Mapping the Human Eye with Sclervey: a New Device to Survey the Sclera

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Introduction

Many people suffer from complex corneal diseases that cause severely impaired vision or even blindness. Extreme dryness of the eyes can lead to these problems as well. The vision of these patients cannot be corrected with ordinary glasses or contact lenses, as the shape of the cornea is no longer a smooth surface. The Boston Foundation for Sight (BFS) has successfully developed a method to restore vision to such patients. PROSE (Prosthetic Replacement of the Ocular Surface) requires custom fitted lenses that form a seal on the sclera, allowing a saline solution to be held between the prosthetic lens and the damaged tissue. The surface of this lens creates a new cornea and thus restores vision, but there is a difficulty in the fitting process, as it is done entirely by trial and error in multiple lens-fitting sessions over several days. This causes patient discomfort as well as increasing the time and cost of the process, making PROSE less appealing and accessible to those in need. The purpose of this project is to develop a device which will map the surface of the sclera (we call "Sclervey"), so the sealing contour of the lens can be established prior to the first lens fitting process.

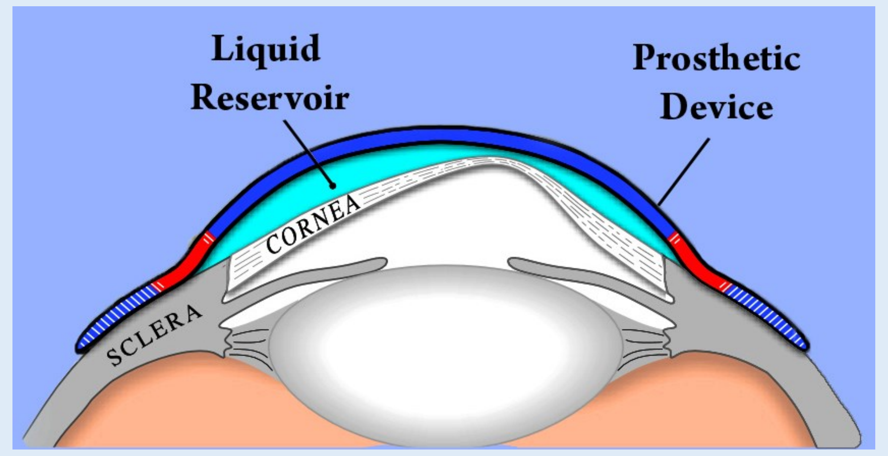


Figure 1: Irregular corneal shape fitted with prosthetic lens. The red represents the ring of scleral surface that needs to be sealed with high precision.

BOSTONSIGHT

Design Constraints

- Survey the shape of the sclera to within 50 µm
- Make no contact with the eye
- Take and stitch multiple images (the entire sclera is not visible at once)
- Be easy to calibrate, maintain, and operate

The Design

Sclervey uses six LED arrays arranged on a spherical cup with the eye at the center, to project a uniform grid of 163 light spots on the surface of the eye, spaced roughly 2 mm apart. Six CCD cameras (plus one in the center) view the dot projection such that each dot is visible to two or more cameras, and stereo-geometry reduces two images into a 3D surface. In order to visualize the complete sclera, images must be taken while the patient looks in four different directions: straight ahead, right, up-left, and down-left, aided by an alignment light that shows the patient where to look. Image stitching software is then used to combine the four partial 3D images into a 3D model of the entire sclera. Stereo vision thus offers a clean way to satisfy two design constraints at once: it is a functional and accurate way of determining the 3D shape of a convex object, and it makes it easy to stitch the four images together into one 3D model.

