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Development of a Basic Robot System for Medical and Nursing Care for Patients with Glaucoma

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***Abstract*—**Medical methods to completely treat glaucoma are yet to be developed. Therefore, ophthalmologists manage patients mainly to delay disease progression. Patients with glaucoma are mainly elderly individuals. In elderly people's houses, having an equipment that can provide medical treatment and care can release their family from their care. For elderly people with the glaucoma to live by themselves as much as possible, we developed a support robot having five functions: elderly people care, ophthalmological examination, trip assistance to the neighborhood, medical treatment, and data referral to a hospital. The medical and nursing care robot should approach the visual field that the patients can see at a speed suitable for their eyesight. This is because the robot will be dangerous if it approaches the patients from the visual field that they cannot see. We experimentally developed a robot that brings a white cane to elderly people with glaucoma. The base part of the robot is a carriage, which is a Megarover 1.1, and it has two infrared sensors. The robot moves along a white line on the floor using the infrared sensors and has a special arm, which does not use electricity. The arm can scoop the block attached to the white cane. Next, we also developed a direction detector comprised of a charge-coupled device camera (SVR41ResucueHD; Sun Mechatronics), goggles (MG-277MLF; Midori Anzen Co. Ltd.), and biconvex lenses with a focal length of 25 mm (Edmund Co.). Some young people were photographed using the direction detector, which was put on their faces. Image processing was performed using Scilab 6.1.0 and Image Processing and Computer Vision Toolbox 4.1.2. To measure the people's line of vision, we calculated the iris's center of gravity using five processes: reduction, trimming, binarization or gray scale, edge extraction, and Hough transform. We compared the binarization and gray scale processes in image processing. The binarization process was better than the gray scale process. For edge extraction, we compared five methods: Sobel, Prewitt, Laplacian of Gaussian, fast Fourier transform, and Canny. The Canny method was the optimal extraction method. We performed the Hough transform to search for the main coordinates from the iris's edge, and we found that the Hough transform could calculate the center point of the iris.

***Keywords*—**Glaucoma, support robot, elderly people, Hough transform, direction detector, line of vision

I. INTRODUCTION

A sudden loss of eyesight induces a serious feeling of disappointment to elderly people and forces them an inconvenient life. Sight occupies 83.0% of all the sensory functions that a human being has (Fig. 1) [1], [2].

The elderly people with a sudden loss of eyesight must live under the condition having almost no sensory function. Glaucoma, diabetic retinopathy, and pigmentary retinal degeneration are the three major diseases that cause sudden loss of eyesight. These diseases account for 50% or more among elderly individuals (Fig. 2) [3].

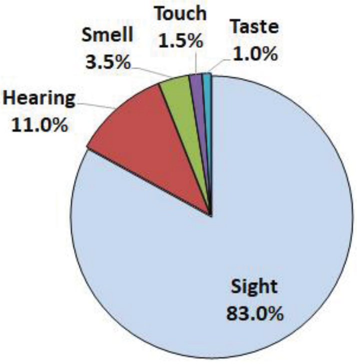

Fig. 1 Perceptional rate of the five senses of humans [1], [2]

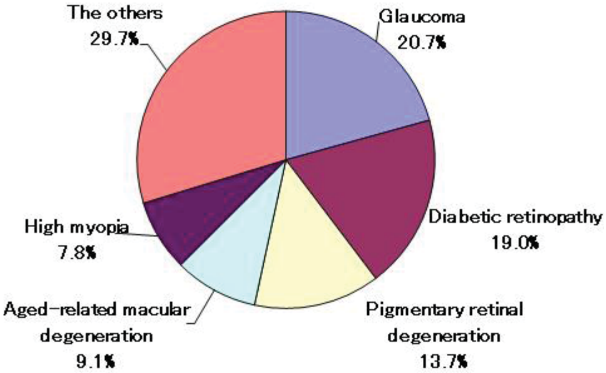

Fig. 2 Ratio of the diseases that cause loss of eyesight [3]

