Title:
Haptic Trajectories for Assisting Patients during Rehabilitation of Upper Extremities

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Introduction:

Patients with motor function disorders due to brain disease are increasing recently in aging societies. The rehabilitation of patients' impairment would help them in performing typical activities of daily living and their quality of life [6]. If a patient's upper extremity is paralyzed, the quality of life dramatically decreases because it becomes quite tough to live by oneself [7]. In order to realize the most performing therapy, the assistance from the physical therapist is absolutely necessary. However, it is difficult to provide an every day therapy program due to the medical expenses and because a rehabilitation therapy, which is based on motion-oriented tasks, requires consistency and time by the physical therapist [5]. In the last decade, robotic and haptic devices for upper motor rehabilitation have been increasingly studied, becoming a promising complement to traditional therapy as they can provide high-intensity, repetitive and interactive treatment of the impaired upper extremities. In addition, these systems can provide quantitative measurement of patients' progress [1]. Following this trend, we have developed several devices and systems in order to provide robotic assistance in the execution of tasks executed on a plane (2D tasks). A first prototype of a guidance haptic concept has been described in [2], and a multimodal assistive system has been described in [3, 4], which consists in a combination of visual, haptic and sound interaction modalities. In these works, pilot studies have been conducted with persons with disabilities (PWD). These prototypes have been tested by people with specific disorders affecting coordination, such as Down syndrome and developmental disabilities, under the supervision of their teachers and care assistants inside their learning environment. Results of these preliminary studies provide conclusive evidence that the effect of using these kinds of assistive systems increases the accuracy in the tasks operations.

In this paper, we present a pilot study of a haptic system that leads the patients' limb to follow trajectories performed on a plane or in space (2D or 3D haptic trajectories). This function is implemented by the Multimodal Guidance System (MGS) whose aim is to provide robotic assistance during the rehabilitation of upper extremities when patients perform 2D and 3D haptic trajectories during manual activities such as drawing, coloring and gaming. The MGS consists of a virtual environment including several technologies as haptic, sound and video gaming.

Main Idea:

The Multimodal Guidance System (MGS) consists of a virtual environment including haptic, sound and video gaming technologies. Haptic technology provides the virtual trajectories of 2D and 3D shapes through a point-based approach; sound technology provides audio feedback related to the hand's velocity while performing the task; the video gaming approach is used to catch the patients' attention and keep high their motivation to recover or to improve their motor skills. The combination of multimodal interaction functions with haptic assistance provides a system that can find application to diverse fields as physical rehabilitation, scientific investigation of sensorimotor learning and assessment of upper extremities. The haptic trajectories are initially generated through the use of a generic Computer Aided Design (CAD) tool. Then the trajectories are saved in the VRML format, which is a standard file format used for representing 3-dimensional interactive vector graphics.

Generation of 2D Haptic Trajectories:

The Multimodal Guidance System can assist patients to follow trajectories performed on a plane (2D trajectories). Figure 1 shows an example of generation of 2D shapes, which are then transformed into haptic guidance trajectories. Figure 1(a) shows an isometric view of a 3D object (2), which is intersected by a plane (1). At the intersection is created the 2D haptic trajectory (4), which is used by the MGS to provide the haptic guidance to the patient. The 3D model is necessary in order to assign the Magnetic Surface constraint, which is a technique used to render force on the haptic device based on a given distance from a virtual surface (3). From the sketching initial point **(5)** up to the haptic trajectory (4) the Magnetic Surface constraint is disabled, allowing free-motion to the patient's hand. Figure 1-b represents the geometry from the patients' point of view, and Figure 1-c shows several geometries that have been used in the tests by the patients.

