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An Embedded Control System for Intelligent Wheelchair

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Abstract— **Due to recent advancement of AI and robotics technology, the research of intelligent wheelchair (iWheelChair) begins to draw attention from both scientific community and industry. iWheelchair is a kind of home welfare tools and can help the handicapped and elderly people to gain mobility and lead to independent life. This paper describes a newly developed intelligent wheelchair. The controller of the iWheelChair adopts the advanced DSP technology, and plays the role of data acquisition and processing of joystick and ultrasonic sensors. 8 ultrasonic sensors are mounted on iWheelchair and can detect the environment changes for safe operation. Experiments are presented to show that iWheelChair is able to avoid obstacles autonomously while controlled by its user via the joystick.**

I. Introduction

Intelligent robots are currently developed to help disabled and handicapped people at a high speed, and will be a certain key area in the next 10 years. Since the average age in our society is increasing notably in recent years (Huaqing He et al, 2003), the number of people with severe motion impairments is increasing. The expenditure for health care and nursing is becoming a big burden for our society. On the other hand, the nursing staff is continuously reduced by the government and health authority in order to cut the cost. Therefore individual healthcare is becoming more expensive than before and people with medium and lower income are unable to afford such service.

Intelligent wheelchairs, as a kind of rehabilitation robots, play an important role in helping the handicapped and the elderly people to live more independently at home and have a low cost on their healthcare. By equipping a wheelchair with an intelligent controller, the control of the wheelchair is shared by the user and the controller. The user performs the global planning by indicating to the wheelchair where he wants to go; the wheelchair avoids dangerous obstacles and performs local planning autonomously. As a semi-autonomous robot, iWheelChair has the responsibility of providing autonomy to its users.

Various research projects on intelligent wheelchair have been executed in the last decade, such as Wheelesley (Holley, H.A, 1995), NavChair (Simon P.Levine et al,1999), the TAO projects (T. Gomi and K. Ide, 1996), SIAMO (M.Mazo et al, 2002), Rolland (Thomas Rofer and Axel Lankenau, 1999) (Axel Lankenau et al, 1998), Maid (Erwin Prassler et al, 1998) and so on. However, all of these projects only represent the outgrowths of mobile robot research and few have made the transition to a commercial product.

The motion control of most intelligent wheelchairs normally relies on a laptop computer as the central controller, and with the help of multiple sensors such as a ring of sensors (ultrasonic sensors, infrared sensors, etc) or cameras. Obviously, this kind of structure is effective in doing some specified research, but it is not proper for a commercialized product. In 2003, the sale of iBot wheelchair (Independence Technology, 2003) was authorized by the Food and Drug administration of United Sates of America. The iBot wheelchair uses sensors and gyroscopes to climb up and down stairs. It can also lift its occupant to standing height. To some degree, iBot wheelchair is unable to autonomously navigate in the real world.

In this paper, we develop an intelligent wheelchair, namely iWheelchair. A DSP device is adopted as the center processor of the controller, 8 ultrasonic sensors mounted around the iWheelchair for obstacle detection. The system is low-power consumption and high computation performance with comparison to that on Windows, which is very competitive in the commercial market as a product.

The rest of this paper is organized as follows. Section II describes its hardware architecture of iWheelchair that has been recently built In Section III the development of the control software of the system is described. The experiment setup and results of our iWheelchair are outlined in Section IV. Finally, a brief conclusion and future research are summarized in Section V.

Fig. 1 iWheelchair built at IAS, Beijing

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II. HARDWARE STRUCTURE

A. Mechanical structure of iWheelchair

Fig. 1 shows the mechanical structure of iWheelchair, which is similar to a commercial power chair and is driven by its two differentially-driven wheels. In order to deal with uncertainty in the real world, it is equipped with 8 ultrasonic sensors for obstacle avoidance.. Instead of using an x86 CPU and Windows operating system, a DSP (digital signal processor) based embedded control system is developed for the iWheelChair. The hardware architecture of the controller is shown in Fig. 2.

B. Architecture of control module

A DSP chip TMS320LF2407 (Heping Liu et al, 2002) from TI Corp is used as the core processor of the control module. Note that all the circuits for iWheelchair control are integrated on a single board.

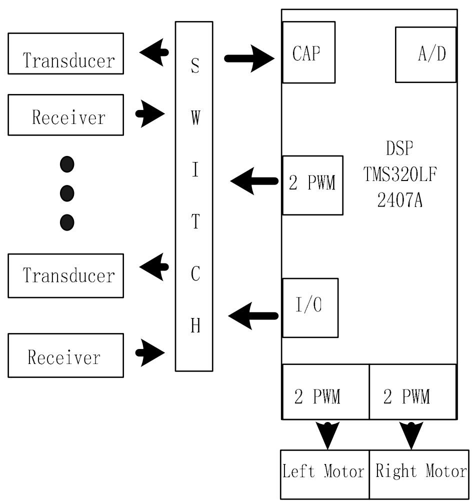

Fig. 2 Hardware configuration

As a member of the TMS320C24x generation of TI DSP chips, TMS320LF2407 offers high-performance processing capabilities (30MIPS) and a high level of peripheral integration. The high-performance 10-bit analog-to-digital converter (ADC) has a fast conversion time of 500 ns and offers up to 16 analog input channels. Its two Event-Manager (EV) optimized for digital motor control and power conversion applications provide sixteen 16-Bit Pulse-Width Modulation (PWM) channels. All of these functional modules make the system qualified with real-time information sampling and high performance driving control.

