Upper limb tracking using depth information for rehabilitative tangible tabletop systems

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ABSTRACT

The motor impairments that affect the upper limb, such as those following an acquired brain injury, are particularly disabling, since this body segment is involved in the majority of the activities of daily living. Virtual reality systems have been reported to stimulate the clinical effectiveness of the rehabilitative strategies, providing intensive and repetitive exercises in a motivating and controllable environment. The tracking of the upper limb movements in the real world is a challenging task that has traditionally involved different tracking systems. The use of depth sensors can provide a non-invasive solution that can be integrated in tabletop systems.

1. INTRODUCTION

Acquired brain in jury (ABI) can cause a wide combination of impairments affecting motor, cognitive and psychosocial skills. The motor complications that involve the upper extremities are among the most disabling impairments and can difficult, and even prevent, the performance of the activities of daily living (ADL). The traditional rehabilitative strategies focus on the restoration and compensation of the lost functionality through conventional physical and occupational therapy (World Health organization, 2006). In the last years there are an increasing number of systems that use the benefits of new technologies to assist patients and therapists in this complex task. Most of these systems exploit virtual reality technology to create controllable and safe environments where the patients are immersed to perform task-oriented exercises (Henderson et al, 2007).

Many of the virtual rehabilitation (VRHB) systems use robotic devices as therapeutic tools that either help the patients or impede them to perform the required movements (Volpe et al, 2009; Gijbels et al, 2011). Other systems require the patients to interact through movements of their upper extremities on a table (Cameirao et al, 2010; Kuttuva et al, 2006). The surface is used to physically support the arms while the tracking is carried out by other systems (optical, electromagnetic, etc.). Recently, the multitouch devices have been considered with rehabilitative goals. The patients are allowed to interact with the virtual environment through finger touches (Annett et al, 2009) or even grasping tangible objects, that are tracked through optical systems from an upper (Numford et al, 2010) or a lower plane of the table (Dunne et al, 2010). These tracking systems determine the position where the finger makes contact with the surface or the position of the tangible object on the surface but cannot discern the movements of the body segments and joints that take part in the natural movements of the upper limb.

However, even the simplest movements of the upper extremities are extremely complex and specific. The implication of shoulder, arm and hand requires the synchronized execution of appropriate motor patterns and the accurate performance of multiarticular dynamics (Kalaska et al, 1992), which cannot be estimated with the aforementioned tracking strategies.

The objective of the work presented here was to design a new interface based on depth information that could be able to track accurately the movements of the hemiparetic upper extremities and that could be integrated in a tangible tabletop rehabilitation system.

2. MATERIALS

The hardware components of the tabletop system consist of a table, a standard computer, a projector, and a depth sensor (DS). In the prototype described here a Kinect sensor is used (Microsoft, 2012). The projector and the sensor are fixed in an upper plane of the table oriented to its surface (Figure 1). This way, the projector displays the virtual environment on the table and the patients interact within it through movements of their own extremities.
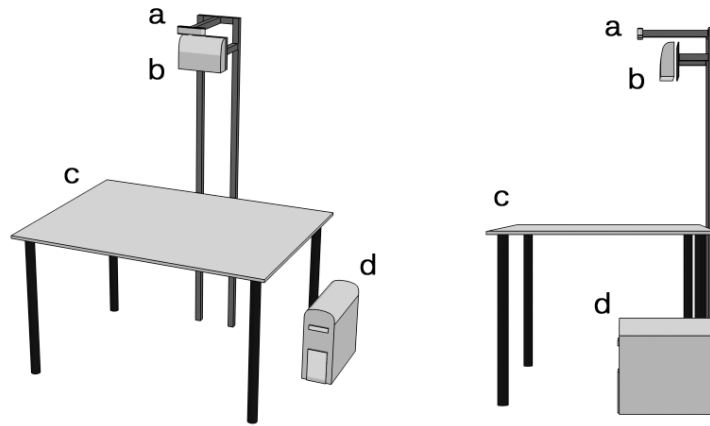

Figure 1. *Hardware components of the system: a) depth sensor; b) projector; c) table; and d) standard computer.*

The DS emits a pattern of infrared rays with different intensity and thickness values over the scene and detects the backscattering rays with a monochrome CMOS sensor that is 5cm displaced from the emitter. The DS estimates images of size 640x480 with 11 bits of sensitivity (2048 possible grey values to describe the distance of the object to the sensor) at a frame rate of 30 fps (Figure 2). The recommended working range of the DS varies from 1.2m to 3.5m but the minimum distance can be reduced to 0.7m, as set in our tabletop system. Since the field of view of the DS is 57° in the horizontal plane and 43° in the vertical plane, the sensor can cover an area of 87cmx67cm over the surface, which leads to a spatial resolution of 1.36mmx1.39mm per pixel.

Figure 2. *Comparison of a scene acquired by a RGB camera and by a depth sensor.*

2.1   Software

To make the tracking possible, its general workflow is divided into 3 main steps: workspace estimation (to estimate the space area that is part of the workspace), calibration (to estimate the depth values for which the segments make contact with the working plane), and tracking (to process the 3D positions of the interesting segments). Each exercise requires a specific calibration to define the position in which the implied segments and external objects (if needed) are in contact with the surface (first and second columns of Figure 3). Generally, the segments and objects are estimated using the depth information and their skeletons and their mass centers are defined using the distance matrix of the segments. In those exercises which mostly imply the metacarpophalangeal and interphalangeal joints, a special effort is done to track the fingers. In this case, the hand is segmented likewise and then the convex hull is applied to estimate the fingers.