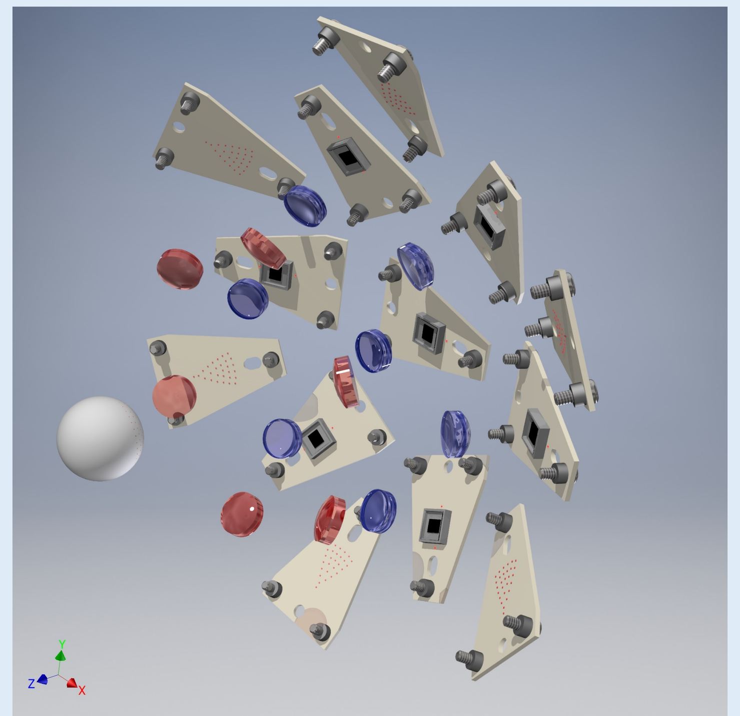


Figure 2: Device with block hidden. The LED arrays are focused through the red-tinted lenses to project a grid of dots on the eye. Each dot is imaged my multiple CCD cameras (behind the blue-tinted lenses), giving the point a position in 3D space.

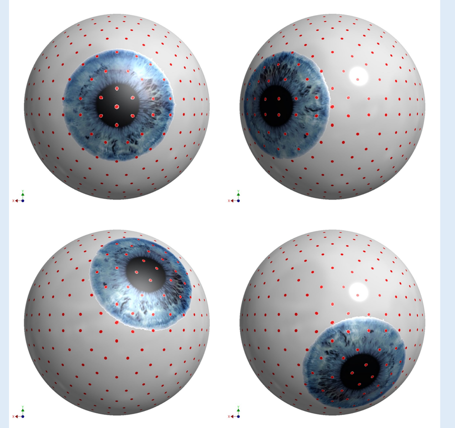
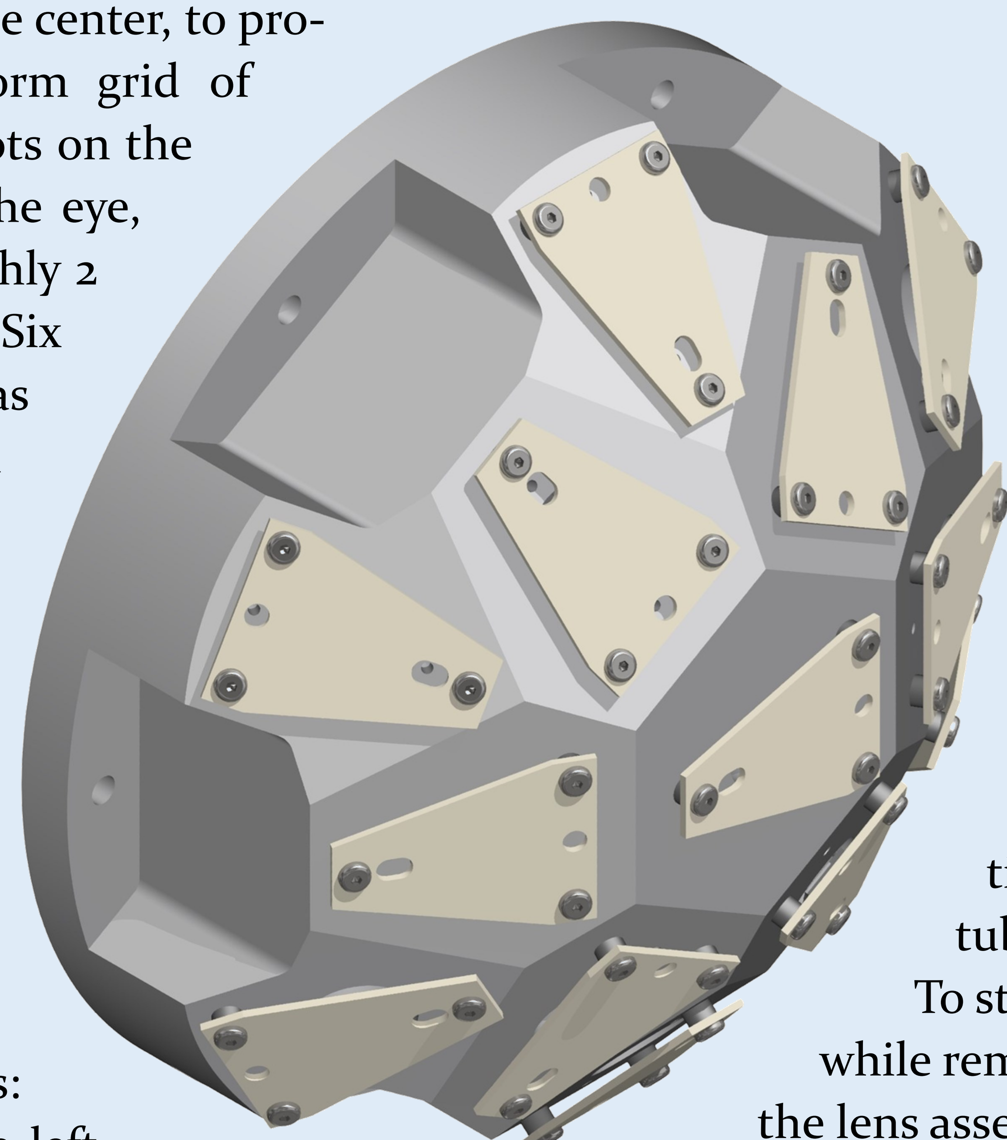


