An Egocentric Computer Vision based Co-Robot Wheelchair*

Haoxiang Li, Mohammed Kutbi, Xin Li, Changjiang Cai, Philippos Mordohai, Gang Hua

Abstract— **Motivated by the emerging needs to improve the quality of life for the elderly and disabled individuals who rely on wheelchairs for mobility, and who might have limited or no hand functionality at all, we propose an egocentric computer vision based co-robot wheelchair to enhance their mobility without hand usage. The co-robot wheelchair is built upon a typical commercial power wheelchair. The user can access 360 degrees of motion direction as well as a continuous range of speed without the use of hands via the egocentric computer vision based control we developed. The user wears an egocentric camera and collaborates with the robotic wheelchair by conveying the motion commands with head motions. Compared with previous sip-n-puff, chin-control and tongue-operated solutions to hands-free mobility, this egocentric computer vision based control system provides a more natural human robot interface. Our experiments show that this design is of higher usability and users can quickly learn to control and operate the wheelchair. Besides its convenience in manual navigation, the egocentric camera also supports novel user-robot interaction modes by enabling autonomous navigation towards a detected person or object of interest. User studies demonstrate the usability and efficiency of the proposed egocentric computer vision co-robot wheelchair.**

I. INTRODUCTION

According to the National Institute of Child Health and Human Development (NICHD), 2.2 million people in the United States depend on a wheelchair for day-to-day tasks and mobility [1]. Most of them are elderly or disabled individuals, to whom independent mobility is very important. However, operating the existing manual or powered wheelchairs could be difficult or impossible for many individuals [30]. Even with powered wheelchairs, people with severe upper body motor impairment may not have enough hand functionality to use the joystick. To accommodate these severely disabled individuals and support their independent mobility, researchers developed a number of alternative wheelchair controls [16], [6], [5], [22], [29], [31], [8], [19], [3], [25]. These hands-free control could improve the life quality of those individuals as well as people with good hand functionality but want to drive powered wheelchairs while keeping their hands free from holding the joystick.

In early years, to support hands-free wheelchair driving, researchers proposed special equipment or specifically designed wheelchairs such as the sip-n-puff control, head control and chin control [16]. In the sip-n-puff system, the user gives commands by applying different pressure on a pneumatic tube by "sipping" and "puffing". It is a solution for severely disabled users as it requires minimal efforts in moving the upper body. However, it requires the user to switch between deep and shallow inhales and exhales, which affects the user's natural breathing rhythms. Therefore it may not be physically comfortable for a long time. Besides, the user cannot communicate with others while operating this control.

The chin-control or head-control can be a feasible solution when the user has good head movement ability. In a head-control system, switches are usually mounted in the headrest, and they are operated by head movement. In a chin-control system, the design allows the chin to sit in a cup shaped joystick handle and to control the handle by neck flexion, extension, and rotation. These two control schemes require the users to frequently move their neck and head and apply force on tactile sensors.

More recent works include the tongue-based human-machine interface [18], [19], brain-controlled wheelchairs [17], [4] and voice-controlled wheelchairs [23], [7]. The tongue-based control is motivated by the observation that the tongue has rich sensory and motor cortex representation. Some work along these lines uses inductive devices installed in the user's mouth and on the user's tongue to provide multi-directional control of the wheelchair [18]. Non-invasive tongue-based control has also been developed. For example, Mace et al. [19] present a system to capture the tongue-movement induced ear pressure for wheelchair control. The tongue-based solution also has the drawback that it interrupts the user's communication with other people.

The brain-controlled wheelchairs have attracted a lot of attention due to their wide applicability [17], [4]. The brain-computer interface (BCI) is based upon the fact that the electrical activity of the brain can be monitored using an array of electrodes placed on the scalp. The user can drive the wheelchair without physically operating any mechanical device. For example, Carlson et al. [4] present a BCI system in which the user controls the wheelchair by performing a motor imagery task. The user is required to imagine the kinaesthetic movement of the left hand, the right hand or both feet. The signals can then be captured and classified into three classes and generate different commands to drive the wheelchair. The brain-controlled wheelchair has great potential in helping severely disabled individuals to obtain independent mobility but it demands the user's full attention in generating the motion commands, which may not be a

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preferred choice for users with more control ability.

