DeforMe: Projection-based Visualization of Deformable Surfaces using Invisible Textures

Parinya Punpongsanon * Daisuke Iwai Kosuke Sato

Graduate School of Engineering Science, Osaka University, Toyonaka, 560-8531 Japan

Figure 1: *With DeforMe, projected graphics are realistically deformed to match the deformed surfaces: (a) infrared-based textures are used to estimate the deformation of the surfaces, (b)(c) and (d) various deformable surfaces can be used with the system, (e) DeforMe can also be used for the case of a self-dilating object.*

Abstract

In this paper, we present *DeforMe*, a new projection-based mixed reality technique for augmenting deformable surfaces with deformation rendering graphics. DeforMe combines a geometry tracking method with a deformation reconstruction model to estimate the tangential deformation of a surface. The motions of the feature points are measured between two successive frames. Moreover, the system estimates the surface deformation on the basis of the moving least squares algorithm, and interpolates the deformation estimation result to the projected graphics. Users can interact in real time with the deformable object, while the realistic projected graphics deform according to the deformation of the surface. We aim to integrate our technique with various types of design-support and interactive applications in spatial augmented reality.

Keywords: Projection-based mixed reality, Interactive system, Surface deformation, Tangential deformation

1 Introduction

Projection-based mixed reality (MR) refers to techniques in which computer graphics are projected on to real objects, to create a realistic appearance without requiring refabrication or user-worn equipment. These techniques allow us to generate the illusion of virtual modification of the physical surface, and create a realistic representation of a virtual reality in the real world. Moreover, with a flexible surface (e.g., deformable surfaces, malleable objects), they allow the user to interact with the projected graphics while obtaining tactile feedback. Several investigations have explored methods of projecting graphics on deformable displays or tangible objects, by measuring the surface deformation using, for example, a depth sensor [Follmer et al. 2012]. However, they are not applicable to tangential deformations that can appear on a surface in a horizontal direction during interactions such as touching, pinching, and pulling, even by the force of gravity.

To address this limitation, we propose a new projection-based MR system to reveal the deformation of the surface as realistically as possible, called *DeforMe*. With our system, the projected graphics can be deformed according to the deformation of the real object. Unlike previous attempts, which utilized the physical characteristics of the materials [Kamiyama et al. 2004], or depth information [Piper et al. 2002], our system has the advantage of performing real-time estimations of the tangential deformation flows with only a small number of feature points, and is not limited to the characteristics of the physical models. It can, therefore, extend the application field of projection-based MR.

2 Related Work

The *Shader printer* [Saakes et al. 2012] solved the limitation of projection-based technologies by painting the object surface with a color-dithered thermochromic ink and changing the neutral color of the surface with a laser projector. The augmented graphics could be painted onto various physical materials, even though they deformed. Nevertheless, this technique cannot change the printed graphics in real time. *Flexpad* [Steimle et al. 2013] provided interactive displays using the deformation of plain paper through a depth camera and a projector. By tracking the depth images of a surface and matching it to a predefined deformation model, the system does not require any marker. Since, the deformation models are required for each surface shape, the system cannot measure deformation when the surface shape is unknown. *ForceTile* [Kakehi et al. 2008] used the tracking method of two layers of markers to detect the force distributions of the elastic body. Although, this system can measure the traction field of surface deformation, it requires a transparent body of deformable material. Because this technique was based on specific physical properties, the number of materials usable as well as the range of interaction techniques available were limited.

In contrast, we aim to estimate the tangential deformation of a surface as realistically as possible, even for the dilatation deformation of a viscoelastic material, whose depth information cannot be measured. With DeforMe, we can visualize in real time the deformation of the non-textured and homogeneous objects used in projection-based technologies. In particular, various deformable materials can be used without prior knowledge of their mechanical properties or deformation models.

