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Haptic Rendering of Virtual Shapes with the Novint Falcon

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Abstract

This paper evaluates the usability of the Novint Falcon for displaying virtual shapes that users can explore actively. Three experiments were conducted to measure the ease with which users can recognize and explore a set of seven haptic shapes. The first experiment deals with shape recognition using haptic feedback only. The second and third experiments propose two different rendering methods in which workspace is or is not limited by the contour of the shapes. Users' results are presented to confirm the suitability of the proposed haptic device.

Keywords: Virtual shapes, shape perception, haptic exploration, haptic feedback, Falcon.

1. Introduction

Haptics has generated considerable interest over these two last decades due to the potentials of touch-based interaction in fields such as robotics, tele- operation/manipulation, virtual reality, gaming, medical/industrial/sport training, education, among many others. Haptic interaction implies the transmission of forces, vibrations, and motion between the user and a computer. This interaction stimulates the user's sense of touch and provides instructions to the computer at the same time.

Surfaces, shapes, and textures have been popular topics in haptic exploration. They have been used in virtual environments (VE) [1], [2] and in several applications for the blind such as visual information transmission [3], [4], mathematical learning and graph exploration [5], [6], and cognitive mapping for mobility assistance [7], [8].

Research on haptics has been done either with self-developed prototypes or commercial platforms (a comprehensive survey on haptic devices can be found in [9]). The Phantom (Personal HAptic iNTerface Mechanism), produced by SensAble Technologies [10], is a popular device in research laboratories. It is a six degree of freedom (DOF) sophisticated manipulator-like desktop device that connects to the computer's input/output port and allows the user to interact with virtual objects programmed in the computer (Fig. 1(a)). The Phantom is considered to have begun the research field of computer haptics. It is commercially

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(a) (b)

Fig. 1. Haptic devices: (a) The Phantom desktop from SensAble Technologies (six DOF) and (b) the Falcon from Novint (three DOF).

available for some tens of thousands of dollars, which makes it hardly affordable for haptic programmers and enthusiasts.

In 2007, Novint [11] released the Falcon, the first consumer haptic device with 3D force feedback destined mainly for video games and entertainment (Fig. 1(b)). The Falcon costs under 200 USD , which makes it an interesting option for computer haptics applications.

This paper explores the use of the Falcon for rendering 3D haptic shapes. We have developed simple models to describe a set of seven haptic shapes and we present the results of user studies that were performed on ten voluntary subjects to test their ability to recognize and explore them with the Falcon.

The rest of the paper is organized as follows: Section 2 gives a brief technical overview of the Falcon haptic device. Section 3 presents three experiments that evaluate haptic shape recognition and exploration under different rendering conditions. Finally, Section 4 concludes summarizing the main concepts and future work perspectives.

2. System overview

The Falcon is an inexpensive three DOF haptic device that uses a delta-robot configuration with three servo-actuated parallel links connected to a moving plate (Fig. 2). All joints in the Falcon are one DOF revolute joints.

According to Novint, the total workspace can be roughly considered a cube with 10 cm side length. However, Martin and Hiller performed a full characterization of the Falcon and report a non-uniform workspace in [12].

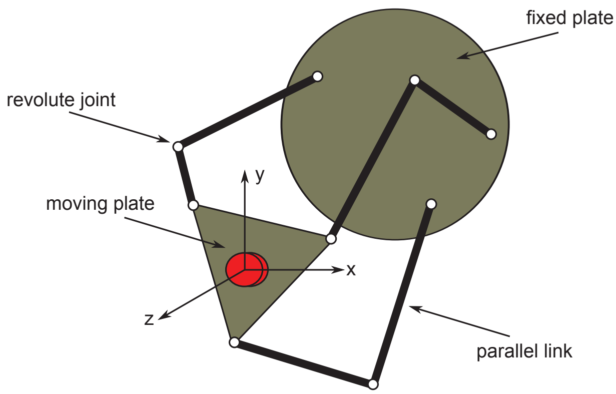


Fig. 2. Kinematic representation of the Falcon haptic device.

All information between the device and the controlling computer is handled via USB port. The Falcon transmits position to the computer which returns a force vector. Position is measured using encoders and the force vector is generated by updating the supplied currents to the servomotors in each parallel link. Position achieves approximately a 400 dpi resolution while force 9 N. The position-force loop occurs at 1 kHz update rate.

