

Development of a Safety Driving System for Electric Wheelchair

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Abstract

The electric wheelchair controlled with a joystick has become an important form of transportation for severely disabled-people. The wheelchair can be operated easily at any speed and in any direction by tilting the joystick to certain angles and directions. But some accidents involving the joystick-type electric wheelchair may occur as, for example, unintended movements of the joystick are caused through involuntary movements by users with disabilities. Accordingly, some differences are found between how the joystick is operated and how the joystick actually moves; thus training is required for beginners among joystick users. Difficulty in using the joystick causes operational errors because the user feels stress caused by its operation while controlling the wheelchair. These types of accidents have been occurring intermittently. Aiming to solve such problems, research and development of an automatic-driving device has been conducted in order to secure safety in driving electric wheelchairs. But so far research has not been conducted into developing an operation-assist device. This type of device can be loaded onto an existing electric wheelchair as an additional device in order to prevent driving accidents, while keeping the additional cost very low. The device in this study was developed and was loaded onto an existing electric wheelchair so that the safety of users of existing electric wheelchairs can be easily assured while at the same time the cost is kept low. The number of electric wheelchairs has already amounted to about 100,000 in Japan. To achieve the aim, a method of measuring a distance by using ultrasonic waves is applied in order to develop a device which can automatically prevent the electric wheelchair from crashing into walls on the left and right sides of the wheelchair. Movements of the wheelchair in forward and back directions are controlled according to the driver's intention. Experiments conducted by using an electric wheelchair loaded with the newly designed device have verified that the wheelchair can drive safely while automatically detecting walls on the left and right sides of the wheelchair and other obstacles.

Keywords

electric wheelchairs, ultrasonic sensor, joystick, safety, automatic control

1. INTRODUCTION

The operation mechanisms of the currently-sold electric wheelchairs can be divided into two types: a joystick-type wheelchair and a scooter-type operated by a handle. The joystick-type electric wheelchair is equipped with levers which move in lengthwise and crosswise directions, and rheostats are connected thereto respectively. The wheelchair can be moved in any direction by tilting the joystick to certain angles and directions. But it is not common to use a joystick as a way to control a transportation device, and thus the operation of a joystick takes getting used to. Otherwise, there are some dangers of operational errors, which include an accident through increasing speed although the driver's intention is to stop the wheelchair in an emergency situation. Careful control is necessary when the wheelchair is traveling or avoid-

ing obstacles on roads. Furthermore, long-time operation of the wheelchair may cause fatigue for the driver and this could cause new or secondary problems.

As the number of electric wheelchairs has increased, the number of wheelchair-related accidents has also increased [National Police Agency, 2003]. Various kinds of causes can be attributed to the accidents. For example, involuntary movements caused by the disabilities of the driver may cause unintended ways of operating the joystick. This can direct the wheelchair in unexpected ways and this in turn can result in crashing the wheelchair into people or objects. The electric wheelchair is very often the only means of transportation by which disabled-people can keep their independence. Thus, how safely they can travel in the wheelchair is closely related to how much they can participate in society, and revision of the safety of wheelchairs is urgently needed.

Current actions taken in developing safety devices of a built-in type for electric wheelchairs include: the "Intelligent Electric Wheelchair" [Nawai, 2007]

which can assure the safety of drivers by analyzing the information in all directions around the wheelchair using stereo cameras which are built into the wheelchair; and, the “Development of a collision-warning device” [Nawai and Futami, 2006] which uses Intelligent Transport Systems (ITS) for pedestrians, in order to prevent a collision between electric wheelchair and cars. [Sato and Sakagami, 2006; Murota *et al.*, 2007; Sato and Sakaue, 2007; Oda and Shimizu, 2006; Hs-yashi, 2002, Kurozumi and Yamamoto, 2006; Komiya *et al.*, 2001; Mizuguchi *et al.*, 2008] These developments may be applied to new electric wheelchairs, but the cost will be much higher than for existing electric wheelchairs, and thus they are unlikely to be used widely. In other words, such a complicated method will not help the actual spread of safe electric wheelchairs.