*email: parinya@sens.sys.es.osaka-u.ac.jp

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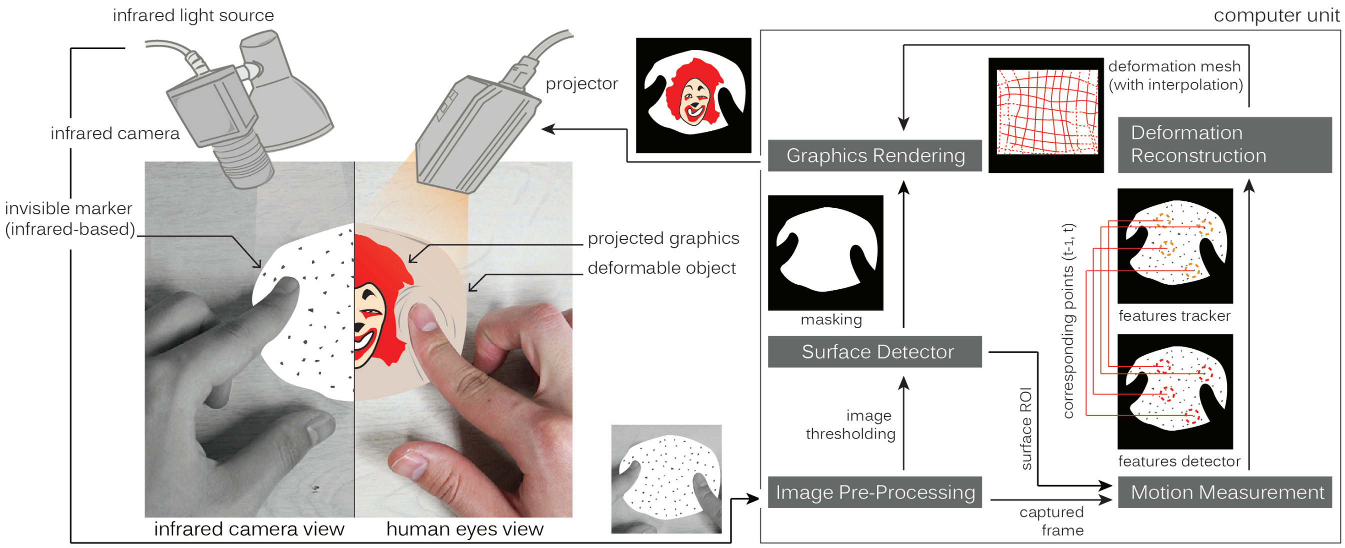

Figure 2: *(left) DeforMe estimates the deformations through captured infrared-based images, and visualizes the deformation result using projection-based, augmented, virtual graphics on the surface. (right) The computational flow of the system which matches the corresponding points in successive frames and estimates the deformations for each state.*

3 The System

DeforMe can work in real time with simple hardware, i.e., a projector, an infrared camera, and an infrared light source. It can use various deformable objects as long as the infrared-based artificial textures are painted or embedded in advance. The user can interact with the object by direct touching, pinching, pulling, and so on, without the need of any special equipment (Fig. 6).

3.1 Deformable Objects

Since projection-based MR provides virtual graphics illuminated on a real surface, the materials should not distract the user experience. Therefore, homogeneous and non-textured materials are required. In this case, it is difficult to estimate the surface deformation because the changing appearance cannot be observed directly with a vision-based approach.

To address this problem, we either paint the objects with invisible ink or embed in the objects pieces of fabric manually painted with invisible ink, depending on the different material properties (e.g., glossy or matte). We use an *IR invisible ink* (Fig. 3), which is invisible to the human eye, but displays high absorption in the infrared spectrum (between 793nm and 820nm). Examples of deformable objects, which are painted or embedded are shown in Fig. 4.

3.2 Proposed Method

DeforMe estimates the deformation of a surface as follows. First, the deformable object (i.e., homogeneous, non-textured surface) is set within the projector's illumination range. Next, the shape and surface of the object are captured by an infrared camera and the region of interest (ROI) is set to the detected surface. Then, the system determines the feature points of a captured frame within the ROI and finds the correspondences in the next captured frame. Because we measure the surface motion between two successive frames rather than tracking the whole captured sequence, the occlusion problem due to user interaction does not affect the result of motion measurement.

The set of feature points and its correspondences are used to estimate the deformation of a surface. DeforMe calculates the tangential deformation of a surface on the basis of the moving least squares (MLS) algorithm [Schaefer et al. 2006]. We estimate the deformation by approximating a surface region with a fixed number of quad grids rather than estimating from every location of the surface. Therefore, the method is not limited to the size of the object's surface, and can achieve real-time performance. Finally, we interpolate the deformation estimation result with a projected graphics.

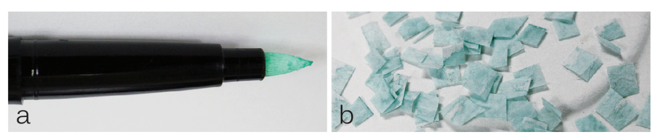

Figure 3: *Invisible ink with high absorption in the infrared wavelength (a), and invisible particles, i.e., invisible ink painted on non-woven fabrics (b).*

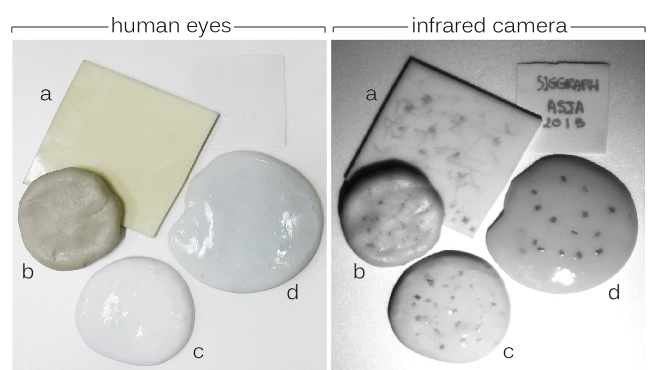

Figure 4: *Deformable objects painted with invisible ink or embedded with invisible ink-painted fabrics: (a) polyurethane gel sheet and (b) elastic clay painted with invisible ink, (c) Slime and (d) commercial silly putty embedded with invisible particles.*