Nearly 3 million Americans aged 40 and older have glaucoma [4], and approximately 70 million are suspected to have this disease worldwide [5]. Glaucoma causes gradual obstruction of the optic nerve resulting in narrowing of visual field. Inspecting abnormalities in a visual field discovers the disease. Visual field examination should be periodically performed because initial symptoms of glaucoma are rarely noticed [6]. Next, diabetic complications affect the liver, nerves, and eyes, with approximately 40% of patients with diabetes having retinopathy. At a high rate of 19% of acquired blindness, diabetic retinopathy is a major cause of acquired blindness. Approximately 3,000 individuals lose their eyesight every year because of this disease [7]. Studies have shown that the number of individuals with diabetes in America has increased from 16 million to 30 million since 1999 [8], whereas the number of individuals with diabetes in Japan, including potential patients, was only 16.2 million in 2005 [7].

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Unfortunately, diabetic retinopathy is a progressive disease, which modern medicine could not completely cure. Consequently, early diagnosis through careful ophthalmic examination is critical in preventing acquired blindness [9]-[11]. Moreover, retinitis pigmentosa is a genetic disorder of the eyes that causes loss of vision [12]. Its symptoms include nyctalopia and decreased peripheral vision. As peripheral vision worsens, patients may experience tunnel vision. It is estimated to affect 1 in 4,000 people, both in the United States and worldwide [13]. The onset of symptoms is gradual and often in childhood, and currently, no cure for retinitis pigmentosa exists [14]. In contrast, we developed a support robot for nursing care, which can perform elderly support and medical treatment, making the following activities possible to elderly people. Our system will help delay the progression of diseases in elderly people, which cause sudden loss of eyesight without the medical treatment method, to ease the psychological burden. The system will help elderly individuals get follow-up examinations and medical treatments from a medical doctor using the robot's communication function. Furthermore, it will release their family from accompanying them to a hospital or caring for them in the house. Many researchers have developed nursing care equipment for elderly individuals in Japan or overseas. For example, the authors have developed a robot that supports elderly individuals with the sudden loss of eyesight [15]-[17]. However, the authors only included elderly individuals who had eyesight loss and those who were incompatible with medical practice and care support. This study will put a next- generation technology into practice using the medical robot, which can perform medical and nursing care for elderly individuals with progressive ophthalmological disease, such as glaucoma. Thus, this medical and nursing care robot should move according to physical and sensory functions of the elderly individuals. The robot motion depends on the grade of their visual performance: visual field and visual acuity. For example, a patient with glaucoma can only see things from peripheral areas and must live using only a little central visual field. If the medical and nursing care robot approaches the patient from a visual field that they cannot see, the robot will be dangerous and should be modified to approach the patient from the visual fields that they can see. Moreover, the robot should approach the patient at a speed suitable for their eyesight. Elderly individuals will be able to use the robot comfortable if the robot understands their visual performance. Fig. 3 shows the medical and nursing care robot system.

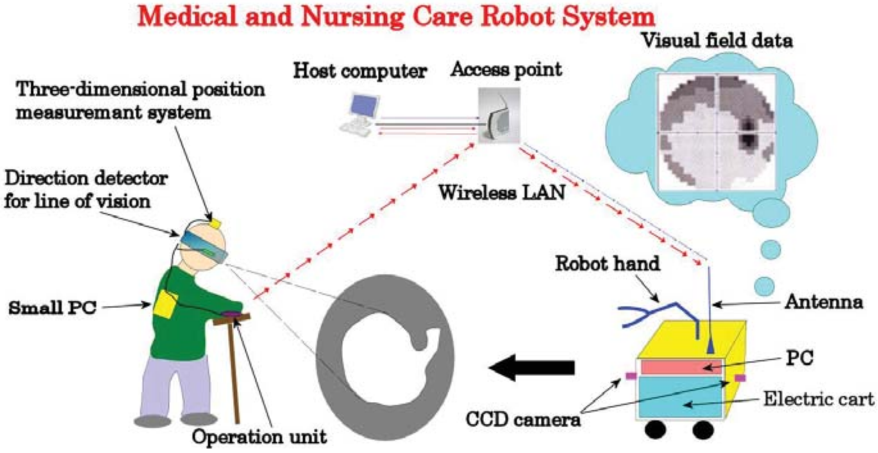

Fig. 3 Overview of the medical and nursing care robot system

We added a cart to the medical and nursing care robot and developed an operational program. A drive experiment was conducted. The elderly person has a three-dimensional position measurement system and a direction detector for the line of vision. The three-dimensional position measurement system measures the position and direction of the person's head. Moreover, the direction detector for the line of vision photographs the iris of the eye and measures the iris's center of gravity: the elderly person's line of vision. When the direction detector calculates the line of vision, we used the Hough transform [18], [19].

