How to use physical parameters coming from the haptic device itself to enhance the evaluation of haptic benefits in user interface?

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Abstract. Experiments are an important part of research in virtual environments for evaluating the benefits and the success of developed applications, systems or devices. In the context of virtual reality using haptic interaction tools, we want to describe a methodology, based on physical parameters coming from the haptic device itself, to evaluate haptic benefits for user interfaces. By giving a framework for active haptic evaluation using parameters coming directly from the haptic device it would be easier to obtain accurate results and validations of haptic user interfaces or of experiments including haptic devices, complementing other techniques, such as surveys, or other devices such as position sensors.

1 Introduction

"Haptics" at large refers to anything that has to do with the sense of touch (from the Greek 'απτομαι', to touch). Many applications in virtual reality call for the implementation of effective means of displaying to the human operator, information on the softness and other mechanical properties of objects being touched. The ability of humans to detect softness of different objects by tactual exploration is intimately related to both kinaesthetic and cutaneous perception [1] and [2], and haptic displays should be designed so as to address such multimode perceptual channel. The emergence of a huge mature offer of haptic devices, such as SensAble Technologies [3][4], Immersion Technologies [5], Percro [6], or Force dimension [7] brings a large variety of configurations for various applications and experiments. The basic idea of haptic devices is to provide users with force feedback information on the motion and/or the force that they generate.

Every virtual reality application should be evaluated in order to analyse if the goal of the application is reached. Usually this evaluation is made through experiments, most of the time user centred. In the following, we detail the parameters that could be taken into account when performing experiments. Ways of collecting data can be identified by two groups: the statistical survey and the physical survey.

1.1 The Statistical Survey

The evaluation of haptic experiments is a sensitive process from which results and conclusions are extracted. Often, the evaluation process consists of a statistical survey, usually based on an experiment scenario that may include some targets that the user should achieve. The choice of these targets is empiric. It has to be selected very carefully as it will help in the comprehension of the experiments results. The experiment target choice should follow a specification procedure and be very well explained. For example, the experiment described in Basdogan et al. [8], concerns a scenario where two or more people are at remote sites, but must co-operate to perform a joint task or play a game in a shared virtual environment. In their experiment, the set-up is an abstraction from a real situation, in order to simplify the interactions that occur in real life and to create a more controlled context suitable for an experimental study in the laboratory. A shared virtual environment was created to play the "*Ring on a Wire*" game.

1.2 The Physical Survey

The evaluation process of haptic experiments or experiments including haptic devices could also be based on physical parameters measurements. We consider two types of these measurements. The first type, usually the one done, concerns parameters collected via external devices, such as electronic sensors, position sensors, sound or video recorder, and could be worn by the user, or placed in the experimental room. The second type concerns parameters such as force, velocity and position, collected directly from the haptic device.

In this paper, we want to make use of haptic parameters. We identify that the physical parameters that need to be collected during the experiment from the haptic device are: the gesture position, the gesture velocity, the gesture oscillation, the gesture amplitude, the force feedback intensity, and the force feedback direction. The potential of using such parameters for evaluating the validity of an experiment or the results of an experiment is often underestimated.

2 Analysis of the Problems

When setting up an experiment, one can use only the statistical survey or combine it together with the physical survey. Finding the good parameters for an experiment is the key to get a good evaluation. The analysis process is highly dependent on the experiment topic and consequently on what the experiment aims to achieve. Depending on the choice of such parameters, results can be very different and also the data collected can be meaningless. We believe that by combining the two different types of survey, the broadness of the results of the analysis can be narrowed and therefore we can provide a more accurate evaluation. Such considerations had already been taken into account for virtual reality experiments. M. Slater and A. Steed [9] describe a new measure for presence in immersive virtual environments (VEs) based on data that can be obtained unobtrusively during the course of a VE experience.

