# Spatially Augmented Reality on Non-rigid Dynamic Surfaces

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(a) (b)

Figure 1: Our setup, comprising **(a)** a RGB-D camera and a projector positioned towards a dynamic, deformable surface. **(b)** The same pro-cam pair connected to a computer and illuminating a model for surgical training.

## Abstract

We will demonstrate a spatially augmented reality system on non-rigid dynamic surfaces like stretchable fabrics. Using a single projector and RGB-D camera, our system adapts the projection to the changing shape of the non-rigid surface automatically. Such systems have applications in various domains such as art, design, entertainment and medicine. In particular, we we will demonstrate the use of the system as a surgical guidance system for cleft palate surgery using a Simulare cleft model.

**Index Terms:** Computing Methodologies—Artificial Intelligence—Computer Vision—Image and Video Acquisition

## 1 Introduction

Spatially Augmented Reality (SAR) systems augment physical objects with digital content which users can explore without any hand-held or wearable devices (e.g. HMDs or tablets). Such a system is built by a projector illuminating the non-rigid dynamic surface with realtime feedback from a camera. SAR on non-rigid dynamic surfaces is challenging due to the need for high-speed 3D shape reconstruction of the surface and low-latency adaptive projection. Therefore, most prior works use custom hardware (e.g. high-speed, coaxial projector camera systems) [4, 10, 12] or specialized invisible markers to achieve SAR [5, 6] on dynamic non-rigid systems. Such systems either rely on coaxial projector-camera systems or involve cumbersome manual calibration of the devices.

In recent years, our lab has developed non-rigid SAR systems that use consumer-grade hardware and do not rely on specialized patterns on the target surface [1, 2]. Using an RGB-D camera (e.g. Kinect) that provides registered high-resolution color and low-resolution depth information, we are able to achieve real-time shape reconstruction and consequent adaptive projection that conforms to the dynamic non-rigid shape – even in the face of strong distortions. Additionally, we have developed a projector and RGBD-camera calibration technique that happens right on the non-rigid surface, removing any manual calibration of the devices. These advances have the potential to enable widespread use of non-rigid dynamic SAR systems.

In order to demonstrate the applications of such easily assembled non-rigid SAR systems, we have explored a medical application of surgical guidance. In close collaboration with two reconstructive surgeons, we demonstrate how our SAR system can be used to provide surgical guidance marks during a cleft palate system. Surgical sites are deformable (e.g. burn tissue, breast tissue, cleft lips and palates) and projecting guidance marks right on the surgical site allows the entire surgical team to view and collaborate together. Such a surgical guidance system can aid in remote guidance, surgical planning and training. We show that by using such a system, we can achieve sub-pixel accuracy, desired in highly sensitive surgeries like the cleft lip repair in 3-6 month old infants. We have also designed methods that allow the guidance marks to be bound to the surgical site even when the surgeon moves the patient. We demonstrate this system on a Simulare model of cleft lip/palate.

## 2 System Design

We propose to bring a SAR system consisting of a projector, a RGB-D camera, a NUC mini computer to drive the system and a laptop to control it. We will demonstrate the system on stretchable elastic fabrics/materials of different flexibility. We will also show that the system is backward compatible to rigid surfaces like a piece of cardboard. Additionally, we will bring a Simulare cleft lip model to demonstrate the surgical guidance application.

We will first demonstrate quick automated calibration of the projector-camera pair within minutes. Next, we will demonstrate the real-time adaptive projection on different fabrics as we stretch and move them in different manners. Users can also move and stretch these surfaces themselves for a more hands-on experience. Finally, we will show examples of surgical assistance where we will be making incision marks on the digital model on the laptop screen and it will show up on the cleft model automatically. We will demonstrate that the marks will quickly bind to the cleft model accurately even in the presence of movement. Figure-1 shows our setup. Figure-2 shows some results of our system. The submitted video also shows our demo in action and can be viewed at the