Without relying on specially designed equipment or devices, speech recognition technology has been adopted to provide voice-based control [23], [7]. It enables the users to operate the wheelchair by uttering pre-defined words or phrases. This interaction method, while being natural, may only support limited number of commands in driving the wheelchair. It would be easy for a speech recognition based control system to provide discrete directional control commands such as forward, backward, left, and right etc. However, it could be challenging to design a speech based interface to support continuous directional navigation and access the full range of drive speed. Besides, the speech recognition may not be robust in a noisy environment and the user may not feel comfortable using voice commands in public.

In this paper, we propose a novel wheelchair control with wearable egocentric camera and computer vision technology. We utilize the wearable egocentric camera which could be a small camera installed on the glasses such as the Google Glass or a web camera mounted on a cap as we will show in our prototype system. The cost of a web camera is very low compared with many of the existing hands-free controls. In driving the wheelchair with the proposed control, the user moves his/her head within a small range to remotely control a virtual joystick shown on a frontal display. The movement of head is slight to keep the amount of required efforts small and no external forces are applied to the neck of the user. The frontal display serves as a virtual feedback of the user's movement to help the user to quickly understand and learn the control.

Compared to previous computer vision based controls [28], [24], [11], [26], [8], [10], the camera setting in our system is different in that instead of having the camera installed on the wheelchair to focus on the user's face, we have a wearable camera on the user's head and a marker installed on the wheelchair to support the vision-based control. The control is realized by tracking the visual marker with the wearable camera to estimate the head motion and generate motion commands.

This setting gives us three benefits. First, our system can be more robust. Gesture recognition and face detection by themselves are challenging problems in computer vision. In a real-world environment, the accuracy of gesture recognition and face detection can degrade due to a number of factors such as face pose changes, lighting changes, cluttered backgrounds etc. In our setting, we can easily enhance the robustness of our method with one or more distinctive visual markers on the wheelchairs. This is not possible with the camera setting in previous works. Second, we do not ask the user to perform any pre-defined expressions. Small head motion is a more natural control and greatly reduces the user's self-consciousness in public. Third, the wearable camera is more than a control device. It is an effective tool for the user to collaborate with the robotic wheelchair. In navigating to a certain target, the user can actively search for the target with the wearable camera instead of waiting

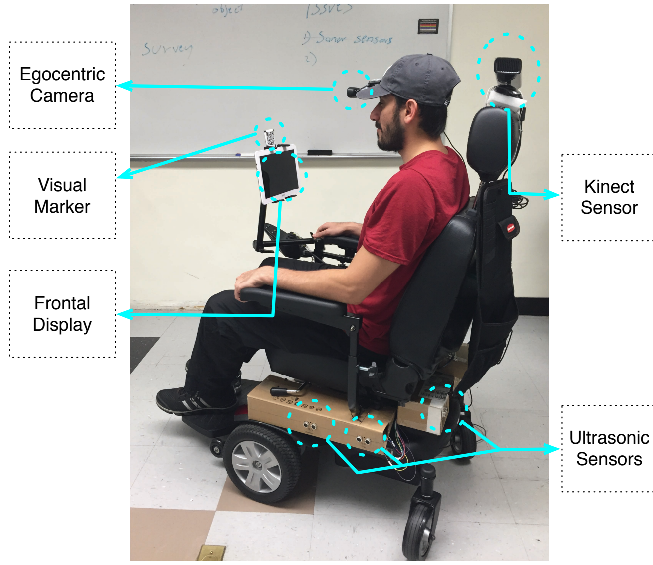


Fig. 1. The robotic wheelchair.

for the robotic wheelchair to progressively turn and scan the scene for the target.

