# Functional Analysis of Haptic Devices

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## Abstract

*This paper presents an attempt of classification of the different functional approaches one can find in the field of haptic research. Our methodology is based on a comparison of the natural interaction scheme involving a human and an object/environment with the very similar interaction scheme that exists in the mediated situation involving the haptic device. Four functional approaches emerge from our classification: Object, Human, Interaction and Task. The task-based approach is then divided into four sub-categories on the basis of topological criteria: Environment, Tool-Handled, Command and Object.*

## 1. Introduction

Haptic science is situated at the intersection of several major disciplines of contemporary science: robotics, electronics, mechatronics, computer music, computer graphics, etc. Historically, haptic devices appeared relatively at the same time in the fields of robotics, teleoperation, computer music or HCI.

The large versatility of human gesture [9] is another important parameter. Indeed, human gesture involves many very different movements such as locomotion or dexterous manipulation, and manual tasks are used in very different aspects of human life. The versatility of human gesture and the broad range of human manual tasks cannot be embraced by only one haptic device, and there are currently as many forms of haptic devices as existing applications of haptics.

Haptics science has entered into a boiling phase, becoming a very complex and diversified field. Therefore marks for paving this particular field seem necessary to get an overview on what was done and to envisage the future. Considering the various domains from which haptic science comes from, the versatility of human gesture and the broad range of applications of the use of haptic devices, it appears that proposing a categorization of haptic devices is a difficult task.

Attempts of classification of haptic devices are found in large reviews of haptic technology and application fields [1], [4]. In these works, haptic devices are classified on the basis of two orthogonal dimensions: technology (grounded devices, exoskeletons, types of actuating and sensing, etc.) and application fields (medicine, telerobotics, etc.).

However, functional aspects of the haptic device are seldom considered. By functional, we understand the role or the function that the haptic device plays in the human-object interaction. We have found only one related work: in the paper presenting the FEELEX device [7], Iwata et al. propose a categorization of haptic devices on the basis of a functional approach. Three functional categories are presented: exoskeleton type force displays, tool-handling-type force displays and object-oriented-type force displays. In addition, several other approaches are laid apart: tactile display, passive input devices based on force sensing.

Our work aims at providing a functional overview of haptic devices in the many works and uses where we may find it. The second part of our paper details the methodology chosen. The third part constitutes a presentation of the different functional approaches that were extracted from our analysis.

## 2. Methodology

Our methodology is based on the comparison of the natural interaction with the mediated situation. It can be considered indeed that the haptic device plays the role of a medium between the human and the simulation "world" inside the computer [2]: this is what we call the "mediated situation".

In the natural situation, the human interacts directly with an object or an environment thanks to mechanical coupling. In an artificial or mediated situation the aim of the haptic device is to reintroduce the mechanical coupling in the interaction. We can distinguish two different cases in the mediated situation. (1) A virtual object is "mediated" by the haptic device. (2) In the case of teleoperation, the object considered is real but manipulated through a haptic device. This situation is similar to the first one if considering the point of coupling between the human and the object.

## 3. Classification of functional approaches

### 3.1. Approach #1. Object

In this approach, the observer is interested in the properties of the object independently from those of the human. The hypothesis is made that the mechanical coupling can be cut so that the object can be studied alone. The object is considered as a separated entity

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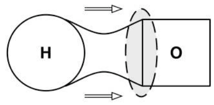
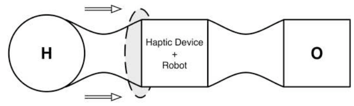
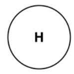
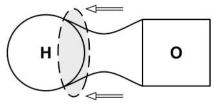
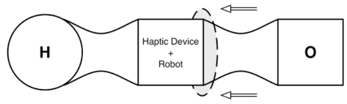
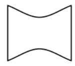
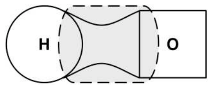
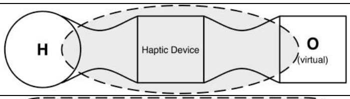
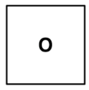
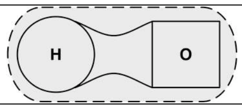
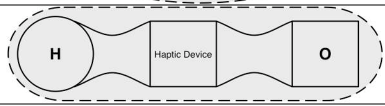
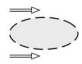
Table 1. Schematic representation of the different functional approaches in the analysis of human-object interaction

| | Natural situation | Mediated situation | Legend | |
|---|---|---|---|---|
| #1 Object |  |  |  | Human |
| #2 Human |  |  |  | Mechanical Coupling |
| #3 Interaction |  |  |  | Object |
| #4 Task |  |  |  | Zone of focus & Point of view |

from the human and is observed from its border limit with the human (Table 1 #1). In the mediated situation, the haptic device is often considered as a part of the object.

