EE 367 Project Proposal
Dermal - A Human-Centric Dynamic Projection Mapping Library

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1 Background and Motivation

Nasiolabial cleft lip repair surgery is a critical procedure for restoring oral functionality and aesthetics in those affected. The operation is initiated by the annotation of the nose and lip area with anthropometric landmarks, which play an important role in guiding the surgeon throughout the procedure. The process of identifying and labeling these landmarks is laborious for the surgeon and difficult to teach to medical students, thus we have dedicated previous work in developing a deep-learning based approach for the prediction of these points on patient faces. We have also designed a hardware platform that consists of a camera, an edge computing device, and a projector. The deep learning model in conjunction with the hardware platform allows us to capture RGB images of a patient's face, predict their anthropometric landmarks, and project the points directly onto the surgery site. A surgeon would then use the projected markings to guide their own annotations, significantly speeding up the pre-operative process. We believe this is a novel application of spatially augmented reality (SAR).

However, our initial testing on 2D printed images of faces masked the errors encountered when projecting on 3D physical faces (such as a mannequin head). To achieve the spatial accuracy needed in surgical applications, our system must be able to account for the 3D structure of the human face. Furthermore, our system must be able to account for the natural movement of the target during the course of a surgery at sufficiently low latencies.

To solve these issues, we propose Dermal, a projection mapping software library which accounts for the 3D anatomy of human faces and adjusts for changes in position and pose in real time.

2 Proposed Approach

Dermal is a Python library which will abstract away the details of accurate and dynamic projection mapping onto human faces. The primary abstraction will be a 2D image canvas of the human face in the scene - anything drawn on the face should be accurately projected to the proper location onto the 3D target.

Specifically, Dermal's features include:

- Automatic Calibration

  Intrinsic and extrinsic parameters of the camera-projector system will be automatically found during initialization of the system. This should only have to occur once for a fixed camera-projector geometry.

- Depth-Aware Projection

  Dermal will use depth information about the scene and target to condition output projected images such that they accurately appear at the proper location.

- Dynamic Projection

  Dermal will track the target surface and move the projected image as needed, with sufficiently low latency to be useful in surgical assistance.

- Human-Centric Abstraction

  Dermal will present the subject's face as the primary abstraction for projection mapping outputs. That is, you should be able to plot / draw on a 2D picture of the target and it should appear at the proper location on the physical 3D object.

We plan on demonstrating the functionality of this library on consumer hardware (laptop, projector, webcam), however access to a depth camera (Intel Realsense) would improve the quality of our depth-maps significantly.

We have a project in parallel in CS 231A which addresses obtaining depth-maps of faces; there is not significant overlap in the technical efforts between these course projects outside of the shared camera-projection hardware platform.

Our final demo will involve using Dermal in an application that allows the user to draw on a 2D image of a face in the scene, and that image appearing accurately on the physical object. Such an application would be a prototype of a surgical assistance tool that would allow physical instruction and guidance during a procedure from a remote location.

3 Related Work

A survey done by Grundhöfer and Iwai [2] serves as a strong overview of current state-of-the-art in general projection mapping techniques. We also take a large amount of inspiration from the Watanabe Lab's work in this space. In particular, we see their work on Dynamic Facial Projection Mapping [1] and recent work on accounting for skin deformation [3] as ideal in terms of latency and accuracy. However, their results will be hard to replicate in the scope of this class due to their use of a custom high speed projector, custom imaging ASIC, and undisclosed algorithms. A paper released from L'Oreal's research group [1] demonstrates and cites economical methods with consumer hardware to achieve facial projection mapping for use in simulated make-up application. We plan on using similar techniques for Dermal.

4 Timeline and Milestones

We have three major deliverables. First, we want to deliver a full calibration, depth estimation, and projection mapping pipeline for static scenes by the end of Week 8. This end-to-end pipeline will then be the basis for optimization for use in dynamic scenes during Week 9. We want to demonstrate accurate tracking as the face moves about in the scene. In Week 10, the user-facing application to allow for "face painting" will be implemented to deliver an interactive demo.

References

[1] P.-A. Bokaris, B. Askenazi, and M. Haddad, "Light me up: An augmented-reality projection system," in *SIGGRAPH Asia 2019 XR*, ser. SA '19. New York, NY, USA: Association for Computing Machinery, 2019, p. 21–22. [Online]. Available: https://doi-org.stanford.idm.oclc.org/10.1145/3355355.3361885

[2] A. Grundhöfer and D. Iwai, "Recent advances in projection mapping algorithms, hardware and applications," *Computer Graphics Forum*, vol. 37, no. 2, pp. 653–675, 2018. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/cgf.13387

[3] H.-L. Peng and Y. Watanabe, *High-Speed Human Arm Projection Mapping with Skin Deformation*. New York, NY, USA: Association for Computing Machinery, 2020. [Online]. Available: https://doi-org.stanford.idm.oclc.org/10.1145/3415255.3422887

[1] http://www.vision.ict.e.titech.ac.jp/projects/faceDPM/