Development of Computer Vision Based Obstacle Detection and Human Tracking on Smart Wheelchair for Disabled Patient

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***Abstract*— People with physical disability such as quadriplegics may need a device which assist their mobility. Smart wheelchair is developed based on conventional wheelchair and is also generally equipped with sensors, cameras and computer based system as main processing unit to be able to perform specific algorithm for the intelligent capabilities. We develop smart wheelchair system that facilitates obstacle detection and human tracking based on computer vision. The experiment result of obstacle distance estimation using RANSAC showed lower average error, which is only 1.076 cm compared to linear regression which is 2.508 cm. The average accuracy of human guide detecting algorithm also showed acceptable result, which yield over 80% of accuracy.**

Keywords-smart wheelchair; obstacle detection; human tracking

I. Introduction

Mobility has been providing support for people's quality of life. Thus, it is essential for human to be able to move independently. For people with physical disability such as quadriplegics, an assistive device can help their mobility. Wheelchair is one of assistive tool which allow mobility for such disabled patient. The advancement of technology has integrated electronics system into conventional wheelchair and transform it into powered wheelchair and smart wheelchair [1].

Standard powered electrical wheelchair is generally controlled via joystick. This kind of electrical wheelchair still has minor problem such as colliding with people, object or walls [2]. Therefore, many researches have been proposed to provide better assistance for the wheelchair user. Most of the researches integrated intelligent capabilities to the smart wheelchair such as for easy navigation [3], obstacle detection [4][5], distance estimation [6], and human following capability [7]. Some of the researches also added more features for the smart wheelchair such as speech recognition, control trough internet [8], and also gesture on touchscreen control via android phone [9]. These smart wheelchair are equipped with sensors and computer based system as the main controller to be able to perform specific algorithm for the intelligent capabilities.

In current work, we develop a computer based obstacle detection to be implemented on the smart wheelchair. We also integrated the capability of the wheelchair to move based on previously tracked human reference. Obstacle detection is a technology to detect and decide the action in order to avoid collision with the obstacle. Many researches

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proposed vision based obstacle detection with the use of a camera [10][11]. We combine line laser and camera imaging technique to accelerate and simplify the mathematical calculation while acquiring the information of the object in front of the wheelchair. The shape of line laser will change based on the pattern of the object surface and also its distance to the wheelchair.

As previously mentioned, standard powered wheelchair uses joystick to control its motion, which means the patient need to use their hand to operate it [12]. This is a drawback for quadriplegics patient since they cannot use their limb to independently operate the wheelchair [13]. As an alternative, another person may help to push the wheelchair but this may be uncomfortable on some cases. Thus, we also develop human tracking capability for the wheelchair to drive its movement. A camera is placed and aimed to front side of the wheelchair. The assistive person need to walk before the wheelchair which will be captured by the camera. An algorithm is developed based on the captured video to track and follow the human movement in order to reach certain location.

This paper is presented in a structure organized as follows. Section 2 explains the system architecture in the proposed methods. Section 3 provides the experiment results and analysis. Finally the conclusion is presented in Section 4.

II. System Architecture

The block diagram of the smart wheelchair system is shown in Figure 1. The main processing unit used by this system was Raspberry Pi 2 with 900 MHz quad core ARM Cortex-A7 CPU, 1 GB of RAM, integrated with Raspbian Wheezy OS and OpenCV 3.0 as the image processing library. The camera that was used is Raspberry camera module because of the processing speed and the Line laser is LN60-650 which has a wavelength 650. As the driver of this smart wheelchair, two DC motors (left and right motor) are connected to each wheel. The speed control implementation on embedded system was done by using Pulse-Width Modulation (PWM) on Raspberry Pi 2.

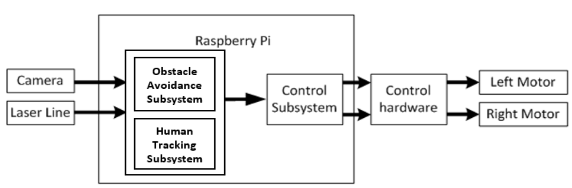

Figure 1. Block diagram of the smart wheelchair system.

A. *Obstacle Avoidance Subsystem*

The obstacle avoidance subsystem contains of two modules, obstacle detection and obstacle distance estimation. The obstacle detection module used camera and line laser to detect the presence of obstacles on the pathway. For the distance estimation of the obstacles, random sample consensus (RANSAC) was utilized. The flowchart of the proposed approach for this subsystem is shown in Figure 2. At the first stage, the camera capture the pathway condition which is include image of the line laser. The capturing activities is done in real time. Using the information extracted from the image, obstacles are detected. At the next stage, the obstacle distance are estimated using RANSAC method [14][15]. The last stage is to set the direction and speed of the wheelchair movement based on the position and distance information of the obstacles.

For the image acquisition, the camera and the line laser were mounted on the wheelchair as displayed in Figure 3. The line laser was mounted horizontally behind the wheelchair in fixed height and at a fixed angle. Meanwhile the camera was placed under the laser line to captures the line laser light in real time while the wheelchair is navigating.