Considering only a statistical survey is not a rigorous method. The answers provided by the users are often dependent on the previous knowledge, their skills and the period of training. A user getting for the first time into an immersive environment or using for the first time a haptic interface will be sincerely impressed and will not be able to judge appropriately the experiment. For example, a user stepping in a CAVE-like environment will be already impressed by the quality offered by the surrounding display capability. It might be however that the stereo glasses were not activated implying that the whole experiment was done without stereovision. For a haptic interface, the quality of the feedback will not be objective especially if the user cannot compare it to other experiences. The typical answer: *"The device is excellent, I had an amazing experience"* is obviously useless in an evaluation analysis. When using a haptic interface, whatever the experiment aims to achieve, one point needs to be evaluated: the haptic rendering. More precisely, the questions can be: *"was the feeling of the gesture realistic, and did the user feel the most appropriate force feedback for the experiment?"*.

In this article, we propose a methodology for evaluating the use of a haptic interface, its appropriateness to a particular experiment and application, or reciprocally if the experiment is appropriate for the evaluation of the haptic interface, and to understand the skills and previous experience of the user. The purpose of this article is to show how to efficiently use the active haptic device during the experiment for obtaining accurate data, in order to evaluate the haptics in the experiment and to make sure that every function was activated during the experiment.

In the following, we explain from a simple application, how to extract the physical parameters coming from the haptic device itself, and how to analyse them. In section 3 we describe the pilot experiment set up. In section 4 we present the data that was recorded during the experiment and in section 5 we explain how we extract information from these data to analyse the results of the experiment.

3 Description of the Pilot Haptic Application

3.1 Introduction

The aim of this paper is to demonstrate the importance of using haptic parameters when evaluating a haptic interface in certain applications. In order to evaluate the validity of this approach, we developed a simple application that we use as a pilot experiment. As the goal of the pilot experiment was to evaluate the haptic rendering, we developed an application that makes use of graphic textures, instead of using directly the geometry, to provide the information used for the haptic rendering. This application is under construction, however, it is expected that the use of graphics texture should present several advantages. For example, the information stored into the texture could be used for coding the force feedback intensity, force orientation, or local surface shape variations, avoiding 3D computations. In this paper, we present an example of use of texture data coming from 3D objects to compute force feedback based not only on frequency to perceive roughness but also based on traditional axis forces to produce stiffness, viscosity or inertia haptic rendering. The word *texture* is used here to define the graphic texture information and not to define a haptic texture as vibration feedback [10]. The Texture Touch, that we develop, will allow users to haptically interact with textured surfaces as a visual model of the haptic rendering parameters. We would like to perform haptic rendering based on texture information instead of geometric mesh. The texture information of a pixel is easily accessible and efficient via OpenGL functions.

3.2 The Haptic Rendering Based on Texture Data

Haptic feedback groups the modalities of force feedback, tactile feedback, and the proprioceptive feedback [8]. Force feedback integrated in a virtual reality simulation provides data on a virtual object hardness, weight, and inertia. Tactile feedback is used to give the user a feeling of the virtual object surface contact geometry, smoothness, slippage, and temperature. Finally, proprioceptive feedback is the sensing of the user's body position, or posture. The haptic rendering consists of touching an object, and feeling its mechanical characteristics, sensitivity specific to the bones, muscles, tendons and joints, which give information about the static, balance and the displacement of the body in space [1]. Haptic interface technology allows tangible realizations of data surfaces, providing an additional modality for data exploration and analysis.

In our pilot application, we use the graphic texture to perform the haptic rendering instead of using a geometric mesh. Graphic texture offers the potential of coding information in four components for exploring or painting vertex colour: the red, green, and blue colour components and the alpha (transparency) component. These components can be used to define the mechanical model of an object and to avoid uniform mechanical characteristics. These components can also be used to explore graphic texture by feeling them instead of only viewing them. As a first step, our haptic rendering method is based on the grey level of the texture: only the black colour is detected to produce force feedback effort. With the haptic texture rendering: the force feedback intensity is calculated depending on whether the touched-pixel colour is black or not (see Fig. 1).

