Expressive Haptic Rendering with Cartoon-Inspired Effects

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ABSTRACT

Non-photorealistic rendering (NPR) rejects a rigid adherence to physically accurate creation of visual imagery in favor of expressive styles that can enhance information transfer or create an artistic feeling. This paper considers those goals in the context of haptic rendering. Expressive haptic rendering techniques are developed for cartoon-inspired haptic rendering effects and demonstrated in three classic cartoon scenarios: super-slippery surfaces, exaggerated recoil and vibration upon hitting an object, and falling from a height based on a character's awareness of danger. Subjectively, these effects create increased interest in a scene and can facilitate transfer of artistic goals to a user. The value of expressive haptic rendering derives from this enhanced interaction experience.

1 INTRODUCTION

Haptic interfaces are human-computer interfaces that involve the sense of touch [3]. For example, a haptic interface may create sensations of contact with a virtual object. These interfaces typically rely upon a robotic device capable of transmitting forces to the user. The computation of appropriate forces to simulate touch sensations is called haptic rendering [9]. Most haptic rendering research is focused on the creation of physically realistic sensations, with current work addressing such topics as contact with deformable bodies [5] and playback of high-fidelity measurements of contact forces [10].

In contrast, this paper advances the idea of expressive haptic rendering. This idea borrows heavily from the non-photorealistic rendering (NPR) community, with its goals of expressive or enhanced visual communication rather than exact simulation of light transport in image rendering. However, while the NPR community has a rich artistic legacy in the visual arts to draw upon for inspiration, it is less clear which techniques may prove effective in the haptic realm.

One possible approach, and the one taken here, is to adapt techniques from visual communication to haptics. Inspired by traditional animation, we have adapted several classic techniques from cartoons to demonstrate one direction in expressive haptic rendering. The particular techniques implemented for this paper are super-slippery surfaces, as encountered on cartoon frozen ponds; exaggerated vibration upon hitting a surface, found when a cartoon character hits an unexpectedly solid object with a mallet or sword; and falling of characters based on their own awareness of danger, often seen near cartoon cliffs. These are only a small subset of possible expressive haptic rendering directions, but they serve to demonstrate the potential for augmenting haptic rendering with expressive or artistic styles.

In summary, this paper explores how some of the goals of non-photorealistic rendering, such as expressive rendering, might be applied in the haptic domain. The specific contribution in this paper is the development of haptic rendering methods that borrow from exaggerated action in cartoon animation. The long-term goal of this research is to develop expressive techniques that will prove useful in multimodal media, such as computer games or haptically enhanced storytelling.

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2 RELATED WORK

There is related work to expressive haptic rendering arising in NPR computer graphics, computer animation, and the haptic rendering community, although none have produced work directly in support of the expressive haptic rendering goals of this research. These efforts are described in the following sections.

2.1 Non-Photorealistic Rendering

While computer graphics research has long had an artistic component [19], non-photorealistic rendering first emerged as a distinct goal in the early 1990's. Two major directions for NPR originated at SIGGRAPH'90, with Saito and Takahashi [21] presenting work on comprehensible rendering in a technical illustration style, and Haeberli publishing his research on painterly rendering of 3D models [7]. These two directions formed the basis for much of the following research energy in this area, with the research community working on issues of interactivity [17, 6], visual coherence [18], and fidelity to established artistic styles [8]. Since then, a thriving community has formed to study NPR for graphics.

2.2 Computer Animation

Since this research is inspired by cartoon-style action, it is worth discussing activities in 3D computer animation that address cartoon animation. Lasseter [13] laid out important principles from 2D animation and discussed their application to 3D computer animation. It is noteworthy that exaggeration is seen as an important element in making animations seem lively and engaging.

Bruderlin and Williams [2] examined the effect of frequency filtering motion paths and joint trajectories. They noted that different filters produced effects such as exaggerated walk, nervous motion, and even anticipation before motion. More recently, [24] demonstrated the use of a simple animation filter that can be applied to motion paths and even video cutouts to create exaggerated motion in a cartoon style. Just as the above sources exaggerate motion to create a cartoon effect in the visual domain, in this paper we have exaggerated forces to create similar effects in the haptic domain.

2.3 Haptic Rendering

Haptic rendering has focused primarily on generating realistic sensations of contact with physically plausible environments. A recent text [15] provides a current view of research approaches in the field. However, some haptic methods aim at generating more expressive sensations, although usually for specific purposes. The idea of virtual fixturing [1], in which the motion of the input device is virtually constrained, can provide guidance in situations where additional precision is required. This can be interpreted as a kind of haptic "technical illustration", with important features artificially emphasized.