C. Sensor modules

Ultrasonic sensors are widely used in various kinds of mobile robots due to their properties of low cost, simplicity, easy installation and low energy consumption. Furthermore, the information from ultrasonic sensors can be processed in real-time easily provided that the processor is powerful enough. iWheelchair is equipped with 8 ultrasonic sensors which are fixed around the wheelchair at a height of 50cm. There are 4 sensors at the front, 2 sensors at the back, each one at the left and right.

Data acquisition and processing of the ultrasonic sensors are also done by the DSP processor. Making use of 8 ultrasonic sensors, the controller of the iWheelchair can obtain the environment information in real time and controls the speed of the wheelchair according to the pre-set strategy. All the processes are realized by software, so it is very easy to change the strategy with respect to the environment, which enhances the agility of the system.

D. Human-machine interface (HCIl)

The control device of iWheelchair is a standard analog Joystick. Through an A/D module, the controller obtains the control commands from the joystick. After a linear transformation and the judgment of environment information, the joystick commands are then changed into the speed and direction command to the controller.

III. SOFTWARE DESIGN

The control software of the iWheelchair is written by assemble language in order to achieve real-time performance. The system software comprises three modules, namely Main loop, Environment Information Processing module and HMI Processing module.

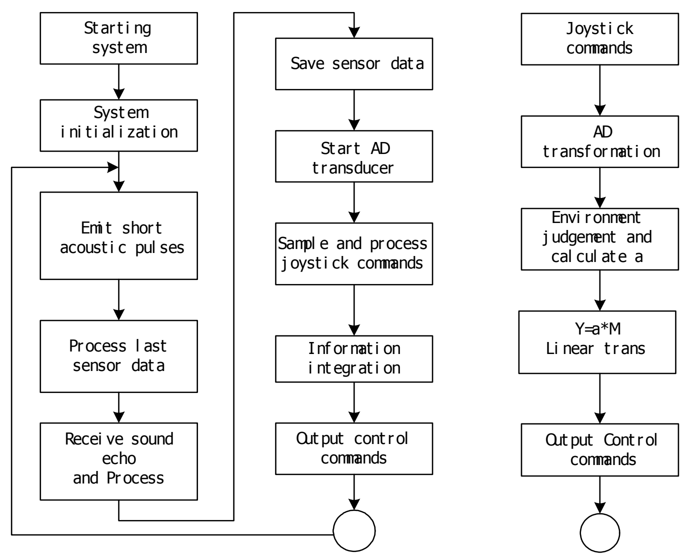

Fig. 3 Software design

A. Main loop

In the main loop, i.e. the left part of Fig. 3, DSP is responsible for the transmission and capture of ultrasonic pulses and the output of real-time driving commands.

First, after initialization, DSP chooses 2 from 8 ultrasonic sensors through analog switch and respectively emits a short acoustic pulse with 40 KHz frequency using its Pulse-Width Modulation (PWM) channels. Before the return echo is detected, DSP processes the last sensor readings. Although here the sensor readings are “outdated”, due to only 100ms cost once a main loop, it does not influence the real-time performance of the system and the judgment to the environment.

After the process of sensor readings, DSP enters a waiting loop for the return echo from the environment. If a return echo is detected or not detected in the specified amount of time, system will jump out of the waiting loop and then begin a delay program (20ms) that plays the role of noises avoidance from the environment. During this period, system starts AD transducer and read the position information from the joystick. With the information integration of sensor readings that has processed and the joystick commands the system controls the speed of iWheelchair in a safe range. After this, the main loop will be executed from the start again.

B. Environment information processing

In this module, ultrasonic sensor readings are processed and then the corresponding mode is set. Considering that the maximal detecting range of the ultrasonic sensors is 2m, the space around iWheelchair is divided into 4 modes according to the distance from the wheelchair, which are No-obstacle mode (above 2m), Detected mode (1m~2m), Approaching mode (50cm~1m), and Stop mode (0~50cm). More specifically, we have

- No-obstacle mode means that there is no obstacle around the wheelchair in the range of 2m. In this mode, the commands from the joystick are passed directly into the actuator module after the linear transformation, similar to a common power chair. The maximal speed is limited to 1.2m/s.
- Detected mode means that some obstacles are detected around the wheelchair, the speed of iWheelchair will be controlled according to the moving direction of the wheelchair and the position of the obstacle. The speed of iWheelChair will not be changed if it is not moving toward an obstacle. But if an obstacle is detected in the moving direction of iWheelchair, its speed will be decreased smoothly and the maximal speed will be limited to 0.8m/s. When iWheelchair moves more closely to an obstacle, the mode will be changed to
- Approaching mode, i.e. the maximal speed of iWheelchair will be reduced to a smaller value (0.4m/s).
- Stop mode sets the iWheelChair speed to zero in the direction that the obstacle appears. At this time, any joystick commands to drive iWheelchair toward the direction of obstacles will be omitted.

