ERGOS: Multi-degrees of Freedom and Versatile Force-Feedback Panoply

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Abstract. This paper deals with the design of a generic force feedback devices technology. System compactness, accessible number of degrees of freedom, morphology, resolution of the physical variables, frequency bandwidth are the main criteria the ERGOS technology answers to. This technology is successfully applied in two various fields: virtual bowed string instrument and nano-manipulator, applications presented in this paper.

1 Introduction

The ERGOS system is a modular tabletop haptic interface whose main features are: a versatile morphology, a potentially high number of degrees of freedom (DOF) and high dynamic performances.

This system has been developed in the context of the artistic creation in the field of the “instrumental arts” like music and animated image synthesis [1]. As a consequence, the mains aims of these developments were a high quality gesture / instrument interaction renderings at the same level as it is with traditional and real instrumental objects. The system can be suitable in many cases of dexterous hand tasks for which, both high bandwidth and number of DOFs are important. This necessity and the quality of dynamics (human gesture is a different task from those of the classic robots) led to the design of a new specific and multi-axis actuator.

These reasons constitute an important difference of ERGOS system from other haptic interfaces in particular from those designed in the field of graphical applications and VR that are based on the idea of a more accurate shape or geometrical properties rendering and on the classic technology of the robotics actuators [2], [3].

After indicating the main criteria retained in the design of this system, the technology of its actuator, sensor and its mechanical architecture are described. Then, two characteristic applications are presented.

2 Main criteria

The design of ERGOS system took into account the following fundamental criteria.
1) The need of *compactness* for integrating haptic devices in our usual digital working space. The ERGOS technology based on “sliced-actuator/sensor” results in a highly compact structure since the motor axis are gathered in a single module.
2) The natural human sensori-motor system involves about 30 DOF for the hand to about 250 DOF for the whole body. Thus, the technology designing for haptic devices with a high and variable *number of DOF* remains a challenge. The ERGOS technology tries to answer to this challenge by the principle of the stackable sliced sensor-actuators [4].
3) For the most existing haptic systems, working space and manipulation morphology are completely defined by the structure of the system itself. It is the case even for the general purpose systems like Sensable technology [5] or Delta Haptic Device [6]. On the contrary, we tried to realize a *versatile* system that provides a set of widely different working spaces from a same main basis.
4) Another criterion concerns the parasitic effects produced by the friction forces and mechanical plays. The difficulty raised by this criterion comes from: (a) the technological level: these two factors are correlated and naturally tend to vary oppositely, (b) the gesture perception is particularly acute to the effects generated by hard non linearities.
5) The need of increasing the *frequency bandwidth* is a well-known demand, especially for the restitution of a hard contact [7]. The frequency bandwidth limitations are determined by the sensor and the actuator, by the computing frequency, and also by the inertia and stiffness of the passive mechanical part [8].

3 Actuator and sensor technology: the “sliced motor”

The designed actuator (Fig. 1) is a multi-axis and linear electrodynamics system (or “voice coil”). It is made of a stack of flat moving coils that are interleaved with flat magnets.

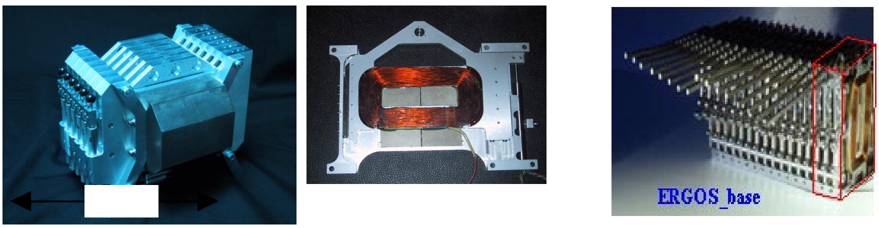

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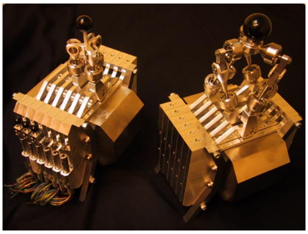
Figure 1. The ERGOS actuator base. (a) A 6 DOF assembly. (b) The opened slice. (c) A 16 DOF actuators assembly showing the 3 slices space occupation.

This stacking creates a single magnetic flow circuit that is shared by all the coils and results in a highly compact structure (Fig. 1a) because the flow canalization pieces are used only at the ends of the stack. This is an "iron-less" structure since no iron parts are subjected to any variable magnetic field [9].
Each slice is about 1 cm thick and 15 cm*10 cm large for a maximum efficient force of 200 N (Fig. 1b). As example, the size of a 3D-device (red block in Fig. 1c) built on this actuator-sensor technology is about 3cm x 15cm x 10cm.
By coupling several slices for an axis, the same structure can be used with a non-equal axis distribution of power level keeping the electrical time constant at its one-slice value.
A high frequency LVDT (Linear Variable Differential Transformer) [10] equips each slice and provides a precise position signal characterized by a high signal/noise ratio (about 90dB) that confines the resolution to 2 μm for a total displacement of 50 mm.

