Available online at www.sciencedirect.com
ScienceDirect
Displays 28 (2007) 118–128
DISPLAYS
www.elsevier.com/locate/displa

Design and implementation of a graphic-haptic display system

Farrokh Janabi-Sharifi [a,*], Vincent Hayward [b], Qing Yuan Wang [c]

[a] Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, Ont., Canada M5B 2K3
[b] Center for Intelligent Machines, McGill University, Montréal, Que., Canada H3A 2A7
[c] Motorola Canada Ltd

Received 24 November 2006; accepted 23 April 2007
Available online 29 April 2007

Abstract

Despite current advances in multimedia environments, tracing the geometrical structures of graphical images using force feedback remains an important research issue. In this paper, the development and implementation of a multi-modal display system (MMDs) for tracing 2D boundaries in graphic images are discussed. A method is proposed that provides a type of haptic feedback designed to assist a user to trace the contours of objects seen in images. This method is an example of a family of haptic synthesis methods whereby the force field explored by the user is dynamic in the sense that it depends both on movement as well as on the object being haptically represented. The proposed performance-based method provides users with a movement guidance through an active haptic sense rather than common impedance technique. The tracing effectiveness of the proposed method is verified experimentally.

Keywords: Haptic interface; Boundary extraction; Image display; User interface; Graphic display

1. Introduction

Real world decisions are usually made based on the combination of senses from environment. Among possible combinations, haptic and vision combination contributes to a large classes of our daily tasks. While vision is the quickest and most efficient sense for the perception of spatial events, touch provides tactile and kinesthetic information. Integrating visual and tactile information, not only provides visually absent characteristics of surfaces, but also, as psychophysical studies show, facilitates the manipulation of objects in terms of reducing cognition loads, errors, time and energy required to complete a task. In human–machine and interactive computer systems, visual and haptic information are expected to be transferred to the user through a coordinated graphic-haptic display system. A coordinated graphic-haptic display can play important roles in several application areas, such as teleoperation, virtual surgery simulation, entertainment, scientific visualization [9], etc. In this work, an effective method for design and implementation of a haptic display for tracing contours in images of a graphic display is proposed.

Tracing contours in digital images constitutes an important class of our daily tasks. This is needed, for example, to quantitatively assess the size of structures in medical images (e.g., to monitor growth over time), or to outline their shape for registration. A good example is provided by NIH's Visible Human Project where thousands of slices were manually traced to segment tissues. Despite assistance from machine vision techniques, most of the work was done manually [3]. Professional image processing tools such as Photoshop™ (for general purpose images) or Manifold™ (for domain specific images) offer automatic assistance to tracing contours, but always in conjunction with manual input. As can be readily appreciated by graphic interface users, manual tracing is straining and error prone. Therefore, there is an opportunity to take advantage of haptic feedback techniques to provide assistance to the task of tracing the contours of the image objects, to facilitate inspection and manipulation.

* Corresponding author. Tel.: +1 416 979 5000x7097; fax: +1 416 979 5265.
E-mail address: fsharifi@ryerson.ca (F. Janabi-Sharifi).

0141-9382/$ - see front matter
doi:10.1016/j.displa.2007.04.004

There have been an extensive research on haptic displays, mostly related to *physics-based* modeling and rendering of deformable objects. Examples include work of [21] where a point-based rendering approach is taken to represent a god-object. Other approaches to physics-based modeling have been also reported [20]. The main challenge is to achieve an optimal balance between the complexity of physical models and the realism of haptic and graphic displays in real-time [4]. There is little prior work compared to ours. Recent work is that of [6] who employed an input device to investigate the human sensitivity to virtual shapes while following their contours when force feedback is available. In other words, almost no attention has been paid to performance of the user. They used an input device comprising a two-dimensional force sensor mounted on the head of an XY recorder. This devices was connected to a computer commanded the device to move in the direction of force applied to the user. Of particular interest here is the work of [11] who studied methods to produce 2D "haptic images" from 2D graphics, and that of [19] who developed a system to demonstrate the automatic generation of haptic interaction with 3D objects derived from stereo 2D images.

These works approach the problem of information extraction from an image in various ways, but invariably, the haptic feedback is synthesized from a static force field which is entirely a function of the graphics under consideration. This is depicted in Fig. 1. One problem with translating a picture into a static force field – for example based on the image gradient – is that the synthesized force feedback does depend on the task which is expressed by the movements of the user. That is what makes the previous work non-performance-based. In contrast, in this paper we introduce an approach whereby the force field is a function of both the image and the movements of the user. Our approach is to automatically extract features from an image and to use them to synthesize a haptic feedback only if the user's movement agrees with what is extracted automatically. This implies that the graphic-to-haptic translation step must be performed inside the interaction loop as represented by Fig. 2. In other words, each movement causes the interaction loop to create a different force field. That is, the role of the machine is limited to task reinforcement. It does not force the user to a particular location and hence it is never inhibitory, i.e., it does not provide haptic guidance as described in [5]. Therefore, the resulting fields can be termed "dynamic" to distinguish them from "static" fields as in previous approaches.

The organization of the paper is as follows. In Section 2, general methodology is given. Section 3 includes haptic display design with the focus on graphic-to-haptic translation methodology. Section 4 describes the experimental results, and finally, Section 5, concludes the work.

2. Approach

In this paper, a multi-modal display system is developed. It consists of two subsystems: a graphic display system and a haptic display system. These two subsystems and information flow underlying interactions between a human user and the machine interface are shown in Fig. 3.

Designing the proposed multi-modal interface between human and machine requires to analyze the tasks that the human is asked to perform and to predict the human performance. The framework presented in this paper is a proposal to assemble several components, including: (i) a graphic user interface for displaying the two dimensional images; (ii) localization of the interaction between a two dimensional cursor which is following the operator's movement and two dimensional images; and (iii) a haptic image display model with algorithms to calculate the reaction force, and application of the reaction force to the operator's hand in real-time. Since this paper is primarily concerned with two-dimension images, the intensity data can be directly displayed pixel by pixel on the screen. A haptic device will be used to build the communication channel between man and machine in terms of providing the position and carrying out the force command produced by the haptic rendering approach for tactual perception. Haptic devices, such as PenCAT/Pro™ (Immersion Canada Inc.), functions not only as an input device, also as an output device by means of force feedback. They complement an information flow between the human and the machine, leading to an enhanced subject's performance and reduced visual load.

While there are other interaction models (such as ray-based models of [1]), the point interaction paradigm greatly simplifies both algorithm and device development. Additionally, a point-based paradigm permits desirable bandwidth and force fidelity that enable a surprisingly rich range of interactions. Furthermore, such a paradigm reduces the problem of computing appropriate interaction forces to one of tracking the motion of a point among objects and generating the force components representing the interaction with these objects. The PenCAT/Pro™, used in our work, belongs to this kind of haptic interfaces. It

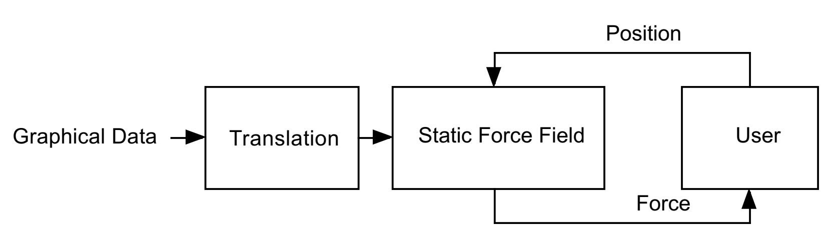

Fig. 1. Block diagram of the standard haptic interaction.