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A Framework for Controlling Wheelchair Motion by using Gaze Information

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Abstract: Users with severe motor ability are unable to control their wheelchair using standard joystick and hence an alternative control input is preferred. In this paper a method on how to enable the severe impairment user to control a wheelchair via gaze information is proposed. Since when using such an input, the navigation burden for the user is significantly increased, an assistive navigation platform is also proposed to reduce the user burden. Initially, user information is inferred using a camera and a bite-like switch. Then information from the environment is obtained using combination of laser and Kinect sensors. Eventually, both information from the environment and the user is analyzed to decide the final control operation that according to the user intention and safe from collision. Experimental results demonstrate the feasibility of the proposed approach.

Keywords: Wheelchair, severe impairment user, head tracking and assistive motion

1. Introduction

In recent years, numerous methods have been introduced for developing smart platform of wheelchairs system to accommodate the needs of people with severe disabilities. These users' limitations to control the wheelchair may be due to several reasons such as cerebral palsy, cognitive impairment, or being fatigue prone [1]. There has been a great deal of research devoted in this area and some recent results can be found in [2] [3], which highlights the setups of various individual systems and their strategies used for assisting the user. The development trend can be broadly classed into three main areas [4]: 1) Improvements to assistive technology mechanics, 2) Improvements to user-machine physical interface, 3) Improvements to shared control between the user and the machine. Users with severe motor impairment (e.g. spinal cord injury) generally lack muscle control, and in the worst case they are unable to command the movement of arms and legs. For such a patient, input devices based on cues or actions generated from the head (e.g. gaze, brain, and bite) can be possible media at all levels of injuries [5]. The medium should provide the users with ability to control the direction of wheelchair, and to initiate/terminate such tasks.

Even though the alternative medium can enable the user to steer the wheelchair; yet some clinical studies found that their patient still find it hard or impossible to operate it [6], especially for avoiding obstacle [7]. These clinical findings provide insights for the importance of devising a computer-controlled platform to assist the users during navigating. Under this framework, the user input along with the environmental information will be seamlessly analyzed for providing necessary assistive tasks. The amount of given assistance usually varies depending on how severe the users` impairments and the assistance can be categorized into three main levels: shared-control, semi-autonomous control, and autonomous control [8]. The level of given assistance should be decided by considering the maximum of users' abilities to control the wheelchair and the computer only complement the loophole [9].

In this paper, the primary objective is to support people with severe motor disabilities. This group of people lacks of muscle control for effectively command a wheelchairs using a conventional joystick, and hence an alternative interface is preferable. When using this medium, the low-level task such as obstacle avoidance usually requires more effort from the user, and hence such burden should be taken over by the designed computer-assisted controller

This paper is organized as follows. Section 2, 3, 4 and 5 presents the system overview consist of software and hardware layer. Next, Section 6 shows experimental results with discussion. Finally, the summary and future research is presented in Section 7.

2. System Overview

The system is implemented on robotic wheelchair (TT-Joy, Matsunaga Corp.) equipped with four types of sensors as shown in Figure1: a standard webcam

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(Logicool), a RGBD Camera (Kinect, Microsoft), a laser range finder (UTM-04LX, Hokuyo) and an Inertial Measurement Unit (IMU) sensor (VN-100, Vectonav).

The webcam works as an alternative medium for inferring user gaze input. Next, combinations of Kinect and laser sensors are used to perceive environmental information. The kinect is located 1.3 meter up from the ground plane while the laser range finder is situated at 20 cm from the ground plane. By combining data from both sensors, detail information about the obstacles in the surrounding can be inferred. Kinect will be used to acquiring 3D information in front of the wheelchair, while the laser detecting objects in the wheelchair surrounding. The final sensor is IMU which provides information about wheelchair's current state in world coordinates. Output from the IMU sensor is calibrated and error compensated using Extended Kalman filter, and hence providing reliable 6 DOF positioning reading

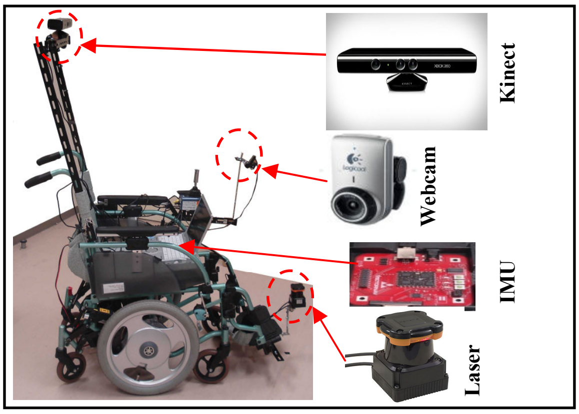


Figure 1. Hardware setting.