In image processing, the Hough transform can detect a straight line from a binary image or a multilevel image efficiently and is the best method for rejecting noise. The Hough transform was suggested by P.V.C. Hough for the first time and was published as a patent in 1962 [20]. Electronic computers suddenly progressed in the 1970s as integrated circuits spread. Various image processing methods, including pattern detection, were studied in earnest. The Hough transform was essentially improved for practical application [21]. With this as the turning point, the Hough transform came to be actively studied and is used until today. In the Hough transform, detecting a straight line is the most important and is its original purpose. The reason is based on the fact that even a straight line, such as a dotted line, is detectable. Furthermore, the Hough transform can offer universal solutions to the pretreatment of image processing. Therefore, animals with sight can easily recognize even an object in the picture photographed in disorder. However, after expanding, reducing, rotating, and moving parallelly the object, detecting and rectifying the object is difficult for a machine. This technique is normalization. The Hough transform can efficiently normalize pictures. Moreover, it can harmonize acceleration and capacity enlargement of information and can respond to the data processing method, which is versatile and easy to handle. In contrast, the wireless LAN transmits the position, direction, and line of vision of the head to the host computer. The elderly person can operate the medical and nursing care robot using the operation unit attached on the cane. Based on the ophthalmological examination data of the elderly person, the medical and nursing care robot can approach at a suitable speed from the direction in which the elderly person can easily see. Moreover, the robot system will inform the elderly person about the robot's approach using a melody. We designed and manufactured the operation unit and the direction detector for the line of vision. The experiment was conducted along with the cart and the operation unit. We developed a software that could detect the line of vision of the elderly individuals. Moreover, we conducted an experiment along with the direction detector for the line of vision and the three-dimensional position measurement system. When elderly individuals go out, we are considering attaching Global Positioning system (GPS) to the medical and nursing care robot as an electric handcart. The medical and nursing care robot will be equipped with pressure sensors and GPS. The elderly person can comfortably walk down not only a road but also a slope, holding a handle on the cart, of course after removing the ophthalmological examination equipment. Visiting neighboring houses will become possible using the robot (Fig. 4). Moreover, the robot will safely guide the elderly person to a destination using GPS. While the elderly person pushes the right and left pressure sensors, which are attached to the handle bar, the person can operate the robot in four movements: forward, stop, right turn, and left turn. When the elderly person walks with the robot, if the charge-coupled device (CCD) camera on the robot detects an obstacle, the robot will stop or detour. Moreover, in an emergency, the elderly person will be able to contact their family via wireless LAN. Here, we verified the "going-out" function of the medical and nursing care robot. If the elderly person feels it difficult to manipulate the pressure sensors, we will use an alternative method, such as a joystick.

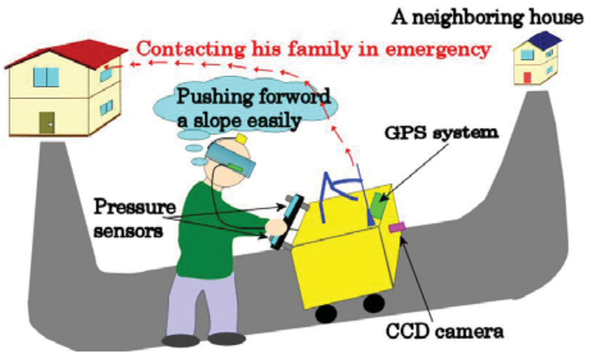

Fig. 4 The supporting robot used as a rollator

II. METHODS

A. Development of the Basic Robot for Medical and Nursing Care

We experimentally developed a medical and nursing care robot that supports elderly individuals with visual impairment. The experimental robot can bring a white cane to elderly people individuals. The experimental robot has a special arm that could scoop the block attached to the white cane (Fig. 5 (a)). The base part of the robot is a carriage, which is a Megarover 1.1 made by Vstone Co., Ltd. We can control the robot using BeautoBuilder2. Figs. 5 (b) and (c) show the two enlarged images: the block and the special arm part, respectively.