4 The mechanical architecture. Modular morphology.

The choice of manipulation morphology particularly the research of its versatility is a crucial issue in haptic interfaces design. In order to answer at this question, we choose to treat separately the two following aspects: (1) the elementary force feedback coupling with high dynamic performances repeated on a set of identical elementary transducers, the sliced actuator/sensor structure, (2) the set of interchangeable transmission mechanisms that can be attached to the above basis according to various morphological demands. This radical separation of the active parts (actuator/sensor base) from the passive mechanism allows integrating known or novel mechanism solutions in a modular design.
A panoply of mechanical adapters have been designed to fit the described structure. The simpler one is the keyboard configuration (Fig. 1c) developed initially for haptic musical applications [11]. It is a general and optimal morphology for gestural tasks that requires fast and high dynamic interaction with a high number of axes. The other developments concern the 2 DOF joysticks that may be combined as pliers and that move in a vertical plan, the 6DOF ball (Fig 2a), the 3 DOF joysticks that can be combined on a same 6d base (Fig. 2b) and the special 3DOF stick for bowing on virtual bow instruments (Fig. 3).



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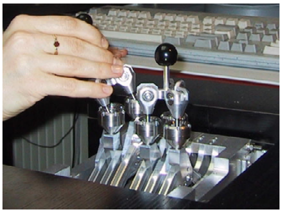

b

Figure 2. The modular morphology : (a) A 3DOF joystick and a 6DOF ball mounted on 6 axis bases. (b) A combination of two 3DOF joysticks on a 6 axis base.

5 Performance sheet

The performances of the developed system are presented in the following.
Actuator/ sensor basis : total displacement 25 mm. Maximum force : 200 N
Force settling time : (0 to 200 N) 100us, (0 to 50 N) : 50us
Moving part inertia : 300g /slice.
Residual force friction < 0,01 N
Displacement resolution : 1um. Position sensing bandwidth : 0- >10kHz.
Force control : analog amplifier.
Mechanical adapters.
Keyboard : displacement 40 mm
2d Joysticks : workspace : 150mm x 150mm
3d joysticks : (W x L x H) 60 x 60 x 25 mm.
6d ball: translations (W x L x H) 50 x 50 x 25 mm rotations : 60° on the 3 axis. All the joints are made of ball bearing and spherical ball bearing.

6 Example of applications

Artistic application: Virtual bowed string instrument
In this application, a 3D manipulator (Fig. 2a) bows a double string virtual instrument. The 3 DOFs control the transversal friction movement and the two vertical pressures on the strings (Fig. 2b). The vibrating reactions and some other characteristic effects of the string are fed back and clearly perceptible. The computation works at 30kHz and the reactive loop at 3kHz [12].

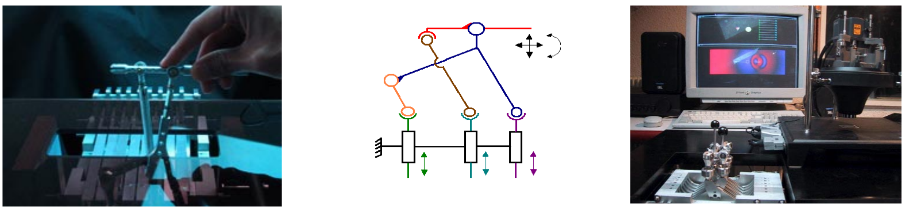

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Figure 2. (a) A 3 DOFs bow manipulator. (b) The kinematical scheme of the bow manipulator. (c) An ERGOS 3DOF joystick (front center) coupled to the AFM (upper right).

Scientific application: Nano manipulation
The 3D joystick (Fig. 2c) is used to operate on a nano-scene through an Atomic Force Microscope [13]. Rendering the nano-world phenomena in a haptic way as well as in a visual way, allow the experimentalist to distinguish the characteristic parameters of a force curve during the nanotip-surface interaction.

7 Conclusion

The designed haptic interface, ERGOS system is presented in this paper. The main characteristic of this system is its versatility that has been developed at three levels: (1) the variability of the number of DOFs with the ability to have a very high number of DOFs, result of the flat actuator design, (2) the adaptability of the manipulation morphology that has been obtained by the separation of the actuator from the passive mechanism and by gathering all the axis actuators in a same compact component, (3) the possibility to adapt the system to high power scale obtained by coupling several slices for a same axis.

The ERGOS system has been evaluated in different applications that require distinctive performances. In the musical field, this technology allows an interesting playing dynamics and a precise instrument control by its multiple degrees of freedom, its dynamical properties and the ability of creating an appropriate morphological interface. In the nano-manipulation field, the system has proved its efficiency by accurately restituting the AFM tip contact with the sillicium rigid surface.

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