3. Gaze Input Interface

We choose to use gaze information as an alternative medium for commanding the wheelchair since during walking or driving humans naturally look at the direction they are heading to, and hence it is a versatile way to infer their intent. Previous works [10][11] successfully utilized this medium for maneuvering the wheelchairs through indoor and outdoor environments while avoiding obstacles. But unlike them, we do not use the input to continuously control the wheelchair; instead we use it for determining the user's intended direction. In our system, the controller takes over the responsibilities for navigating and avoiding obstacles, while the user takes care only about the general directions for traveling. This results in a low user involvement, and therefore higher user comfort. For initiating and terminating each control command (i.e., start and stop) we use a bite-like switch button (i.e., not an actual bite switch but imitating the nature of the switch operation). When the user press and release the switch (i.e., momentary action), the wheelchair either move automatically to the direction that the user look at or terminating its current action. When the user press and holding the switch, wheelchair executes a pure rotation movement (left or right) depending on the user's gaze direction.

3.1 Head Detection and Tracking

Since we want the system to continuously infer the user gaze information, tracking his/her head is necessary. In wheelchair coordinates system, the head's region at time t in the RGB image is represented as $h_t = [x_t\ y_t\ w_t\ \alpha_t]$ where x_t and y_t are the region's center coordinates, w_t is the region's width and α_t is the yaw head angle. To continuously predict such information, the head's region is tracked by the particle filter framework presented in [12]. Particle filter (*PF*) is a Bayesian sequential importance sampling technique, which recursively approximates the current state information using a finite set of weighted samples from noisy measurement called particles. Given a current state observations ($p(z_t|h_t)$), a transition state ($p(h_t|h_{t-1})$) and a previous state information ($p(h_{t-1}|z_{t-1})$), the *PF* predict the current state information ($p(h_t|z_t)$) by solving a Bayesian problem in equation (1).

$$p(h_t \mid z_t) = p(z_t \mid h_t)\int p(h_t \mid h_{t-1})p(h_{t-1} \mid z_{t-1})dh_{t-1} \qquad (1)$$

To initialize a *PF* cycle, an estimation of initial target region is required. Here, initialization is triggered by the output from the Adaboost based head detector with haar-like features [13]. From this process, numbers of possible head's localities (h^d) is obtained. To assimilate such information into the tracker, a cross check procedure is performed between h^d and currently tracked head regions (h^c) using Euclidean distance measure. Regions h^d are assigned as newly tracked objects if their distances from all h^c regions exceed the minimum threshold. Otherwise, we the regions h^d are currently under tracked.

For each h^c, *PF* samples at time t are projected according to equation (2) where n is the number of particles, Of^n is the 8 points optical flow distributed evenly within h^c region, and the random vector $N^n(\mu,\sigma)$ provide the system with a diversity of hypotheses.

$$h_t^{cxn} = h_{t-1}^{cxn} + Of^n + N^n(\mu,\sigma) \qquad (2)$$

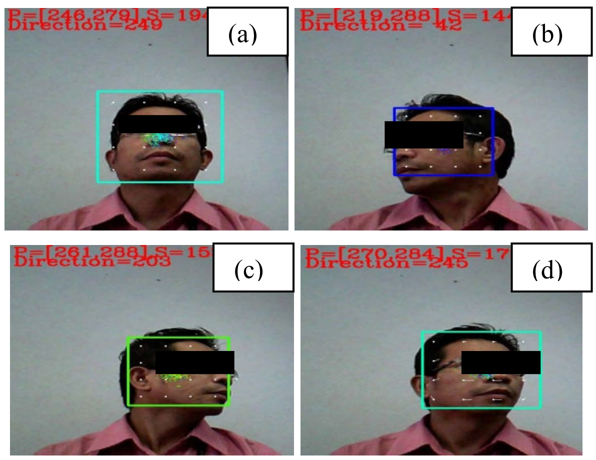


Figure 2. Sample of the head detection and tracking

result. The direction values resemble the estimation of head orientation. (a) Front. (b) Left. (c) Right. (d) Front.

The observation model is used to evaluate the particle confidence level by computing its weight. We use two evaluation methods based on image contour obtained from Sobel edge detector and pre-trained seven cascades for classifying frontal face, left 45˚, right 45˚, left 90˚, right 90˚, left back and right back respectively. The overall weight of each particle is computed by fusing the likelihoods from the image contour and the cascade classifier. Eventually, the target current state, h_t^c, is estimated by using the average weight of all *PF* samples. Sample of the detected and tracked user head orientation is shown in Figure 2.