Figure 3. The four eye positions for imaging in Sclervey. The four corresponding images are later stitched together.



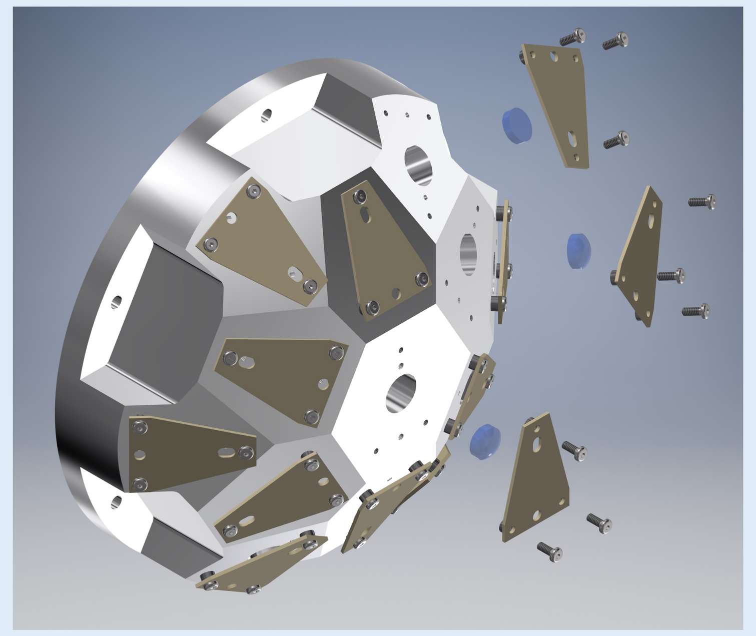


Figure 4. Partially exploded view of the device. Lenses are glued directly into the block. The LED and CCD PBCs are positioned and then bolted into the block.

Figure 5. Printed Circuit Board (PCB) design for CCDs and LED arrays used in Sclervey (only the CCD and LEDs are shown). The larger hole and slot are used for positioning. The smaller three holes are mounting holes. The single LED next to the CCD is used to direct the patient's gaze.

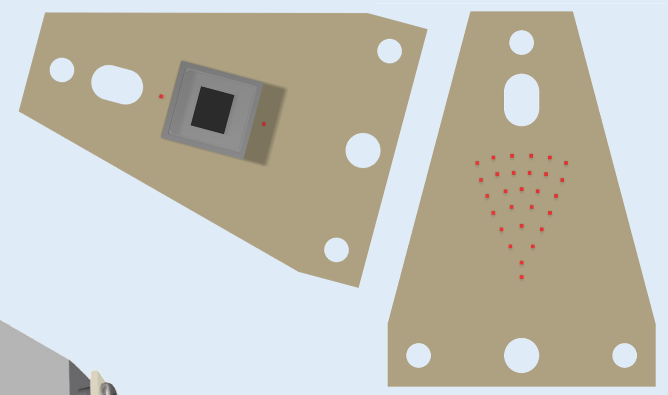
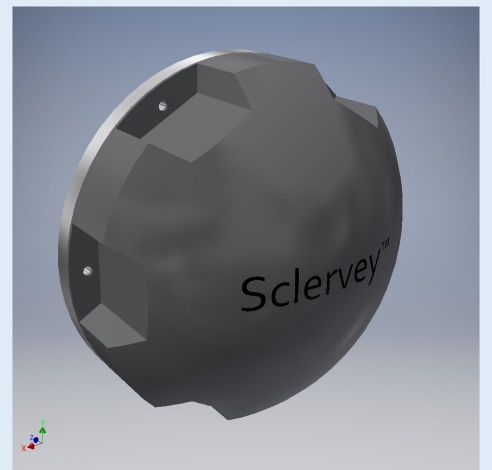


Figure 6. The device is shown with its protective cover, which bolts over the block to cover the PCBs.



