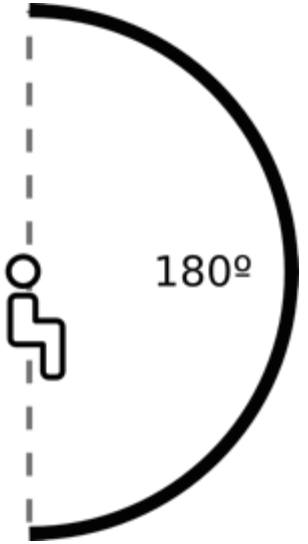
IEEE Consumer Electronics Society

Calibrating a VR Camera

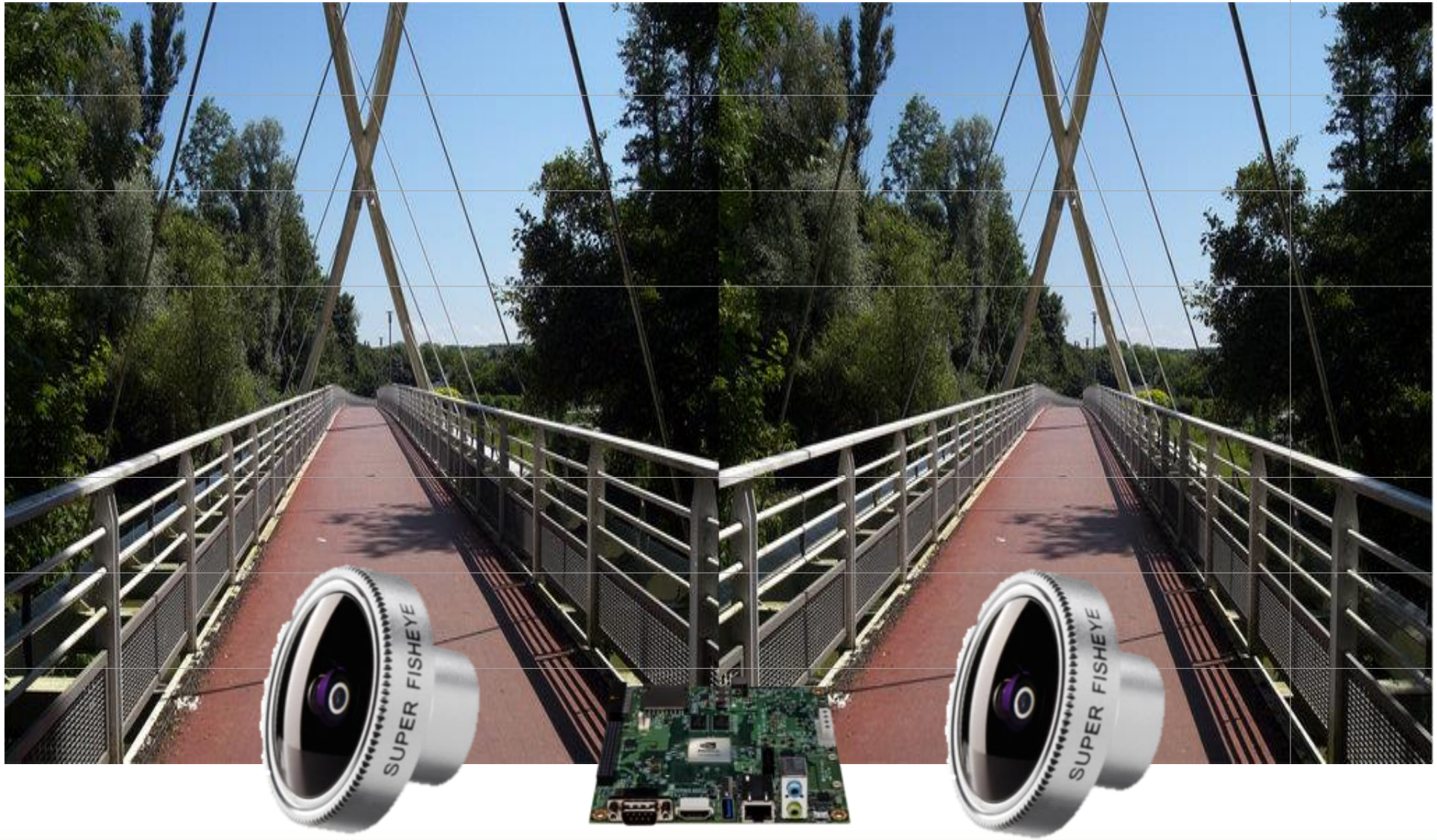
Adam Rowell
CTO, Lucid VR
adam@lucidcam.com

Virtual Reality Cameras



Lucid VR Camera

How Does it Work?



Lucid Software Technology

Recording:

- Synchronization
- Color correction
- Stabilization
- Video encoding
- Streaming

Playback:

- Optimize stabilization
- Color enhancement
- De-warping / rendering
- Add overlays

Post-Processing:

- Video stitching
- Stereo calibration
- Color calibration
- Video editing

How do we transform raw camera frames into great VR video?