The creation of the graphic texture via the haptic tool is a feature that opens new area for haptic use. Using gestures, the user creates a painting on a flat surface or a 3D object, which he/she can feel during and after the process. Different levels of painting are possible: the main parameter of this process is the texture width around the pixel touched; see Fig. 2, it acts like an adaptive brush sizing.

The graphic texture width can be generated according to a parameter that the user can modify during the experiment. The graphic texture width can also be adjusted dynamically. Its value depends on the force intensity: the greater the force intensity is, the wider the texture is.

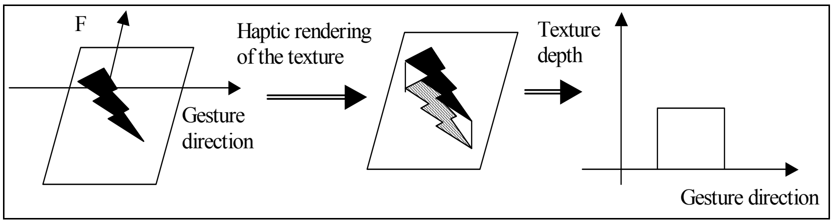


Fig. 1. Haptic rendering via texture data

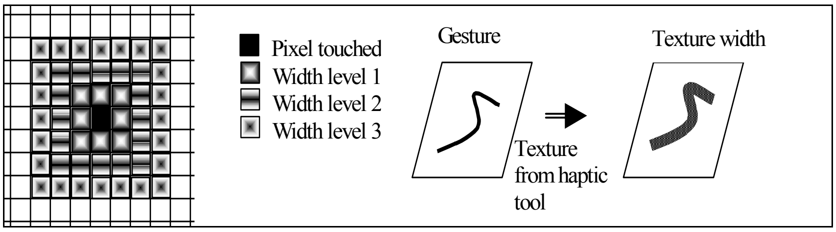


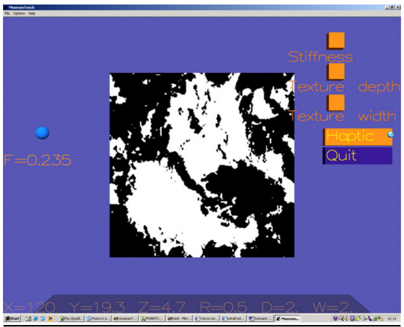
Fig. 2. Creation of texture via haptic tool

3.3 The "Texture Touch" Pilot Experiment

The "Texture Touch" application makes it possible to paint on the texture and create or modify it. The users can draw on the object and feel their modifications at the same time. It allows generating a file in Bitmap format or Portable Pixmap (PPM) format. For the purpose of this paper, we built a pilot experiment using this application. The users were given a document, which explained the tasks they need to perform during the experiment. There were two steps to perform. A first step was to explore haptically an image and to feel the difference when going from one colour to another. The second step was to draw using the haptic interface with the possibility of immediate feeling of the drawing.

Scenario proposed for the evaluation.

- ✓ Exploration step: Click on the haptic button with the HAPTIC legend. Touch the image and feel it as a 3D object (see Fig. 3(a)).
- ✓ Action/Art expression step: Draw and feel the texture generated (see Fig. 3(b)).


(a)

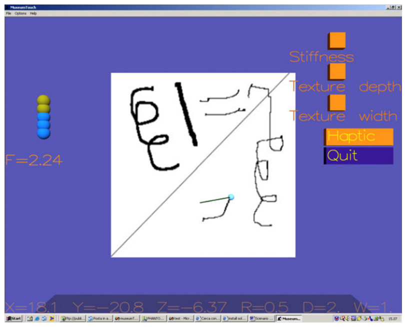

(b)

Fig. 3. (a) Exploration step, (b) Action step

4 Data to record

The data that we can collect during the experiment depends on the haptic device itself, its functionalities and properties. In the Table 1, we list the identified parameters, which are important for the analysis and need to be recorded during the experiment. In the Table 2, we indicate the information given directly from the specifications of the haptic device.