The thirteen PCB boards containing the cameras and LED arrays along with their thirteen corresponding lenses are held in place by an aluminum block, which mounts the PCBs to its back surface. The lenses are mounted in cylindrical assemblies which are inserted into tightly-fitting tubes in the block. To stay firmly in place while remining adjustable, the lens assemblies are lined with a compressible rubber surface.

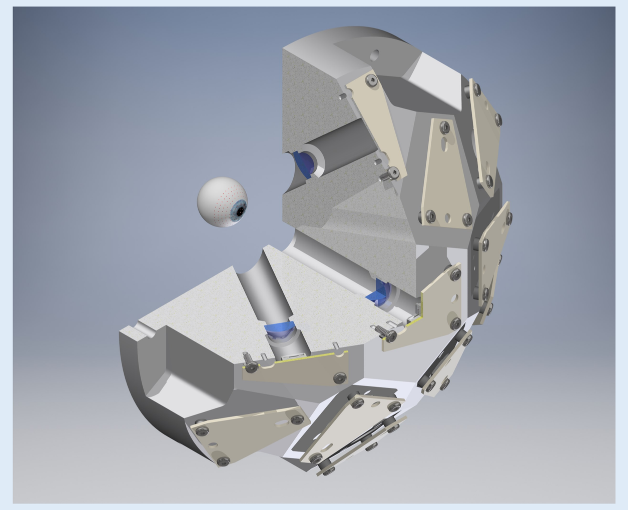


Figure 7. 3/4-section view of device with eye in position #1.The channels that maintain line-of-sight between the eye and the LEDs and CCDs are clearly visible.

SPARK-funded developments

- Custom-made array to test stereo imaging over non-rectangular surface
- New high-quality color image sensors for image stitching tests
- Image stitching algorithm research in the works (Initial contributions by Karishma Reddy Khan, CS PhD Candidate)
- We have successfully filed a provisional patent for this device

Future Goals

- Reproduce stereo imaging results with custom-made array

Proof of Concept

For proof of concept of the device, a simplified version of the product was used, featuring one LED array and two cameras. The LED array projected a square dot pattern onto a hemisphere, while cameras, 30° to each side of the LED array, viewed the dot projection from 120 mm, using the stereo vision software to locate the position of each point in 3D space. The precision of these measurements was compared to the known values of a sphere to measure the deviation.

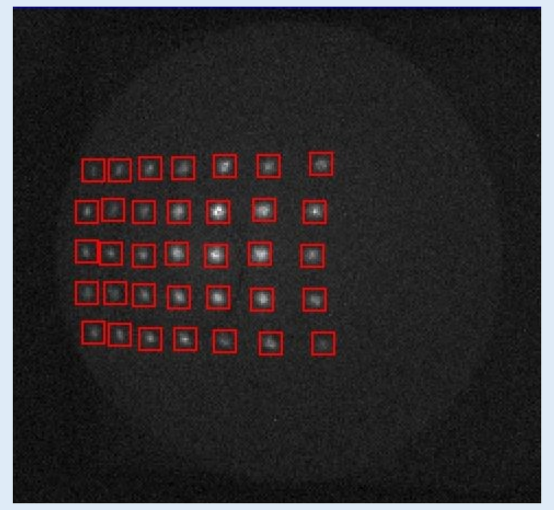


Figure 8: Projected 5X7 LED array image in Kevan Hashemi's Long Wire Data Acquisition software (LWDAQ). By seeing the same spot from two cameras, we can find its 3D position through stereo imaging.

