# Analysis and Design of a New Haptic Box Display Based on Magneto-Rheological Fluids

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**Abstract.** In this paper we describe a design of an innovative immersive Haptic Black Box (HBB) based on Magneto Rheological Fluids (MRF). By exploiting results from an accurate analysis performed on a previously operating haptic display a new device capable of exciting the MRF with improved performance in terms of magnetic field intensity and spatial resolution has been developed. Due to the core structure and feeding conditions, only a 3D numerical analysis, taking into account the material non-linearity, provides an accurate prediction of the excitation field and, consequently, of the rheological behavior of the fluid. The results of the present paper will be used in subsequent work where the realization of the prototype and the results of several psychophysical tests on excited MRF in terms of softness and/or shape reconstruction will be described.

## 1 INTRODUCTION

In virtual environments an unconstrained hand during manipulation allows better compliance perception and removes perceptual artifacts generated by wearing heavy, cumbersome exoskeletons, or by dealing with rigid linkage. To achieve an ideal haptic display without mechanical constraints, a material capable to change its physical features, such as shape and softness, by modulating external stimuli should be employed [4]. In this scenario MRF could represent a good candidate technology for this purpose. These fluids consist of a micron-sized magnetically active particles immersed in a carrier medium and respond to an applied magnetic field with a change in rheological behavior [2]. Such properties have suggested the possibility to use these fluids to mimic the rheology of some viscoelastic materials and to realize haptic displays. A MR-HBB display, presented in previous works [1, 4], has been envisioned as a box containing a given volume of the MR fluid properly excited by a magnetic field distribution. An operator, putting his hand inside the box without mechanical constraints, can interact with the virtual object magnetically controlled and perceive different shapes and compliance with a non exhaustive excitation of sensory receptors

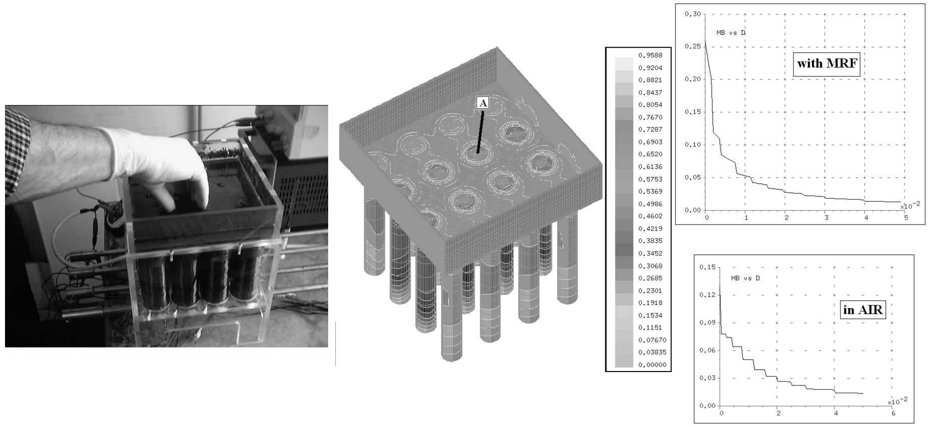


**Fig. 1.** Presently operating haptic device based on MRF (left); FE model of whole simulated system (middle); Flux density in the whole system with the profile of **B** along the underlined direction (A) in air and with MRF (right).

on the whole hand. Starting from a preliminary haptic display the present paper aims of improving its performance, identifying a new device which can better energize the MRF.

## 2 Description and analysis of the preliminary prototype

The preliminary prototype of HBB is shown in figure 1. It has been built vertically placing 16 cylindrical ferromagnetic cores, arranged in a matrix form of $4 \times 4$ below a plastic box with a square base of $18 \times 18\,cm$ and a height of $4\,cm$. Such a box was filled by a given volume of MR fluid. The excitation of a specified region of MRF is obtained feeding the coil below the corresponding portion of fluid. The magnetic field produced by the current, allowed to change the softness of the MR fluid. Some psychophysical tests, described in previous works [1, 4], have shown the ability of replicating the softness (of some viscoelastic materials) and shape 2-D virtual figures (like squares, triangles, etc...), by magnetically tuning the properties of MRF. Although the results were encouraging, currently the realism of this display is quite low. The goal of the present work is to improve the performance of the proposed haptic display in terms of spatial resolution and field modulation, identifying a new display based on MRF. Since an analytical method can't perform an accurate investigation of the proposed system, some simulations have been carried out by using of 3D Finite Elements code [3]. Such a code can take into account the B-H function for nonlinear materials, the leakage flux due to the presence of different magnetic paths in air, as well as the presence of different feeding coils. The knowledge of $B$ everywhere inside the fluid allows to characterize its rheological behavior. Firstly the density **B** has been simulated