In this functional category we can find most of the reference analyses that attempt to delimit the conditions of acceptable behaviour for the haptic simulator. Transparency [8] and passivity [3] are two very important theoretical positions for haptics that apply to this functional category. Briefly speaking, one can say that they both try to define optimal conditions for the simulation of haptic objects.

In this functional category one can also cite some of the works for task simulation that are not oriented on the task but rather focus on the properties of the simulated object (e.g. simulations for surgery practice).

## 3.2. Approach #2. Human

In this approach, the observer is interested in the human and measures the physical human behaviour when involved in a task in interaction with a given environment (Table 1 #2). It is the symmetrical of the object-based approach. In the mediated situation the function of the haptic device is to transmit correctly the human action and behaviour to the object.

Similarly to the object-based approach, the point of observation is the border limit between the human and the object. The object-based approach is based on the measure of invariant properties such as stiffness, viscosity, mass or impedance. Conversely, the human is an active system with numerous DoF. Hence, the characterization problem becomes more complex, and the study of human action deals with motions and forces that can hardly be reduced to invariant properties.

The human-based approach is related to the field of psychophysics in general: the object of study of phsychophysics is the Human, and the mediated situation is considered as a mean to provide new stimuli. Two complementary positions exist:

1. The haptic device is be used to provide stimuli that would not or hardly be possible with common real objects [10].
2. The human is considered in the perspective of the mediated situation. Considered as a new situation for human perception and action, it becomes a case of study in itself [6].

## 3.3. Approach #3. Interaction

This approach focuses on interaction, by considering the human-object as a whole undividable dynamical system at its low mechanical level. The criteria induced on the function of the haptic device are in this case related to the comparison of two physical systems: (1) the natural one constituted of the human and the natural object and (2) the hybrid one constituted of the human and the mediated object (Table 1 #3).

In the natural situation, the “finger on the glass” is an exemplary case of this approach: the particular way the glass can “sing” comes from the very specific interaction (the slip-stick effect) that arises between the glass and the wet finger sliding on its border.

In the mediated situation, the haptic device is situated at the core of the interaction system that is observed. Indeed, the properties of the interaction system (and therefore the properties of the simulated object) are strongly related to the mechanical properties of the haptic device. This approach is related to the simulation of artificial situations where the quality of the human-object interaction plays a fundamental role. The general hypothesis is that the instrumental gesture, especially in the case of excitation gestures such as in violin bowing, must not be reduced to a simple control model from the player to the instrument [5].

## 3.4. Approach #4. Task

### 3.4.1. Introduction

In this approach, the observer is interested in the whole human-object system at many possible levels of observation (Table 1 #4). This level of analysis is the most general and includes all the very different interaction schemes that are not taken into account by the three previous categories of functional approaches.

The global methodology still consists in comparing the natural situation to the mediated one, but we introduce another level of analysis related to the topological relationships that exist between the human body, the object and other possible media like tools or environment.

### 3.4.2. Line of mobility

We assume that in every task there is necessarily at least one borderline of mobility along which the mechanical links are non-permanent during the duration of the task. This is what we call the line of mobility: it concerns the task, the mechanical objects and the linkages involved. The state of the line of mobility presents a temporal dimension as topological relations can evolve along time, but we can consider that there is a non-reducible amount of time during which the topological relationships will not evolve.

For example, when operating with a screwdriver during a session task that consists in unscrewing a screw the line of mobility is situated between the tool and the screw. When playing on a keyboard the line of mobility is situated between the hand and the keyboard.

### 3.4.3. Limit of the Virtual Environment

In the mediated situation, we need to examine the relationship of the line of mobility with another border: the limit of the virtual environment. Hence, a mediated object can have different status according to the point of view chosen [2]: (1) it can partially or totally become a part of the human body in the embodiment situation; (2) it can be a part of the environment. One can consider the two following extreme cases for reference of the limit of the VE:

**"Restricted" virtual environment.** The virtual environment is completely enclosed in the computation supported by the real-time simulator. In this case the haptic device is an interface that provides to the human operator the interaction access to this environment. Non-immersive environments often apply to this restricted definition.

**"Enlarged" virtual environment.** The virtual environment encompasses the physical separation between the human and the haptic device. This approach is used in spatial and immersive applications in which visual co-location is an important characteristic. The virtual environment may contain the operator's hands and then overlaps the real world.

### 3.4.4. Situation #a. Relation with a general environment

This situation concerns all tasks where the human link with the environment is not specified in the relationship with a particular type of object. In this case the line of mobility is necessarily situated at the limit of the human body (H) (Table 2-#a-left).

All kinds of navigation tasks are included in this category, such as body locomotion, but also more abstract kinds of navigations that include human action, such as sorting books in shelves.

