Electro-Pneumatic System for Imparting Controlled Postural Perturbations on Human Subjects

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***Abstract*—This work deals with the study of human postural responses to external perturbations, performed using a novel mechatronic electro-pneumatic system. The device, which must be handled by a clinical operator, has been designed, developed and tested on human subjects. An Hardware-in-the-Loop equipment is designed and developed reproducing the behavior of the operator, the automatic perturbator and the subject. Results underline a good capability of the device to reproduce the reference of the impact force.**

Keywords—posture, perturbation, actuator, robotics, human responses, mechatronics, force control

I. Introduction

Assessment of human balance is a key point for studying the biomechanical aspects of postural control [1]. Delivery of an external perturbation activates a postural response based on a coordinated recruitment of many limb and trunk muscles aimed at maintaining balance [2]. Understanding how the central nervous system recognizes an external perturbation and reacts to it, is of interest in many research fields. Objective analysis and quantitative description of postural reflexes may support the diagnosis and treatment of several clinical conditions presenting impairments in motor control [3, 4]. Many robotic and mechatronic systems may be used as perturbators, but not all of the impact frequencies are useful for studying human sensory feedback [3]. In [5], a perturbator device for proprioceptive and reactive balance training and therapy is presented. It is composed of a base where the subject is positioned in standing position. In [6], a pressurized fluid is used for developing the impact force.

In this work, the authors present a novel mechatronic system developed and tested in some recent works [7-9]. Figure 1 shows two different developed perturbators (manual (MP) and automatic (AP)) and a sketch of the operator imparting a perturbation on the back of the subject.

In [7], the design and operational principles of the device are shown. In [8, 9], a novel Hardware-in-the Loop (HIL) equipment, able to reproduce the behavior of the operator, the automatic perturbator and the subject, shown in Fig. 2, is presented.

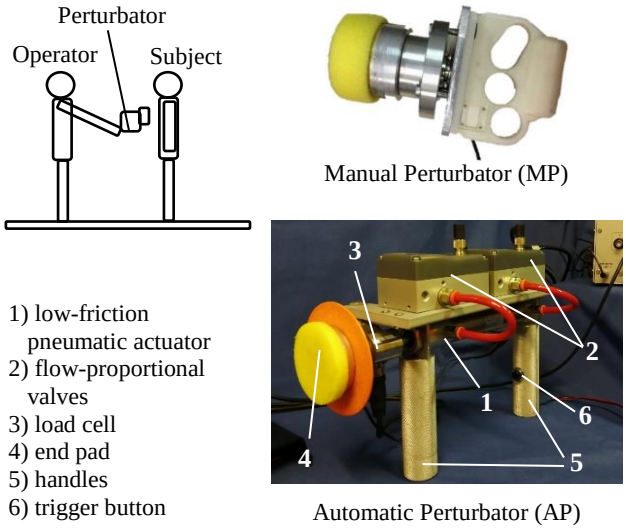

Fig. 1. Sketch of perturbation provided by an operator with two versions of the perturbator: Manual Perturbator (MP) and Automatic Perturbator (AP)..

II. Design of the Perturbator

A. First Version: Manual Perturbator (MP)

The first version is shown in Fig. 1 (top, right) and it is conceived as a manual perturbator (MP), used by the operator for imparting impact forces on the back of the subject. It is designed for an ergonomic grasping and is provided with a soft pad to avoid pain to the subject and a load cell for real-time measuring of the impact force.

B. Second Version: Automatic Perturbator (AP)

The second version is the Automatic Perturbator (AP), whose main components are shown in Fig. 1 (bottom).

The two handles (5) are used by the operator for positioning the end pad (4) near the back of the subject. The trigger button (6) starts the control process, activating the low-friction pneumatic actuator (1). The motion of the actuator is controlled by the two flow-proportional valves (2). The contact force between pad and subject is measured by the load cell (3) and fed back to the controller. The control system of the entire process is described in detail in [7-9].

C. *Hardware-In-the-Loop (HIL) Equipment*

The development and test of the AP has been made by means of a proper HIL equipment, which allows to reproduce the behavior of the whole system (see Fig. 2). The AP is connected to a fixed frame by means of a viscoelastic damper; a second similar damper is placed between the frame and the stricken mass, which simulates the subject's body. The AP is free to slide on a guide fixed to the frame, and interacts with the two mechanical impedances of the operator and the subject. More details are presented in [8, 9].

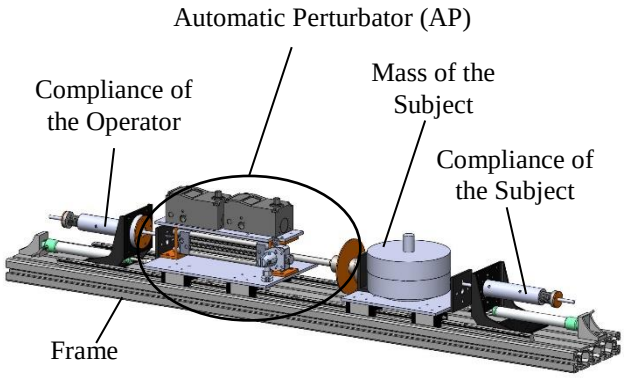

Fig. 2. CAD of the Hardware-In-the-Loop (HIL) equipment.

III. Some Experimental Results

The previous studies carried out on human subjects using the MP [7-9] allowed to define the characteristics required for the perturbation. In fact, it has been observed that the postural response of the subject is directly correlated with the impulse of the imparted force, defined as the integral of the force over time, rather than with the peak value of the force itself. Furthermore, in order to distinguish the passive mechanical response of the subject from the active neuromuscular one, it is necessary that the impulse has a limited duration (< 250 ms). This led to the definition of the performance to be provided by the AP.

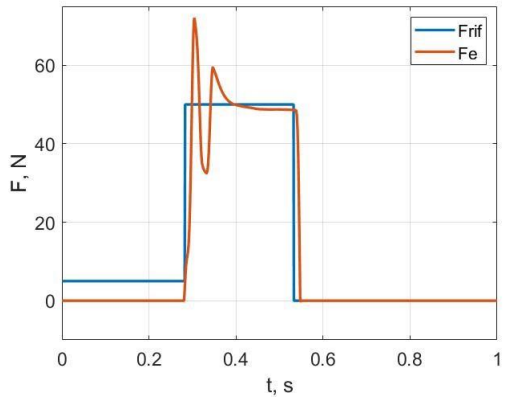

Fig. 3. Comparison of the impact force (F_e) with respect to the reference (F_{rif}).

Fig. 3 shows the comparison between the reference of the impact force (F_{rif}) and the measured one (F_e) in experimental tests. As can be seen, the AP is able to reproduce the force impulse with a good approximation, while presenting an overshoot peak, which is less relevant for the purposes of the posturographic survey than impulse accuracy and repeatability. However, it could be reduced by adopting more effective control algorithms than the simple PID control used in these tests. As shown in Fig. 3, the piston was driven with a constant force reference (5 N) during free motion before impact.

IV. Conclusion

An automatic perturbator, aimed at imparting force disturbances on human subjects for the study of balance control, was created and tested using a special HIL equipment. The specifications to be achieved by the perturbator were defined on the basis of previous clinical tests on subjects, which highlighted the need for high dynamic performance and, in particular, a strong correlation of the postural response with the impulse of the force exerted. The automatic perturbator created has demonstrated adequate characteristics and performance, thus representing an innovative element for the study of postural control as it allows to carry out investigations with wide possibilities of configuration and adaptation to the specific subjects under test.

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