Haptic Illusions: What You Feel Isn't Always What You Get

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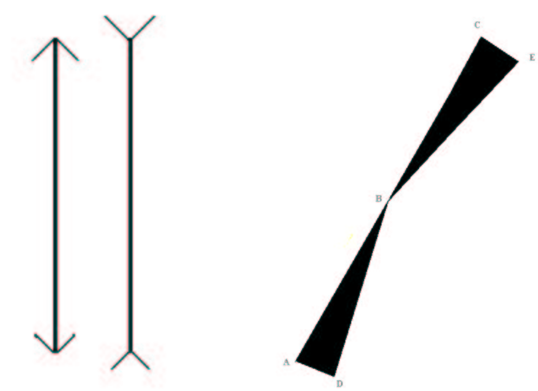
ABSTRACT

In this paper, we present the discovery of new haptic illusions, and a method for creating further haptic illusions. Pure haptic illusions were created by mixing force cues with geometric cues to make people feel shapes that differ from the actual shape of the object. In particular, we found that an area that feels harder to move through and easier to move out of can be interpreted as a region of high curvature. These haptic illusions were implemented into user experiments with a haptic interface. Preliminary user tests have shown that this method can be effective at masking true object geometry by making a circle feel like an ellipse and a straight line feel like a curved line.

Keywords

Haptics, Haptic Illusions, Perception, Psychophysics, Virtual Environments, Lateral Force Fields



(a) Muller-Lyer Illusion

(b) Bourdon Illusion

Figure 1: Examples of Visual Illusions

1. INTRODUCTION

Perceptual illusions occur in all sensory modalities. The most well known and widely studied are visual illusions (See Figures 1(a) 1(b)). Visual illusions are a relatively mature field of research and are commonly used in the entertainment industry. The study of haptic illusions, however, is still in its infancy.

Until recently, the only pure haptic illusions have been created by mimicking existing visual illusions in haptic space. R.H. Day (1990) [2] created a volume equivalent to the shape that when traced with the thumb and index finger created the same illusion as the visual Bourdon illusion (Figure 1(b)). Volker *et al.* (2000) [11] showed that people are subject to the Muller-Lyer illusion (Figure 1(a).) in haptics as well.

Recently, Robles-De-La-Torre *et al.* (2001) [8] [7] showed that the perception of geometry by active touch is dominated by force cues. Their experiment compared users perception of a real bump contour with a haptic force distribution generated by a Pencat^{TM} interface that was restricted to a single plane of motion. The users could not tell the difference between the two.

Inconsistencies and limitations in the human proprioceptive system are an ongoing topic of research in psychology, physiology, and psychophysics. Wong (1977) [12] found that radial movements toward and away from the body are judged longer than equal lateral movements along the front or side of the body so that the perception of the relative lengths of two sides of a rectangle depends on the location in the workspace.Tan (1994) [10] reports findings on the resolution of human position sensing. Additionally, Pang, (1991) [6] found a discrepancy between absolute and relative position sensing. Relative position sensing is more precise than absolute.

We have built on this work to create new haptic illusions using an available haptic interface. The work of Robles-De-La-Torre *et al.* relies on single finger touch. We want to extend the principle of using force cues to influence perceived geometry to gross arm motion. We use a programmable haptic interface to generate force constrained planar paths. By adding force cues to the path, a perception of geometry different from the actual path can be induced. The illusions were strengthened by using the principles found by Wong [12] and Pang [6].

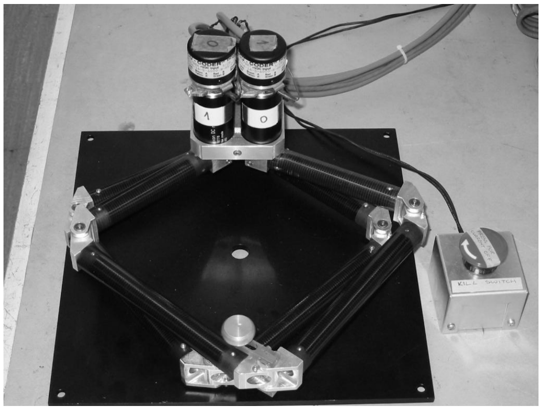


Figure 2: Twin planar pantograph interface

2. EXPERIMENTS

We created a test-bed to identify new illusions using the 3DOF twin planar pantograph haptic interface that was designed and built in the Robotics and Control Laboratory at UBC (Figure 2). This interface employs a teleoperation principle, where the real-time simulation code, robot dynamics code, and control code are run on a 733 MHz PC running VxWorks[1]. VxWorks allows the interface to run at 512 Hz, giving a very smooth haptic rendering of force feedback. Graphics, although not used for the user tests, is performed on a separate Windows[2] PC. The two PC's communicate via a UDP socket for simulation communication and a serial port for terminal communication. Control Software was developed with SIMULINK and the Real-Time Workshop [3] [3, 1, 9].

In all experiments, the haptic interface constrains the user to follow a predefined path. Software was written to allow for easy definition of arbitrary paths consisting of straight line and arc segments. The user is kept on the path by using a spring-damper constraint applied normal to the path, as shown in Figure 3.

