Optimal Design of a Haptic device for a particular task in a Virtual Environment

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Abstract. When we create an environment of virtual reality based training that integrates one or several haptic devices sometimes the first choice to make is the device to use. This paper introduces an algorithm that allows us, for a particular task to be simulated in a virtual environment, to find key data for the design of appropriate haptic device, or to select the clues in order to get optimum performance for that environment and that particular task.

Keywords: Virtual Reality, Haptics workspace, Manipulability, Optimal designing.

1   Introduction

Learning based on virtual reality (VR) is widespread in the field of training of different techniques, such as surgery [1-6]. In this field significant improvements have been obtained in the combination of traditional learning with VR based simulators [7, 8]. The use of this type of simulators has spread to other techniques [9, 10] apart from entertainment [11].

When finding the haptic device which is more suitable for our task we consider two possible ways: On the one hand we have the ability to design a custom haptic device, so that the system requirements are the conditions of the design of the new device [12] or may be composed of various devices [13]. Moreover we will be unable to create a new device but we need a tool that allows us to choose between different haptic devices, one that best suits our needs.

The question to answer is whether we can nevertheless find the haptic device suitable for our design. The first thing we have to study is the virtual environment in which we work. If you want a versatile system that includes many different environments, we must choose a device obviously generalist, but it is possible that this device is pretty good at all, but not the best in any of the environments.

There are several methods to optimize the design of a manipulator and to evaluate the suitability a haptic device in a specific application [14]. Frequently, a criterion

consists of obtaining the highest Manipulability measure in the whole workspace [15-20]. The contribution includes several measures of quality of the mechanical design of a virtual training system [21, 13].

In this paper we present an algorithm that allows an easy measurement of the proper dimensions of a manipulator-type device, to work on a particular task.

Finally we present the results in each case allowing the key data in order to design the optimal haptic device for each duty.

2   Defining the virtual environment

A task to be performed in a simulated environment can be defined by two characteristics: first the virtual environment (VW), the volume where the simulation is performed (Fig. 1), the space in which the End Effector (EE) is moving.
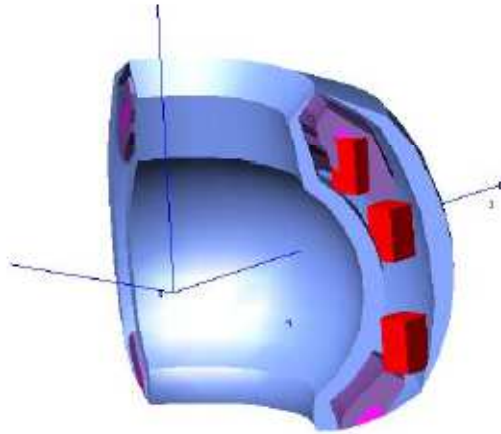

Figure 1. Detail of positioning options of a VW inside the RW.

Moreover, the movement within this environment is not homogeneous and define a navigation frequency map (NFM) according to the zones of VW the EE is visiting (fig. 2).

Figure 1 shows the problem to be solved: first we have the volume (RW) represented by the points in space that can reach a haptic device with EE. Of course the VW is smaller than the RW. We must find out what part of RW we select to work, given that the distribution in RW is not homogeneous.
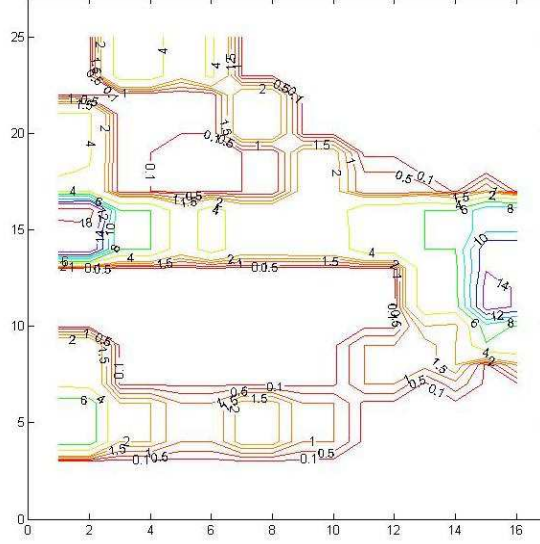
Figure 2. Section 2D of the NFM corresponding with the simulation of the working of a machine tool.

3 Study of the quality of the workspace

The VW is a subset of all the space a haptic device can achieve: the Real Workspace (RW). This space is a characteristic of each device, and depends on their mechanical properties. Because of this, the space is not homogeneous, for instance, near the singular points of the mechanism, we find points where the quality of the device efficiency is very low.