With the described tracking capabilities it becomes possible to design a set of exercises as a part of a rehabilitation protocol for hemiparetic patients with acquired brain injury taking into account the brain plasticity and motor learning principles (Krakauer, 2006). The exercises cover movements that were likely to belong to the motor repertoire of the patients previously to the injury and aim to maximize the correlation of the virtual tasks with the real tasks of the ADL. For instance, the objectives of some exercises are to dial a telephone number, to cook, to knock a door, and to play a keyboard (Figure 3, rows 1 to 4, respectively).
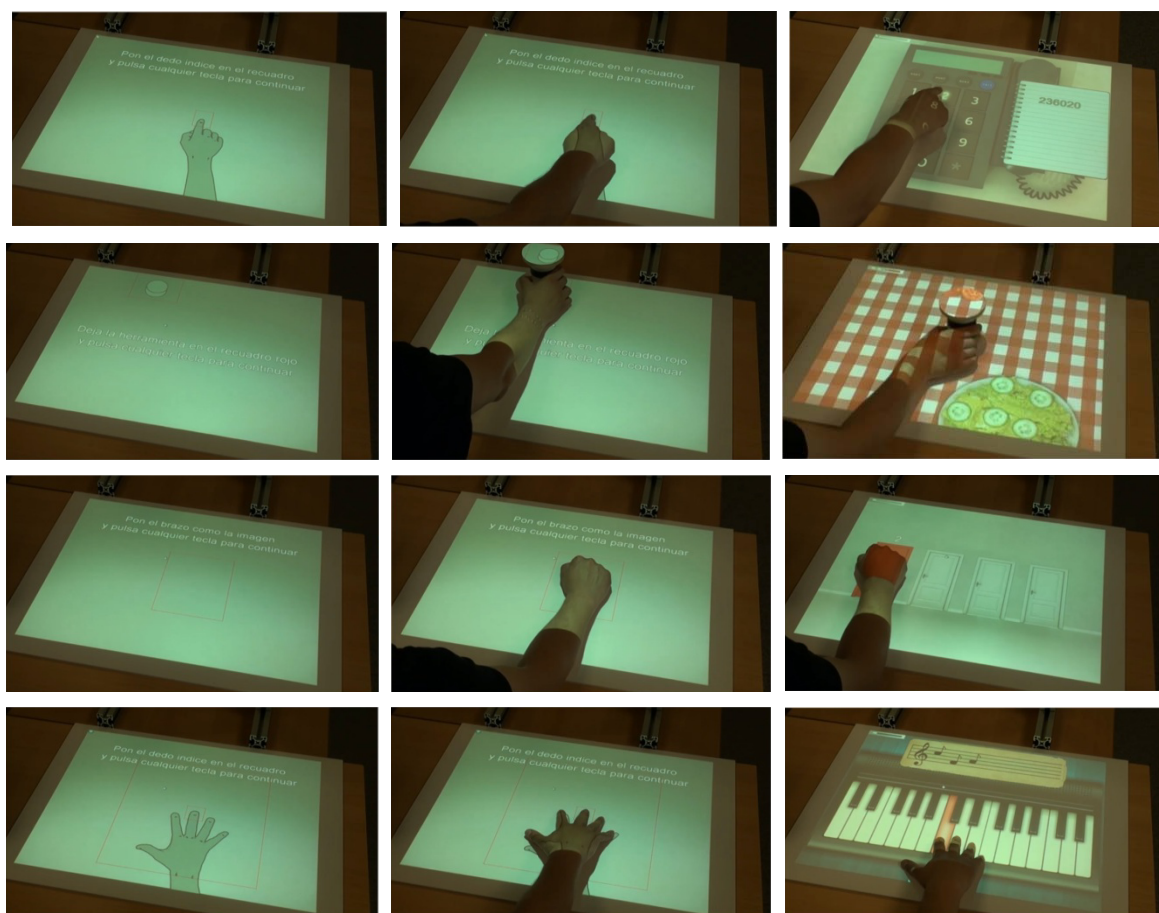

Figure 3. *Examples of exercises.*

3. CONCLUSIONS

The presented work describes a tracking solution for the upper extremities using a depth sensor that provides accurate tracking of the main segments and joints of the arm, including the movement of the fingers.

The tracking is especially interesting for being used in tabletop frameworks. This way, the patients can lean their arms on a table, which is especially interesting for those who cannot hold their arms against gravity. The tracking is not invasive since it does not require any device or sensor to be attached to the arms and it allows the free movement of the extremity. In addition, the tracking makes possible the manipulation of tangible objects with different shapes and sizes, even detecting grasps and pincer grips, which are recurrent in the ADL. However, the optical nature of the DS prevents the therapists from assisting the movement, since their arms can enter in the tracking area and mislead the tracking system (the disambiguation of the extremities of both subjects is not obvious) or occlude the patient's extremity. In addition, the DS is inevitably subject to noise that can induce a 'jitter-like' effect that distorts all the estimations.

The described tracking solution has been integrated in an upper limb rehabilitation system for hemiparetic ABI patients. A set of exercises has been developed considering the motor learning principles and maximizing the correspondence with the ADL. The exercises cover a wide range of movements commonly trained in conventional therapy programs: flexion and extension of the wrist or of the metacarpophalangeal joint, grasping, tapping, etc. To prove the clinical effectiveness of the tabletop system in the rehabilitation of

ABI patients, a randomized controlled trial is being carried out in the neurorehabilitation service of a large metropolitan hospital.

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