Detecting obstacles on roads before accidents happen and altering course automatically to avoid the obstacles are a highly valid method for increasing the safety of transportation of electric wheelchairs. A method where the driver of the wheelchair controls only the speed in forward and back directions while the movements of the wheelchair in right and left directions are controlled automatically seems to be the most suitable way when developing a device which can be added to the existing electric wheelchair and which has the necessary functions. Based on this assumption, a control method was developed so that the distance between the wheelchair and obstacles is detected and the distance is kept constant. More specifically, the principle of measuring distance by ultrasonic digital means was used for developing a device which makes it possible for the electric wheelchair to move safely while keep-

ing a certain distance from walls. This paper describes the results of the development. A method using ultrasonic waves for distance measurement has been developed to prevent collisions of robots into a wall. [Ishihara *et al.*, 2009] According to the method, two ultrasonic sensors are loaded on one side of the robot, and the robot moves parallel to the wall according to the two sets of data about the distance between the wall and the robot. In a case where the wall is parallel to the direction of movement of the wheelchair, the wheelchair can keep moving parallel to the wall based on the data obtained from two sensors as long as a certain distance is set as the control target. But, in a case when the wall appears as convex, sensors which are placed parallel to the wall can not prevent the wheelchair from colliding with the wall and the control of the wheelchair becomes complicated. With the method described in this paper, a simple control of the wheelchair has become possible which eliminates the possibility of collisions by measuring the distance between the wheelchair and walls or obstacles ahead with one distance-sensor. The principle and method are described in detail below.

2. PRINCIPLES FOR A SAFETY DEVICE FOR TRANSPORTATION

In the method using two distance sensors placed on one side of a wheelchair, the wheelchair can move parallel to a wall on its right or left side by keeping a certain distance from it. This is possible by eliminating the difference between the distances indicated by the two sensors. The method in this paper—unlike this method described above—can make a wheelchair move parallel to a wall by using one sensor which is

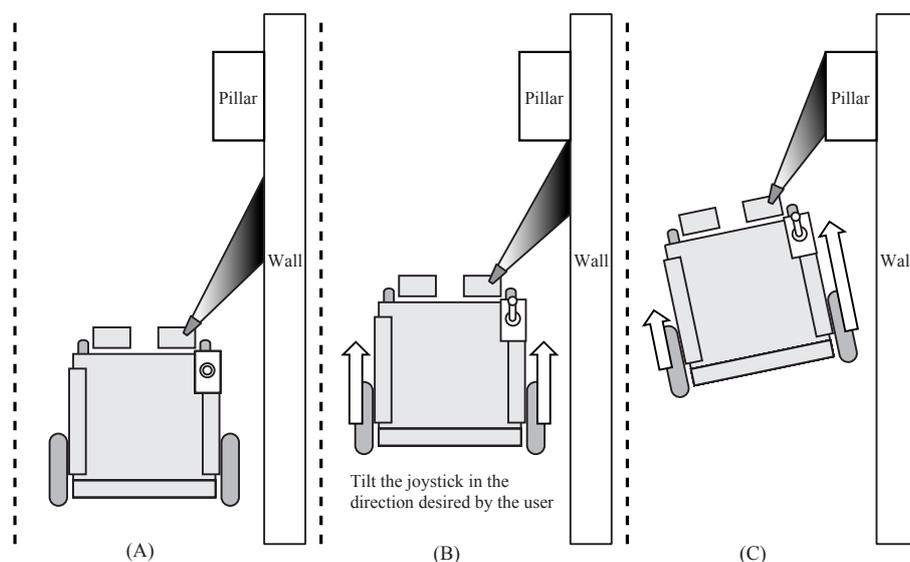


Fig. 1 The electric wheelchair can move forward avoiding obstacles, with the help of two ultrasonic distance sensors placed one on each side of the wheelchair.

placed on the side of the wheelchair, as shown in Figure 1. This is made possible by measuring the distance between the wall and the wheelchair using ultrasonic waves, which are emitted from a fixed angle in an oblique direction to the direction of movement. In order to keep the distance measured constant, the two driving wheels of the wheelchair are rotated differently. The speed of the wheelchair in forward and back directions is controlled by the driver by operating the lever of the joystick. The system described in this paper aims to prevent the collision of the wheelchair with walls on both sides of the wheelchair as well as with obstacles ahead, while the travel speed of the wheelchair remains controllable by the driver.

