# Optical Touch Sensing on Non-Parametric Rear-Projection Surfaces

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**ABSTRACT**

The field of augmented reality (AR) has introduced many novel input and output approaches for human-computer interaction. As touching physical objects with the fingers or hands is both natural and intuitive, touch-based graphical interfaces are ubiquitous, but many such interfaces are limited to flat screens or simple objects. We propose an optical method for multi-touch detection and response on non-parametric surfaces with dynamic rear-projected imagery, which we demonstrate on two head-shaped surfaces. We are interested in exploring the advantages of this approach over two-dimensional touch input displays, particularly in healthcare training scenarios.

**Index Terms:** H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Animations, Artificial, Augmented, and Virtual Realities; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; I.3.8 [Computer Graphics]: Applications

## 1 INTRODUCTION

User interfaces based on touch provide natural, intuitive mechanisms for a variety of human-computer interactions, such as in smartphones, computers, kiosks, and video games. Generally, such interfaces have two tasks: *detecting* touches and *responding* to them via an integrated graphical display. Unlike traditional input devices such as a computer mouse, touch interfaces can support multi-touch interactions. Users are able to perform certain touch tasks with higher throughput and less movement time than with a mouse [7].

While smartphones allow for touch input with dynamic imagery, they are typically restricted to flat graphical displays, which may make interaction with 3D content difficult and which lack a sense of real physical presence that may be useful in training scenarios. In spatial augmented reality (SAR), devices such as projectors display graphical content onto physical objects in the user's environment. Current optical SAR touch interfaces are also generally limited to 2D tabletops or simple parametric objects. Capacitive sensors can be used for touch sensing on more geometrically complex objects, but this prevents augmenting them with dynamic projected imagery.

Our work focuses on developing an optical touch sensing technique that is *generalizable to non-parametric surfaces with rear-projected imagery*, making it broadly applicable to SAR touch tasks. We plan to investigate *scenarios for which non-parametric touch surfaces are preferable to flat ones* in terms of performance metrics (e.g. cognitive load and task completion). Unlike some current AR touch interfaces, our proposed method *does not require instrumenting the surface or user*, leading to more natural interactions. Furthermore, we are particularly interested in *exploring the advantages of this method for healthcare training* by creating touch-sensitive patient simulators with the physical shape and presence of a mannequin, the dynamic visual capabilities of a virtual patient, and the ability to respond naturally to touch. Ultimately,

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2018 IEEE Conference on Virtual Reality and 3D User Interfaces
18-22 March, Reutlingen, Germany
978-1-5386-3365-6/18/$31.00 ©2018 IEEE

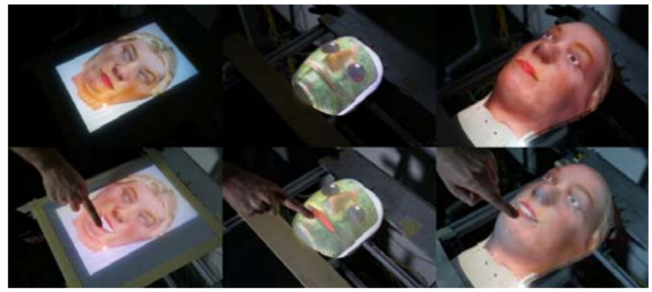

Figure 1: Touch sensing on one flat and two head-shaped rear-projection surfaces. Detected touches prompt graphical responses.

we intend for our simulators to serve as a complement to existing training interfaces.

## 2 PROGRESS

### 2.1 Touch Sensing

We developed a touch sensing method that we have applied to one flat and two non-parametric head-shaped surfaces with virtual face imagery (Figure 1). Inspired by approaches for planar surfaces [6, 9] and parametric objects such as spheres [1], we use calibrated cameras, a calibrated projector, and rear-diffused infrared (IR) illumination. IR light is reflected by fingers touching the surface and captured by cameras; detected touches are linked to their corresponding positions in projector space and on the object to prompt appropriate responses. As a finger comes closer and closer to the surface, the camera imagery converges in projector space (Figure 2). Briefly, our approach (Figure 3) consists of a preprocessing phase in which correspondences between camera pixels, projector pixels, and 3D coordinates on the surface are found and stored in a unified correspondences lookup table and a runtime phase in which touches are detected and used to initiate simulator responses, such as raising and lowering the eyes and lips of a virtual model [4, 5].