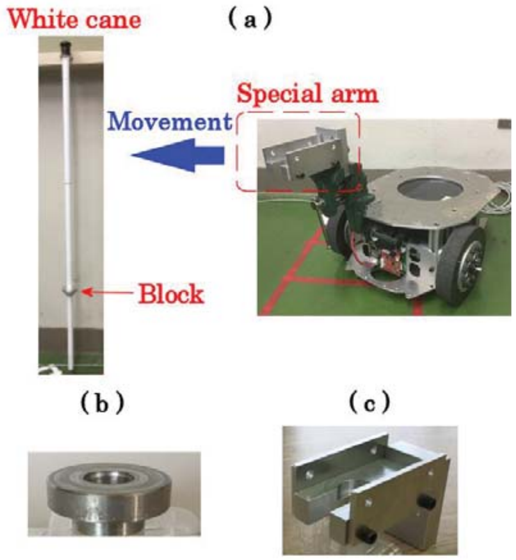

Fig. 5 The support robot and the white cane with a block

B. Development of the Direction Detector for the Line of Vision

The experimental model of the direction detector for the line of vision consisted of a CCD camera, goggles, and a holder (Fig. 6). The CCD camera is the SVR41ResucueHD developed by Sun Mechatronics. The camera's focal distance is 6 m. To make it correspond to close-up photography of an anterior ocular segment, biconvex lenses with a focal length of 25 mm (Edmund Co.) were set in the holder and in front of the camera. However, the front limited field of view was larger than we had expected. The goggles are the safety goggles MG-277MLF developed by Midori Anzen Co. Ltd. The holder was made of aluminum. Some persons aged from 19 to 22 years were photographed by the direction detector.

C. Measuring the Direction for the Line of Vision

We performed image processing for the photographed color image using the cross-platform numerical computational software, Scilab 6.1.0, and Image Processing and Computer Vision (IPCV) Toolbox 4.1.2 [22]-[24]. The direction for the line of vision was calculated as the center of the iris. We set various parameters using the "all-directions" method and attempted processing. Image processing comprised the five processes: reduction, trimming, binarization or gray scale, edge extraction, and Hough transform (Fig. 7).