Some researchers have attempted to use haptic stimuli for expressive purposes, rather than for simulation. MacLean has done extensive work on haptic icons [16]. This work uses haptic stimuli to express symbolic information. Verplank and others have emphasized expressive haptics for such tasks as media control [22]. However, in that context expressive haptics is better understood as a desire to preserve nuance of sensation, such as feeling the click of virtual gear teeth representing film frames. Non-realistic haptic rendering is developed in [11], which modifies purely geometric representations through simplification and information layers to aid perception by blind users. The focus of this paper, instead, is to explore what techniques might enhance haptic rendering for the sake of artistic expression.

3 Methods and Apparatus

In the work, all the haptic interface scenarios were developed using the Chai3D libraries [4]. Forces were computed and rendered at a variable servo rate greater than 1kHz. The scenarios were adapted and implemented for two commercially available haptic devices, the Novint Falcon and the Phantom Omni. In the following examples, a mesh model is attached to the haptic interaction point (HIP) for visual interest, but forces are computed based only on the HIP contact with the virtual scene.

4 Expressive Haptic Rendering

In order to explore the potential of expressive haptic rendering, three scenarios were developed based on classic cartoon effects: a super-slippery surface, exaggerated vibration upon hitting a surface, and falling based on character awareness. Unlike the majority of haptic-enabled applications that strive for realistic interaction forces between the user and the environment, the scenarios described here exhibit non-physical, non-realistic interactions. These non-realistic interactions create whimsical and entertaining haptic experiences and are intended to make interaction with the virtual world more engaging and expressive. The following sections detail the approach, implementation, and results for three different expressive haptic rendering concepts inspired by cartoon animation.

4.1 Super-Slippery Surface

The rendering of friction forces in a haptic environment has received significant attention and has been found to improve the performance of haptic-interface controlled tasks (see, for example, [20]). Realistic friction, however, is a subtle property of materials and changes in friction have to be relatively large in order to be perceived by a user [23]. If an obvious change in friction was desired for a hapticly-enabled game or storytelling environment, exaggerated friction forces would be needed to make the change in friction apparent to the user. Similarly, cartoons often exaggerate friction properties so that they are obvious to the viewer, for example, impossibly slippery ice upon which a character slides or falls.

We have implemented the haptic equivalent of a super-slippery surface. Real surfaces display a combination of coulomb friction and viscous friction. Coulomb friction is given by

$$F = \mu_s N \quad (1)$$

where F is the friction force, μ_s is the coefficient of coulomb friction and N is the normal force between the object and the surface. Viscous friction is calculated as

$$F = \mu_v v \text{ where } \mu_v < 0, \quad (2)$$

where F is the friction force, μ_v is the coefficient of friction and v is the velocity between the object and the surface. Both types of friction always exert a force opposing motion.

In contrast, the friction properties of cartoon ice seem to exert a force that increases motion, pulling the feet out from underneath a character or sliding a character inexorably toward a cliff. We have implemented this effect in a haptic environment. The force exerted from the virtual surface onto the hand of the user has two components: a force opposing penetration of the surface (to simulate a stiff surface) and a friction force. The super-slippery friction force F is in the direction of motion, proportional to the speed of the user's hand:

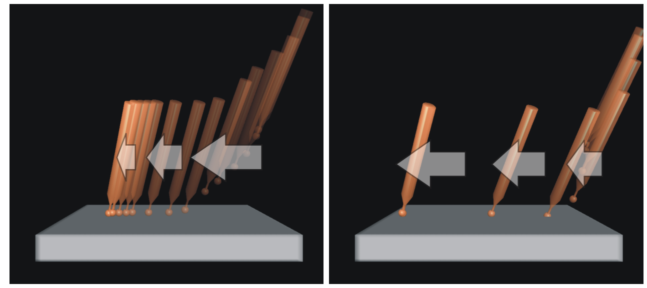

Figure 1: These figures show a time-lapse rendering of typical interactions with a physically-correct virtual surface with friction (left) and with a cartoon-inspired super-slippery surface (right). Contact with the realistic surface tends to slow down the motion of the hand and stylus. In contrast, contact with the super-slippery surface exerts a force in the direction of motion, making stable, controlled interaction with the surface difficult.

$$F = \mu_v v \text{ where } \mu_v > 0, \quad (3)$$

where F is the friction force, μ_v is the coefficient of friction and v is the velocity between the haptic interaction point and the virtual surface. This is similar to realistic viscous friction, but where all real surfaces have $\mu_v < 0$, the cartoon surface exhibits $\mu_v > 0$.