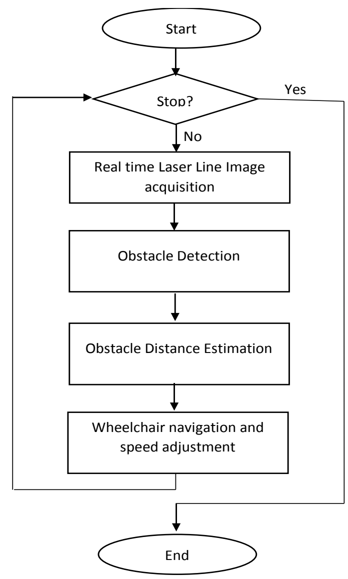

Figure 2. Obstacle Avoidance System Flowchart.

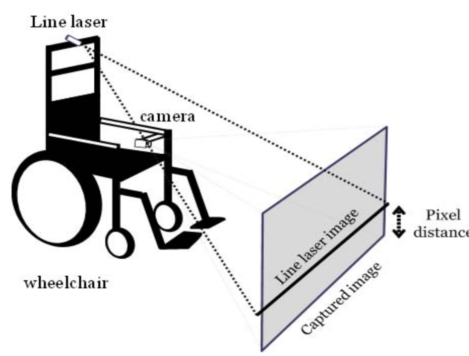

Figure 3. Laser line and camera mounting configuration.

The illustration of the line laser image with different conditions of obstacles that was captured by the camera, is shown in Figure 4. Figure 4(a) show the case when there is no obstacles in front of the wheelchair. The captured image contains only one straight laser line, indicating that there is no obstacles detected. When there is an obstacle in front of the wheelchair, the shape of the line laser light will change according to the size, shape, and distance of the obstacle. Clearly there is a difference in the appearance of the group of line, 3 exactly for this case, compared to the position in the previous condition which only contains one straight laser line.

The line laser image that touching obstacles will appear on higher position. The closer the object, the higher position it will appear on.

1) Obstacle Detection Module

The obstacle detection methods was done using laser line image blob that was captured by the camera. Figure 5 show the laser line image blob with different number and positions of obstacle. To obtain the laser line blobs, segmentation process is applied to the line laser image. The output of the segmentation step is a binary image that highlights the laser line blobs where the laser line blobs are drawn in black and the others in white as shown in Figure 6.

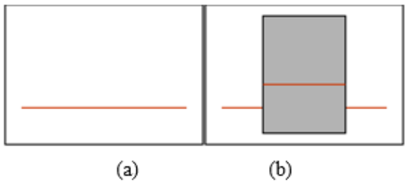

Figure 4. Image captured by the camera with (a) no obstacles, (b) an obstacle in front of the wheelchair.

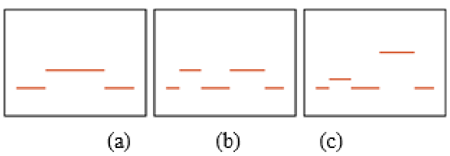

Figure 5. Image of the laser line with (a) one obstacle, (b) two obstacles of the same distance, and (c) two obstacles of different distances.

Figure 6. Binary image containing laser blobs (a) before morphological operations are applied and (b) after morphological operations are applied.

In some cases, the segmentation process does not provide satisfactory results due to the dynamic range of laser light hue. The segmentation result displayed some noises appearing around the laser line blobs and also some discontinuities in the laser blobs, as figured in Figure 6 (a). To enhance the segmentation result, two morphological operations are applied. The improved result of the segmented binary image is shown in Figure 6 (b).

A blob in binary image is a region of adjacent connected-component. After detecting all blob that contained on the image, then searched the midpoint (centroid). Various information can be obtained by performing some analysis on the blob and the midpoint. The extracted information make it enable to obtain some important properties include the number of blobs, their position and their size. Using this method, we can detect the presence of obstacles as well as their position and their size easily.

2) Obstacle Distance Estimation

Recall that the line laser image that touching obstacles will appear on higher position. The closer the object, the higher position it will appear on. There is a relationship between the distance of the obstacle to the wheelchair and the difference in the blob position. Technically, there is a relationship between the distance of the obstacle to the wheelchair and the distance between the centroid of blob with the lower limit of the blob on the image. The estimated distance can be calculated by counting the number of pixels that exist between them. The relationship between the obstacle distance and laser blob distance was then modeled using a regression method. Finally, the RANSAC model can be used to estimate the distance of an obstacle from the known laser blob distance in the captured image. The RANSAC model used some training data obtained from experiments.

B. *Human Tracking Subsystem*

The general method of the human tracking subsystem is explained in the Figure 7. The input of the system is video where HOG is applied at the first phase for detecting human [16][17][18]. It is possible to have more than one detected human in one frame, thus to decide a specific guide, the user must calibrate the system first. The user have to selects which person to follow as a guide first.