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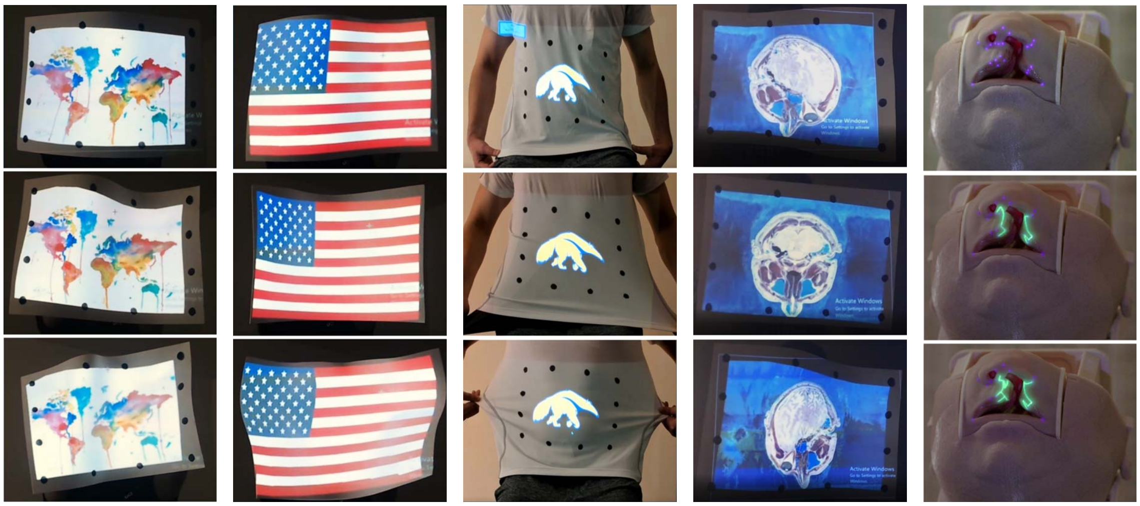

(a) (b) (c) (d) (e)

Figure 2: Our demo showing the capabilities of non-rigid SAR: **(a)** on a marker-based deformable fabric, **(b)** a marker-less deformable fabric, and various applications in, **(c)** t-shirt design, **(d)** non-planar cross-section of CT-scans, and **(e)** surgical training for cleft lip repair

following URL: `https://youtu.be/k9nnV5OcbmY` [3].

## 3 Research Lab

iGravi (Interactive Graphics and Visualization) Laboratory) in University of California-Irvine, led by Prof. Aditi Majumder and Prof. M. Gopi, has spearheaded research in projection- based displays, in particular in camera-based registration of geometry and color for multi-projector displays. From 2006 till present, iGravi has advanced the frontiers of VR display design and deployment in multiple ways. We have developed inexpensive VR environments with commodity products and sophisticated and robust registration algorithms, especially for immersive non-planar display shapes including vertically extruded surfaces (e.g. cylinder), swept surfaces (e.g. truncated domes) and spherical surfaces (e.g. domes) [8,9]. We have also developed the first complete color registration method that works better than any method available in the commercial marketplace today [7]. Next, we developed methods which allow completely uncalibrated devices in a multi-projector system on complex shapes and designed techniques that use cross-validations and cross-references to achieve accurate and consistent geometric registration [11]. This has led to a large body of literature in multiple communities, in particular in the VGTC via multiple best paper awards. Recently, we have started looking into non-rigid surfaces and intend to expand capabilities to multiple projectors on such surfaces in near future.

iGravi is also known for their work on computational camera and displays, computational geometry, appearance editing interactive rendering, non-photorealistic rendering and collaborative work with domains of neuroscience, medicine and ophthalmology. iGravi from UCI is a known name in many different venues including IEEE Visweek, IEEE VR, ACM Siggraph, ACM VRST, IEEE CVPR, IEEE Procams, EuroVis, Eurographics, and Interactive 3D Graphics. We have collaborators in many places including MIT, Purdue, and Disney. For the sake of brevity, we have only provided a few select references most pertinent to this demo. More information is available at http://www.ics.uci.edu/ majumder/pub.html.

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