The front wheels of the electric wheelchair are on casters without driving force, while the rear wheels are controlled by the joystick and each wheel moves forward and backward independently from the other. This mechanism makes the wheelchair move freely from forward to back or from right to left. The joystick has two levers for controlling the wheelchair in forward-back and left-right directions. The rear wheels can be accelerated equally by tilting the control-lever for forward and back directions. Tilting the joystick to the left or right direction causes differential rotation in the rear wheels, and thus the wheelchair can be controlled. In order to move the wheelchair forward by keeping the distance from the wall constant, two different pressures of voltage should be placed in the amplifier for the joystick's left-right signals and, in this way, the distance measured by the ultrasonic sensors is kept equal to the set level. Figure 1 shows the principle described above. As the Figure shows, when the wheelchair moves forward, the ultrasonic sensor detects any obstacles ahead, like a pillar, in advance (Figure 1 (B)). As a result, the differential rotation of the rear wheels is set off in order to keep the distance measured between the wheelchair and obstacle equal to a set-up distance. In consequence, the wheelchair can move forward while avoiding the obstacle (Figure 1 (C)). In this way, the wheelchair can always move avoiding collision with obstacles.

Figure 2 shows the control system in detail. The Figure shows that the wheelchair moves forward while keeping a constant distance from the left-side wall. The distance between the wheelchair and the wall is measured obliquely by the ultrasonic pulse obliquely emitted. In order to keep the difference between the distance level and a set-up voltage zero, the signal processing circuit sends an appropriate output of differential rotation to both rear wheels. The system in this study is characterized by the feature whereby actions become possible using only one pair of the ultrasonic sensors, which are tilted forward at 60 degrees.

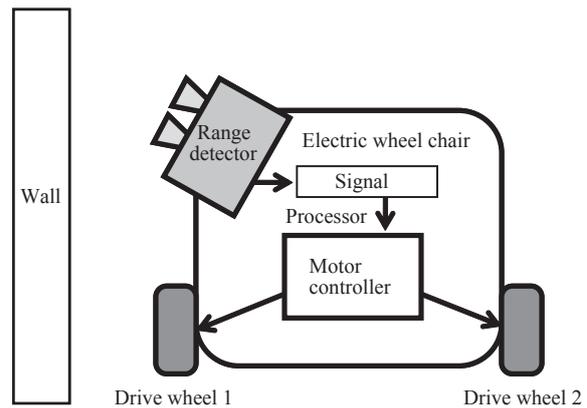


Fig. 2 The control method which makes the wheelchair move forward while keeping a certain distance from the wall is rendered possible by using the distance measured obliquely from the wall with the help of ultrasonic distance sensors placed obliquely on the wheelchair.

3. METHOD OF DISTANCE MEASUREMENT USING ULTRASONIC WAVES

A method of distance measurement using ultrasonic pulses was utilized for measuring the distance between the wheelchair and wall. As shown in Figure 2, this method consists of a pair of sensors, one transmitting and one receiving, for ultrasonic waves. The time lag between the rise of the transmitting pulse and the rise of the reflected pulse is measured as a distance.

Figure 3 shows the circuit for achieving analog signals for a control which is in proportion to distance. The propagation time of ultrasonic waves is measured between the time from the point when about 0.2 ms of ultrasonic waves are transmitted and to the point when they return to the receiving sensor after the waves are reflected off the wall. The number of oscillations of an oscillator which can oscillate only when the emitted ultrasonic waves are propagated was achieved by converting them to analog output in an integration circuit. The number of voltage oscillations is in proportion to the distance. Figure 4 illustrates the wave form of transmission (as lower trace) and the received wave form (as upper trace) of the ultrasonic pulse.