Fig. 6 Prototype of the direction detector for the line of vision

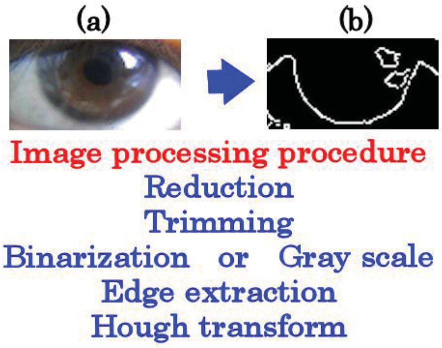

Fig. 7 Image processing procedure

"Gray scale" converts RGB images to gray images. "Binarization" converts images to binary images. "Edge extraction" has five methods: Sobel, Prewitt, Laplacian of Gaussian (LoG), fast Fourier transform (FFT), and Canny filters. First, the differentiation filter is one of the representative examples to perform edge extraction of images. In image analysis, the edge is an outline for an observation object. If the brightness difference between contiguous pixels is larger, the edge of the image will be understood easier. Therefore, the first differentiation filter will react with the only part where the brightness difference is larger and emphasize it. The kernel of the first differentiation filter disregards all pixels, except for the pixels that are contiguous with the central pixel, and calculates both differences. The first differentiation filter has two kinds of filters: the Prewitt and Sobel filters. The Prewitt filter uses a kernel that adds a smoothing process to the first differentiation filter and performs the process using the difference between surrounding brightness values. A horizontal process creates images that have an emphasized vertical edge. Similarly, a vertical process also creates images that have an emphasized horizontal edge. The Sobel filter strongly emphasizes the edge with less brightness difference. Therefore, the Sobel filter could easily emphasize the edge. The kernel of the Sobel filter emphasizes brightness differences more than the Prewitt filter. Therefore, the filter also clearly emphasizes thin edges. However, the Sobel filter has a high possibility that a noise will be emphasized because the filter has a strong emphasizing effect. If the noises are worrisome, the Prewitt filter is more suitable than the Sobel filter. However, as the Sobel filter clearly emphasizes the edge that individuals can visually recognize, the effect of appearance is good. Next, the LoG filter is a filter that combines the Gaussian and Laplacian filters. After the filter smooths an image using a Gaussian filter and reduces a noise, it extracts an outline using a Laplacian filter. As the Laplacian filter has a secondary differentiation function, the filter could easily emphasize noises. Therefore, the Gaussian filter smooths the image beforehand and reduces the noise. The FFT filter is a filter that uses FFT. We processed some images using the FFT filter. In the case of an image having many low-frequency components, the high brightness band concentrates on a central portion in the processed graph. Meanwhile, in the case of an image having many high-frequency components, the high brightness band is extensively distributed in the graph. Moreover, after eliminating the high-frequency band from the graph processed with a FFT filter, we performed inverse FFT to the image. The image lost the high-frequency components and turned into a blurred image. Furthermore, after eliminating the low-frequency band from the graph processed using the FFT filter, similarly, we performed inverse FFT to the image. The image lost the low-frequency components, and only edges remained in the image. Finally, the Canny filter is a filter that combines the smoothing process of the Sobel filter with the Gaussian filter and can obtain edges that underwent thinning. First, an image underwent smoothing using a Gaussian filter, and noises were reduced from the image. Next, the first differentiation factors were acquired in both lengthwise and transverse directions from the smoothened image using the Sobel filter. The slope and direction of the edges were calculated in the two differentiation images. Pixels unrelated to the edges were removed from the images. Thus, we checked whether the pixels have the maximum value to the direction of a slope to each pixel.

III. RESULTS

A. Measuring the Direction for the Line of Vision

We calculated the direction for the line of vision as the center of iris. As shown in Fig. 7, we performed image processing for the photographed color image using Scilab 6.1.0 and IPCV Toolbox 4.1.2. Original pictures were 720 x 480 pixels in resolution. To improve the speed of processing, the images were reduced to one-eighth. The program performed the trimming of the image. The images became 89 x 47 pixels in resolution. Then, the program performed the binarization or the gray scaling of the images. In the binarization process, we can specify a threshold value in the range from 0 to 1, regardless of the class of the input image. We set the threshold value to 0.5 for the binarization. Fig. 7 (a) was reduced and trimmed, and Fig. 7 (b) was processed in the Canny filter. As the parameters for the Sobel filter, we set the threshold level to 0.53 and the direction to "both." The threshold level was set from 0 to 1. If negative, the output image will have the un- thresholded gradient image. The direction may be "horizontal," "vertical," or "both." This determines the direction to compute the image gradient. Fig. 8 shows the output image using the Sobel filter.

Fig. 8 (a) underwent gray scaling, and Fig. 8 (b) underwent

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binarization. As parameters of the Prewitt filter, we set the threshold level to 0.2 and the direction to "both." Fig. 9 shows the output image using the Prewitt filter.

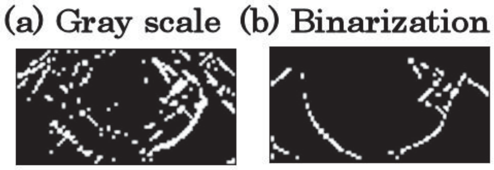

Fig. 8 Output image using the Sobel filter

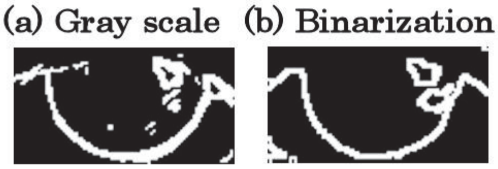

Fig. 9 Output image using Prewitt filter

Fig. 9 (a) underwent gray scaling, and Fig. 9 (b) underwent binarization. As parameters of the LoG filter, we set the threshold level to 0.1 and the sigma value to 1.5. The sigma value controls the amount of high-frequency attenuation in some methods. This can be used to obtain different levels of detail and filter out high-frequency noise. Fig. 10 shows the output image using the LoG filter.