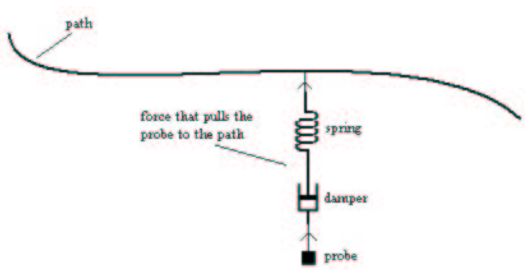


Figure 3: Spring damper constraint, normal to path

Equation 1 describes the force law where F is the magnitude of the force applied, k is the spring constant, d the distance along the path normal to the user's hand position, c is the damping coefficient, and v the velocity of the user's hand. To maintain stability and a stiff wall feel, the value of damping coefficient was set to 200 Ns/m, and the spring constant was set to 10,000 N/m.

$$F = kd + cv \tag{1}$$

[1]Trademark Wind River Systems
[2]Trademark Microsoft Corporation
[3]Trademark Mathworks Corporation

To modulate the force required to move along the path, a modified Karnopp [5, 4] friction model was added.

A set of haptic experiments was created to test the shape perception of users. Each experiment was formulated to take advantage of the limitations in human perception as explained below.

2.1 Straight line with varying force

Robles-De-La-Torre [8] used a combination of opposing and aiding forces to induce the perception of an upward movement followed by a downward movement in active touch. In this experiment, we want to investigate if an increasing opposing force along a straight line gives the illusion of curvature. Figure 4 top shows the straight diagonal path. The bottom shows the linear increasing friction distribution along the path. The path was chosen to be diagonal because the movement of the arm and shoulder is more complex, and hence the perception is more likely to be strayed with additional cues.

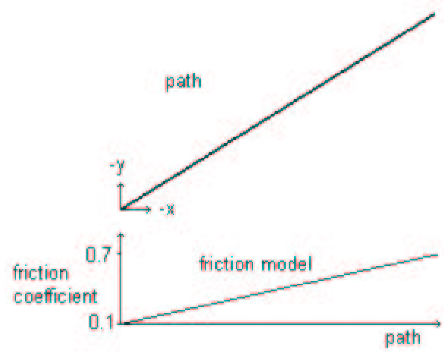


Figure 4: Varying friction along a straight line

2.2 Circles with varying force

To further investigate the perception of increased force as curvature, two experiments based on circles were tested. The effect found by Wong [12], can be emphasized in a circle because the user experiences translation in both x, and y directions semi-independently. Figure 5 shows a circle with maximum friction at the top and bottom and zero friction at the most lateral points. The grey shaded area is an indication of the friction distribution along the path. In this symmetric configuration we expect the increased-curvature cues to work together with the effect reported by Wong to elicit the feeling of an ellipse. In Figure 6, friction of constant value was placed alongside a quarter of the circle trajectory.

2.3 Lateral force fields

We created a setup similar to Robles-De-La-Torre [8]. A lateral opposing force field was created to elicit the illusion of bumps. Where in the original paper an active propelling force field was used in the trajectory corresponding to the downward side of the bump, we wanted to investigate whether the same perception could be derived from the natural acceleration of the user's hand caused by leaving the opposing force field. Figure 7 shows the variation in the opposing force field along the lateral trajectory.

3. EVALUATION PROCEDURE

During the experiments, the subject were required to have eyes closed. They were positioned with the interface square, and slightly

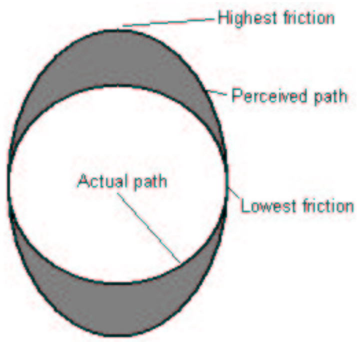


Figure 5: Symmetric friction cues on a circle

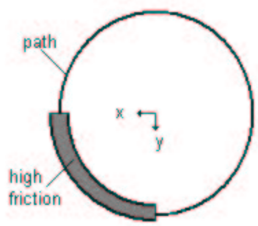


Figure 6: Asymmetric friction cue on a circles

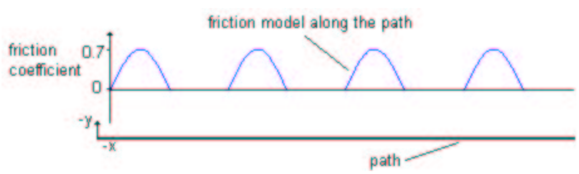


Figure 7: Friction pulses along a straight line

to their dominant side. Each subject went through the following test procedure:

1. Familiarization: Prior to the actual illusion tests, the subject was allowed to experience the feel of the haptic interface both in free motion and when constraint to paths. The training paths consisted of a line, a circle, a sine and a closed path consisting of two circle segments. All paths had a constant friction applied along the entire trajectory ($\mu = 0.1$).