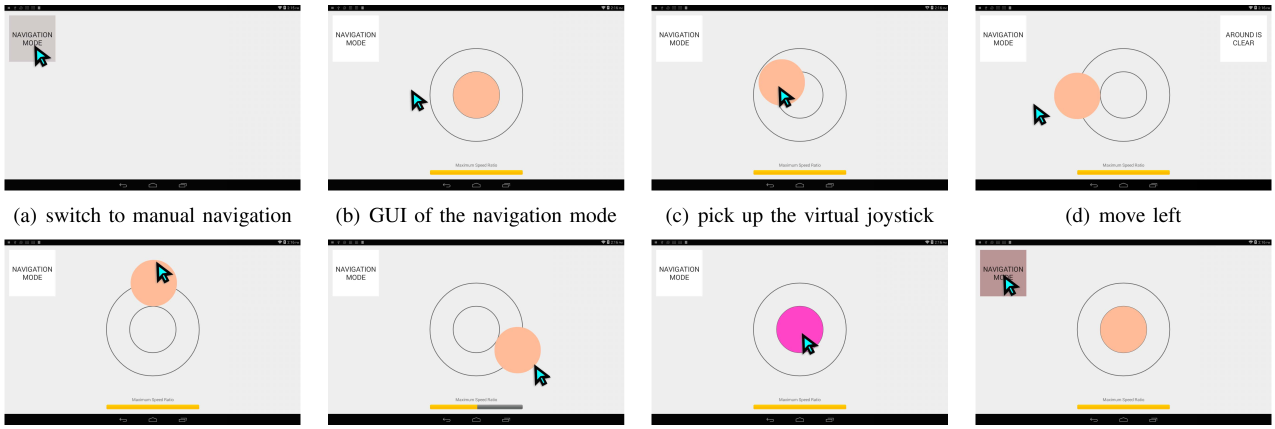
In this paper, our work makes two contributions: (1) we propose a natural and convenient interaction method with an egocentric camera based on computer vision technology; (2) we present that the same wearable camera enables efficient human guided navigation.

II. RELATED WORK

While our computer vision based control has many advantages, it is not the first time computer vision technology has been adopted to assistive wheelchairs. We will briefly review related work introducing computer vision technology to wheelchairs.

Quintero et al. [28] use computer vision technology to control a wheelchair mounted assistive robot manipulator. Directly controlling a multiple degree-of-freedom (DOF) arm could be very difficult for disabled individuals. Their proposed interface reduces this task to a discrete selection task. Instead of manipulating the robot-arm to reach a specific point, the user simply selects between the target objects or locations detected and processed using the camera. Besides its help in manipulation, computer vision also helps in navigation. Pasteau et al. [24] use computer vision technology to help disabled people drive in the corridor. The virtual guide progressively activates an automatic trajectory correction to avoid collision into the wall. These works are not directly relevant to ours, but similar designs are applicable with the egocentric camera in our system.

Kim et al. [11] present a robotic wheelchair with only a pan-tilt-zoom (PTZ) camera. They utilize special visual markers, which have some black parts called black-peak that moves according to the viewing angle. Hence, the robotic wheelchair can localize itself more accurately with the help of these special markers to complete challenging tasks such



(a) switch to manual navigation (b) GUI of the navigation mode (c) pick up the virtual joystick (d) move left

(e) move forward (f) automatic brake (g) put back the virtual joystick (h) stop manual navigation

Fig. 2. The control GUI of the robotic wheelchair.

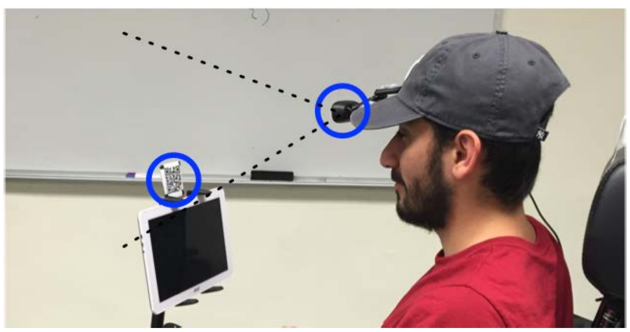


Fig. 3. The setup for head motion tracking. The camera and visual marker are highlighted.

as passing a door. Our method works well with a simple marker printed on paper.

Other relevant works utilizing computer vision include the wheelchair control with gaze direction and eye blinking by Purwanto et al. [26], the head gestures based control by Gray et al. [8] and the face and mouth recognition based control by Ju et al. [10]. Purwanto et al. set up a camera in front of a wheelchair user to capture the control information expressed through horizontal gaze direction for driving direction and eye blinking timing command for commands such as ready, backward movement and stop. Gray et al. present an intelligent wheelchair with head gesture recognition based hands-free control. They have a similar setting with a camera focused on the face of the user and a set of pre-defined head gestures that are detected with the camera to drive the wheelchair. The system presented by Ju et al. is similar except that they further utilize the shapes of the user's mouth to generate control commands.

