# The Potential Importance of Perceptual Filling-In for Haptic Perception of Virtual Object Form

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## Abstract

*The aim of this paper is to discuss the possibilities of Perceptual Filling-In to be useful in haptic displays, especially for perception of 3D form. Examples of the functioning of this mechanism in vision and natural haptics are reported, and obstacles for its application in haptic displays are pointed out, such as the lack of extended surface contact, restriction (usually) to one point of contact and the impossibility of performing exploratory procedures known to be effective in natural haptics. It is stated that the haptic information obtainable in the haptic displays developed so far is not sufficient and accurate enough, and that conditions favouring mechanism such as Perceptual Filling-In should be seriously looked for.*

## 1. Introduction

Visual displays can mirror the real world to a very high degree. So far, haptic displays lag far behind visual displays in efficiency of displaying representations of the real world. The success of visual displays depends both on the ability of vision to handle large amounts of complex information and the technical possibilities to imitate this information. However, the visual imitation is not perfect but utilises also the fact that vision can successfully handle also optical information deviating from the information presented in the real world. This simplifies the technical task considerably. One example of this is that a series of still pictures separated by black intervals (film) is perceived as a continuous, constantly changing event. This is based on the so-called phi-phenomenon (motion perceived from still pictures under certain conditions), and the perception is further improved by the perceptual fusion of high-frequency flicker. Another example is TV that is possible because of the fact that the eye has not sufficient spatio-temporal resolution to be able to perceive the rapidly moving dots but integrates instead the scene perceptually.

The aim of this paper is to discuss the possibilities of utilising related options for haptic displays, especially for 3D form perception. One possibility might be to utilise a perceptual mechanism that is important for vision and natural haptics and potentially useful also for display haptics. The mechanism is called *Perceptual Filling-In (PFI)*. The emphasis here will be on the problems of 3D form perception in haptic displays and the possible contribution of PFI. For comparison, some related visual phenomena will also be shortly presented.

## 2. PFI in vision

PFI handles situations where stimulation is incomplete or totally missing. Well-known examples of this mechanism in vision are the PFI of stimulation corresponding to the blind spot in the eye, as well as some kinds of scotoma; where the non-existing visual information on the retina corresponds perceptually to a surface of the same kind as the surrounding areas. Other examples are cases where whole figures and objects are perceived from incomplete artefacts when gaps in the stimulation are filled in perceptually. The Gestalt psychologists suggested a law of closure to account for perception in such cases. Subjective contours (also called illusory or cognitive contours) are phenomena of a related kind.

### 2.1. Visual point stimuli

Especially analogous to the stimuli presented by present-day haptic displays are visual point stimuli. It is well established since Johansson's motion perception experiments [11, 12] that two points in motion are perceived under many conditions as the endpoints of a rod. These results have been further elaborated concerning patterns consisting of a few dots in motion [2, 3]. Biological motion patterns [13] consisting of 12 moving dots are perceived as human beings with straight invisible lines of constant length connecting the dots. A point line pattern can also be perceptually connected by curved lines, for instance as a bending line [6, 19], and it has been demonstrated that the number of points in such a line can be considerably reduced without destroying the perception of an object bending smoothly [14].

## 3. Compensation with Visual Information

The problems with 3D form perception for haptic displays may not be identified as problems as long as haptic and visual information are available together. Vision provides an overview and thereby "fills in" the gaps in haptic information. It also suggests interesting parts of the scene to be explored, which makes haptic exploration more effective. This means that haptic PFI is less needed in this case.

The dominant role of vision for the judgement of 3D form of real objects with both visual and haptic information available has been experimentally demonstrated [16]. When vision was available together with optional haptics, the observers typically used only vision for judgements of geometric properties, such as size and form. Haptics was used mainly for material properties, such as texture and hardness. A similar result was obtained in a study concerning virtual objects [1].

## 4. Perception of Form by Haptics Alone

During natural conditions also haptics alone has a high capacity. In his studies of haptic perception of real objects, Gibson [4, 5, pp. 124-126) found that the observers can be quite successful under these conditions.

When observers have to rely on haptics alone when using haptic displays, as, for instance, blind people have, the situation is quite different. When natural and virtual perception of 3D form of small objects of simple geometric forms were compared, the virtual cases (explored with a PHANToM) were found to be both less accurate and requiring longer exploration times [7]. Even if performance was improved when objects were larger (up to 100 mm) [7], and when practice was allowed [10], the performance never reached the level obtained when real objects were involved. Effective presentation of virtual objects with a complex form is still a difficult problem [8].

### 4.1. The Importance of Exploration

The hand as a haptic sense organ may be described as a touch unit consisting of five fingers as suggested already by Katz [15, p. 59]. Considered in this way, the stimulus properties available when grasping an object is at each moment obtained from up to five small surfaces spatially separated by (sometimes) large gaps and from the kinaesthetic information from muscles, tendons and joints during the grasp. The haptic perception is usually further strengthened by exploratory movements, and total perception is based on integration over time. According to Gibson [4, 5], observers when exploring tactually curved their fingers around the face of the object, used all their fingers and fitted them into the cavities and used oppositions of thumb and the other fingers. In haptic perception of real objects an essential role was also played by finger directions and finger spans, the "bone space"[5, p. 125].