The actions of the circuit for distance measurement are illustrated in Figure 4. The transmitting pulse signal controls starts, stops and resets of the integrator, and it also resets the sample-and-hold circuit. Once the integrator is reset by input pulse, a positive pulse-signal applies the level trigger to the integrator composed of Resistor R1 and Capacitor C. At this point, the sample-and-hold circuit, which is composed of IC_{1B}, Condenser C and IC_{2B}, acts as a sample mode only when the input pulse-signal is high, and the output of the integrator is

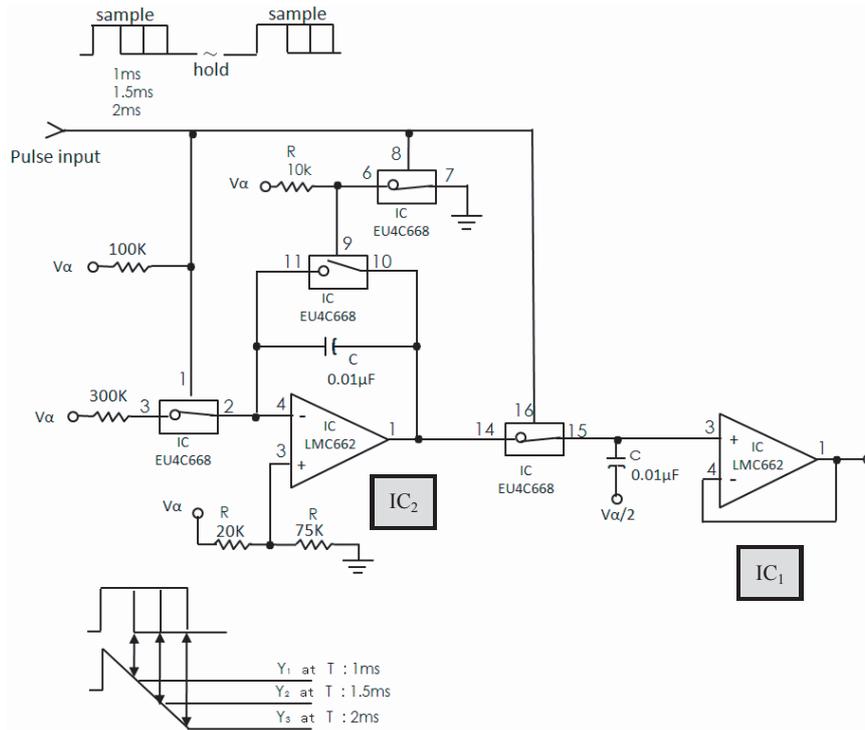


Fig. 3 The circuit to convert the number of voltage oscillations during the propagation of ultrasonic waves to a pulse width and then it is converted into analogue DC voltage (convert it to direct voltage).

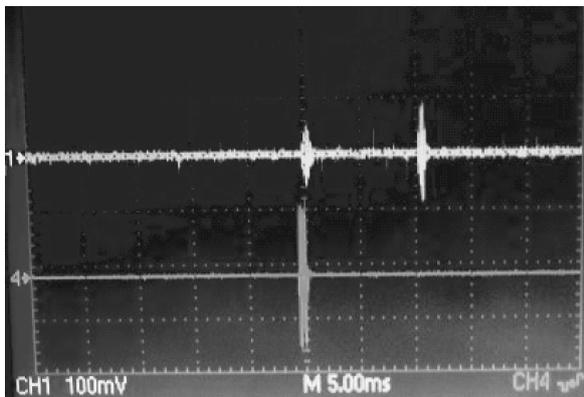


Fig. 4 An example of the ultrasonic transmitting pulse (lower trace) and receiving pulse from the surface of a wall (upper trace) in a distance measurement (5 ms/div).

taken as a sample. By doing this, the distance signal is continuously held and output, even when the transmitting pulse is not output.