Therefore, in open areas, iWheelchair is in a free-driving mode and the controller does not affect the instructions of the user. While in a narrow space, the controller will regulate the speed with regard to the remaining distance to the closest obstacle.

To avoid a sudden change of the iWheelchair speed, which will make the user feel uncomfortable and sometime will be dangerous, speed commands to the driving wheels are generated by linear interpolation when the driving mode is switched from one to another.

Experiments have shown that the control strategy described above can not only guarantee the agility of operation with the joystick, but is also very effective to control iWheelchair in a safe range.

C. Human-machine interface

The human-machine interface (HCI) of iWheelchair is a standard analog joystick. In order to control the movement of the iWheelchair correctly, the driving signals to the two driving wheels must be in accordance with the position command from the joystick exactly.

Define the position of the joystick as the coordinate of x and y axis, a linear relationship between the position of the joystick and the driving signal to the two driving wheels can be built respectively.

The relationship between the position of the joystick and the two driving wheels can be described as:

$$(V_l, V_r) = a \bullet (X, Y)$$

where (X,Y) represents the position of the joystick (Fig..4), (V_l, V_r) is the speed values of the wheels, and a is the coefficient of the linear transformation.

By setting speeds for two wheels respectively, iWheelchair can move in all direction under the differential control of the two wheels.

Tthe position of the joystick is divided into four parts shown in Fig. 4, which corresponds to four directions. After sampling the position information of the joystick, the system judges which part the joystick is in and then combines the sensory information to decide the maximal speed of iWheelchair. The whole process flow of HMI is shown in the right part of Fig. 3.

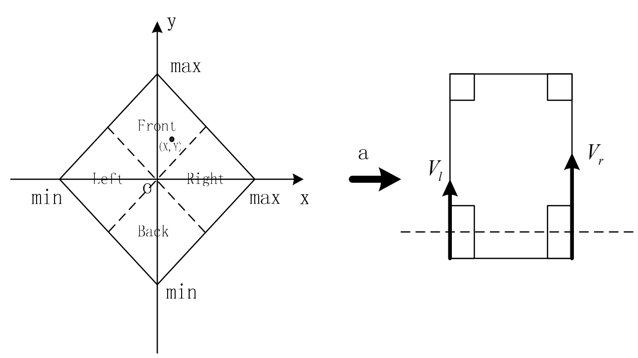

Fig. 4 Linear transformation of the joystick

IV. EXPERIMENTAL RESULTS

To test the effectiveness of the developed system, an experiment is designed for iWheelchair. An obstacle is put in the center of the room, as shown in Fig. 5(a). When the user is driving the iWheelchair toward the obstacle and the distance between iWheelchair and the obstacle is in a range of 2m, the controller of iWheelchair is set to *Detected* mode (the maximal speed is 0.8m/s) automatically, as shown in Fig. 5(b). When iWheelchair is approaching to the obstacle, its speed will be decreased again and the control mode will

Fig. 5 A sequence of experiments: (a), (b), (c) are at the top level (from left to right); (d),(e),(f) are at the bottom level

be switched to *Approaching* mode and the maximal speed is limited to 0.4m/s. Under the same command of the joystick, the speed of iWheelchair will be decreased continually until it enters the Stop mode and finally stops, as shown in Fig. 5(c). In this way, iWheelchair is able to stop before the obstacle so that to avoid a possible collision with the obstacle.

As we can see from Fig. 5(d) at the lower corner of Fig. 5, our iWheelchair turns away from the obstacle being detected by ultrasonic sensors, and then navigate in the room continuously, as shown in Fig. 5(e) and Fig. 5(f).

It has been proved by the experiments that the user of the iWheelchair can be very relaxed and do not need to worry about the possible collision with the environment, which often occurs for the users of a common wheelchair. The only thing the user needs to do is to give the moving direction command by the joystick to iWheelchair.

V. Conclusion

This paper describes the hardware architecture and control strategy of a newly developed intelligent wheelchair, iWheelchair. Based on the DSP techniques, the controller of iWheelchair is quite compact and has a good performance and real-time response. Our iWheelChair has a high performance-price ratio and is competitive in the commercial market.

In the future work, more functions, such as door-passing, wall-following, etc. will be developed in order to make iWheelchair fully autonomous and adaptive to environment changes. Also, multi-mode communication will be used for users to control iWheelchair via voice, hand gesture, facial expression and head movements. In this way, the user of iWheelchair will be able to focus on high-level tasks such as shopping and going home, and the iWheelchair motion is controlled by the DSP based controller autonomously.

Acknowledgment

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