Table 1. Data to be recorded during haptic experiments

Position Sensing	Force	Mechanical properties	Time tracking
Coordinates	Force intensity	Stiffness	Total duration
Rotation angles	Vector force	Viscosity	No force feedback duration
	Torque	Inertia	Time

Table 2 Data given by the haptic device specifications:

Position Sensing	Force	Mechanical properties	Time tracking
Workspace dimensions	Number of DOF	Apparent mass at tip	Servo loop frequency
Number of degree of freedom	Max exertable force	Backdrive friction	
Nominal position resolution		Stiffness	

The data listed in Table 1 and Table 2 are the most common accessible via current haptic devices. Depending on the context of the application, the haptic device used, some data should be added or deleted. These two tables are shown here as a template that could be followed. In this paper we focus on a three degrees of freedom (DOF) haptic device for our experiments, as we use a phantom Desktop from SensAble technologies [3]. Then, the data coming from the specifications of the device and needs to be recorded during the experiments is:

- *Position sensing*: the Workspace is defined as 16 x 13 x 13 cm, the position sensing is 6 degrees of freedom (x, y, z, yaw, pitch, roll), the position coordinate (X, Y, Z) and the rotation (α, β, γ), the nominal position is 0.02mm. Due to the application itself the relevant coordinates to evaluate are (X, Y).
- *Force:* the Force feedback has 3 degrees of freedom (x, y, z), there is no torque and the maximum exertable force is 6.4 N.
- *Mechanical properties:* the apparent mass at tip is inferior to 75g, the Backdrive friction is 0.06N, and the Stiffness of the device is 3.16 N/mm.
- *Time tracking*: for the time tracking we can use the servo loop rate of the haptic device, which is a regular one and acts each one millisecond.

5 Evaluation Process

The evaluation process is based on the desktop haptic device specificities. The maximum force is 6.4 N; the linear resolution is less than 0.02mm and the workspace is defined as 16cm of width 13cm of depth and 13cm of height.

The velocity is: $v=X_t-X_{t-1}$, t the time in ms, X is the position in mm: $X=\begin{pmatrix} x \\ y \\ z \end{pmatrix}$

We define movements with high velocity when: $\|\vec{v}\| > 1$ mm/ms

We define movements with low velocity when: $\|\vec{v}\| < 1$ mm/ms

We define lose of control when: $\|\vec{v}\| > 1$ mm/ms and the force exerted is above 6.4 N.

During the evaluation process, we use four different outputs from the data recorded during the experiments, combined with the statistical survey. We extract the information to evaluate the control, the exploitation of the feedback forces, the agility and the workspace used. These are summarized into four graphs. We illustrate the evaluation method for the “Texture Touch” experiment, which was carried out by six users, recording a total of 52MB of data to analyse. All six users were skilled in the haptic interface usage and were equally composed of males and females. The time spent on the experiment for each user was 5 minutes.

Graph 1. The control graph informs us of how the user controlled the haptic device during the experiment (see Fig. 4), relating velocity intensity to the force intensity feedback. From this we can deduce for example if the user lost control during the experiment, and therefore if the haptic device was appropriate for the experiment.