3.2 From Gazing Direction to Motion Command

To control the wheelchair, we use the switch input and the yaw angle value (α_t). The former is responsible for triggering the "start" and "stop" command while the latter determine the preferred heading direction. Basically, the system works by letting the user look and issue a "start" command every time s/he wishes to change the heading direction. When the user issues the "start" command, in static condition it will initiate moving action according to the α_t direction; while moving, it will dynamically alter the goal direction directly depending on the α_t value. When such direction is beyond the gaze's reachable spot, the user can select it by performing the following sequence of commands: "stop"→purely rotate to the desired direction→aiming to the spot→"start".

By using this procedure, the system manage to give freedom to the users to partially maneuver the wheelchair by letting them change to the new goal direction as they wish in an easy and natural way, while at the same time allowing them to perform what they want to do during maneuvering.

4. Safety Map

The safety map is responsible for inferring information in the wheelchair surrounding to ensure the instructed motion is safe and collision free. For satisfying such requirement, the sensor used must capable to perceive the environment as accurate as possible. A vision system is extremely useful for detecting various obstacles' shape since it has vast amount of data. However, this sensor normally has a small field of view. On the other hand, laser sensor has wide field of view but cannot accurately detecting objects that not uniform in shape such as tables and chairs. By combining both sensors we can control the tradeoff between the FOV limitation and the accuracy requirement.

Once both sensors are fully calibrated, we can easily overlay both data to produce the navigation map for the assistive motion control. Sample of the safety map as a result of the sensors fusion is given in Figure 3 where the black areas rooted from the Kinect and the red area sourced from the laser sensor.

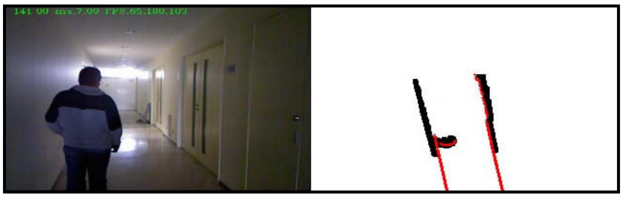
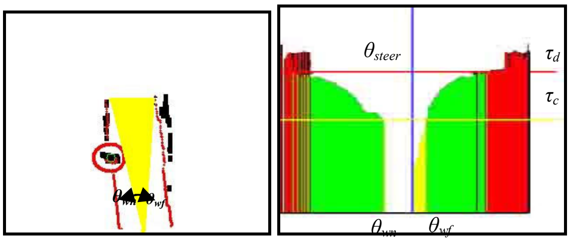


Figure 3: RGB image (*left*) and Navigation map image (*right*). Black areas and red areas sourced from Kinect and laser sensor respectively.

5. Assistive Motion Control

Wheelchair's movement can be characterized by a tuple of (υ_w, ω_w) represented translational and rotational velocity. The pure translation (υ_w, ω_w=0) produced straight movement, while pure rotation (υ_w=0, ω_w) produce a circle movement based at the wheelchair's origin. Combination of both velocities (υ_w, ω_w) will decompose into arcs trajectories, in which higher velocities will produce sharper curvature movement.



(a) (b)

Figure 4: Sample of navigation map for Figure 3. (a) The black area source from Kinect, laser area is denoted by red color and yellow area indicates free spaces. (b) Visualization of the generated POD

To allow reasoning of the safe trajectory planning, an extension of Vector Field Histogram (VFH+) [14] is adopted with a slight modification. VFH uses the 2D Cartesian histogram known as active window built around the wheelchair within a squared shape. Each active cell in the window grid is transformed into the 1D histogram representation known as Polar Obstacle Density (*POD*) in the form of $POD(\omega_{ij}) = m_{ij}$ using equation (3), where (x_{ij} , y_{ij}) is the coordinates of an active cell , (x_o,y_o) is the coordinates of sensor's origin (SO), C_{ij} is the certainty value of obstacle in the cell, d is the distance to the cell from SO , and a and b are positive design parameter constants.

$$\omega_{ij} = \tan^{-1}\left(y_{ij} - y_o / xi_j - x_o\right),$$
$$m_{ij} = c_{ij}^2 \times \left(a - bd_{ij}^2\right) \qquad (3)$$

To develop the primary *POD* we use the information provided by the navigation map as visualize in Figure 3.