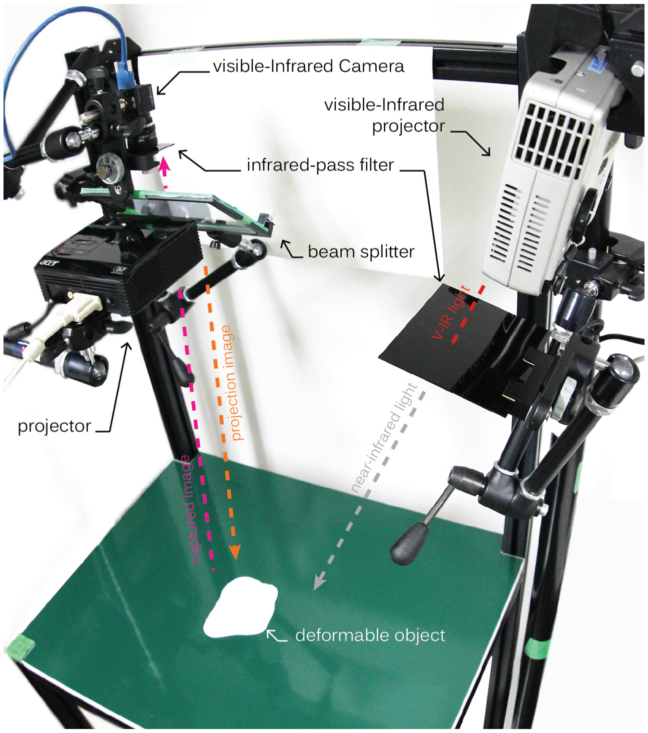

Figure 5: *DeforMe prototype consists of simple hardware: a projector, an infrared camera and an infrared light source.*

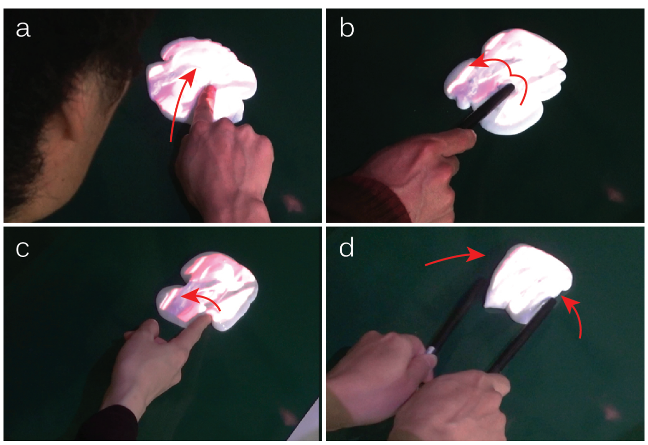

Figure 6: *DeforMe allows for various types of interaction with the deformable surface, such as a) pushing, b) touching, c) pulling, and d) pinching.*

The deformed graphics reveal the deformation as realistically as possible on the target surface dynamically. The proposed method and computational flow are shown in Fig. 2.

4 Implementation

The implementation of the DeforMe prototype is shown in Fig. 5. The projector is placed at 90 deg to the visible-infrared camera with an infrared-pass filter (above 720nm). A beam splitter is placed at 45 deg so that the projector and camera share the optical axis. A visible-infrared projector with an infrared-pass filter (the same as the camera filter) is used as an infrared environment light source. Various deformable objects (non-textured and homogeneous surfaces, see Fig. 4) are used in the preliminary experiments of our prototype system (Fig. 1). Viscoelastic materials (e.g., Slime, Flubber[1]) exhibit the best performance as deformable objects for our system. They exhibit both viscous and elastic characteristics, i.e., they flow like liquids over long periods, but are rigid for short periods. This demonstrates their usefulness for both interactive purposes involving user interaction and with gravitational forces.

5 Summary and Future Work

To the best of our knowledge, there has been no empirical work that addresses the augmentation of deformed graphics according to the tangential deformation of a surface using projection-based MR technologies with a simple technique. DeforMe could successfully be used in a number of interactive applications. For example, it can improve the science-learning experiences of children through their touching the objects and seeing the resultant motion. It can also support a graphical designer in creating deformed graphics with a free-form tangible interface on which the deformation is visualized through projection. Moreover, it has the potential to enhance the advertising of a non-rigid product in a retail store where customers can interact with projected ads on the real product by deforming it.

DeforMe still has some problems, for example, improving the realistic feel of the deformed virtual graphics, and exploring new interaction types, such as twist and rotate. We hope that the current work will trigger further developments in this field, and encourage new applications in other research domains.

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[1] see: *http://en.wikipedia.org/wiki/Flubber_(material)*