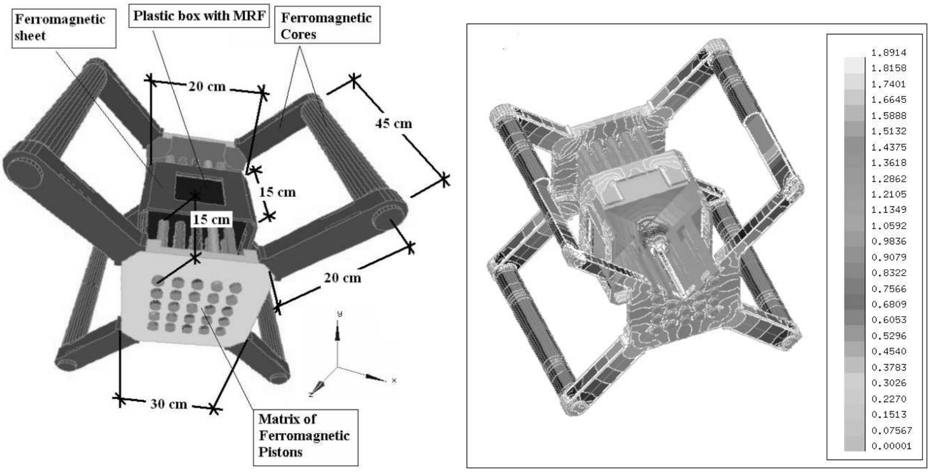


**Fig. 2.** A schematic view of the whole system with the main dimension (left) and map of the flux density (evaluated through FEM analysis) in the system (right).

along the axis of a centered coil (see figure 1), by using various excitations. Then, by using a portable gaussmeter some measurements of magnetic field has been performed. The maximum percentage error less than 8%, showed a very good agreement between the simulated field and measured one. The simulations have indicated that the magnitude of flux density B (and consequently of the yield strength), just outside the coils base, immediately decreases (e.g. at 1 cm far from the box base the field is reduced of about 55%).

## 3 Design of a new Haptic Black Box device

As a result of the FEM simulations, it is possible to report some general considerations on the design of a new MRF haptic device. Main points to improve the performance of the whole system are the reduction of the reluctance of the magnetic paths by the introduction of ferromagnetic yokes and cores to close the magnetic flux and the increase of the number of ferromagnetic cores to achieve a suitable spatial resolution. The first modification in the new design with respect to the previous device, concerns the plastic box which now a cubic shape with a square base of $20 \times 20\,cm$ and a height of about $15\,cm$; moreover, the box is internally endowed with a latex glove able to handle the magnetically excited fluid. Such a modification allows to reduce the reluctance of the magnetic paths and allows a better operation of the system with a good accessibility. In figure 2 is shown the whole device with a second modification that concerns the insertion of closing the magnetic paths. It is composed by a couple of a series of little cylindrical ferromagnetic "pistons" long $15\,cm$ and with a base diameter of $2\,cm$. Such a system, arranged in a matrix form and symmetrically positioned with respect to the center of the plastic box, is used to dynamically address the magnetic flux in different regions of the MRF. All the pistons are winded by secondary coils of about 2500 ampere-turns for a fine control field resolution, and present a conic shape head to better address the magnetic flux in the fluid. In this way the current in the coils modulates the value of field in the MRF while the position of each couple of pistons with respect of the box's walls controls the field spatial resolution. A ferromagnetic sheet, positioned around the plastic box, allows to collect a part of the leakage flux and the spatial resolution inside the fluid is increased. Finally, the whole system is feeding with four main coils of about 32000 ampere-turns.

## 4 Conclusions

In this paper a new design of a haptic immersive interface, based on magnetorheological fluids has been investigated. In order to obtain some design criteria for the development of the new prototypal device, an accurate 3D numerical analysis of a previously operating system has been carried out. The obtained results, in terms of magnetic field, have been compared with experimental ones giving a very good agreement between the simulated model and the operating device. Then this preliminary analysis led us to design and develop a new system for the energization of MRF. The knowledge of the magnetic field inside the fluid allowed to predict rheological behavior of MRF specimen. Work done so far is the preliminary stage for implementing a new device able to mimic softness and shape of virtual objects with more reliability. Furthermore, performance of this new device will be assessed by a suitable experimental psychophysical protocol.

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