The most similar work to ours could be the active vision control proposed by Halawani et al. [9]. However, instead of having continuous directional control, they use the head motion to generate discrete commands such as moving left, moving right, and etc. In addition, in their system there is no frontal display as in ours. The display serves as an important feedback for the user in controlling the wheelchair.

These computer vision based methods have advantages compared to other approaches [16], [17], [4], [23], [7]. First, web cameras are low-cost devices making these systems more affordable. Second, the computer vision based methods do not ask the users to physically operate certain devices to protect the user from the repetitive stress injury or repetitive motion injury. Third, the computer vision based methods enable the user to communicate with others while operating the wheelchair. Finally, the computer vision based methods can be complementary to existing methods.

III. Robotic Wheelchair

We briefly introduce our assistive robotic wheelchair. As shown in Figure 1, the robotic wheelchair is developed based on a powered wheelchair driven by a joystick (Drive Medical Titan Transportable Front Wheel Power Wheelchair). We emulate the electrical signals in manipulating the joystick with signals generated from an Arduino micro-controller. To detect obstacles around the wheelchair, we install six ultrasonic sensors around the wheelchair. The ultrasonic sensors can detect obstacles within a range of 2 centimeters to 3 meters.

In order to obtain the distance of objects to the wheelchair, a Kinect sensor is mounted on the wheelchair looking forward over the user's head. The Kinect sensor can be used for autonomous navigation with RGB-D visual SLAM, but this is out of the scope of this paper. A tablet mount is set up to hold a tablet as a display device in front of the user. A visual marker is on the tablet mount to assist the hands-free control. A wearable camera is mounted on a baseball cap and the user wears the cap and control the wheelchair with head motion. The software system is built with the Robot Operating System (ROS) [27]. Figure 4 shows a diagram of our system.

IV. Egocentric Computer Vision based Control

A. User Interface

In the proposed system, we have a Graphical User Interface (GUI) on the tablet as shown in Figure 2(b). The head

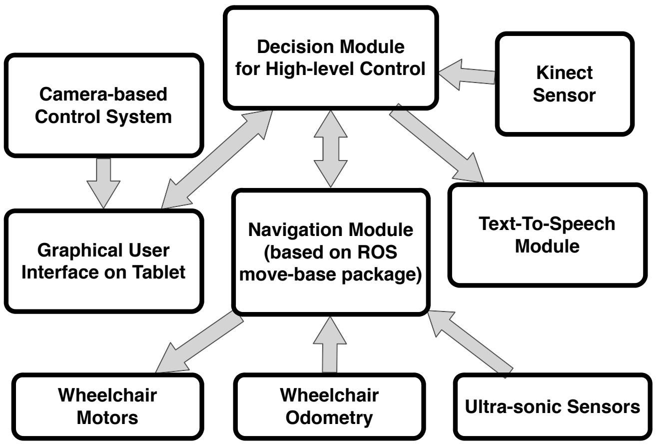


Fig. 4. The diagram of our system: arrows indicate the directions of flows of commands or information. In the egocentric computer vision based control mode, the driving commands from the virtual joystick are passed to the navigation module, which is aware of the surroundings. The navigation module passes feasible commands to the motors. In the human guided navigation mode, the navigation module is given a target position and generates a series of driving commands for the motors to move to the goal.

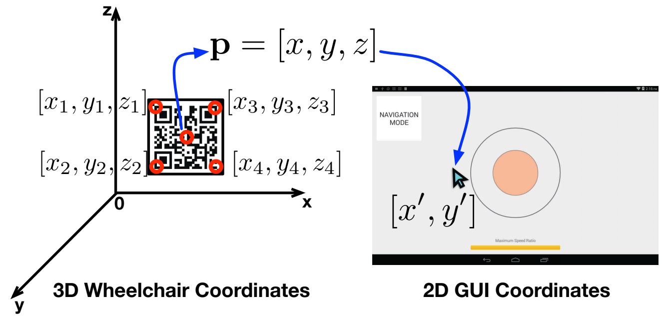


Fig. 5. The pre-defined 3D point $\mathbf{p}$ drives the cursor in the GUI.

motion of the user moves a cursor on the GUI. Some pre-defined actions could invoke GUI events of the cursor. For example, a button click is invoked by hovering the cursor over a button for a pre-defined time length.

