Robotic Assistance to Reconnect the Daily Life Interactions for Sensing, Locomotion and Manipulation from Paralysis

ROBOT DESIGN COMPETITION
Design a New Bridge for H-R-I
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For people with paralysis due to severe sensory-based motor disorders or musculoskeletal disorders, daily life interaction with the environment in terms of sensing, locomotion and manipulation may no longer be possible. Robotic assistance is a promising solution to help them reconnect with interactions for daily activities. We propose a design concept of robotic assistance to realize extended sensing, locomotion as well as manipulation for a user to interact with the environment only utilizing gaze control considering the availability and directness of gaze modality. Specifically, the proposed method focuses on the situation where a user desires to explore the surrounding environment beyond their physical perception capability, requiring the robotic assistance of realizing extended sensing. The proposed 2D/3D gaze interface is wearable, unrestrained, and it straightforwardly gives commands to the robot for motion control. The effectiveness of the proposed design method was validated by a proof-of-concept study.

INTRODUCTION

For people with partial or total paralysis of upper limbs as well as lower limbs due to severe sensory-based motor disorders, musculoskeletal disorders, spinal injuries or stroke, robotic assistance has been the most promising solution to help improve their daily living standards. To realize robotic control according to a user's free will, brain–computer interfaces (BCIs) aim to establish the direct communication between the brain's electrical activity and an assistive device. BCI methods can be invasive and non-invasive and have been demonstrated in various applications (e.g. [1,2]). However, BCI methods with good cost-effective performance are still far away from practical usage. On the other hand, utilizing a user's retained modalities for communicating with robotic devices is a much more common approach to implement. Usually, human-robot interaction involves multiple modalities of human perception. However, for the majority of people with severe sensory-based motor disorders or musculoskeletal disorders, the visual modality may be the best or the only communication channel for them to interact with their surroundings. For the visual modality, 2D gaze clue has commonly been utilized to estimate intention as well as to realize interaction (e.g. [3,4]). Rather than realizing robotic control and intention estimation using 2D gaze, 3D gaze information of a user can be directly incorporated for robotic control in Cartesian space as presented in [5,6]. In this study, as shown in Fig. 1, we also adopt the method of only utilizing a user's visual modality, specifically the user's 3D gaze, to interact with the environment and the robot. Besides the most needed robotic assistance for locomotion and manipulation, we focus on another important function of robotic assistance - helping a user to sense the invisible part of the environment. Invisible parts of the environment can result from occlusions, limitations of human visual capabilities in temporal and spatial domains, or simply due to physical properties of objects that are beyond human visual perception. Robotic assistance for sensing is also very important for people with paralysis to restore their daily interactions with their surroundings. In this robot design competition showcase, we demonstrate the effectiveness of our design concept with primary results of a proof-of-concept study.

