Real Time Image Processing Based Obstacle Avoidance and Navigation System for Autonomous Wheelchair Application

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***Abstract*—Wheelchairs have played an important role in both disabled young people and adults not only in term of physically but also psychologically. The idea of electrical wheelchairs has been brought up and carried out as to help these disabled people to be more independent instead of always depending caregivers. However, electronics wheelchairs are not enabling for every patient such as people who have lost mobility due to brain injury or loss of limbs. Thus, the idea of Smart Wheelchair or Autonomous Wheelchair where it is intelligent enough to provide navigation with a series of navigation assistances has brought up to the table. The purpose of this project is to design a navigation system and an obstacle avoidance system for an autonomous wheelchair application. The obstacle detection system is done merely using the camera sensor with the knowledge of image processing. The techniques used are including Canny Edge Detection, Erosion and so on where algorithms are developed to identify and detect the obstacle. The navigation system is performed with the use of compass sensors where the compass calibration, compass reading and compass value comparison are done to ensure the autonomous wheelchair move in a correct direction towards the targeted destination. Enhancement of autonomous wheelchair with Internet connectivity can be achieved using our designed system for enabling Internet of Things (IoT) application on independent disable people.**

I. Introduction

Wheelchairs have played an important role in both disabled young people and adults not only in term of physically but also psychologically. The idea of electrical wheelchairs has been brought up and carried out as to help these disabled people to be more independent instead of always depending caregivers. In term of physical, the disabled people able to easily move their wheelchairs to the desired location with various type of control systems such as hand-gesture control, eye gaze control or even brainwave control. On the other hand, in term of psychological, using the electrical wheelchairs is not only able to reduce the dependence on caregivers or family members but also able to promote the feelings of self-esteem and self-reliance as the lack of exploration and control often produces a cycle of deprivation and reduced motivation to learn helplessness. A move to a more enabling environment such as assisted living may be necessary when user unable to wheel them to the commode and help is not routinely available at home when needed.

However, electronics wheelchairs are not enabling for every patient such as people who have lost mobility due to brain injury or loss of limbs. For example, patients with nerve and muscle disorders such as muscle weakness, lack of coordination, nerve damage, the stiffness of joints or even Amyotrophic Lateral Sclerosis (ALS) would probably impossible to control the mechanical wheelchair nor the manually controlled electrical wheelchair properly. Thus, the idea of Smart Wheelchair or Autonomous Wheelchair where it is intelligent enough to provide navigation with a series of navigation assistances has brought up to the table. Such autonomous wheelchairs could make the patients with severe motor impairments to be more enabling and independent.

In order to allow wheelchair users to move without caregivers attention, the uncertainties in the surrounding environment have to be taken into consideration where here comes the implementation of both navigation system and obstacle avoidance system into this autonomous wheelchair. The main objectives in this paper are: The first objective of this project is to perform not only real-time observation by the camera via capturing a stream of images in milliseconds but also perform a series of fast image processing techniques to obtain the end result which is the obstacle detection or tracking. A Precise feature of the obstacle is not necessary for fulfilling this objective. The second objective of this project is to develop an algorithm to allow the autonomous wheelchair to have navigation system which allows it to reach the targeted destination accordingly and correctly. The third project objective is meant to allow the autonomous wheelchair to react accordingly based on the systems above in order to reach the desired locked location correctly and safely.

II. Related Work

In todays digital age, the wheelchairs in the market have been evolving from mechanical wheelchairs to electronically controlled wheelchairs where joysticks are widely used in the market of disabled or handicapped patients. There are more types of electronic sensors-based control methods have also been explored, experimented or even implemented onto the wheelchairs such as hand gesture (glove), eye gaze, voice or speech recognition, brain wave and so on. Not only that, the ideas of autonomous wheelchairs are also proposed by many researchers all over the countries. The difference between the autonomous wheelchair and the other electronics sensors based wheelchairs are sensor based wheelchairs require the control of user from time to time where the user has to keep on sending signals no matter in the form of gesture or speech depending the controlling method in order to reach the targeted location while the autonomous wheelchair only requires the attention of user to give signal regarding the desired destination to be reached where the path planning, the navigation, the obstacle avoidance and motion control would be done by the system automatically after the targeted location is locked and confirmed. Such discrete difference has clear enough to draw a line between the common electronics sensors based controlled wheelchairs and the futuristic autonomous wheelchairs. Therefore, in order to explore and understand more proposed or even existed a type of wheelchairs in the market; in this paper, we categorized three types of most commonly used wheelchair control technologies.