To quantify the efficiency of the device, we will implement different measures based on the concept of Manipulability [22][23][24]:

$$\mu = \sigma_{min}(J_u)/\sigma_{max}(J_u)$$

where $\sigma_{min}(J_u)$ and $\sigma_{max}(J_u)$ are the minimum and maximum singular values of J_u. $\mu \in [0;1]$ being 1 the optimal value.

or the average value

$$\mu_{\mathrm{v}} = \frac{\displaystyle\int_0^{V_T} \mu_i \cdot v_i \cdot dv}{V_T} \quad (2)$$

where μ_i is the value of Manipulability in each sub-volume v_i of iso-Manipulability

4   Problem to be solved

Since VW is a subset of RW can also study the problem in reverse, that is, defining the minimum quality required in each of the proposed virtual environments (fig.3-1, 3-2). From that minimum desirable quality, and each VW, we can design the right device.
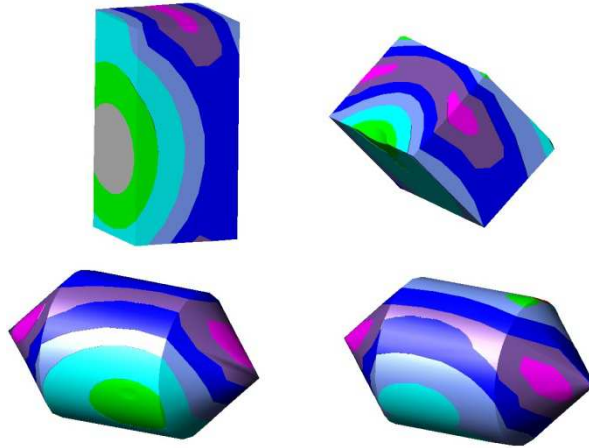

Figure 3. Two different examples of VW. In each VW we can see subsets in different colors representing different values of desired Manipulability.

The desired design is based on a device similar constructively to PHANToM family. First we draw the volume enclosing the VW, so any point of the virtual environment is not beyond the range of the device. More important is the quality of the workspace. To build that RW will be used spheres of uniform value of Manipulability.

5   Methodology

Firstly it is necessary to define in the VW to study the average desired values, as shown in Figures 3. The proposed method begins from the ideal configuration of a manipulator, that is with both arms of equal value L (unknown already and defined in the algorithm) forming an angle of 90°. As shown in the map of Figure 4, Manipulability maximum values coincide with that configuration.
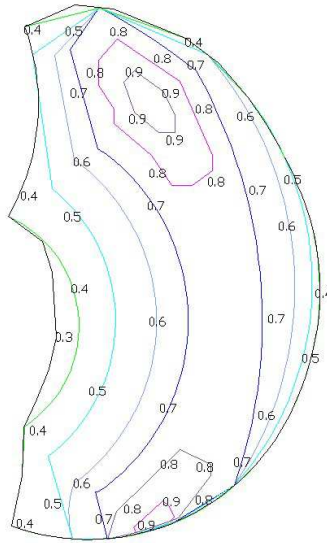

Figure 4. Subspace 2D of Manipulability defined for the real workspace of a OMNi.

We place the center of the subset of VW where the best values are requested, exactly in the EE of the initial configuration described above. We will define the RW from this point. Around this point we create a sphere of initial radius 2 mm (in this space can be assumed constant value calculated by (2)) and the algorithm begins:

1° It is increased the size of the sphere (the initial resolution 1mm).
2° Mean value of Manipulability is checked in the current sphere.
        2-1 If the average value is greater than or equal to the required value:
                -    It must be check that the sphere includes the all VW zone with the iteration value of Manipulability.
                        o   Yes: Next subset of VW.
                        o   No: the area is still too small, it is increasing the radius of the sphere. Step 1.
        2-2 If the average value is lower than the required value:
                -    We modify the value L, the considered length of the arms of the manipulator and proceed to step1 recalculating the sphere of radius 2mm.

After the first iteration and an initial value of L, is passed to the next subset of VW with the immediately lower Manipulability value. Once all subsets we can divide VW are studied, the algorithm terminates.

The object of the algorithm is twofold, first the manipulator, and RW should reach all points of VW, and the other, in each zone should be achieved with a minimum efficiency value.

6   Results

In order to evaluate the result of the algorithm, there are three different examples (Simulating arthroscopic surgery, simulation of a boiler inspection, and operation of a machine tool-figure 2) with different sizes of VW and different tasks within. We check that the haptic device designed for each job, has different mechanical characteristics.

Case1.- Simulating arthroscopic surgery. Best value of L=142 mm. Similar to Sensable's PHANToM OMNi.
Case2.- Simulation of a boiler inspection. Best value of L= 118 mm. Similar to Force Dimension's OMEGA.
Case3.- Operation of a machine tool. Best value of L= 129 mm. Similar to Sensable's PHANToM OMNi.

7   Conclusions

It has presented an algorithm that allows the optimal design of a haptic device that will be used for a specific simulation task.

It has been determined that if this task varies, the most suitable device has different dimensions.

When confronted with the task of a simulation involving a haptic device, we can use the path defined in this paper as well to design the best possible device properly or to choose from a set of existing devices.

8   Acknowledgements

9 Bibliography

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