2. Exploration: The subject is allowed to explore the illusion test path for up to 15 seconds. The only information given to the subject about the path is whether it is a closed trajectory or open. The subjects were free to chose the velocity of hand movement with which to explore the path, with only one exception. When exploring the line with friction pulses, the subjects were asked to change their speed of motion when it was judged by the authors to be to fast. This exception was made to prevent subjects from pushing the probe away from the path when trying to overcome the friction pulses.

3. Feedback: The subject is asked for a verbal description and sketch of the path and continues with the exploration of the next illusion.

All subjects were graduate students in the ECE, CS and ME departments of UBC. Subjects were 50% male and 50% female.

4. RESULTS AND DISCUSSION

The diagonal line (Figure 4) was judged a successfull illusion if the subject perceived the line as being bend in a consistent trend. (Either increasing or decreasing slope). The circular path with high friction in the upper and lower sides (Figure: 5) was accepted as a successfull illusion, if the subjects feel it as an oval or an ellipse, which indicates that, increased friction is perceived as increased curvature. The circular path with high friction in only one quarter of the path (Figure: 6) was counted as a succesfull illusion if the subjects feel the path as an irregular circle, or a circle with distorted shape, or as an "egg" description. The straight line with friction pulses was considered succesfull if it was perceived as a "bumpy" line.

Illusion	Results
Diagonal line (Figure 4)	5/6
Ellipse (Figure 5)	5/6
Egg (Figure 6)	3/5
LFF pulses (Figure 7)	1/4

Table 1: User results: succesfull results over number of subjects

The most successfull illusions were the ellipse and the diagonal line. We expected the subjects to perceive the circle with lateral friction as an ellipse with the short axis in lateral direction. A number of subjects drew the ellipse with the longitudinal axis slope. Also under different angles , to the right and to the left. Some of the diagonal straight lines were perceived as S-shapes. We expect that to be a result of the limits in hardware (see next paragraph). We found that the illusions tend to be less strong when people are familiar with the underlying hardware and software. The person who works with test apparatus on a daily basis, immediately recognized the trajectories as having synthetic damping and did not feel a change in path. Also, it is apparent that the longer and more carefully the subject explorers the path, the illusion of curvature is diminished. This is likely due to the subject getting used to the feel of friction and distinguishing the force cues from position cues.

5. LIMITATIONS

This work shows results from a preliminary study of the feasibility of pure haptic illusions in gross arm movement. At time of writing, it has the following limitations:

- The maximum force output of the haptic interface is approximately 8 newtons, which is easily overcome by a human arm. As such, the subject feels a constant force once he/she has deviated from the path by approximately $1mm$. This limits the ability for the user to be truly constrained in the path. Additionally, in regions where the friction coefficient is high, pushing against the spring/damper constraint can feel similar to pushing along the path, and the subject can loose the track of the path, limiting both the maximum frictional force that can be used and the accuracy of path constraints.

- The interface can translate in x and y, and rotate around z. This rotation was not used in the tests, and was left unactuated. This caused the interface to near singular configurations in certain regions of the workspace, limiting both maximum force output and linear measurement accuracy. Although, subjects were encouraged to hold the interface rigidly in rotation so that singular configurations were not reached, the interface would occasionally near these configurations and compromise the strength of the path.
- The interface is strictly planar. It would be useful to test illusions in higher degrees of freedom (a sphere instead of a circle) and with the addition of gravity.
- The workspace of the haptic interface is 21x13 cm. This size restricts the experiments from testing a full range of arm motion.
- Only opposing force models (friction) were used in this research. This gives the feeling of 'damped' movement and users notice that it is harder to move through regions with increased friction. The immediate perception of the slower movement is increased curvature, but once the subject has felt the path several times, the strength of this illusion diminishes. This fact is most likely why the "egg" illusion was not as successfull as the ellipse illusion since the egg illusion followed the ellipse illusion in the user tests. Also, friction does not emphasize the force cues experienced from curvature as well as other lateral force fields could.

6. FUTURE WORK

In our time frame we were able to test the experiments with six subjects. To substantiate the results a larger, more diverse group is required. Limitations in our hardware might have influenced the outcome. For optimal results, a hardware configuration that would allow stiffer path constraints is required. To investigate the influence of object size and subject joint angles on the perception of the illusions, a test-bed with a larger workspace is necessary. The influence of a friction model was used to generate opposing forces. Bidirectional force fields as discussed in [7, 8] may elicit a stronger, more realistic sense of curvature and should be added to the existing set of illusions for comparison.

7. CONCLUSIONS

An experimental set up was developed to test human shape perception with gross arm movement. Several experiments were conducted to test recognition of simple planar shapes using a programmable haptic interface. Lateral force cues were introduced into the shape experiments, to augment the perceived shape with success. From these results, we conclude that gross arm shape perception can be misled with the addition of force cues. Preliminary results suggest that a resistive force that increases and decreases shortly thereafter can be perceived as a local curvature. The results from this paper merely break the surface of an understanding of how the human proprioceptive system interprets geometry in the absence of visual feedback. These findings could influence future research and development in the haptics and virtual environment fields.

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