To convert this *POD* into a Binary representation (POD_b), a threshold is needed. We defined two values namely τ_c and τ_d in which $\tau_d > \tau_c$. The former is for discriminating high and low *POD*, while the latter for determining high risk obstacle (*HRO*) location. We need to consider the *HRO* since humans normally move in the environment, and sometime can suddenly appear inside the wheelchair's security buffer for a certain period. A sample of the generated *POD* is given in Figure 4, where the RGB image, the safety map and the *POD* distribution image are shown from left to right. In the *POD* image, the yellow and green bars represent the low and high *POD* regions, respectively, while the red bars show *HRO* locations.

6. Results and Discussion

As described previously, we introduced the foundation of the gazing command (GC) and how it can be used for controlling the wheelchair and assign/reassign the new direction of travel. Here, we assess the implementation of such reaction in real navigation. In this experiment, the user was asked to use the GC for maneuvering the wheelchair in hallway and lab environments shown in Figure 5 and Figure 6. We would like to evaluate the wheelchair reaction for responding to the given command, and intervals of the user give command to the controller. In both figures, the lower part visualizes the wheelchair's motion overlay with the user's head orientations and the state transition of the GC, while the upper part display a series of snapshots captured from the wheelchair's viewpoint with the illustration of the generated path.

In hallway navigation with an ample space, the user provided less command and changed to the desired direction without the need to stop. As can be seen in Figure 5, the user start navigate at position s#1 and only need to provide three more GC "start"(s#2, s#3, and s#4) while moving, to successfully navigate through the environments. The controller responds instantaneously by re-orientate the wheelchair (θ_{wch}) according to user preference. In between of #s1 and #s2, we may observe the planner executed the obstacle avoidance task (#frame 50-100 in the bottom figure) automatically without the need of user intervention to prevent collision

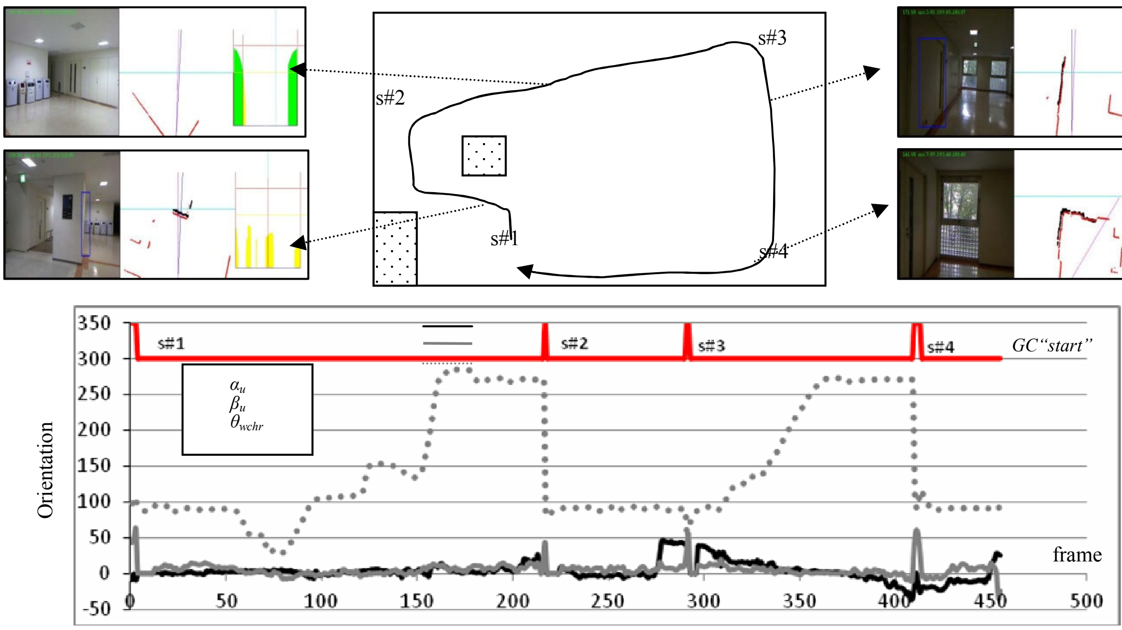


Figure 5: GC in hallway navigation. (*Top*) Illustration of maneuvering path with sample snapshot. (*bottom*) Command state transition and its effect to overall maneuvering direction.

In lab atmosphere, as given in Figure 6, unlike hallway, the user tends to stop before changing to the desired action. Apparently, such action is executed because of often the desired direction is beyond the user's FOV, or sharp turning is needed. As shown in Figure 6 (*bottom*), the controller successfully respond to the GC, for example "stop"→"right" in ii and iv, and "stop"→"left" in vi. In term of the quality of the generated path for this particular condition, with more user intervention (i.e. i, iii, iv, v), it may take longer to travel due to combination of multiple GCs, but apparently shorter in distance. On the other hand, with less GC, the driven path (i.e. vi and vii) is more lengthy but faster.