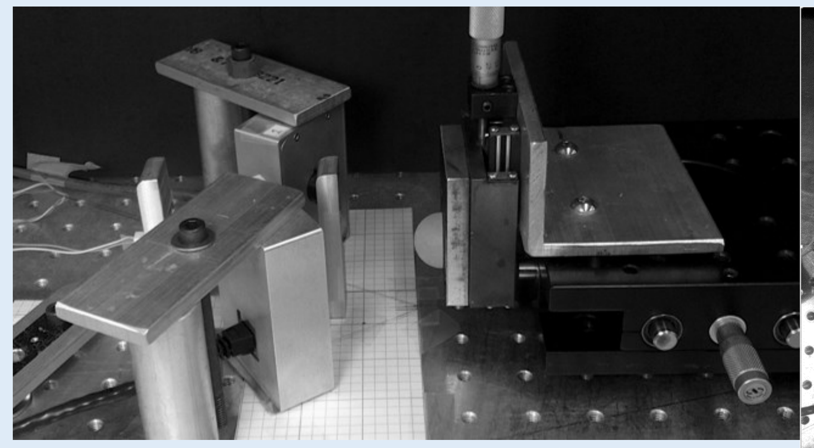


Figure 9a. Setup of Proof of Concept experiment, with 2 cameras and one square LED projection onto a hemisphere.

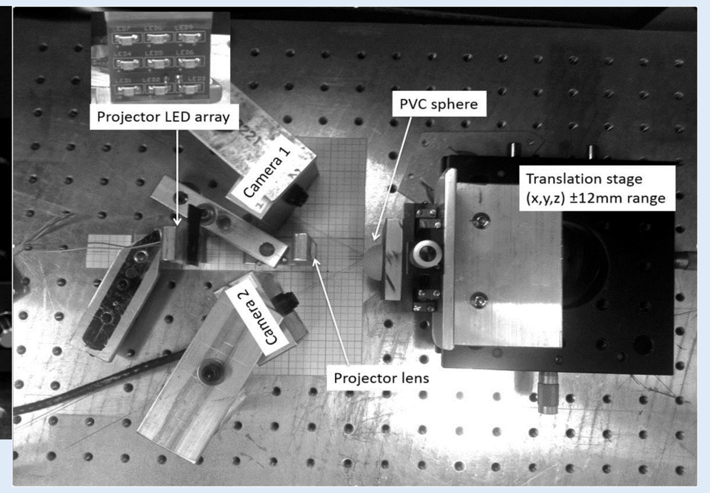


Figure 9b. Aerial view

Results

A simple two camera setup with a single LED array projected on a spherical object was able to correctly model the surface of the sphere, determining the position of each point on the surface with a standard deviation of 17 microns, vastly exceeding the 50-micron tolerance required by the prosthetic lens.

With every point captured by at least three cameras (as opposed to only two in the proof of concept experiment), and with many swathes of sclera visible from multiple eye directions, the full device can only improve on these numbers.

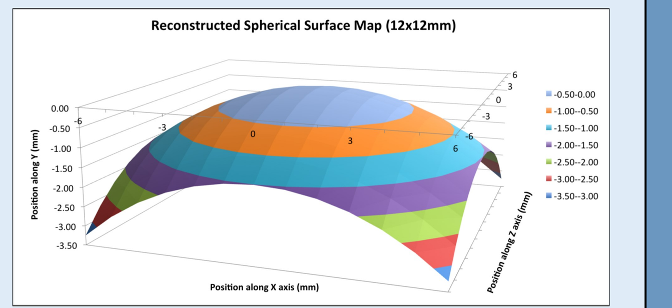


Figure 10a. Reconstructed spherical surface using a 12x12 grid of data. (Projecting one light spot, moving the sphere to position the light spot at appropriate intervals)

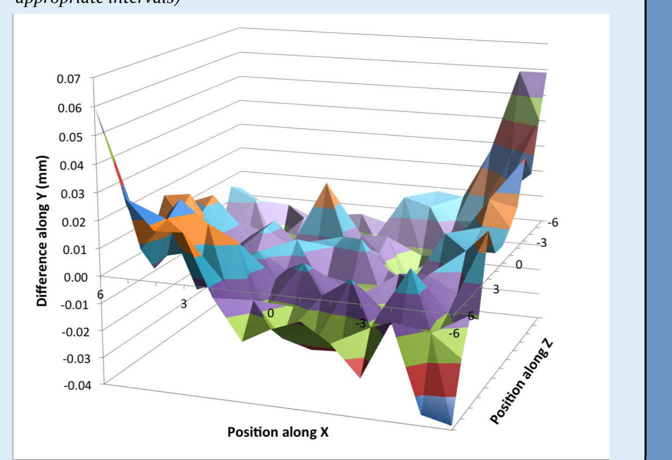


Figure 10b. Difference plot showing deviation of Fig. 5 data from the shape of the actual sphere. Standard deviation is 17 microns, which satisfies the 50 micron requirement.