Figure 4. Speech command process

Figure 4, includes several procedures: Data preprocessing, feature extraction, training process, command recognition and result output etc. The function of the training process is to obtain the reference patterns of the real speech commands which will be stored in the system with typical parameters. The recognizing process is to match the user’s voice commands to the reference patterns and give the correct command, then output to PHP (a D/A module) to control the motion of the wheelchair. In addition, the speech processing module can also report the environmental information to the user. A real experimental picture of the MiiChair running on speech interactive mode is shown in Figure 5.

Figure 5. Experiment on speech interactive mode

B. Visual Navigation Mode and Module

The structure of visual navigation module is shown in Figure 6, which includes visual sensor, image processing module, control and decision module, and PHP. The visual sensor is a CMOS camera which is fixed on the crutch underneath the cushion, as shown in Figure 7, according to the experimental result of vision field. There are two lights beside the sensor to assist the visual navigation running at night or in dark environment. Image processing module performs line and frame scanning of the vision field, and some related computation. Decision and control are made by the control and decision module in PHP to control the motion of the wheelchair. The control is based on the deviation between the center-axis of the marked line and center-axis of the wheelchair. A fuzzy control strategy is adopted according to the value of the deviation. One image of the vision field is shown in figure 8. MiiChair running on visual navigation mode in different light conditions is shown in Figure 9 (Left: bright; Middle: dark; Right: less bright). When there are no marked lines or it meets the stop-signs, the wheelchair will stop automatic and give corresponding voice hints to the user.

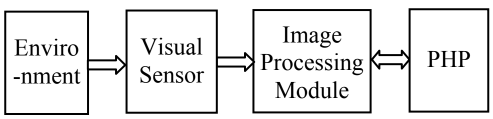

Figure 6. Structure of visual navigation module

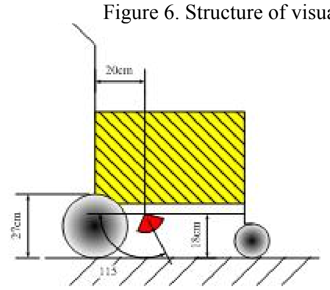

Figure 7. Position of visual sensor

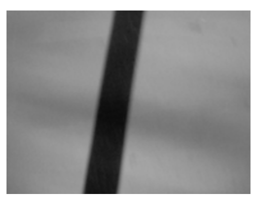

Figure 8. A vision field image of visual sensor

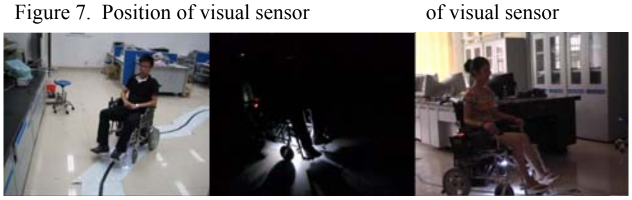

Figure 9. Visual navigation mode running in different light conditions

C. Autonomous Running Mode and Module

The structure of autonomous running module is shown in figure 10 which includes ultrasonic sensors, multi-channel analog switch, ultrasonic emitting/receiving module (E-module/R-module) and PHP. Ultrasonic sensors are used to detect obstacles around and pits ahead according to the echo waves, the time of flight and the speed of sound. Distance measuring of the ultrasonic sensors and partial control strategies on the autonomous running mode of MiiChair are demonstrated in Figure 11. Dead zone (Blind distance) is the distance that can not be measured by the ultrasonic sensors because it is too short. Security threshold is the distance that guarantees the chair running safely. When distance between the chair and the obstacle is less than the Security threshold, the control system will force the chair to stop and give voice hints to the user. Far-off distance is the far distance that the sensors can measure and it is also set concerning the chair running speed and the processing time of MCU. When the distance of the wheelchair and the obstacle is between the Far-off distance and the Security threshold, the control system will make decisions of turning direction and angle based on a fuzzy control strategy of the obstacle information detected by different ultrasonic sensors. The distribution of the sensors is shown in Figure 12 (2: front direction; 6: back direction; 1: left-front direction; 3: right-front direction; 4: left direction; 5: right direction; 7: front section of left wheel; 8: front section of right wheel). Sensors of 1, 2, 3, 4, 5 and 6 are used to detect the obstacles; Sensors 7 and 8 are used to detect the pits. Some indoors experiments of autonomous running mode are shown in Figure 13. Even in narrow space and corners, the MiiChair can run through and out successfully as shown in Figure 14.