4. EXPERIMENT IN DIRECTIONALITY OF ULTRASONIC ELEMENTS

4.1 Ultrasonic sensor

The ultrasonic-sensor distance-measurement is an important component in determining the performance of the device in this study. Besides the method of using an ultrasonic sensor, there is a method using a laser to measure distance. There is also a method to measure

distance at a wider-range of angle ahead by scanning the angle of a laser. [Hokuyo Automatic, 2009] Though the accuracy of these methods is certainly high, a complicated data processing system is required for gaining an appropriate distance-control signal, and thus it is impossible to apply the method to products where the goals are a low price and widespread usage. In contrast, the method of ultrasound distance measurement achieves a relatively broad width of ultrasonic beam with low directivity. But the broad beam-width has an advantage in that it can produce a stable and average measurement level where the distance between uneven objects, such as fences with gaps, and the wheelchair is measured, or when the measurement is conducted in crowded places. When the beam width is broad, the propagation pulse which reaches the receiving sensor earliest among the reflected waves is measured as a distance, based on the characteristics of distance measurement shown in Figure 3. That is, the shortest distance from the wall where irradiated by an ultrasonic beam with a broad width is measured. The ultrasonic distance measurement has the advantages of: (1) Measurement can be conducted under bright sunlight in daytime. (2) Measurement can not be influenced by dust or mist. (3) It can be done at a cheap cost. (4) Measurement can not be influenced by the color or softness of walls. (5) Distances can be precisely measured even if the targets are glass-made

or transparent walls. As for feature 5, the criterion for the occurrence of scattering action is decided by the ratio between the wavelength and the size of the object. The ultrasonic wave used is 40 kHz. The wavelength is about 7.5mm at room temperature. Thus, an object which is smaller than that length is not recognizable and collisions are unavoidable.

When ultrasonic waves are used for measuring distance, it is important to know the beam width of the ultrasonic wave in order to avoid collisions. In order to find a safety standard for such measurements, it is necessary to measure the beam width of the ultrasonic sensor, and thus measurement was conducted.

With the device in this study, the ultrasonic beam is emitted obliquely. The shortest distance between the wall—which is irradiated by the beam width—and the wheelchair is used as the set-up distance. Therefore, in general, the sensor does not simply measure distance, which is changeable according to the tilt of the beam. However, if there is an obstacle in front of the wheelchair, the distance measured is recognized as the shortest distance from the sensor and a safe measurement-value from the obstacle is provided. With the control system in this study, the wheelchair turns around or avoids walls or other obstacles by keeping the distance between the wheelchair and the obstacle constant, based on a set-up distance-value.

The center frequency of the ultrasonic sensor in this study is 40 kHz and this is the most common type. This sensor uses a piezoceramic as an oscillator, and the ultrasonic waves are emitted most effectively into the atmosphere when signal voltage is added, a curved oscillation is started, and the frequency of machinery oscillation and the frequency of signal voltage are coincided. Table 1 shows the specifications for the ultrasonic sensor used in this study.

Table 1 Specifications of the ultrasonic sensor

Center frequency	40 [kHz]
Sound pressure level	115< [dB]
Sensitivity	-64< [dB]
-6 dB Directivity	50 [deg]

The ultrasonic sensor has the characteristics of low directivity and detection of objects in a wide range. Generally, the reflected waves of the shortest distance are measured to know the existence of objects on a flat surface, and when the beam width is too broad, the distance from non-target objects is also measured; thus, a collision-avoidance system with an ultrasonic sensor can perform unstably. As a way to control the beam width, there is a method whereby a cone is at-

tached to the transmitting and receiving parts of the sensor. The ultrasonic sensor and its performance and characteristics were evaluated in experiments as basic data for designing the control system for the device in this study. The results of the experiments are as follows.

Directivity of ultrasonic elements used in this study was measured in cases both with and without resinous acoustic-cones. The results are shown in Figures 5 and 6. In the experiments, the ultrasonic elements for transmitting and receiving are placed at 2 m apart from each other in opposite positions. Then the transmitting element was turned around and it was placed with its face front, in order to measure and make comparison of the attenuation which is shown as [dB]. The acoustic cones used in the experiment are shown in Figure 7. The aperture of the cone has a diameter of 30 mm, the length is 65 mm and the angle of aperture is about 20 degrees.

It was found that, when an acoustic cone is used, the half width is about 40 degrees, and when the cone is not used, it is about 80 degrees. In reality, the shaft of the sensor is built into the wheelchair at 60 degrees, and thus 80 degrees for the angle of aperture is too broad. Therefore, it was concluded that the use of acoustic cones is more suitable.