Overall, both experiments proved that the proposed GC capable to steer the wheelchair into the user's desired direction. From our finding, the intervals of the user provided the GC is quite related to the environments. The user give less command in spacious area compare to narrow and crowded space. But we does not generalize this relation, since it is highly depends on the user intent while driving which is quite hard to quantitatively measure. The system may analogy an auto-cruise system, which when the desired target direction is fixed, the user can remain seated while the controller steer the wheelchair safely. But on top of that, the user can override the command every time s/he wishes.

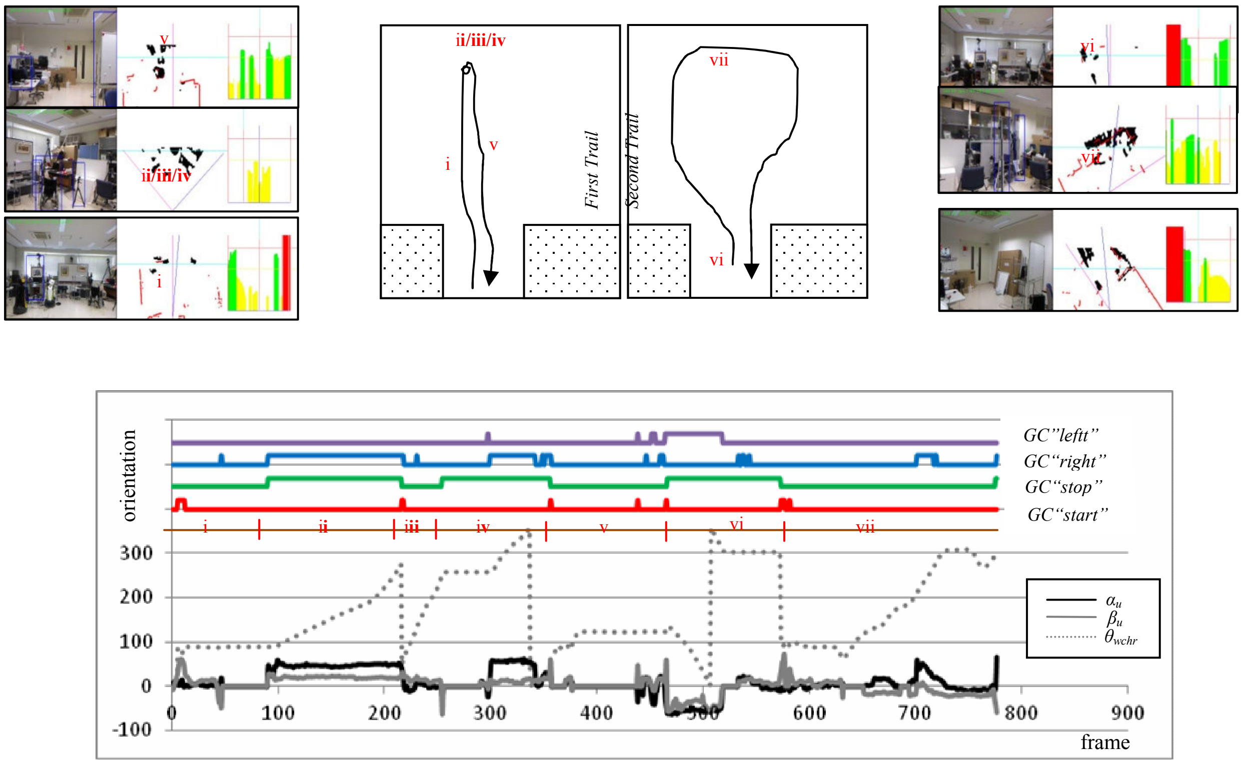


Figure 6: GC in lab navigation. (*Top*) Illustration of maneuvering path with sample snapshot. (*bottom*) Command state transition and its effect to overall maneuvering direction.

7. Conclusion

In this paper, a framework for enabling and enhancing the wheelchair controllability to cater the need of users with severe motor disabilities is proposed. With the use of gaze and bite-like switch as alternative inputs, the user can easily steer the wheelchair in manual and semi-auto control mode. By incorporating the safety map, apparently collision can be avoided in both modes, i.e., manual and semi-auto, and hence may reduce user burden of continuously monitoring the surrounding while maneuvering.

In future work we will evaluate the system with more participants to gain the generality of the overall system reliability. Besides that, we will also measure the cognitive complexity of users using a secondary task tool.

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