Figure 1(left) shows a haptic environment with realistic friction; the stylus slows down as in comes into contact with the virtual surface. Figure 1(right) shows a haptic environment with cartoon-like, super-slippery friction properties as described by the previous equation. In this scenario, the stylus speeds up when in contact with the super-slippery surface.

The simulation successfully renders an unrealistically slippery surface that is easily perceived by the user. As the coefficient of friction becomes more positive, it becomes difficult to achieve controlled interaction with the surface. When implemented on the Phantom Omni, the effect of the surface is to make the end of the stylus slide out from under the hand of the user. Such difficult interaction could be desirable, for example in a game, where it would be challenging to move a character or object over an icy surface. This implementation of a super-slippery surface successfully translates the effect of cartoon ice into something that can be felt by a user in a haptic environment.

4.2 Exaggerated Vibration and Recoil from Impact

The realistic rendering of contact with a stiff, virtual surface is an active area of haptics research (see, for example, [12]). Lawrence et al. found that the perceived stiffness of a virtual surface depends on the forces that can be generated by the haptic device, and how fast those forces can be applied [14]. Commercially available haptic devices have difficulty rendering stiff surfaces because of their limited force output.

However, there is potential for effectively rendering cartoon-like stiff surfaces. Cartoons often depict impact with a stiff surface with an exaggerated recoil and oscillation effect, for example a hammer striking a wall bounces back and shakes in the character's hand with violent vibrations. We have implemented a similar effect in a haptic simulation, allowing a user to feel the cartoon-like recoil and vibration resulting from impact with a stiff object.

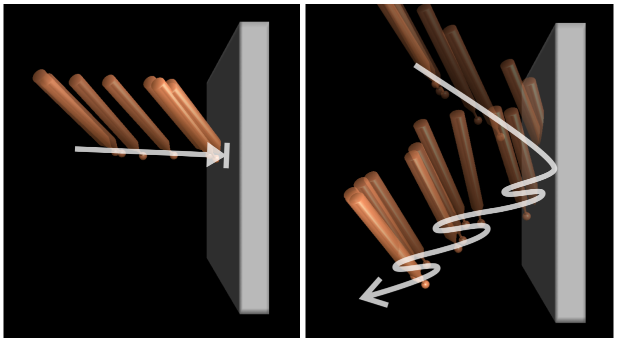

Figure 2: Contact with a standard penalty-based wall (left) and a cartoon wall (right). The realistic wall simply brings the stylus to a stop. The cartoon-like wall causes the stylus to rebound with exaggerated oscillation.

Virtual surfaces are typical simulated with penalty spring forces, rendering forces proportional to how far the haptic interaction point has penetrated into the virtual surface:

$$F_{wall} = -k_{wall}x,$$

where F is the penalty force that pushes that haptic interaction point out of the wall, k_{wall} is a spring constant, and x is the penetration distance. Increasing the spring constant k_{wall} increases the stiffness of the virtual surface. Penalty-based approaches such as this commonly are used in haptic rendering instead of impulse methods since the haptic hardware has limitations on maximum force. Figure 2 shows an example interaction with a wall using a penalty force based method.

Cartoon-like behavior was achieved by adding a recoil force and an oscillation force, both of which are scaled with the impact velocity. This is similar in spirit to the event-based haptics research done by Kuchenbecker et. al., where vibrations were added at the time of impact to improve realism [12]. In this paper, forces are added at the moment of contact for artistic effect, rather than for realism. The recoil force is computed as

$$F_r = v_i k_r (d - t) \text{ for } t \leq d,$$

where v_i is the impact velocity, k_r is a constant scaling the recoil force, d is the duration of the recoil force, and t is the time since initial impact. The oscillation force is computed as

$$F_{osc} = v_i k_{osc} (d - t) sin(\omega t) \text{ for } t \leq d,$$

where k_{osc} is a constant scaling the oscillation force and ω is the frequency of the oscillation.

A sample cartoon impact with a wall is depicted in Figure 2. The trajectory of the stylus in one dimension for standard and cartoon walls is plotted in Figure 3. The trajectory plot shows the exaggerated recoil from the surface and the subsequent oscillations.

The forces rendered by adding recoil and vibration to a virtual wall effectively create a cartoon-like feel in a haptic environment. We found the cartoon impact effect to translate well into a haptic simulation, resulting in an engaging and playful interaction. An unexpected effect of the cartoon-like effect was that it effectively masked the penetration of the stylus into the virtual wall. Haptic environments, particularly those rendered by inexpensive devices, generally feel soft and springy. By adding recoil and vibration to impact, the stylus is expelled from the surface. This cartoon-like effect could therefore be useful when developing applications intended for use on consumer-level haptic devices.