As programming interface, Novint provides a software development kit (SDK) based on C++ for Windows. Programmers use functions defined in the SDK to calculate and send force vectors to the device. Alternatively, *libnifalcon* is an open source C++ cross-platform driver [13]. With the intent of further cross-platform research, our development employs the open source solution.

3. Haptic shapes with the Falcon

The goal of our tests is to determine the usability of the Falcon for displaying haptic shapes. In three experiments, subjects explored haptic shapes by moving the Falcon's moving plate. We tested their ability to recognize and explore them under different rendering conditions. Each of the three experiments is described below.

Ten subjects (eight men and two women) participated voluntarily in the experiments. All subjects were healthy (i.e. no known impairments in tactile sensory, cognitive, or motor functions) undergraduate and graduate students at Panamericana University. No special criteria were used to select them but availability. Their ages ranged from 19 to 25 years old with an average age of 22. None of them reported previous experience using force feedback devices. All were right-handed.

During the experiments, the subjects were seated in a chair in front of the Falcon. Before each session, they were totally naive about all aspects of the test and were given general instructions concerning the task. A short familiarization time with the Falcon was granted prior to the tests. All three experiments were conducted consecutively for all subjects. Average duration of the ensemble of experiments was 20 min.

3.1. Experiment 1: Shape recognition

3.1.1. Method

Seven haptic shapes were modeled for the tests: square, triangle, circle, star, F, B, and a square wave. For the recognition test, workspace was limited by the contour of the shapes. In particular, the Falcon limited the exploration to the outer side of the shapes.

Subjects were asked to match what they felt haptically with one of these seven shapes. No information from sight could be obtained. Each shape was presented once during the trial. Subjects had no time restriction to provide their answers. Movements and exploration time were recorded for each shape and for each participant.

3.1.2. Results

Fig. 3(a) summarizes the results obtained for the ten subjects. In general, haptic shapes were easy to identify. Note that the B was the most difficult shape to identify. It was often taken for the square. This is due to the morphological similarity between these shapes and to the fact that subjects misperceived the round contours and the central line. Fig. 4 shows four shapes recorded from subjects' movements. The star and the square wave were never fully explored. After some movements, subjects were capable of recognizing these figures.

Fig. 3(b) shows the exploration times by shape. Note that the basic shapes (square, triangle, and circle) took the less time to recognize, while the star and the square wave required more exploration time from the subjects.

3.2. Experiment 2: Shape exploration - Rendering method I

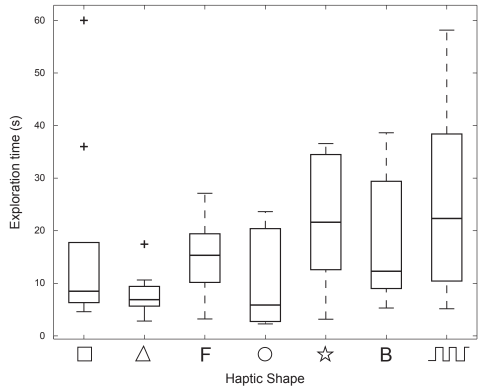
3.2.1. Method

The purpose of this test is to evaluate the subjects' performance while exploring the set of haptic shapes. We are particularly interested in evaluating speed and precision while manipulating the Falcon. Again, the rendering method delimiting the Falcon's workspace to the outer side of the shapes was used.

answered (%) / presented

presented \ answered	□	△	F	○	☆	B	⎍⎍⎍
□	**90**	0	0	0	0	10	0
△	0	**100**	0	0	0	0	0
F	0	0	**90**	0	10	0	0
○	0	0	0	**90**	0	0	10
☆	0	0	10	0	**80**	10	0
B	40	0	0	0	0	**60**	0
⎍⎍⎍	0	0	10	0	10	0	**80**

(a)



(b)

Fig. 3. Haptic shape recognition experiment: (a) distribution of answers (%) and (b) box plot analysis for the exploration time by shape.