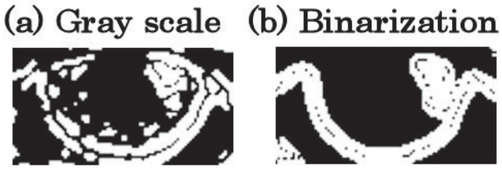

Fig. 10 Output image using the LoG filter

Fig. 10 (a) underwent gray scaling, and Fig. 10 (b) underwent binarization. As parameters of the FFT filter, we set the threshold level to 0.2, the direction to "both," and the sigma value to 1.0. Fig. 11 shows the output image using the FFT filter. The FFT method made almost the same image as that obtained using the Prewitt filter.

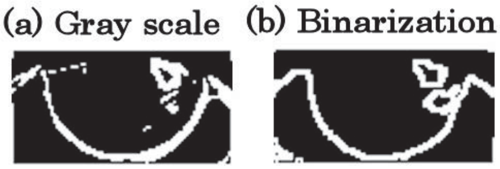

Fig. 11 Output image using the FFT filter

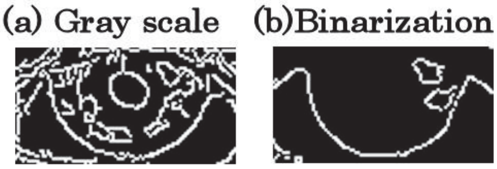

Fig. 12 Output image using the Canny filter

Fig. 11 (a) underwent gray scaling, and Fig. 11 (b) underwent binarization. As parameters of the Canny filter, we set the threshold level to 0.41 and the sigma value to 3.0. Fig. 12 shows the output image using the Canny filter.

Fig. 12 (a) underwent gray scaling, and Fig. 12 (b) underwent binarization. These values have expressed the iris's outline most correctly. In this stage, the Canny method was deemed the optimal extraction method.

B. Image Processing Using the Hough Transform

The output image using the Canny filter could clearly extract the iris's outline and was the best image. We performed image processing using Scilab 6.1.0 using the Canny image. The Hough transform was performed to the edge element in the Canny image. It computed the iris's central point. Thus, we drew many red circles that have a center point on the edge element (Fig. 13). The iris's center was estimated to be the point where the red circles superimposed at the maximum number of times. The light blue cross shows the iris's center in Fig. 13.

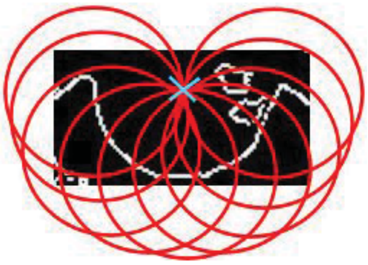

Fig. 13 Estimate of the iris's center point using the Hough transform

We performed the Hough transform to search for the main coordinates from the iris's edge. Fig. 14 shows the calculated center point of the iris in the yellow circle.

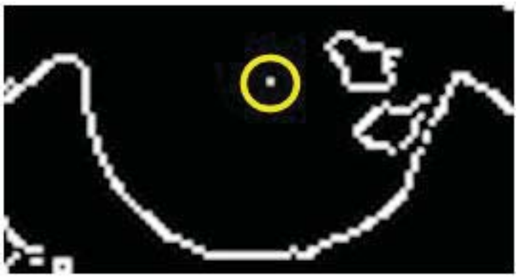

Fig. 14 The iris's center point calculated using the Hough transform

IV. CONCLUSION

We developed a direction detector for the line of vision and a basic robot for medical and nursing care for patients with glaucoma. The line of vision was estimated to calculate the center of the patient's iris. The Hough transform could calculate the iris's center from the edge of the binarization and Canny filter image, which could clearly extract the iris's outline.

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