A typical work-flow with the proposed control includes the following steps:

1) move the cursor to the "navigation mode" button and keep the cursor on the button for 3 seconds to start the manual control;
2) move the cursor to the center and keep it there until the center round button is "picked up" by the cursor;
3) move the cursor to the target direction and use the distance of the cursor to the center to control the moving speed;
4) once the target is reached, move the cursor back to the center to reduce the speed to zero and keep it there until its color changed to "put back" the center round button;
5) move the cursor to the "navigation mode" button and keep the cursor on the button for 3 seconds to exit the manual control.

As described above, this hands-free control simulates the full functionality of a real joystick so that it provides similar driving experience. As a result, it is easy for the user to learn to use this control and this proportional control supports continuous directional drive and access to the full range of drive speed.

An example work-flow is shown in Figure 2. In our system, we include an automatic brake for safety in case the user is distracted during the manual navigation. As shown in Figure 2(f), the bar below indicates the maximum speed of the wheelchair. When the visual marker is outside of the field of view of the wearable camera, the maximum speed decreases gradually to zero. For example, when the user is interrupted to look to his/her left in driving the wheelchair, the wheelchair will gradually apply the automatic brake to keep the user safe.

B. Head Motion Tracking

As shown in Figure 3, the head motion tracking uses a web camera mounted over the user's head and a visual marker mounted on the wheelchair. To make the visual marker distinctive from common objects in daily life, we use a Quick Response (QR) code marker. We also use the ViSP library [20] to detect and read the QR code.

In the mirror of the image captured by the wearable camera the movement of the visual marker is analog to the movement of the cursor in the GUI. To obtain the position and orientation of the wearable camera, we formulate and solve a Perspective-n-Point (PnP) problem. First, we calibrate the wearable camera to obtain its intrinsic matrix $\mathbf{K}$ using OpenCV [2] and a chessboard. Then we define the 3D coordinates of the four corners of the QR marker in the coordinate system of the wheelchair as $[x_i, y_i, z_i], i = 1 \cdots 4$. With the QR marker detection from the image captured by the wearable camera, we have the 2D coordinates of the four corners points as $[x_i', y_i']$. With these data, we solve this PnP problem [12] to get the position $\mathbf{t}$ and orientation $\mathbf{R}$ of the wearable camera.

To drive the cursor in the GUI, we select a 3D point in the wheelchair coordinate $\mathbf{p} = [x, y, z]$ which is projected near the center of the image captured by the wearable camera when the user is in a neutral pose, so that it remains visible in wide range of head poses. As shown in Figure 5, in the proposed control, the location of the cursor $[x', y']$ is calculated by projecting $\mathbf{p}$ into the image plane, i.e.,

$$\begin{bmatrix} \mathrm{f}x' \\ \mathrm{f}y' \\ \mathrm{f} \end{bmatrix} = \mathbf{K} \times [\mathbf{R}|\mathbf{t}] \times \begin{bmatrix} \mathrm{x} \\ \mathrm{y} \\ \mathrm{z} \\ 1 \end{bmatrix}. \tag{1}$$

In tracking the marker, we use the Consensus-based Matching and Tracking of Keypoints for Object Tracking (CMT) tracker [21]. As shown in Figure 6, tracking a distinctive visual marker is robust to motion blur and hence the control is reliable. In Figure 7, we show 4 head poses each of which gives the maximum speed in that direction.

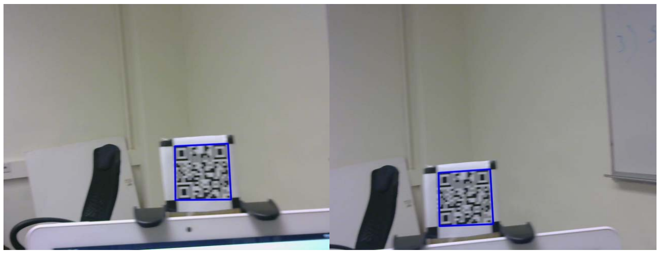


Fig. 6. The visual marker is reliably tracked in presence of motion blur. See blue outlines.