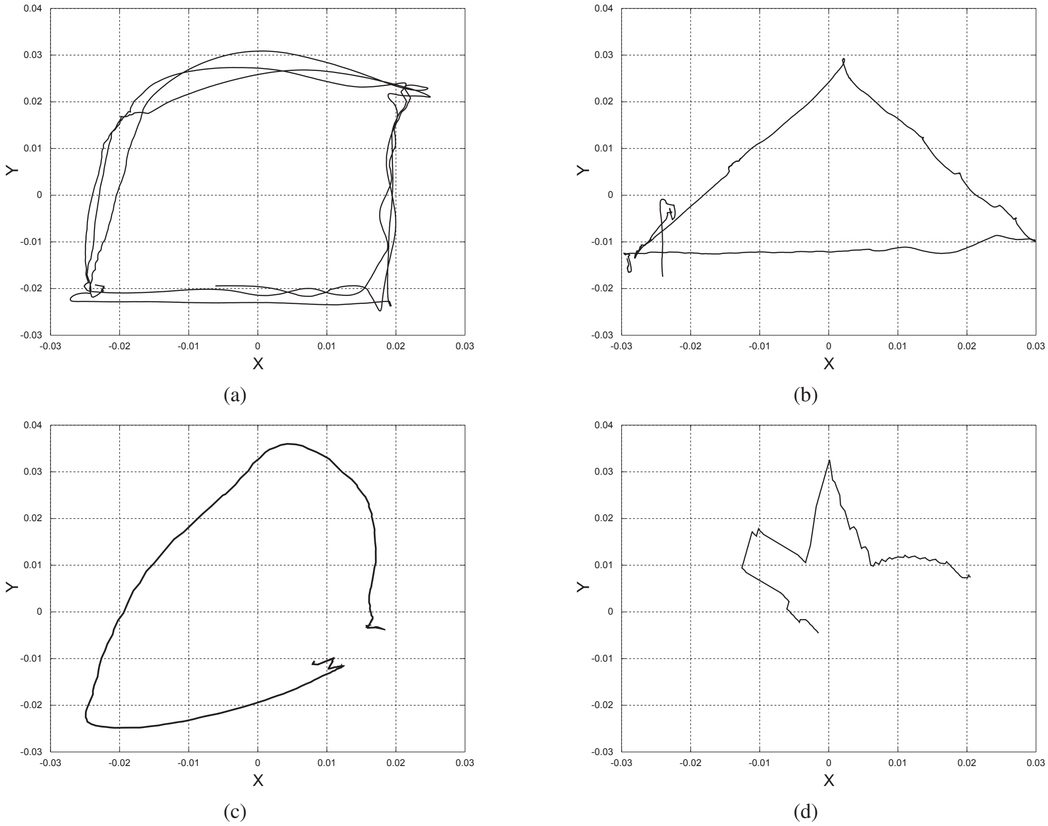


Fig. 4. Haptic shape recognition experiment - examples of movements recorded from the subjects: (a) square, (b) triangle, (c) circle, and (d) star.

This time, subjects were seated in front of the Falcon and the controlling computer. Subjects watched the shape on the screen at all times. They were first required to contour each shape the fast as possible and then to contour it the most precise as possible. Again, movements and exploration time were recorded for each shape and for each participant.

3.2.2. Results

Fig. 5 compares the exploration times by shape and condition. Both fast and precise conditions observe the same trend: the simplest shapes (square, triangle, and circle) were the fastest to explore followed by the letters (F and B). Letters are also formed by simple traces but involve over tracing, which implies non-negligible delays in haptic shape exploration. The star and the square wave are also formed by simple traces and do not involve over tracing. However, subjects required more time due to the number of traces.

Fig. 6 illustrates the movements recorded for the square shape by the same subject according to condition. Note the difference in performance between exploration conditions.

3.3. Experiment 3: Shape exploration - Rendering method II

3.3.1. Method

The purpose of this test is to evaluate the subjects' exploration skills with a different rendering method. For this test, workspace was not limited by the contour of the shapes. Subjects could move between the outer and inner side of the shapes. When touching the contour, subjects could feel a bump.