The first category, hand gesture based controlled wheelchairs. There are two different researchers papers have found proposing using two different type of Micro-electromechanical system (MEMS) based sensors on hand gesture to control the motion of powered wheelchairs which are the acceleration technology and the flex sensor (strain gauge) technology implementing on the glove that would be worn by the patients. The proposal of using acceleration technology has implemented the MEMS accelerometer sensors in the glove to sense the angle of the hand where the slight tilt of the hand would give voltages to the micro-controller and from here the directions would then be decided with different level of voltages. The whole system proposed in this research paper, not only including the movement control via the accelerometer mounted on the glove but also the Ultrasonic sensors for hole detection as well as the Infrared (IR) sensors for obstacle detection. The value of the 3 Axis accelerometer based on the hand movement would be measured and converted into digital with the help of ADC0816 as proposed. These digital data would proceed to the micro-controller for the further purpose of controlling the motor of the wheelchair. The direction control based on the accelerometer orientation proposed in this researcher paper has shown in Table below while the corresponding relays transistor ON or OFF values based on the directions desired is shown in Table below. Hence, the proposal of accelerometer technology in a powered wheelchair has shown the ease of controlling of a wheelchair using MEMS-based sensors in this journal paper [1].

Another researcher paper here had proposed the idea of using another MEMS-based controlled sensor which is the flex sensor (strain gauge sensor) mounting onto the hand glove. The main concept of controlling the powered wheelchair here is the movement of the wheelchair can be done just with a bend of two fingers. The aim of the proposal in this paper is to aid the communication of severely handicapped patients and enhance the controlling method of a wheelchair by patients themselves. Not only that, wireless communication has also been proposed in this researchers paper in order to allow the patients to move the wheelchair towards themselves easily from anywhere near within 100 meters as this range of distance is the maximum range of coverage for the Xbee communication used in this proposed project [2].

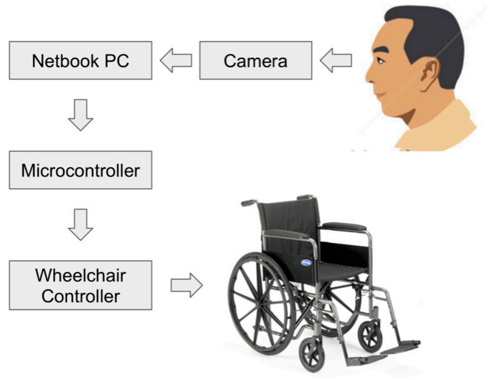

Fig. 1. Configuration of the Eye Gaze Controlled Wheelchair System [4].

The second category, voice recognition based controlled wheelchairs. Many researchers have already explored more methods of controlling the wheelchairs via senses other than using hand gestures. This is to consider the condition of the patients where he or her not only disabled in term of mobility but also suffering in arm muscles and nerves disorders. Therefore, various sense control methods to move the wheelchairs are then being explored, experimented and implemented by researchers all over the countries. One of the most widely studied control methods would be the voice or speech recognition based controlled wheelchairs. Shekar, P et al. [3] proposed to develop a system where solutions are provided to people who physically handicapped severely using voice or speech commands by interfacing the micro-controller selected with the Speech Recognition kit (HM2007) for the powered wheelchairs. This is to reduce human effort further in driving a wheelchair compared to hand gesture based controlling method. The big concept of the project proposed here is the motors of the wheelchairs which decide the motion control are controlled by the direction commands given by the wheelchair users through a microphone prepared. The micro-controller selected with the Speech Recognition kit are then used to interpret the speech command before giving signals to the motors accordingly.

The third category, eye gaze based controlled wheelchairs. Arai and Mardiyanto [4] proposed an eye based Electric Wheelchair Control (EBEWC) where the patients would just need to gaze in the specific condition in order to carry out corresponding motion control of the motors as what the author or programmer programmed. The eye based controlled wheelchairs proposed in this research paper is mainly based on the eye gaze where image analysis method is heavily required in order to capture and process the images of the eyes to identify the different conditions of eye gazes where the characteristics of the eye pupil are determined. These conditions are then used to control the motion of the wheelchair. The overall system could be briefly described as Fig. 1 shown. The IR camera serves as an input by capturing the image of the eyes of patients while the Netbook PC is used to perform

Fig. 2. A customised electrical wheelchair.