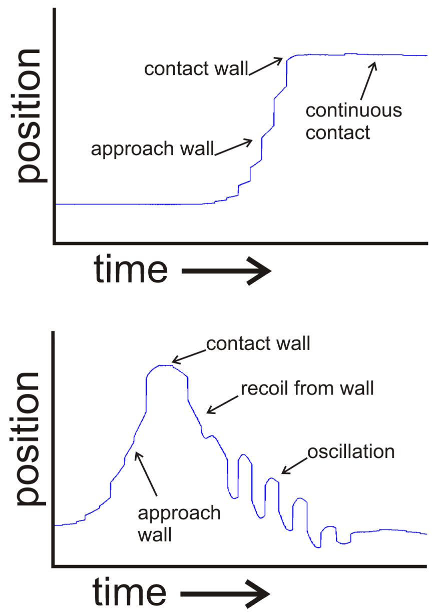

Figure 3: Position vs. time plots of contact with a realistic virtual wall (top) and cartoon-based virtual wall (bottom). Note how the cartoon wall still causes oscillations even when the stylus is no longer in contact with the wall.

4.3 The Cartoon Cliff: Falling Based On Character Awareness

Edges and cliffs often have very different properties in cartoons than in reality. Cartoon characters are able to pass over precipices if they are moving fast enough and they do not fall if they do not stop and look down. This is an example of a mutable cartoon environment where physical properties change based on the behavior and awareness of the character.

We have implemented one such environment in a haptic simulation. A gap between two surfaces is rendered visually (Figure 4), but the haptic rendering of the gap changes with behavior of the user. While the application cannot directly know the thoughts of the character, certain metrics can be applied to estimate how the user is reacting to the gap. If the speed of the character (i.e. the speed of the user's hand and the haptic device) is above a threshold value, then haptic forces are generated to simulate a continuous virtual surface. Thus, the character is able to pass over the gap and the user feels a solid surface even when the character is in free space.(Figure 4(bottom)) If the speed of the character drops below the threshold value (i.e. the user approaches the gap tentatively, or pauses in mid-air), the haptic environment changes to match the visual environment. In this case, no upward forces are rendered when the character is over the gap and the character falls.

Figure 4(top) shows an example of falling off a cliff based on simple metrics using the user's lateral hand velocity. One could imagine a game where the action was distracting enough that the user would not necessarily notice visual gaps such as presented here, making falling a probabilistic occurrence. This concept could be extended to other aspects of a virtual environment, creating a cartoon-like world with force-feedback properties that adapt to user actions to create entertaining and humorous haptic effects.

5 Conclusion and Future Work

In this paper, we have developed and implemented three cartoon effects adaptable to haptic interfaces. These are examples of a larger concept in multimodal interfaces: expressive haptic rendering. The

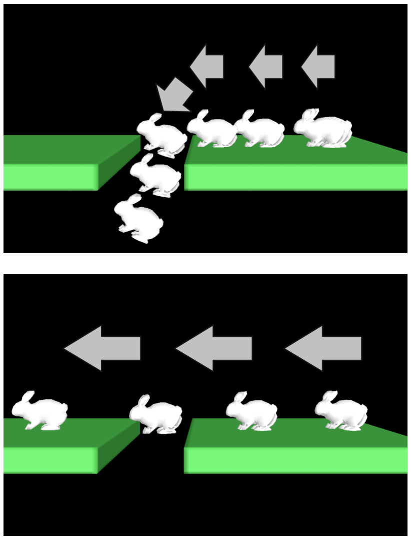

Figure 4: A cartoon cliff with properties based on estimates of the character's awareness of danger. (top) If the character moves tentatively or pauses, indicating awareness of danger, the haptic constraints are removed and thee character falls according to the normal rules of physics. (bottom) If the character moves decisively over the gap, then haptic forces are rendered to prevent falling.

goals of expressive haptic rendering are to place communication as a goal above physical realism. In our cartoon-inspired scenarios, we were able to express feelings of playfulness and gain user engagement by doing so. Certainly, these conclusions are very subjective. Additional work is needed to develop tests that can measure the impact of these techniques in appropriate environments.

All three haptic environments also exhibited an interesting interaction between haptic and visual rendering. Our haptic environments couple visual and haptic rendering in a closed loop. The cartoon-like forces applied to the user's hand result in cartoon-like motions of the device. These motions are then reflected in the graphic rendering of the environment. Thus, effective cartoon-like graphic effects are created as a by-product of our haptic effects.

There are also other approaches that should prove valuable to the larger goal of expressive haptics, although one difficulty is the lack of relevant cultural references to provide inspiration for expressive touch interfaces. The approach taken in this paper, adapting visual cues to the haptic realm, may also provide additional directions for expressive haptics.

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