After having a certain frame that contains guide area using HOG, the specific feature of the area that can be extracted using entropy. In this study, we use the upper third part of detected block from HOG detection, which is extracted from a third of height and width, respectively. This approach is chosen because if we use the whole area of detected human, it generates noise, because the area contains a part of background as well. The background in the dataset has various degree of disturbance such as extreme light condition. Therefore, getting smaller areas in this case reduces noise that leads to higher accuracy in human tracking.

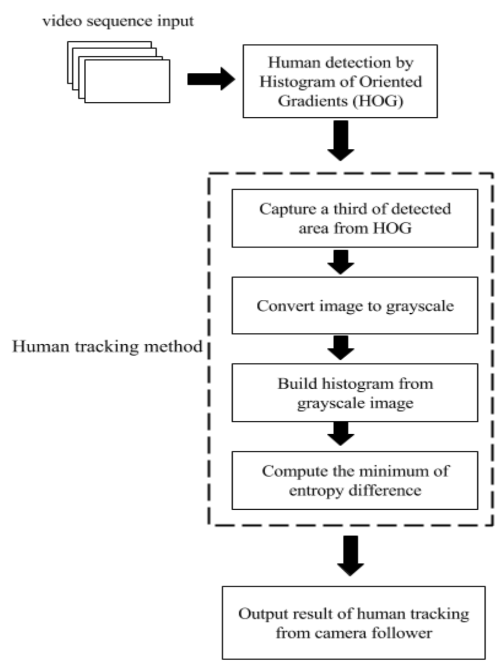

Figure 7. HOG-EDM method for human tracking.

The detected area from HOG is converted to grayscale image and its Entropy Difference Minimization (HOG-EDM) is calculated. The process is repeated for every frame. The entropy minimization is used as matching function in the tracking subsystem to determine the candidate of tracked object in the upcoming frame.

III. Result And Analysis

A. *Obstacle Avoidance Subsystem Evaluation*

To assess the performance of the proposed system, experiment was performed to ensure that it performs well. The experiment was performed using 50 images captured using the camera with various obstacle position and distances. The images were divided into 19 images with no obstacles and 31 images with obstacle. Experiment result show that the obstacle detection module provide a very satisfactory result with 100% precision and 100% recall.

The 31 images with obstacle were then divided into 25 training images and 6 testing images. The training images were used to create the RANSAC model that describes the relationship between the distance of the obstacle and the distance of the laser blob. The testing images are then used to measure the error between the prediction distance and the actual distance. The error of each image is described in Table 1. From the experiments, it can be concluded that our system performs very satisfactorily with average error of 1.706 cm. The RANSAC method showed a better performance than the Linear Regression result which is showed average error of 2.508 cm.

The last module, the navigation system, also show a very satisfactory result with 100% accuracy of movement. The wheelchair was navigated quickly and correctly in real time responding to the obstacles appearance on the pathway.

B. *Human Tracking Subsystem Evaluation*

To evaluate performance of the proposed method for tracking human guide under unstable lighting and background environment , we used accuracy method [19]. The testing scenario are based on the number of frames which contains a guide detected by HOG and the number of frames which contains guide sequentially detected by HOG and EDM as a powerful method for detection and tracking.

TABLE I. Obstacles Distance Estimation Experiment Result

Actual Distance (cm)	Estimation Using RANSAC (cm)	Estimation Using Linear Regression (cm)
80	79.98278	82.62343483
90	93.39174	95.18861839
100	103.8653	105.0030869
110	112.8377	113.410889
120	120.5407	120.6291991
130	131.2916	130.7035716
Average Error	**1.076**	**2.508**

There are 5 videos tested using the proposed algorithm in numerous condition. In an entire videos, only several frames containing human and EDM always depends on whether there is human or not in a frame. In some cases, there are some deviation in the dataset such as overlapping human or more than one human are detected in a frame. Table 2 shows the accuracy result in each video as well as the average accuracy for whole dataset and yield over 80% of accuracy.

TABLE II. The Accuracy Of Human Guide Algorithm Using Self-Made And Public Dataset

Video	Number of guide frames HOG	Number of guide frames HOG-EDM	Accuracy
Video 1	38	25	0.656
Video 2	45	37	0.822
Video 3	53	36	0.679
Video 4	145	137	0.945
Video 5	427	404	0.946
Average			**0.810**

IV. Conclusion

In the current work, we have developed smart wheelchair system which is equipped with obstacle detection and human tracking algorithm based on computer vision. We mounted a camera placed in front of the wheelchair and a line laser which is aimed toward the obstacle. Later, the pattern of captured image of the line laser will be calculated using RANSAC method to estimate the distance and the position of the obstacle. For the human tracking part, HOG is applied on the image sequence containing human as guide. After having a certain frame that contains guide area using HOG, the specific feature of the area that can be extracted using entropy. In this study, we use the upper third part of detected block from HOG detection, which is extracted from a third of height and width, respectively. The experiment result of obstacle distance estimation using RANSAC showed lower average error, which is only 1.076 cm compared to linear regression which is 2.508 cm. The average accuracy of human guide detecting algorithm also showed acceptable result, which yield over 80% of accuracy.

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