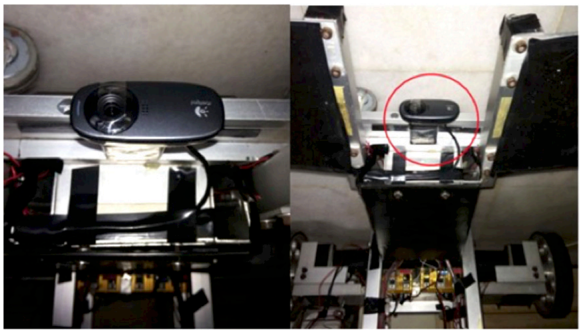

Fig. 3. Mounting of Camera Sensor on Wheelchair. (Left) Front View. (Right) Top View.

image processing and analysis on the images capture in order to further provide useful information to the micro-controller before sending motor commands to the wheelchair controller which control the motion of the wheelchair.

III. System Platform

As for the hardware platform for this paper, we designed and built a customized electrical wheelchair, as shown in Fig. 2.

We use a low-cost, Logitech 8 MegaPixels 1080 HD Webcam, to perform real-time image processing based obstacle avoidance and navigation system. The mounting of the Logitech Webcam has been done as shown in Fig. 3 which are mounted on the foot pads of the wheelchair. The camera sensor is mounted 3 inches from floor level as well as tilted approximately 15 downward.

For navigation system, we use two compass modules (Triple axis Magnetometer HMC5883L) serves as the input for the navigation system. The calibration and the reading collection of the compass modules will be further discussed in chapter behind. The mounting of both the compass sensors are as shown in Fig. 4 where one of the compass sensors will be mounted on the pan and tilt servo unit which would remain in the same orientation after target locking representing the orientation of targeted direction while the another compass sensor will be mounted on the stand attached to the wheelchair serves as the input representing the current orientation of the wheelchair moving direction.

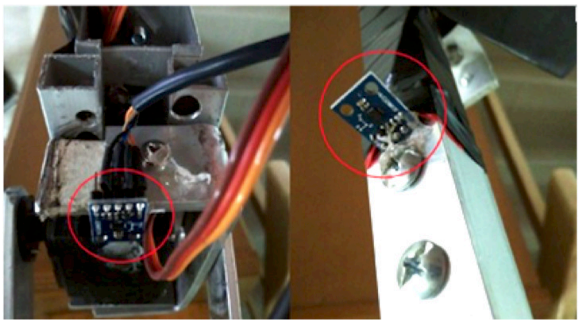

Fig. 4. Compass Sensors. (Left) Mounted onto the Pan-and-Tilt Servo Unit (Right) Mounted on the Stand attached to the wheelchair.

Y \ X		0	1	2	3	4
	0	0	1	2	3	4
	1	5	6	7	8	9
	2	10	11	12	13	14
	3	15	16	17	18	19
	4	20	21	22	23	24

Fig. 5. The location of pixels corresponding to the coordinate of X and Y in an image frame in *Processing* software.

IV. Methodology

In order to detect the dynamically moving obstacle with a very fast detection speed and high precision image capturing, the software selection is one of the most crucial parts in developing algorithm efficiently and effectively. We use the *Processing* software platform. This is because the communication between IoT device (i.e., Arduino) and *Processing* is easily be done in order to transfer the final output of the image processing done in *Processing* software to the input of Arduino for motion control. Open CV is also installed as a library package in *Processing* to ease complicated programming writings by using the prepared syntax in Open CV library.

In *Processing* software, in order to perform image processing which involves pixels, one must understand how the location of pixels is converted from an image frame. Unlike the conventional method of getting pixels, pixels in *Processing* software do not have coordinate like (x,y). The pixels in *Processing* are actually in the form of the stream such as Fig. 5 shown below. The pixel array actually goes column to column in X directions and continues to next row until the formation from coordinates of points in the image frame to pixel array is done (when it reaches the right bottom corner of the frame) as shown in Fig. 5.

As Fig. 6 shown, the obstacle detection system with image processing based has been clearly shown in the block diagram above.

Firstly, the image capturing is done in real time in order to perform fast tracking and fast retrieval of the raw RGB image. This could be done by using the camera sensor which is the Logitech Webcam as an input device to obtain the stream raw RGB images. Then, grayscale conversion has been applied to the raw RGB images in order to remove the hue and saturation information while retaining the illuminance as these details

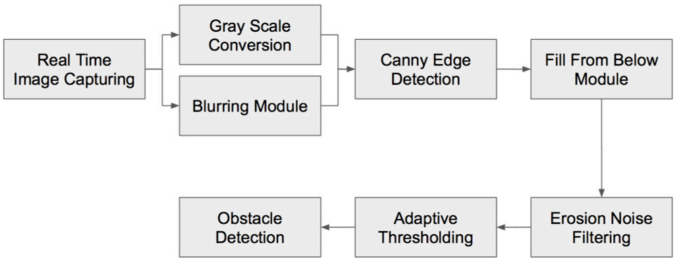

Fig. 6. Block Diagram of Obstacle Detection System.

would not be required in this autonomous wheelchair system. Next, blurring is applied onto the converted grayscale image in order to reduce the unwanted fine edges and lines to be detected caused by the scratches or patterns of the floor surface or even due to the fluctuation in light intensity.