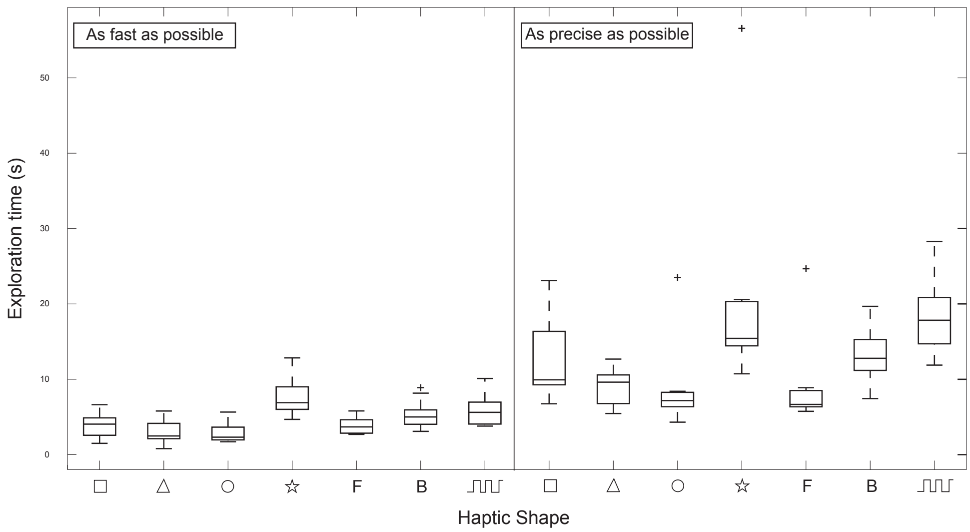


Fig. 5. Rendering method I: comparison of exploration times by shape between fast and precise conditions. The same trend is observed.

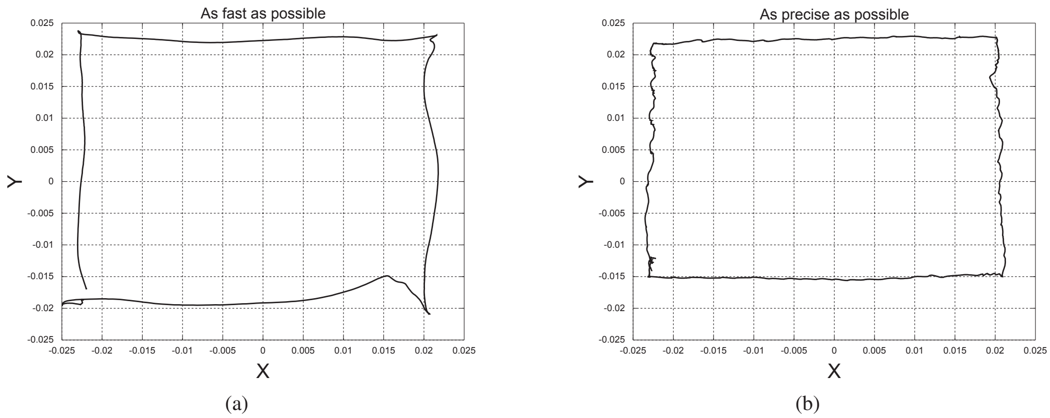


Fig. 6. Rendering method I: comparison of performance between fast and precise conditions for the square (same subject).

As in the previous test, subjects were seated in front of the Falcon and the controlling computer. Subjects watched the shape on the screen at all times. They were first required to contour each shape the fast as possible and then to contour it the most precise as possible. Movements and exploration time were recorded for each shape and for each participant.

3.3.2. Results

Fig. 7 compares the exploration times by shape and condition. As in rendering method I, both fast and precise conditions observe the same trend: the simplest shapes (square, triangle, and circle) were the fastest to explore, followed by the letters (F and B). The star and the square wave took the longest time.

Fig. 8 compares the movements recorded for the square shape by the same subject according to condition. Note the difference in performance between exploration conditions.

