Integration of a Gripper-Equipped Humanoid Social Robot for EEG-Monitored Action Observation Experiments in Stroke Neurorehabilitation Research

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Introduction: Stroke affects approximately 795,000 individuals annually, often resulting in disabilities such as motor impairment. Action observation (AO) therapy has emerged as an effective rehabilitation method for post-stroke patients, enhancing motor function by promoting brain plasticity and engaging the mirror neuron system (MNS). While the use of human actors in conventional AO therapy is well established, the role of socially assistive robots (SARs) in this context remains less understood. SARs used in rehabilitation interactions could potentially boost patient motivation and engagement, but the neural mechanisms behind their positive effects in stroke rehabilitation are still unclear. To address this, our study aims to integrate the Flo robot, a small humanoid SAR, into AO therapy to evaluate its neuromodulation effects. The existed design of Flo robot to deliver rehabilitation activities was verified in our previous studies; however, the current mitten-like hands of the robot limit the variety of actions it can perform. Our objectives include enhancing the robot's design with gripper-like hands and developing an experimental protocol that incorporates the robot into AO tasks, focusing on examining the neuromodulation effects of robot-assisted AO therapy.

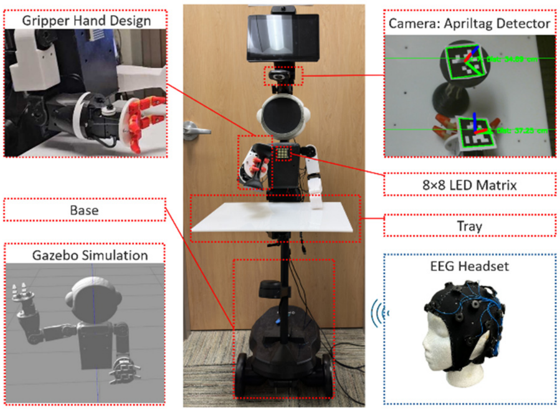

Figure 1: A picture of robot system

Materials and Methods: The hardware development of the robot features a humanoid upper body with two arms, each fitted with grippers inspired by the Yale OpenHand Project's model T, but scaled down for a small social robot. These grippers have four flexible resin fingers, controlled by a single motor via high-strength fishing lines for coordinated movement and minimal motor use. The arms are powered by DYNAMIXEL motors, integrating motors, gearboxes, controllers, and communication systems, which provide better controllability and higher control accuracy and speed. The upper body is mounted on an Ohmnilab telepresence base, enhancing mobility and interaction in dynamic settings, and includes a tray for placing objects. An 8x8 LED matrix in the chest displays patterns to synchronize with EEG signals during rehabilitation, facilitated by visual feedback. Software-wise, the system runs on ROS, combining computer vision and robotic control to boost manipulation skills. It employs an AprilTag Detector package for real-time 3D localization and path planning in Gazebo. The LED matrix and EEG recordings are synchronized using the Emotiv Cortex API, ensuring tight coordination for precise tasks and data acquisition essential for patient assessment and rehabilitation.

Results and Discussion: The new arms designed after the existing Flo robot can mimic the human arm's range of motion and perform several activities of daily living (ADLs). The gripper is capable of reaching for objects within a spatial range of 9.5 cm by 12.5 cm in front of the arm. It can also grasp objects with diameters ranging from 1.5 cm to 5 cm, securely handling objects weighing up to 120 g, which is sufficient for ADL objects such as a dumbbell and a cup that are designed for AO tasks. Additionally, the margin of error for the vision recognition and grasping system was measured at 0.5 mm. The “mqtt” package was used to synchronize the EEG signal as well as the robot's actions, and testing with a total of 1000 “mqtt” topics sent over 16 minutes showed an average latency of 43 ms, well below the average human reaction time of 300 ms.

Conclusion: The improved design of the Flo robot, featuring a gripper hand and camera-based object detection, enables the demonstration of various activities of daily living (ADLs). The integration of the Flo robot system with the EEG acquisition system creates a new modality of action observation (AO) therapy involving a humanoid robot as the actor. This groundwork will support our future research on the neuromodulation effects of social robot-assisted AO therapy for stroke rehabilitation, compared to traditional AO that employs human actors.