After the blurring of the image, canny edge detection is then applied to the image in order to eliminate other features leaving the outline of the floor level and the obstacle to be detected. This method is very sensitive to noise which leads to fake edge detection or losing the real edges. This is the reason why blurring is required before the canny edge detector is applied to the image in order to reduce the number of fake edges detected. Then, the binary image with edges shown is then applied with fill from below module where segmented the image into two portions to indicates possible pathway and obstacle detected. The segmented image then goes then go through the noise filtering or erosion to shrink the white portion as well as remove the impulse noise.

Lastly, adaptive thresholding is applied in order to detect the obstacle. When the obstacle (black portion) is below the threshold, the center of the obstacle would be detected and hence the obstacle is considered detected.

V. Results and Discussion

The image processing stages need to be processed are: gray-scale and blurring; canny edge detection; fill from below module; erosion and filtering; and adaptive thresholding for obstacle detection. First, the raw Red-Green-Blue (RGB) image is captured by the camera as shown in Fig. 7. Second, the gray-scale conversion has to be applied to the raw RGB image stream to eliminate the information containing hue and saturation. These details are not necessary for the application of the proposed obstacle detection system. On the other hand, blurring is applied before the edge detection because the undesired edges and lines would appear very obvious if the grayscale image is not blurred as Canny edge detection is vulnerable to noise where fake edges might occur in the processed image. The output image from both the conversion and blurring are shown in Fig. 8.

Third, Canny Edge Detection is applied onto the blurred image to get rid of all other features in the image except edges and lines which representing the outlines of the floor level and the obstacle detected. As mentioned earlier, this method of edge detection is easy and fast to apply but it is very vulnerable to noise which may affect the quality of the processed image.

Fig. 7. Raw RGB Image captured by the camera.

Fig. 8. Converted Grayscale and Blurred Image.

The output of the blurred grayscale image after the canny edge detection would be as Fig. 9 shown, where most of the horizontal outlines are shown.

Forth, the module of Filling From Below is actually meant to segment the image with edges into two portions: white and black. A Black portion would be representing either obstacle or unnecessary part of the image which is above the floor level assuming that the obstacle hanging in the air is not required to be detected while the white portion is indicating the path where the wheelchair is allowed to proceed. The output of the edge detected image after filled from below would be a binary image segmented into two portions with noises as Fig. 10.

Fifth, the output image from the previous stage is actually containing a lot of impulse noises which may resulted in misjudgment of an obstacle. Erosion not only able to shrink the clustered portion but also able to reduce or even remove the noises shown in Figure 10. The algorithm proposed in this Erosion and Filtering module is using a kernel matrix size of 19X19 where it is large enough to remove at least 10-pixels width of impulse noise. The output result of Erosion and Filtering module is shown in Fig. 11, where the side is addressed with black pixels to avoid the kernel from crashing due to lack of pixel content to load into.

Lastly, adaptive Thresholding is the last stage of image

Fig. 9. Image applied with Canny Edge Detection.

Fig. 10. Binary Image with Segmented Regions with Noise.

processing before sending commands to Arduino to carry out suitable motion control depends on conditions. This module is actually used to create a threshold which is varies with the number of white pixels in the image. This is to ensure that when the obstacle detected is too small (equivalent to too far) no action but moving forward will only be taken place by the autonomous wheelchair. By doing so, the thresholding function is considered as more reliable than just giving a constant value of the threshold. the centre of the obstacle is calculated as formula shown in the code segment in order to identify the distance (in pixels) between the centre of the image (green vertical line) and the centre of the obstacle (red vertical line) as shown in Fig. 12. The range of pixel width difference will be the conditions for the motor to react accordingly.

We tested the performance of image processing with different blurring coefficients. The experiment is carried out to test the performance of image processing as well as the obstacle avoidance function for the autonomous wheelchair under different blurring coefficients. The constant parameters are listed in Table I whereas the manipulated parameter in this experiment would be the coefficient of the blurring set in the program. The value of the blurring coefficient set would be set as 0, 9, 25, 49, 81. 10 attempts would be carried out where 10 readings of the white pixel amount would be recorded for each blurring coefficient. The responding parameters to be recorded in this experiment would be the successful rate of avoiding obstacle and number of white pixels in the binary image where the best condition resulting image would be used as a baseline or standard measure of performance.