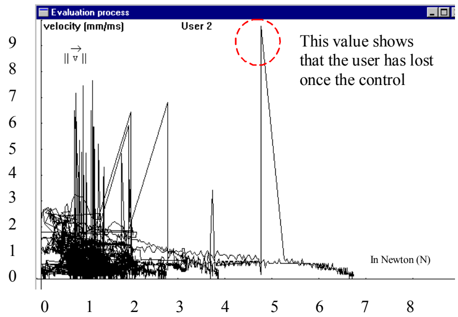


Fig. 4. Control graph from user 2 during evaluation of Pilot Experiment

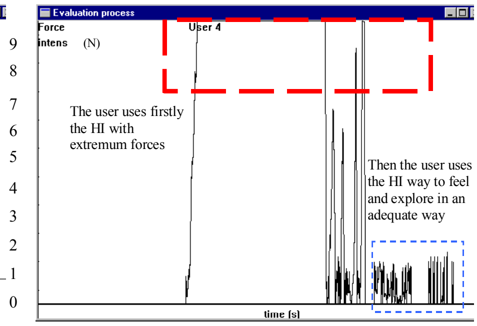


Fig. 5. Haptic rendering graph of user 4 during evaluation of the Pilot Experiment

Graph 2. The haptic rendering graph shows the force intensity variation during the experiment duration (see Fig. 7)and provides data on the exploitation of the haptic device itself during the experiment. As shown in Fig. 6, it gives the maximum force exerted, the minimum force exerted, and the average of the force feedback intensity. This graph provides data on the haptic coverage of the experiment. The duration of the experiment without force feedback is a parameter that informs us on the haptic rendering. The rate between the total duration of the experiment and the duration of the experiment without force feedback gives information on the percentage of the haptic device use. The haptic rendering graph informs also on the quality of the use of the haptic device. For example, as can be seen in Fig. 5, if the user uses it in a binary mode, force intensities often equal to the extreme value or null appear in the graph. In this case, this graph can help to demonstrate that the haptic device is not suitable for this experiment or that the user is not skilled enough, or that the application doesn't do what was expected. The results should be interpreted in any case.

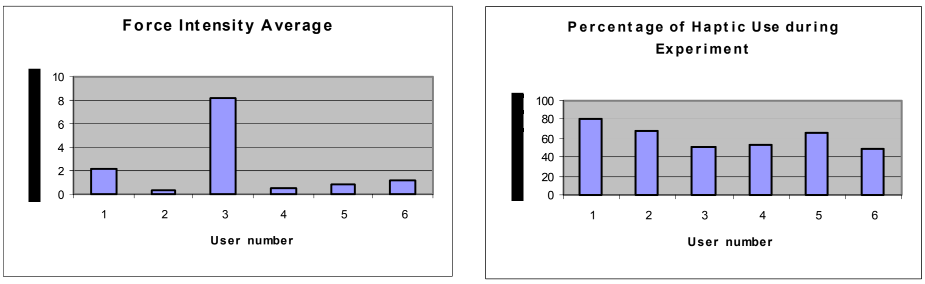


Fig. 6. Global reports on haptic use for the Texture Touch application

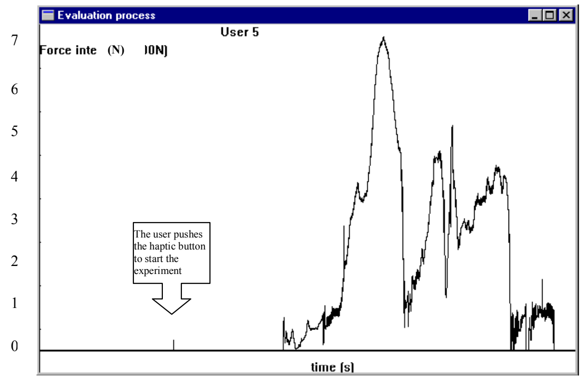


Fig. 7. Haptic rendering graph during the Texture Touch application evaluation

Graph 3. The agility graph reveals the level of the user knowledge concerning the haptic device used during the experiment. The agility graph shows the gesture velocity intensity variation during the experiment. On the Fig. 8, we observe that user 5 used two types of movements: one with high velocity intensity, and the other with low velocity intensity. This last type is the most often used during the experiment. Movement with high velocity intensity are not appropriate for our application. In order to complete a good exploration step and to paint, it is more suitable to process with slow gestures. So here we can observe that user 5 has some short periods that are not in adequate with what is expected.