The artificial situation is mediated by means of an exoskeleton that consists in a permanent link with the operators' body (Table 2-#a-right). It places the human in an immersive situation for at least a part of the degrees-of-freedom (DoFs) of the body, the degree of immersion depending of the part of the body attached to the exoskeleton. For example, arm exoskeletons are completed by hand or finger exoskeleton in order to support hand manipulation tasks.

### 3.4.5. Situation #b. Handled tool

In this situation a main line of mobility is located between the tool (T) and the operated object (E) since the link between the human's hand and the tool is supposed to be permanent all along the session task (Table 2.-#b). In the usual tool-object interaction two types of motions have to be considered that constitute the tool–object mobility:

- A "selection gesture", which consists in the evolution from non-contact to in-contact state (between T and E).
- An "ergotic gesture" [2], by which the tool (T) operates on the object or environment (E). Various relative motions and forces during the contact state are possible depending on the respective material and tribologic properties of the tool–object system.

The handled part of the tool is in the real world, whereas the non-handled part is in the virtual world, where it interacts with the virtual objects. Since the line of mobility is not situated at the border of the human body it can be easily included in the *restricted* virtual environment while a high level of transparency is not mandatory. On the other side since the dynamic system created by tool-object interaction is completely supported by the simulation software (the restricted VE), this type of configuration has to synthesize actions of complex tools including selection and contact motions.

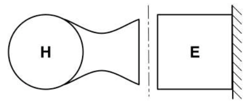
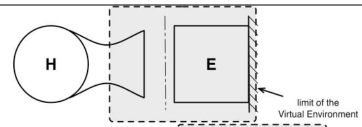
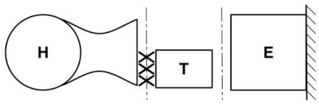
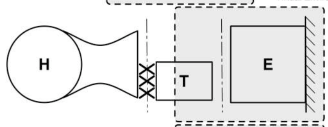
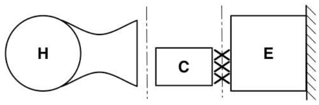
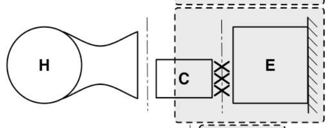
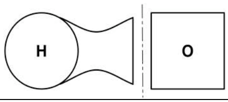
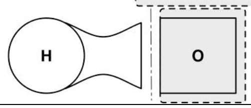
### 3.4.6. Situation #c. Actuating an artificial device

This category contains the hand actuating various types of artificial devices. This is usually done by the means of levers, buttons, handles, cranks, which we can categorize under the general term "command". In this situation the line of mobility is situated between the human (H) and the command (C) (Table 2-#c).

An example of this type of task is the manipulation of the gearbox lever. In this case the line of mobility is situated between the hand and the lever. Indeed the other parts of the mechanical chain from the lever to the ground are made of permanent joints and links. An other interesting case of this category is the piano keyboard playing.

In this situation the virtual environment does not necessarily contain the line of mobility. Indeed, the main difference with the situation #b is that the only

Table 2. The four categories of situations in the task-based functional approach

| | Natural situation | Mediated situation |
|---|---|---|
| #a Environment / Immersion |  |  |
| #b Tool-handled |  |  |
| #c Command |  |  |
| #d Object manipulation |  |  |

pertinent gesture around the line of mobility is the selection gesture and not the ergotic one. The ergotic gesture is performed in permanent grasping mode and the eventual sliding or local compression motions at handle-level have no incidence on the task.

#### 3.4.7. Situation #d. Manipulating objects

This situation consists in direct interactions with objects. The line of mobility is situated between the human body and the object. The main difference with the situation #a is that objects are determined at the level of their interaction border by shape and possible limitations of the number of degrees of deformation. For example in the moving or actuating material objects, the interaction session may include contact and release phases. Like in the case of situation #b two main types of gestures can be distinguished: selection gestures that consist in free movements to reach a target object, and ergotic gestures associated to the contact phases.

In the mediated situation, the limit of the virtual environment includes the haptic device, and is concomitant with the limit of the object (Table 2.-#d). The gesture interface of the haptic device must present very particular properties because the line of mobility is *between* the human and the object.

## 4. Conclusion

We have extracted four main functional approaches of haptic devices through the analysis of theoretical positions, the design of new devices and applicative works. We have separated the task-based functional approach into four categories. These categories are not hermetically separated one to each other, but are at least differentiated on the basis of the topology of interaction, and on the limit of the virtual environment in the mediated situation.

This attempt of a functional analysis of haptic devices is a contribution to the numerous works reviewing haptic technology. We conceive it also as an opening into investigations and new analysis that could lead to a new approach or understanding of haptics.

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