Fig. 11. Filtered and Eroded Binary Image with Segmented Region.

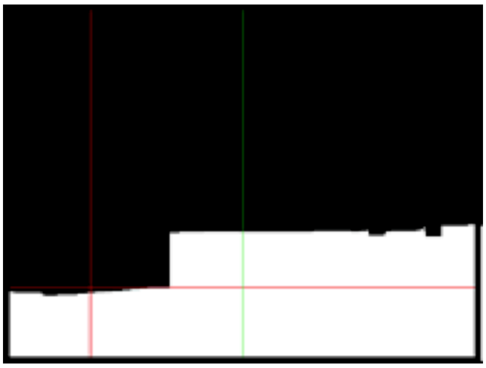

Fig. 12. Binary Image with Centre of Obstacle Detected (Red Vertical Line).

From the Table II and Fig. 13 shows that the coefficients of blurring ranged from 25 to 49 give the optimum blurring requirement on the grayscale images where resulted in 100% successful rate in avoiding obstacle as Table shown. If there is no blurring before edge detection, the undesired details in the image could also be applied on edge detection where making the Filled from Below module could not be implemented properly as Figure shown (Top Left). On the other hand, if the blurring coefficient is too high, the outline of the floor lever which is crucial could be hard to detect where losing real edges happen as Figure shown (Bottom Left). A lower blurring coefficient (9) would only bring 20% successful rate in avoiding obstacle because misjudgment by the Adaptive Thresholding module and Obstacle Detection module due to the noise where the blurring is insufficient. Therefore, the best range of blurring coefficient would be somewhere from 16 to 64.

VI. Conclusion

On the whole, the Image processing techniques have been implemented into the obstacle detection system using the camera in order to perform real-time obstacle detection. Besides that, a simple navigation system has been developed by using the compass sensors in order to allow the autonomous wheelchair to reach the targeted destination without any manual control while avoiding obstacles is still performing within the routine. Lastly, these two systems are integrated with the motion control system where obstacle avoidance takes place by taking inputs from the obstacle detection

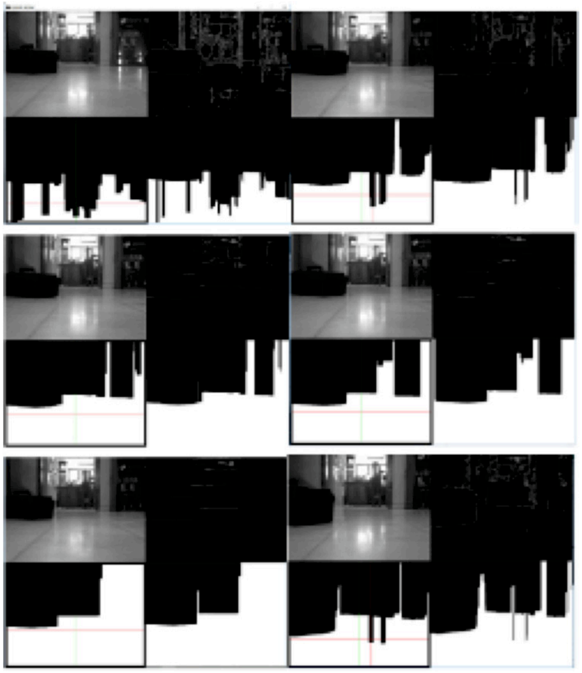

Fig. 13. Image output for different value of blurring coefficient (Top Left) 0 (Top Right) 9 (Centre Left) 25 (Centre Right) 49 (Bottom Left) 81 (Bottom Right) Fail Attempt for Coefficient of 9.

TABLE I
CONSTANT PARAMETERS FOR THE EXPERIMENT

Constant Parameters	Description
Lighting Condition	Ceiling Light
Floor Surface	Sealed Tiles Floor
Filtering Kernel Size	19×19 Matrix
Adaptive Thresholding Offest	-10

TABLE II
THE NUMBER OF WHITE PIXELS AND SUCCESSFUL RATE OF AVOIDING OBSTACLE CORRESPONDS TO THE BLURRING COEFFICIENT

Blurring Coefficient	Responding parameters	
	Number of White Pixels	Successful Rate % of Avoiding Obstacle
0	46088	0
9	119445	20
25	132124	100
49	137462	100
81	178083	0

system while navigation system notices the desired location the autonomous wheelchair should approach to. In addition, autonomous wheelchair can be extended for embedding Internet of Things (IoT) features to allow remote monitoring on disabled people. Hence, the main objectives have been completely accomplished in this project.

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