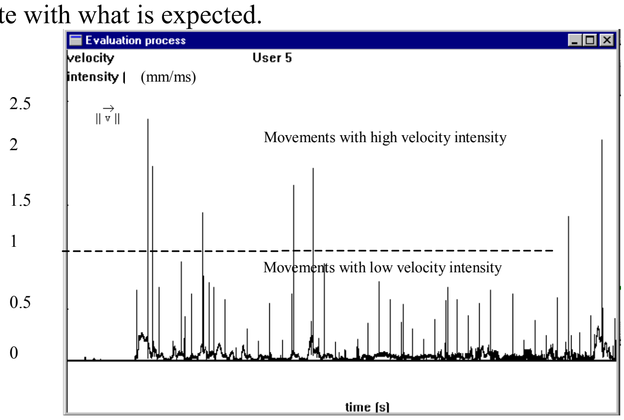


Fig. 8. Agility graph of User 5 during the Texture Touch application evaluation

Graph 4. With the workspace graph, we get direct information about the haptic interest area of the experiment (see Fig. 9), and the workspace used. It also gives information about the areas visited haptically identified by a force feedback intensity superior to 0 and other area visited without force feedback. This provides a representation of what is perceived haptically by the user during the experiments. In our case, we can deduce from this graph the part of the image that has been more explored. Users 3 and 4 have made a very good exploration as nearly all the surface is shown to be haptically explored. User 1 has concentrated the exploration in 4 main parts of the image, and user 2 has made a very short exploration step. In our experiment, the expected result was a uniform and complete exploration of the image as users 3 and 4 have done. In a more general case this information can be used to track what was really done by the user in regard of what was expected.

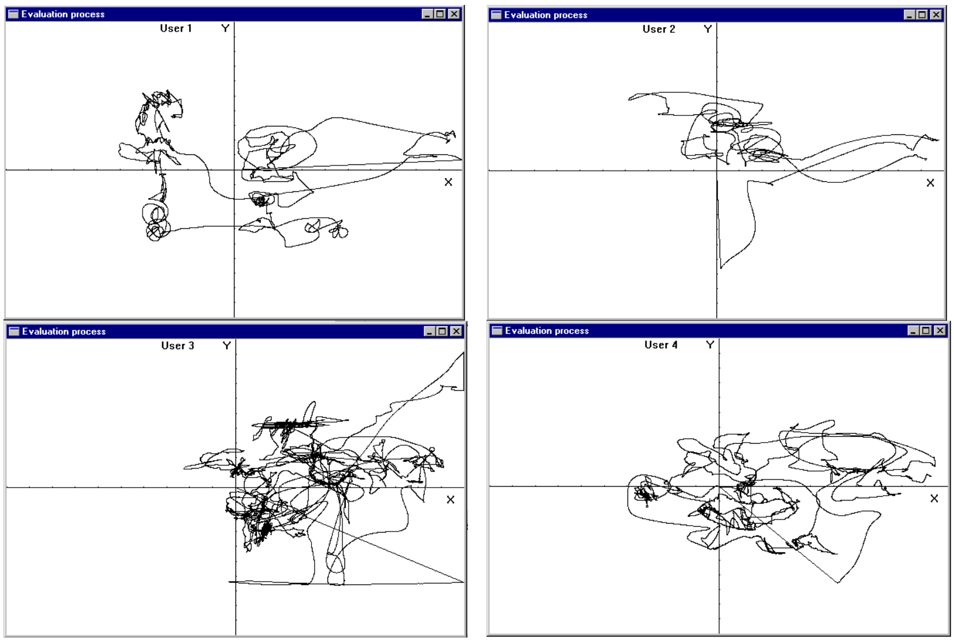


Fig. 9. Workspace (X, Y) to show haptic interest area of users during the evaluation of the Pilot Experiment

For six users experimenting the Texture Touch application, the method exposed in this article generated 52MB of data to analyse. It represents a total of 30 minutes of non-stop haptic records. We wrote an application to extract the graphs.