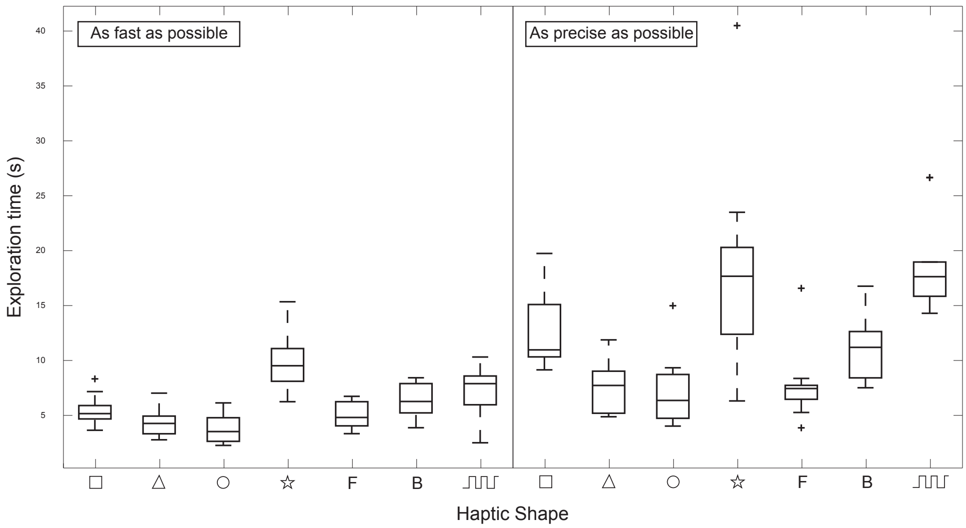


Fig. 7. Rendering method II: comparison of exploration times by shape between fast and precise conditions. The same trend is observed.

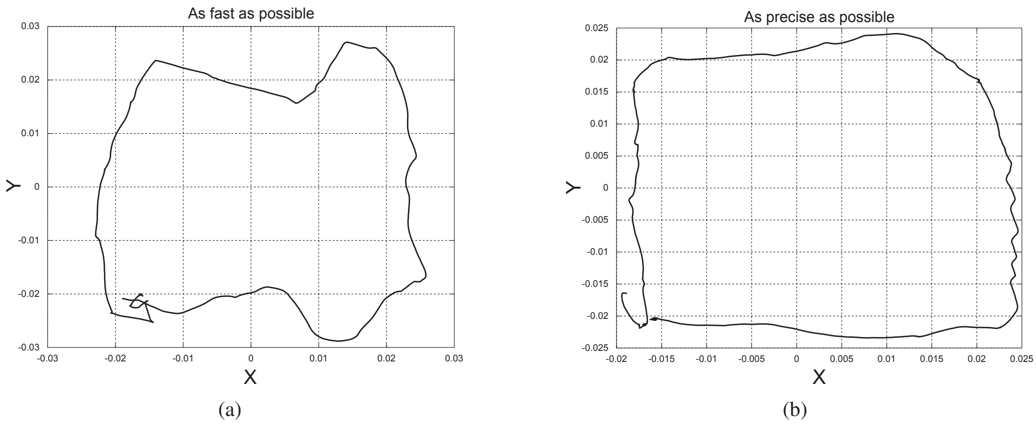


Fig. 8. Rendering method II: comparison of performance between fast and precise conditions for the square (same subject).

3.4. Discussion

Both rendering methods reveal the well-known trade-off between speed and precision. Precise haptic movements require more exploration time (Figs. 5, 7).

Haptic shapes delimited by their outer contour are significantly easier to explore than those which are not (Figs. 6, 8). Subjects find difficult to moderate the applied force to avoid surpassing shape contours. Also, subjects are slightly more time efficient at exploring shapes delimited by their contour.

4. Conclusion

Many applications using haptic environments inherently include shape perception as a fundamental task. In this paper, we examined the Novint Falcon, a low cost 3D force feedback commercial haptic device, for displaying virtual shapes. The motivation behind this project is to test the capabilities of this platform and develop custom applications to allow a broader range of students to experience haptic feedback.

Three experiments were conducted on the Falcon: shape recognition and shape exploration using two different rendering methods.

The results of our user studies show that the Falcon haptic device does allow users to recognize shapes with much better than chance performance. Recorded movements show that users explore reasonably well the proposed haptic shapes to make an accurate mental representation of them. We found that round contours and any other information diverging from the main contour are often misperceived. Shapes delimited by their outer contour are easier and faster to explore than shapes with both outer and inner explorable space.

Future work will continue exploiting the Falcon in haptic exploration of textures and objects' physical properties (mass, stiffness, etc).

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