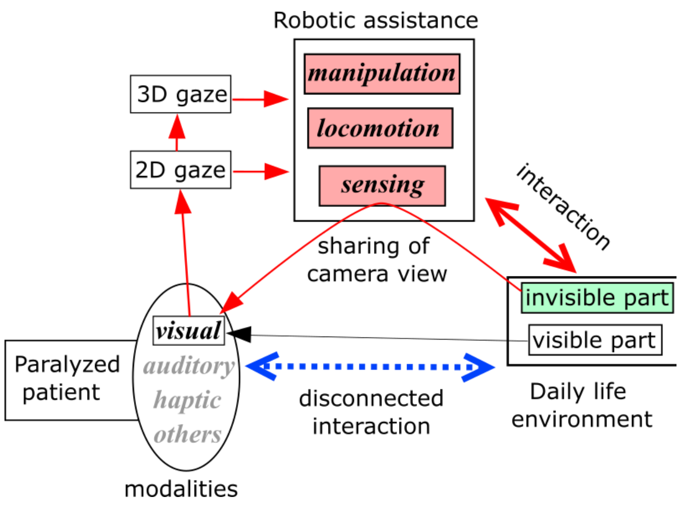

Figure 1. Design concept of robotic assistance

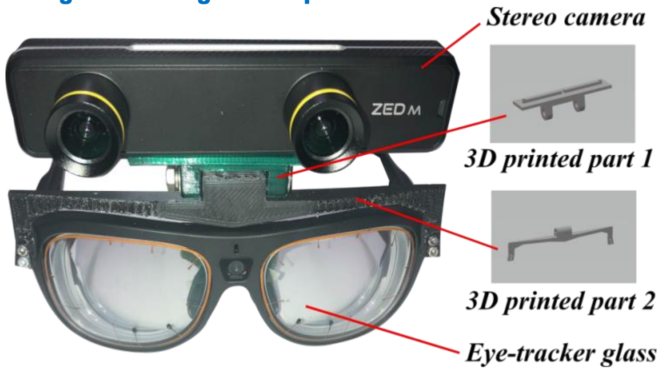

Figure 2. The developed 2D/3D gaze interface

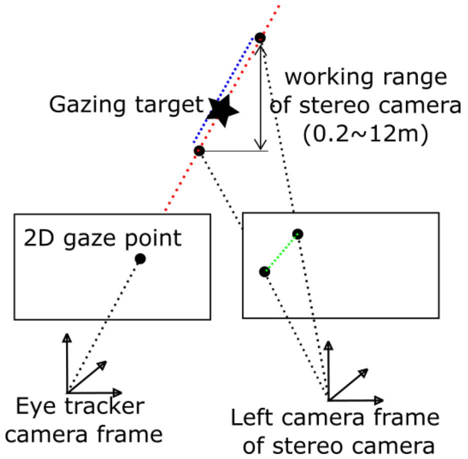

Figure 3. 3D gaze estimation from 2D gaze point

2D/3D GAZE INTERFACE DESIGN

Gaze fixation

The 3D gaze interface shown in Fig. 2 consists of a pair of eye-tracker glass Tobii Pro Glasses3[1] and a stereo camera ZED Mini[2]. They are connected by 3D printed parts that enable view angle adjustment. To prevent unnecessary saccades and microsaccades during fixation, a low-pass filter is firstly implemented on the raw data of 2D gaze. A fixed number of gaze candidates in time sequences are then extracted from the low-pass filtered gaze stream with a fixed time interval. Gaze fixation is then determined if the distances between each pair of the gaze candidates are smaller than a calibrated threshold value. If the gaze fixation is determined as true, then the 2D gaze point is calculated as the average of the gaze candidate group.

3D gaze estimation

After the 2D gaze point is retrieved, the corresponding 3D coordinate is then estimated to enable the wheelchair as well as the robotic arm to work in Cartesian space. To get the 3D position of a gazing target captured by the eye-tracker, we firstly implement the stereo calibration between the eye-tracker's camera and the left camera (C_L) of the stereo camera. We then set the frame of left camera, which is the base frame of the stereo camera itself, as the base frame for stereo calibration between it and the eye-tracker camera (Fig. 3). In order to find the correct corresponding 3D point, we acquire the point cloud data from the stereo camera and match it with the 3D gaze candidate points. Firstly, a hypothesis depth Z is assumed to transform the gaze point in the eye-tracker's frame to the stereo camera's frame. We then calculate the error e_Z between Z and the depth value retrieved from the stereo camera. The estimation problem is then transformed into the search for an optimal hypothetical Z that associates the smallest error e_Z. The search range is limited to 0.2 – 12 m according to the workable range of the stereo camera, and a Newton's method is applied to find the optimal solution. We apply the basic Newton's method as follows to compute the optimal depth Z with n noted as the number of iterations:

$$Z_n = Z_{n-1} - \frac{f(Z_{n-1})}{f'(Z_{n-1})}$$

$$f(Z_n) = |depth_n - Z_n|$$

$$f'(Z_n) = \frac{f(Z_{n-1}) - f(Z_n)}{Z_{n-1} - Z_n}$$

On average, we only needed four iterations to find the optimal Z for every gaze frame in implementations.

[1] https://www.tobii.com/products/eye-trackers/wearables/tobii-pro-glasses-3

[2] https://www.stereolabs.com/zed-mini/

OVERALL SYSTEM DESIGN

The developed overall system is shown in Fig. 5 (left). The wheelchair is a WHILL Model CR[3] with a 7-DoF robotic arm KINOVA Gen3[4] configured on the wheelchair's left side. For navigation of the mobile platform, a depth camera D435 is configured on the wheelchair. Another depth camera D405 for close-range sensing is utilized as the hand-eye configuration. A tablet projecting the images of the hand-eye camera provides the extended perspective of the robotic arm towards objects that are beyond the user's visual perception. All sub-systems were integrated in ROS Noetic running on Ubuntu 20.04 (Focal) release.