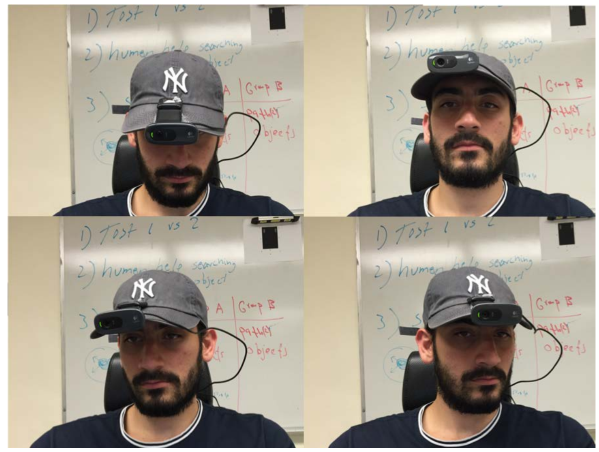


Fig. 7. The head poses giving maximum speed in different directions including forward, backward, right, left from top left to bottom right in clockwise order.

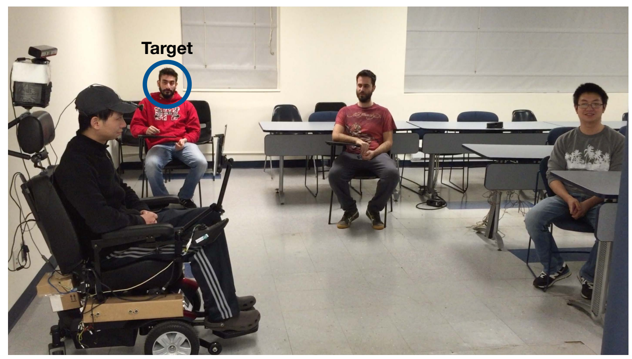


Fig. 8. An example scenario for human guided navigation: the robotic wheelchair may start to look for the target by turning right while the user knows the correct direction to turn to efficiently find the target.

As we can observe, since the proposed head motion tracking can accurately capture small head movements, the proposed control requires little efforts in driving. This is advantageous compared to typical chin-control and head-control. For feedback, chin and head-control devices impose certain forces on the head and indirectly to the neck. The frequent movement of neck combined with the feedback forces may potentially cause neck problem due to repetitive stress injury or repetitive motion injury.

V. Egocentric Computer Vision based Human Guided Navigation

The user of our system has several options for moving from one place to another. In a new environment, the user can easily drive around with the camera-based control. In addition to this manual control mode, the user can fully rely on the robotic wheelchair for an autonomous navigation between places, in known environments such as the user's own home. This is not shown in this paper. Besides these two options, we present in this section, a human guided navigation mode in which the user selects a person or object of interest and the wheelchair autonomously approaches it.

With a pre-built map, there are many solutions for generating an efficient path for navigation between two selected locations. However, it could take considerable time for the robotic wheelchair to locate the target location. For example, as shown in Figure 8, to navigate to the other person the robotic wheelchair needs to search for the target person. The search process requires turning the wheelchair until the target person is detected with the on-board camera. However, periodically moving and stopping could be uncomfortable for the user and the search process may take considerable time. On the other hand, manually driving the wheelchair to the target person requires the full attention of the user during the whole driving process.

Hence we present a human guided navigation approach to improve the efficiency. As an example, the steps for navigating to another person are:

- the user looks for the target person with the egocentric camera without moving the wheelchair;
- once the egocentric camera detects and recognizes the person, it asks for confirmation using the frontal display;
- the user confirms the request from the tablet with the hands-free control;
- the robotic wheelchair autonomously navigates to the target.

This proposed human guided navigation can benefit from the facts that a) the user is usually aware of the location of the target; b) the wearable camera has a combined field of view larger than a static camera. We illustrate the combined field of view in Figure 9.

In order to guide the robotic wheelchair to search in the correct direction for the target object, the robotic wheelchair needs the relative head pose when the target object is detected from the wearable camera. As discussed in Section IV-B, we can track the user's head motion with the visual marker. Hence when the visual marker is in the field of view, the robotic wheelchair is aware of the current head motion. When the visual marker is out of the view of the wearable camera, we will infer the relative location of the marker by keeping track of the head motion direction.