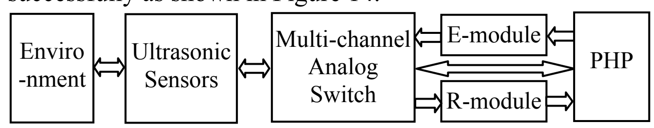

Figure 10. Structure of autonomous running module

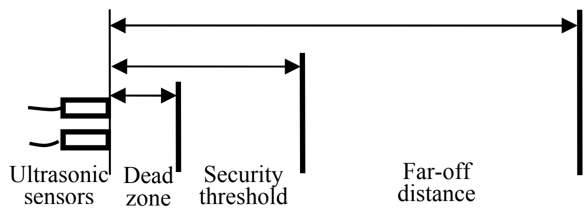

Figure 11. Distance measuring of ultrasonic sensors

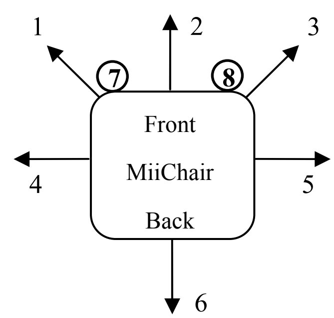

Figure 12. Distribution of ultrasonic sensors

Figure 13. Indoors experiments of autonomous running mode

Figure14. Indoors experiments of autonomous running mode in corner

IV. FUSION CONTROL STRATEGY AND SECURITY MEASURES

Some security measures are considered to further improve the effectiveness and fluency of interaction by the multi-mode method. The flow of the MiiChair control process is like this. When the power is turned on, the system is firstly initialized. Then it enters in the status of speech command waiting. The user can either give a speech command to select a running mode of the wheelchair or manually select a running mode by pressing a button on the controller. After initializing you can simply move the joystick to enter into the manual operation mode and to control the wheelchair at any moment even it is running under other modes. After entering one running mode, the wheelchair will be controlled accordingly by the mode's control strategy. During the process there are several security measures and fusion control strategy are designed.

(1) Manual operation mode has the first priority to control. It is in accordance with the reaction of the normal users when facing emergency situations according to the experiments. The wheelchair will switch into manual operation mode whenever you move the joystick.

(2) Multi-mode fusion control strategy is designed. (a) Environment detection of autonomous mode and speech hints of speech mode can be used at the same time in other running modes. (b) When the wheelchair is running, the distance measuring function of autonomous mode is on, even in manual operation mode. When there is a pit ahead or the measured distance is less than the security threshold, the wheelchair will be forced to stop. And the speech system will "report" the information to the user.

(3) An "emergency switch" is designed as an additional security measure. In case of emergency, it will cut off the power supply and the brake will engage and force the wheelchair to stop.

In the following we will give several real experiments of fusion control. Figure 15 is the experiments of speech fusion mode with autonomous obstacle detection function (Left: There is an obstacle behind the wheelchair when moving backward; Right: There is a pit in front of the chair when moving forward). Figure 16 is the experiments of visual navigation fusion mode with autonomous obstacle detection function (Left: There is an obstacle in front of the wheelchair when moving forward; Right: If the wheelchair can not find the marked line, it will stop automatic). They all combine with the voice hint function of speech mode, and can report the situation information to the user. All the experiments are carried out successfully.

Figure 15. Experiments of speech interactive fusion mode

Figure 16. Experiments of visual navigation fusion mode

V. SUMMARY

In this paper, we developed an economical embedded multi-mode control system for intelligent wheelchairs. The system has the following main features.

(1) The system is based on a single chip system. That makes the system more compact and cost lower compared with the systems based on a PC, laptop, or DSP.

(2) We can integrate the speech command, vision guidance, manual operation, and autonomous running four modes into one economical system. It improves the effectiveness and fluency of human-machine interaction for different users and different situations.

(3) The functional modules can be customized according to users and working situations. The customized control system is more compact and cheaper.

(4) Each mode of the system has the function of security and voice-hints. It improves the reliability of the system and friendliness of interaction.

(5) The design of the intelligent modes can provide entertainment for normal elder users.

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