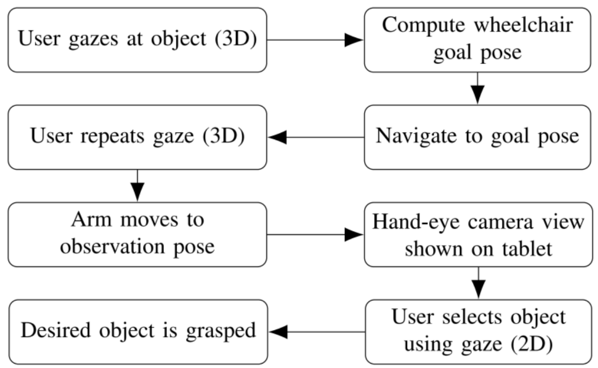

Figure 4. The flowchart of POC test

[3] https://whill.inc/jp/model-cr

[4] https://www.kinovarobotics.com/product/gen3-robots

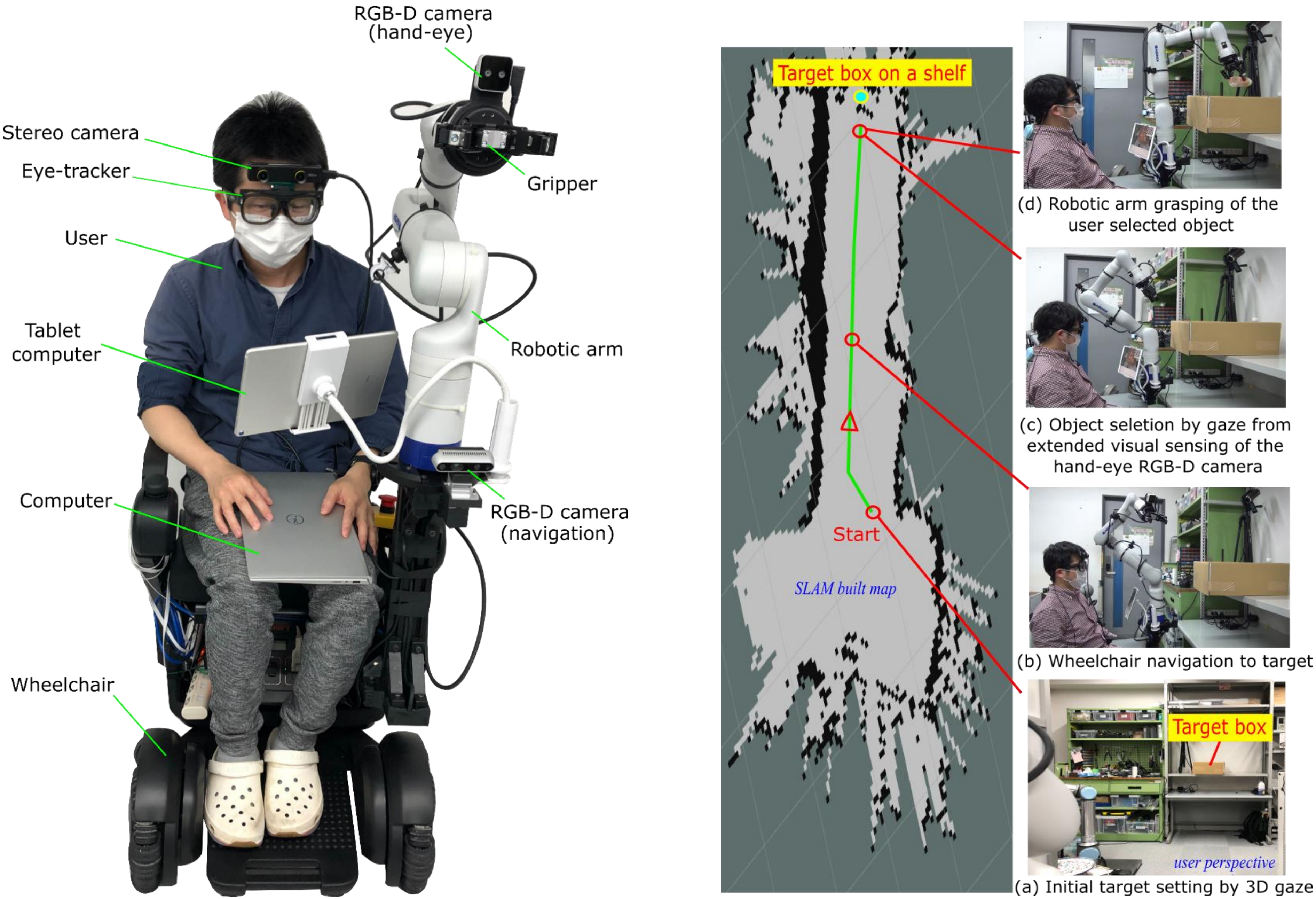

Figure 5. The developed system (left) and proof-of-concept evaluation (right)

Figure 6. Example images of hand-eye camera shown to the user on the tablet. The chessboard marker in the upper right corner is used to transform the 2D gaze point from the glasses frame to the tablet frame. Red contours indicate the object selection results by the user's gaze.