For example, if the target object is detected when the user is looking to the right but the visual marker is lost, we can infer that the marker is to the left of the target object and hence be aware of the correct direction to turn to the target

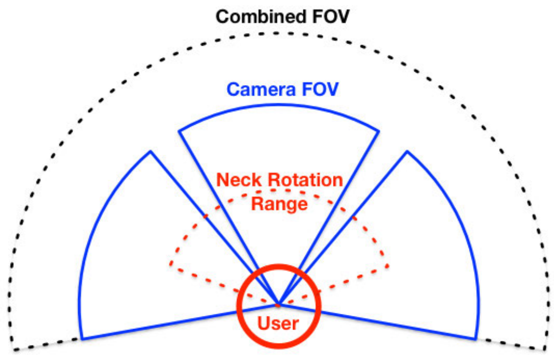


Fig. 9. Combined field of view of the wearable camera: the field of view of typical web camera can be as small as 40 degrees; by rotating the neck, the wearable camera covers a large field of view.

object is right.

The human guided navigation combines autonomous and manual navigation. It supports a more natural behavior of the co-robot wheelchair in looking for an object or person in a large area. For example, when the expected target is in another room, the autonomous navigation is activated upon the detection of the target object during the following process:

1) the user switches to the manually drive mode and drives the wheelchair into the other room;
2) the user looks at the target object/person to detect the target object/detection with the wearable camera;
3) once the target object/person is detected, the autonomous navigation starts and the robotic wheelchair moves to the target.

VI. EXPERIMENTS

To evaluate the proposed method, we conduct lab studies with 10 participants (9 male, 1 female in their 20s and 30s). A navigation task is designed to evaluate the usability of the proposed egocentric computer vision based control.

A practical advantage of our system is that it is mostly calibration-free. We need to calibrate the web camera once beforehand but do not need any calibration process for different individuals.

A. Egocentric Computer Vision based Control

Previous hands-free mobility solutions such as the brain-computer interface, voice commands based control and face or head gesture based control provide discrete motion commands to drive the wheelchair. For example, a typical set of 5 motion commands can be *LEFT*, *RIGHT*, *FORWARD*, *BACKWARD*, *STOP*. In contrast, our method enables continuous directional control as well as access to the full range of drive speed. Our method is of higher usability compared with the conventional method.

In our experiment, to compare with previous solutions, we implement a baseline control method which provides the 5 motion commands. The baseline control method uses the same egocentric camera but only supports the *four-directional control*. In the *four-directional control*, the user controls the wheelchair to move in one of the 4 directions (left, right, forward and backward) with 4 kinds of head motions same as the ones in Figure 7. The neutral head pose stops the wheelchair.

We set up a navigation task in a corridor as shown in Figure 10. We place empty boxes in the scene as obstacles. In this task, we ask participants to drive the wheelchair from the start-point to the end-point without running into any box.

Before the experiments, we show the two driving control methods to all participants to help them briefly learn the driving controls. To reduce the influence of driving experience obtained during the experiments, we ask 5 out of the 10 participants to drive the wheelchair with the *continuous directional control* first and switch to the *four-directional control* after successfully accomplishing the task. The others test with the *four-directional control* first.

We use two metrics to evaluate the quality of the navigation, *elapsed time* and *number of attempts*. We count how many times users failed before they successfully accomplish the task. The wheelchair is autonomously stopped when it is about to hit an obstacle. When this happens during a navigation task, the navigation is regarded as failed. The elapsed time is recorded when the participant successfully accomplishes the task. In general, a control method is more difficult to learn when the number of attempts is large. But it does not indicate that the control method is hard to use. The user may take more than one attempt to learn a control method. However, once the users understand how to drive the wheelchair with the control method, it can take them less time to accomplish the task. We observed this case in our experiment with two participants.

The two metrics objectively measure the usability of a control method. Besides, we ask the participants to take a questionnaire on their experience in driving the wheelchair each time after they finished the task with one of the two control methods. We generally follow the Computer System Usability Questionnaire by Lewis et al. [13] to design the questionnaire. The participants are asked to report their agreement to the statements listed in Table I with a score between 1 to 7 in which 1 indicates *strongly disagree* while 7 indicates *strongly agree*. After they finish evaluating all the control methods, we ask them to choose their preferred control method.