### 2.2 Cognitive Load

We investigated the effect of the physical display surface on user performance. In a user study involving touch tasks on a virtual

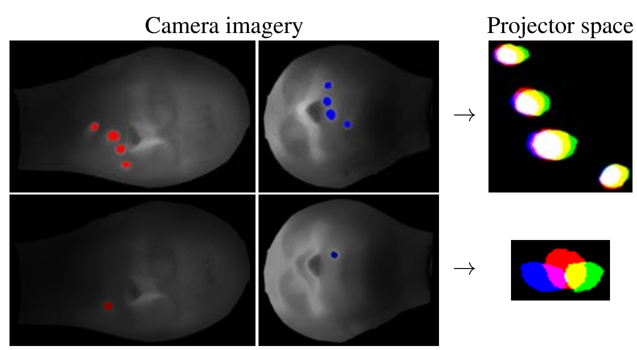


Figure 2: Combining camera imagery of touches (first row) and hovers (second row) into projector space. Only two cameras are shown for space purposes. Camera contributions show much greater projector space overlap for touches than for hovers.

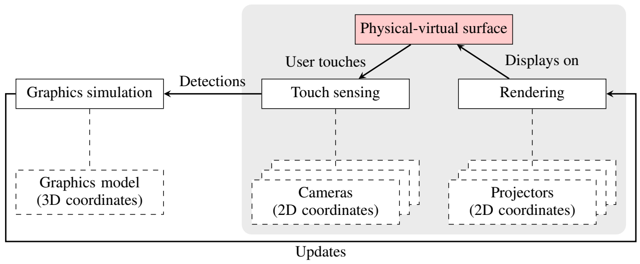


Figure 3: Overview of touch sensing method. Touches on the surface are imaged by cameras and converted to 3D graphics model coordinates to trigger appropriate updates.

head model, we observed trends indicating decreased cognitive load for interactions on a matching head-shaped surface as compared to a flat one [3]. Users overwhelmingly preferred the head-shaped surface and subjectively found it easier to touch targets on it.

### 2.3 Healthcare Training

A healthcare provider who suspects a patient is experiencing a stroke will perform neurological and psychomotor assessments that include examining visual cues (e.g. smile asymmetry, facial droop) and touch response (e.g. localized numbness). Typical training relies on task trainers and human actors, which are often unable to realistically simulate these specific symptoms. With a head-shaped surface, we created a physical-virtual patient capable of exhibiting many of the visual, auditory, and touch-related symptoms of a stroke (Figure 4), which could afford more natural, engaging training experiences [8, 2]. We ran a preliminary user study in which nursing students interacted with the head in a stroke assessment scenario. Participants appreciated the physicality and the realism of the head, particularly regarding the synchrony between verbal and non-verbal cues and the ability to directly interact via touch, both of which can be difficult or impossible to simulate with a conventional mannequin.

## 3 Recent Results

We evaluated one of our touch-sensitive head surfaces using localization and camera agreement metrics (Table 1). For *projector target localization*, we sequentially projected visual targets onto the head, localized them in the camera imagery, and combined them into projector space. Additionally, we instructed a user to touch each target carefully and precisely to compute *touch target localization* errors. We define *n-camera agreement* to be the number of pixels in projector space at least *n* cameras "agree" is a target divided by the total number of pixels at least one assigns as a target.

We experimented with two methods for improving these metrics. Observing all camera-projector correspondences (*dense* tables) led to modest improvements over observing a subset (*sparse* tables). We obtained significantly improved results for both metrics

Table 1: Localization error and 5-camera agreement results for detected projector and touch targets. *Sparse* tables: observed subset of camera-projector correspondences. *Dense* tables: observed all camera-projector correspondences. *Corrected* tables: applied inverse of projector target localization errors to sparse tables.