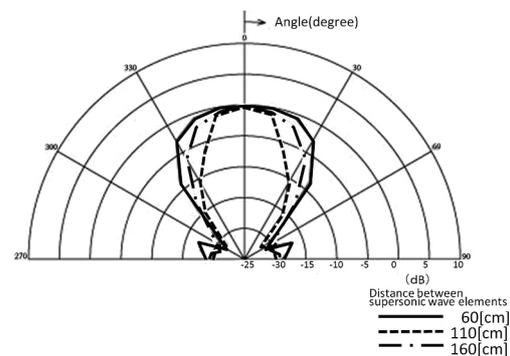


Fig. 5 Directivity of an ultrasonic sensor without a sound cone

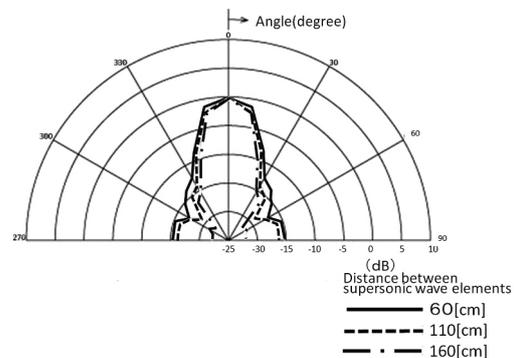


Fig. 6 Directivity of an ultrasonic sensor with a sound cone

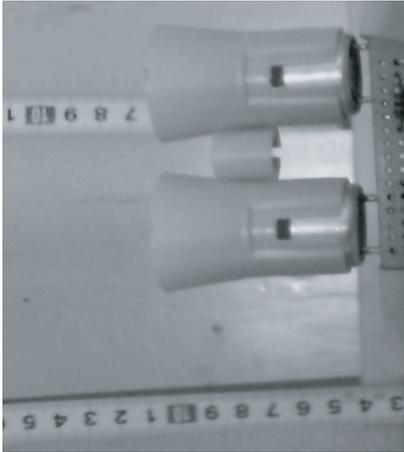


Fig. 7 A photograph of the acoustic cones attached to each transmission element and receiving element

5. CONTROL SYSTEM OF ELECTRIC WHEELCHAIR USING ULTRASONIC DISTANCE SENSOR

In the system for this study, the speed of forward and back directions is controlled by the driver of the wheelchair, and two ultrasonic sensors are used, placed one on each side of the wheelchair at a 60-degree tilt forward, in order to detect and to avoid walls or obstacles on roads. For this, the following methods were employed.

- (1) An ultrasonic distance sensor is used.
- (2) The distance from walls and the existence of obstacles on roads are detected simultaneously by ultrasonic pulses emitted obliquely from the wheelchair.
- (3) The distance-measurement signals are compared to the set-up voltage (set-up distance), and if a difference is found, rotations of the two rear wheels of the existing electric wheelchair are differentiated and they are used for keeping the distance from the wheelchair to obstacles constant, when the wheelchair moves from side to side.

Figure 8 shows a circuit for the control part where distances are compared.

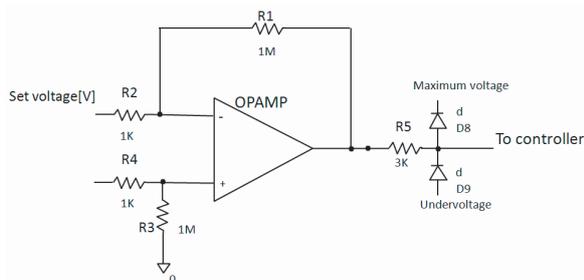


Fig. 8 The distance control circuit used in this study

6. EXPERIMENT FOR CHECKING PERFORMANCE OF WHEELCHAIR

A wheelchair with an ultrasonic digital sensor, which was designed according to the system in this study, was operated in order to check performance. An electric wheelchair (Imasen EMC-230), which is common in the electric-wheelchair market, equipped with a completed version of an operation-assist device with an ultrasonic sensor, was used in this experiment. Figure 9 shows a picture.