The experimental results are shown in Table II. Most participants accomplish the task in the first attempt, which indicates that the head motion based control is very intuitive. As we observed, it takes the participants far less time to accomplish the tasks with the proposed continuous directional control. Even for some participant, such as participant b, who takes 2 attempts to accomplish the task with the continuous directional control, it takes him less time to finish the task with the continuous directional control. On average, the participants agree that the proposed control method is easier, more comfortable to use and more effective in completing the task. All the participants prefer the proposed *continuous directional control* over the baseline *four-directional control*.

View from the start-point in the task

View from the end-point in the task

Fig. 10. The task: participants are asked to navigate from the start point to the end point.

TABLE I

QUESTIONNAIRE FOR THE PARTICIPANTS: THE PARTICIPANT IS ASKED TO GIVE A SCORE FOR HOW THEY AGREE WITH EACH STATEMENT AFTER EVALUATING A CONTROL METHOD.

1.	It was easy to learn to use this control method.
2.	I feel comfortable using this control method.
3.	I like using the interface of this control method.
4.	The control method is effective in helping me complete the tasks.

B. Human Guided Navigation

We include an instance of human-guided navigation in the supplementary video. In the experiment, the user wants to move to a specific person in a scenario with three people present. Prior to the experiment, we have a registration process to enroll two of them into with the face recognition system of the robotic wheelchair. In registration, we ask each enrollee to stand in front of the wheelchair, look at the Kinect sensor and record a 5 second video. After registration, the face recognition system has their names and face appearance representations.

In the experiment, the two enrolled people with one unseen person as imposter sit in a classroom. The target person, who is enrolled in the system, sits out of the field of view of the Kinect sensor. We then let the robotic wheelchair drive to the target person guided by the user. When the user looks around for the target person, faces are detected and recognized from the wearable camera. Once the target person is discovered, the head motions are used to guide the robotic wheelchair to turn to the correct direction to approach the target person. Once the Kinect sensor sees the target person, it tracks him and the user is free to look around while the wheelchair autonomously drives to the target.

In this experiment, we used the Cascade Convolutional Neural Network based face detector [15], the Probabilistic Elastic Part based model face recognition system [14] and the CMT face tracker [21].

VII. CONCLUSIONS

This paper has proposed an egocentric computer vision based co-robot wheelchair. It uses an egocentric camera to provide hands-free control which enables elderly and severely disabled individuals to obtain independent mobility. The users control the motion direction and speed of the wheelchair with their head motions. A frontal display is setup to provide the user a feedback loop to make the controlling experience natural and convenient. Compared with many of the previous solutions, the proposed hands-free control provides continuous directional drive and access to the full range of drive speed. With a low cost device, our solution is more affordable. The proposed method is of higher usability without asking the user to perform special expressions or to speak out commands in public. Besides providing this novel control, the egocentric camera in our method further supports the efficient human guided navigation. The human guided navigation combines the convenience of autonomous navigation and the efficiency of the manual navigation. Instead of waiting for the robotic wheelchair to search for the target, the user is able to actively locate the target by the egocentric camera. Once the target is detected, the robotic wheelchair starts the autonomous navigation to the target

TABLE II

EVALUATION OF THE CONTROL METHODS IN THE NAVIGATION TASK.

	cont-directional control						four-directional control					
	Questionnaire				Metrics		Questionnaire				Metrics	
Participant	1	2	3	4	Elapsed Time	Num. of Attempts	1	2	3	4	Elapsed Time (s)	Num. of Attempts
a	7	6	7	7	65	1	6	5	7	3	175	3
b	6	4	5	5	182	2	7	4	5	5	262	1
c	6	6	5	7	63	1	4	4	5	4	190	1
d	7	7	7	7	66	1	5	5	4	6	250	1
e	7	7	7	6	68	1	5	4	7	4	245	1
f	7	7	7	7	95	1	7	6	5	5	241	1
g	7	7	7	7	71	1	7	7	4	5	180	1
h	7	7	7	7	101	2	6	3	3	2	193	1
i	7	6	5	6	80	1	7	5	6	5	209	1
j	6	6	7	7	96	1	6	5	5	5	254	1
Average	6.7	6.3	6.4	6.6	88.7	1.2	6	4.8	5.1	4.4	219.9	1.2

without asking the user for help. Our experiments demonstrate the effectiveness and the efficiency of the proposed egocentric computer vision based co-robot wheelchair.

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