Lederman & Klatzky [17] presented more detailed studies of the exploratory procedures in haptics. Concerning perception of form/shape, they identified two main exploratory procedures: *enclosure*, which is performed by more than one finger and often both hands, and *contour following*, which may be executed by one or more fingers. These exploratory procedures may be performed in sequence. The efficiency of these procedures, also for quite complex object forms, is remarkable concerning both accuracy and speed.

## 5. PFI in Haptic Displays

The importance of PFI for visual perception has been demonstrated. Stimulation from two or more points may give perception of an object filling the space between these points. The present discussion concerns the possibilities of a similar mechanism in haptics, especially for the perception of 3D form of virtual objects. That such forms can be perceived is a critical feature for the usefulness of haptic displays when haptics is the only form of information available. If form perception under this condition is not sufficiently accurate and fast, the use of such a display without visual assistance may be questioned. It is therefore important to try all potential options to increase accuracy and speed in these cases.

### 5.1. 2D Form

That PFI can work also in virtual haptics is demonstrated by the relative success of displays consisting of a matrix of tactile point stimuli, such as the Optacon. The raised points of this kind of display are typically perceived as lines and areas in 2D. It should be observed, however, that in these cases a larger skin surface is in contact with the display, and some displays allow also the use of more than one finger.

### 5.2. 3D Form

The perception of 3D form by haptics is more complicated than, for instance, the perception of 2D form and of texture. A uniform texture (the microstructure or high frequency properties) can be explored rather similarly in natural and display haptics, by lateral movements over the surface, and the resulting perceived properties of the surface may be quite similar in the two cases [9]. In contrast, the exploratory procedures available when the task is to judge global form (the macrostructure or low spatial frequency properties) are quite different in natural and display contexts.

### 5.3. Differences in Exploratory procedures between Natural and Display Haptics

In natural haptics the exploratory procedures pick up information from both extended skin surfaces and from the kinaesthetic sensory system. When a real object is explored for judgment of form, the result is that an object is perceived that fills the space between the contact points. The goal for haptic displays should be to construct them such that sufficient information can be picked up to make perception of a virtual object between the contact points possible.

Important features of most haptic displays are that the contact between observer and virtual object is restricted to a minimal point of a virtual object and is mainly based on kinaesthetic information. 3D form may be perceived in this situation, but not with the same accuracy and speed as in real haptics [7]. That the elimination of spatially distributed information at the skin is an important factor was demonstrated by experiments where a similar restriction was applied to real object exploration [18]. The results in these experiments were that several haptic functions were substantially impaired.

Information about 3D form of a virtual object can in these cases be obtained only over time. Such exploration, for instance with a one-point stylus, is not common in natural haptics. Exploring with a thimble is more similar to natural exploration, but in natural haptics it is not the only available exploratory procedure.

### 5.4. Can Multi-Finger Displays Solve the Problems?

For PFI to function in simultaneous stimulation there must be at least two points of contact. For perception of 3D form there ought to be at least three. As with visual point stimuli it can be expected that stimulation changing over time increases the efficiency. With a one-point display it is not possible to enclose the virtual object in order to get information about its form. An important exploratory procedure is thus not available.

Haptic exploration of a real object is an effective but complex activity, which may be difficult to mirror for virtual objects. The object is moved around by fingers of one hand or both hands, which provides a richness of both cutaneous and kinaesthetic information far from the poverty of information obtained when only one small point at a time is in contact with the object.

There are efforts to provide the observer with more contact points. Using two PHANToMs, for instance, is possible, and a six-degrees-of-freedom PHANToM has been constructed (http://www.sensable.com), as well as multi-finger displays, for instance the CyberGlove and the CyberForce (http://www.virtex.com). Such devices increase the number of contact points, but to what extent they improve the perceptual potentials of virtual 3D form perception does not seem to have been studied. A six-degrees-of-freedom stylus gives an opportunity to get more than one contact point. However, to what extent is information from minimal points along a stylus useful for judging the form of a virtual object?

It remains also to be studied if multi-finger displays offer stimulation sufficiently similar to that obtained in natural haptics to make effective 3D form perception possible. The availability of information from several minimal points may not be sufficient. The exact form of the kinaesthetic information is probably also critical. It is still an open question if such information is provided via the present multi-finger displays with force feedback in a few directions.

## 6. Conclusion

Natural haptics alone is quite accurate and fast in perceiving 3D form, but haptic displays developed so far are not as successful. They do not mirror very closely the haptic information obtained naturally, which means that the information they provide is not sufficient and adequate enough. The finding of conditions favouring haptic PFI ought to be seriously considered. It works in vision and natural haptics. If such conditions can be found, the performance of users may be improved and the technical development of new devices simplified.[1]

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