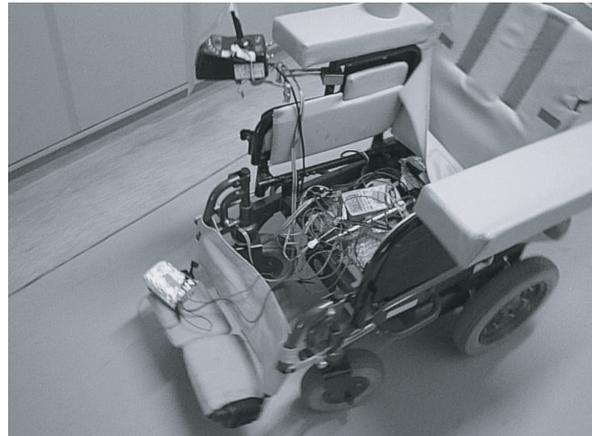


Fig. 9 A photograph of the experiment conducted with an Imasen EMC-230 to which the device in this study is attached (The ultrasonic sensor is positioned on the pedal used to place legs.)

The place used for the experiment was a corridor of 2m-width and 20m-length, with some pillars, lockers and other obstacles. This sort of condition is considered close to a situation in which electric-wheelchair users are likely to move. The designed device is used by the driver only for deciding the direction and speed of the wheelchair, while control over side-to-side movements of the wheelchair, to avoid collisions with obstacles, was controlled by the ultrasonic sensor. The aim was to travel safely to the goal by detecting the distance from either the left or right wall and keeping the set-up distance constant while the wheelchair was moving towards the goal, and avoiding obstacles when obstacles were detected ahead.

An experiment for evaluation was conducted with a wheelchair to which a completed-version of a control device was attached and the tilt of the lever for moving forward was fixed at a certain level with the speed for moving ahead kept constant. Also checked was whether collision with the walls on the right and left of the wheelchair could be avoided automatically. As a result, it was found that the wheelchair could travel safely and stably by keeping the distance from the walls at about 50 cm, while two ultrasonic sensors placed one on each side were used and a feedback

control was conducted in order to keep the measured distance constant. It was also found that the wheelchair could move while avoiding an approximately 50 × 50 cm concrete pillar which was sticking out, as well as a polyethylene bag with a diameter of 50 cm which was placed ahead of the wheelchair.

7. CONCLUSION

In this study, a safety-support device which can be added to existing electric wheelchairs at a low price was developed in order to prevent collision- and fall-related accidents with electric wheelchairs. The method applied in this study was a system of using a pair of ultrasonic sensors placed one each side of the wheelchair in order to measure distance. The speed when the wheelchair moves in a forward and backward direction was controlled by the driver of the wheelchair while the movements of the wheelchair in left and right directions were controlled by detecting the distance from walls or obstacles. The system controls only the distance automatically.

The ultrasonic distant-measurement sensor was placed at about 60 degrees tilted forward, and a control circuit was designed so that the distance between walls and the wheelchair was kept constant with the help of distance measurement signals. In order to keep the difference between the distance level and voltage zero after measuring the distance between the wheelchair and walls or an obstacle by using ultrasonic pulses emitted from the device of this study, a system was developed to send an appropriate output of differential rotation to the right and left wheels through a signal-processing circuit. Ultrasonic sensors are the core of the system developed in this study; thus the directivity, which is responsible for the stability of movements, was measured under two conditions, with and without acoustic cones, and it was confirmed in the experiments that acoustic cones with a beam-width of 40 degrees were effective for the device. The system assembled based on the results of the experiments was loaded onto an existing electric wheelchair and driving tests were conducted. As a result, it was confirmed that the wheelchair traveled to a goal while adjusting the stability of the loop of the control circuit and avoiding obstacles.

The conventional purpose for designing a device is to produce high precision wheelchairs at a high cost, and thus the device developed in this study is different. This study has achieved its aim of finding the possibility of adding a low-cost system to existing wheelchairs—allegedly, the number of these amounts to more than 100,000 in Japan—and to increase the number of new types of electric wheelchair. Hopefully, the system introduced in this study will un-

dergo more experiments to evaluate its utility so that improvements will be made in flexibility as well as adaptability to different types of wheelchairs, so that it will be beneficial for disabled people. It is believed that the development of the device in this study forms a preface for future development.

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