| **Targets** | **Lookup Tables** | **Local. error mm** | **Local. error Pixels** | **5-Camera agreement** |
|---|---|---|---|---|
| Projector | Sparse | 0.89 | 3.74 | 65.62% |
| | Dense | 0.79 | 3.27 | 68.63% |
| | **Corrected** | **0.12** | **0.63** | **93.40%** |
| Touch | Sparse | 2.71 | 10.71 | 68.39% |
| | Dense | 2.68 | 10.49 | 72.85% |
| | **Corrected** | **2.04** | **8.18** | **88.03%** |

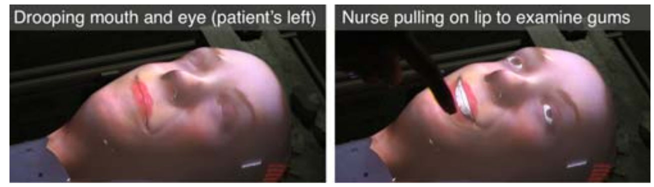


Figure 4: Graphical and touch capabilities of stroke simulation.

by applying the inverse of the projector target localization errors as per-pixel correction vectors to the sparse set of correspondences (*corrected* tables).

## 4 Potential Next Steps

We are currently working on extending this approach to handle multiple projectors, allowing for larger touch-sensitive surfaces. In addition, we plan to investigate optimizing sensor placement as part of the preprocessing pipeline to improve the camera imagery. For instance, given a starting camera configuration, we could develop a cost function that attempts to maximize multi-camera visibility of the surface and amplify the disagreement of hover contours. We are considering machine learning approaches to classifying camera contours as touches or hovers.

Along with finger touches, we will work on detecting gestures or other types of touch, such as palm touches, pinching, spreading, rubbing, and wiping, which may be used for diagnostic or therapeutic purposes in healthcare. We are also interested in recognizing other objects: for instance, stethoscope contact events could trigger appropriate lung and heart sounds in wireless headphones. Similarly, we plan to detect non-contact events, such as shining a flashlight into a virtual patient's eyes to observe pupil dilation.

## References

[1] H. Benko, A. D. Wilson, and R. Balakrishnan. Sphere: multi-touch interactions on a spherical display. In *Proceedings of the 21st annual ACM symposium on User interface software and technology*, pages 77–86. ACM, 2008.

[2] L. Gonzalez, S. Daher, J. Hochreiter, and G. Welch. Student nursing assessment of discrete neurology symptoms using an interactive physical virtual head. *Presentation at International Nursing Association for Clinical Simulation and Learning*, 2016.

[3] J. Hochreiter, S. Daher, G. Bruder, and G. Welch. Cognitive and touch performance effects of mismatched 3D physical and visual perceptions. In *Virtual Reality (VR), 2018 IEEE, to be published*. IEEE, 2018.

[4] J. Hochreiter, S. Daher, A. Nagendran, L. Gonzalez, and G. Welch. Touch sensing on non-parametric rear-projection surfaces: A physical-virtual head for hands-on healthcare training. In *Virtual Reality (VR), 2015 IEEE*, pages 69–74. IEEE, 2015.

[5] J. Hochreiter, S. Daher, A. Nagendran, L. Gonzalez, and G. Welch. Optical touch sensing on nonparametric rear-projection surfaces for interactive physical-virtual experiences. *PRESENCE: Teleoperators and Virtual Environments*, 25(1):33–46, 2016.

[6] N. Matsushita and J. Rekimoto. HoloWall: designing a finger, hand, body, and object sensitive wall. In *Proceedings of the 10th annual ACM symposium on User interface software and technology*, pages 209–210. ACM, 1997.

[7] F. Sasangohar, I. S. MacKenzie, and S. D. Scott. Evaluation of mouse and touch input for a tabletop display using Fitts' reciprocal tapping task. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 53, pages 839–843. SAGE Publications Sage CA: Los Angeles, CA, 2009.

[8] G. Welch, S. Daher, J. Hochreiter, and L. Gonzalez. Poster: Interactive rear-projection physical-virtual patient simulators. In *22nd Medicine Meets Virtual Reality (NextMed / MMVR)*, Los Angeles, CA, USA, 2016.

[9] A. D. Wilson. TouchLight: an imaging touch screen and display for gesture-based interaction. In *Proceedings of the 6th international conference on Multimodal interfaces*, pages 69–76. ACM, 2004.