PROOF-OF-CONCEPT RESULTS

A proof-of-concept study was conducted with the flowchart shown in Fig. 4. A cardboard box with several objects in it was placed on a shelf (height: 1.15 m). At the initial state, the cardboard box was about 5 m away from the wheelchair that the user sat in. The objects within the cardboard box were not directly visible to the user during the whole process. The complete sequence from start position to grasping a user interested object is shown in right side of Fig. 5. The user firstly gazed at the cardboard box to set the initial target position for wheelchair navigation as shown in Fig. 5-(a). The wheelchair was then autonomously navigated towards the cardboard box (Fig. 5-(b)). Once the navigation finished, the user gazed the cardboard box again to update the relatively accurate position of the cardboard box, such that the robotic arm proceeded to the observing pose (Fig. 5-(c)). The user then selected the target object from the extended visual information of the hand-eye camera using the gaze control (Fig. 6). Finally, the robotic arm implemented grasping of the target object as shown in Fig. 5-(d). Primary results verified the feasibility of our proposed robotic assistance method to help the user realize extended sensing of invisible objects besides locomotion as well as manipulation.

SUMMARY

With the goal of restoring the daily life interactions with the environment in terms of sensing, locomotion and manipulation for people with limbs paralysis, we proposed a design concept of robotic assistance utilizing a 2D/3D gaze control interface. Besides the mostly investigated robotic assistance for locomotion and manipulation, we specifically focused on the objective of utilizing robotic assistance to meet a user's desire to explore the environment beyond their physical perception capability, such as to sense the invisible part of the environment resulted from occlusions as successfully demonstrated by the proof-of-concept study. We are working on realizing a much broader range of extended sensing by robotic assistance with the developed system. Finally, we are planning to evaluate the system with multiple test-persons to gather valuable feedback that can be used for improving our system.

TEAM MEMBER

Shouren Huang: Conceptual and methodology development, system design.
Sune Lundø Sørensen: Overall system integration in ROS environment.
Yongpeng Cao: Gaze interface development.

REFERENCES

1. E. Garc´ıa-Cossio, M. Severens, B. Nienhuis, J. Duysens, P. Desain,N. Keijsers, and J. Farquhar. 2015. Decoding sensorimotor rhythms during robotic-assisted treadmill walking for brain computer interface (bci) applications. PLoS ONE, vol. 10, no. 12-e0137910, pp. 1–21.
2. Y. He, D. Eguren, J. M. Azor´ın, R. G. Grossman, T. P. Luu, and J. L.Contreras-Vidal. 2018. Brain–machine interfaces for controlling lower-limb powered robotic systems. Journal of Neural Engineering, vol. 15, no.021004, pp. 1–15.
3. D. P. Noonan, G. P. Mylonas, A. Darzi, and G.-Z. Yang. 2008. Gaze contingent articulated robot control for robot assisted minimally invasive surgery. In Proceedings of the 2008 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 1186–1191.
4. S. Dziemian, W. W. Abbott, and A. A. Faisal. 2016. Gaze-based teleprosthetic enables intuitive continuous control of complex robot arm use: writing drawing. In Proceedings of the 6th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob), pp. 1277–1282.
5. M.-Y. Wang, A. A. Kogkas, A. Darzi, and G. P. Mylonas. 2018. Freeview, 3d gaze-guided, assistive robotic system for activities of daily living. In Proceedings of the 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 2355–2361.
6. A. Shafti, P. Orlov, and A. A. Faisal. 2019. Gaze-based, context-aware robotic system for assisted reaching and grasping. In Proceedings of the 2019 IEEE International Conference on Robotics and Automation (ICRA), pp. 863–869.
7. R. B. Rusu and S. Cousins. 2011. 3D is here: Point Cloud Library (PCL). In Proceedings of the 2019 IEEE International Conference on Robotics and Automation (ICRA), Shanghai, China, pp. 1–4.