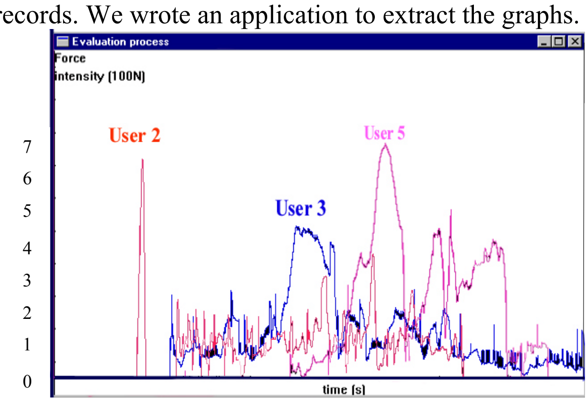


Fig. 10. Comparison of a 5-minute haptic experiment for users 2, 3 and 5

As we can see on the Fig. 10, user 3 has a very good and smooth haptic rendering graph. On the statistical survey this user is the one that has a very good general feeling and a very good haptic perception of the pilot experiment. User 5 has also a very good part on his haptic rendering graph, situated on the middle of the graph, but also lots of oscillations. User 2 has a good haptic rendering but was not very active during the experiment. Notice also from Fig. 9 that the workspace exploration is very reduced.

Statistical survey. In addition, we asked the users to complete a short questionnaire (for statistical analysis), see the Fig. 11. All users were skilled in the haptic interface usage and equally composed of males and females.

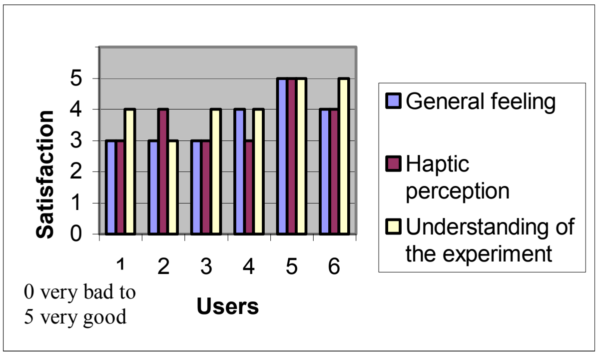


Fig. 11. Extracted from the statistical survey results of the " Pilot Experiment evaluation

User 2 had more or less significant losses of control, but this user thinks to have had a good haptic feeling. Thanks to the data that was collected, we can compensate for the evaluation of the user. User 4 successively produced too large forces. His/her evaluation of the haptic feeling is average. We can probably deduce that the user's manipulation of the haptic device was not adequate for the application. User 1 had a correct use of the space but the statistical survey indicates that the user's feeling was average.

Results can also show that the haptic device was appropriate for this kind of application. The workspace didn't need to be larger, and the force capabilities of the device were large enough. However parameters could have been better adjusted, for example for user 4, so that the exerted forces could have been lower.

6 Conclusion

In this paper, we presented a methodology to guide in the design of an experiment set up as well as to provide the necessary data to perform more precise evaluation. We complete previous existing methodologies by the use of the inner parameters given by the haptic device itself and the haptic rendering. We identified four different data to record during experiments: position sensing, force, mechanical properties, and time tracking; those needing to be associated to the specifications of the device itself. From this recorded data, we extracted four different kinds of information: the control, the agility, the force exerted during the haptic rendering, and the workspace used. This methodology was tested using as simple application, the "Texture Touch", experimented by six different users. When compared to the statistical survey conducted in parallel, we showed that the measure of these physical parameters is essential to validate the results of the evaluation.

In the future we would like to test this methodology on other kinds of experiments and on more varied haptic interfaces. This should help us to strengthen the methodology and to better understand haptic rendering perceived by the user. The "Texture Touch" application was developed in order to test our method. However we see a great potential in the use of information stored in images, and we would like to continue the research in this area.

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