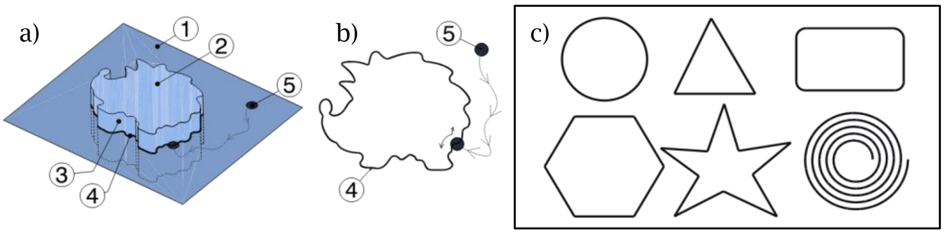
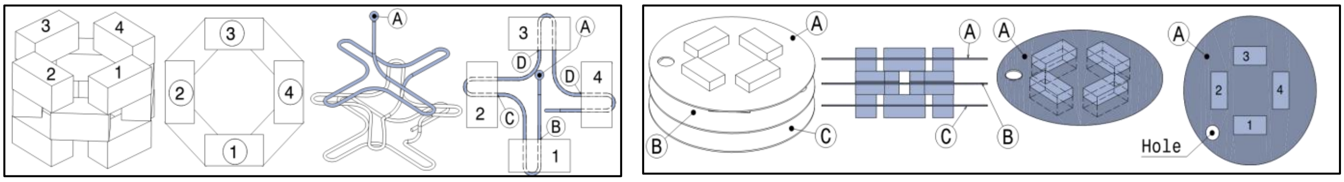


Fig. 1: Generation of 2D haptic trajectories: a) Isometric view, b) Top view and c) Basic geometries.

Generation of 3D Haptic Trajectories:

The Multimodal Guidance System can assist patients to follow also trajectories performed in space (3D trajectories). In this case we have developed an application that combines a video game with 3D haptic trajectories. The game consists of a tower made of bricks that the patients should throw down. A first case consists of a single 3D trajectory that is used to assist the patient in hitting and moving the tower bricks (Figure 2-a). A second case is a simplification of the task, and introduces three circular planes that are used to restrict the patients' motion along the vertical axis (Figure 2-b).



a) Single 3D trajectory approach

b) 3D trajectory restricted by three circular plates

Fig. 2: Generation of 3D haptic trajectories.

Preliminary Tests and Results:

We have carried out several preliminary tests in order to test the system usability and to verify the patients' improvements while performing 2D and 3D operations.

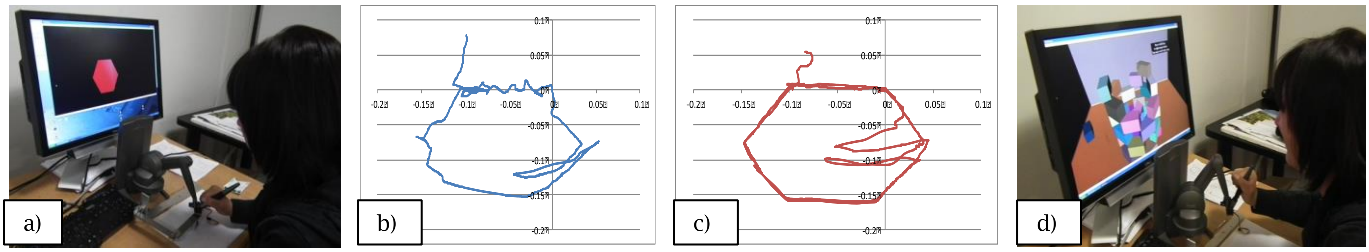


Fig. 3: Tasks performed by a patient: (a) Drawing a 2D geometry, (b) Results without the haptic trajectory, c) Results using the haptic trajectories; d) Patients performing a game using the 3D haptic trajectories.

Conclusions:

The results of our study showed that the haptic trajectories help patients during manual tasks by means of using the MGS as a rehabilitation tool. The main outcome of this pilot study is that the patients significantly reduce the time required to draw the 2D shapes when the 2D haptic trajectories are enabled, which indicates that each patient learned to use the device and felt more comfortable with the exercise. In addition, we have compared the sketching data obtained by using the device with and without the haptic trajectories. The comparison shows considerable difference in the accuracy of the operation. Regarding the 3D haptic trajectories, results also reported that the patients reduce the time required to move and hit the tower bricks. It is planned to reference the data from patients to evaluate the effect of the MGS in a rehabilitation program.

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