STEREOSCOPIC CAMERA CALIBRATION

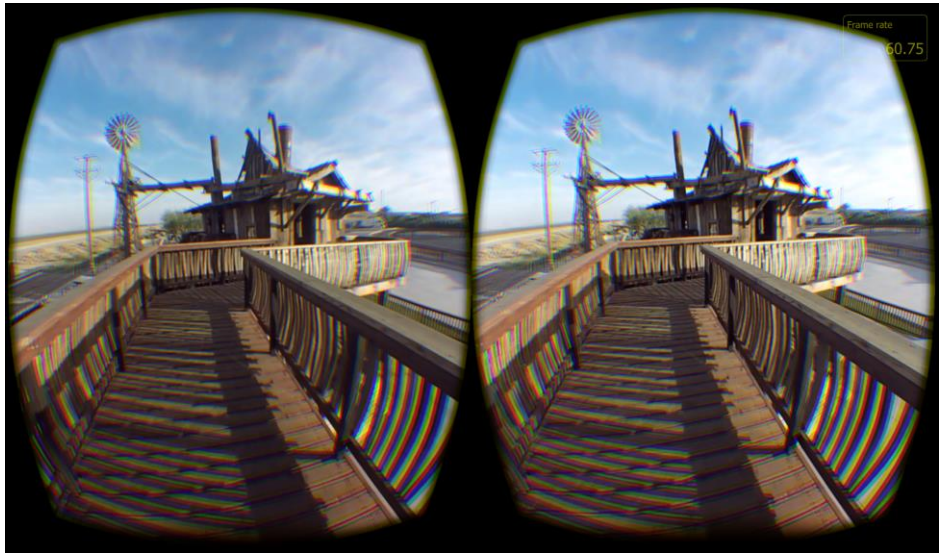
Stereoscopic Recording & Playback

4K image

4K image

4K x2

(math)



Oculus: 1080x1200 per eye
(2160x1200 total)

Straight Lines Have to be Straight

Calibration fixes the “warping” introduced by the camera lenses

Uncalibrated Video Frame

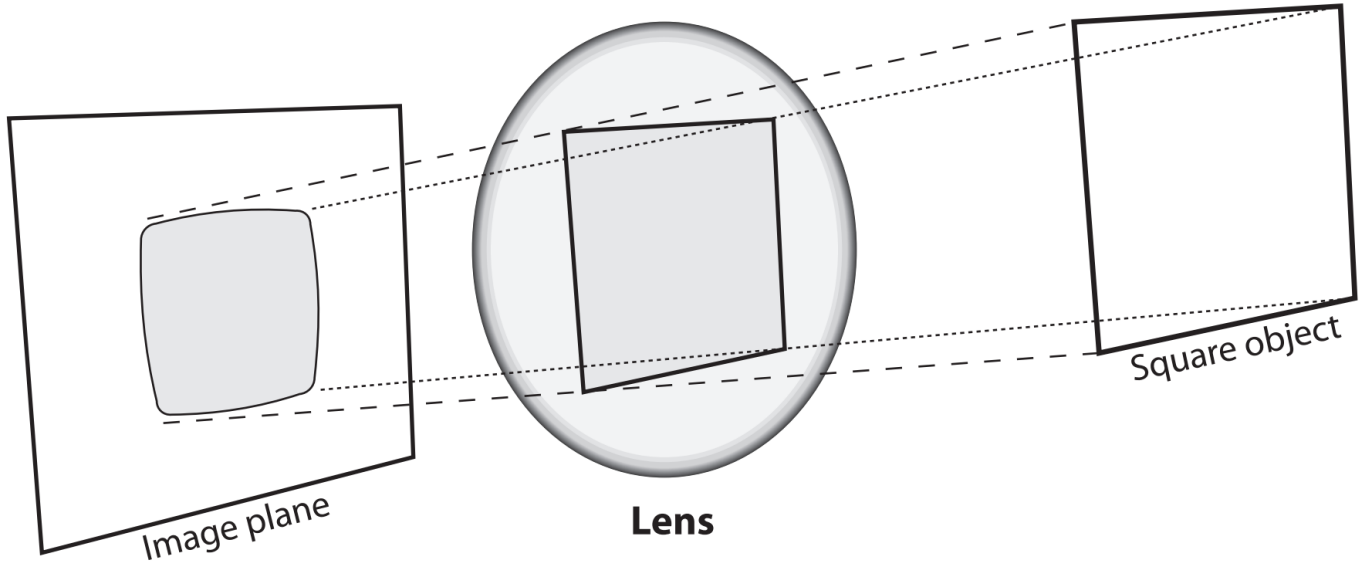
Calibrated Frame

Fisheye Lenses

The Lucid Camera has two **fisheye lenses**

Fisheye lenses introduce two main forms of distortion:
Radial and **Tangential**

Radial Lens Distortion



Radial distortion makes straight lines appear **curved**

All lenses have radial distortion – fisheye lenses have extreme radial distortion, especially at the edges

Image Credit: Bradski and Kaehler, *Learning OpenCV*

Radial Lens Distortion

The normally straight trees appear to curve around the center of the image

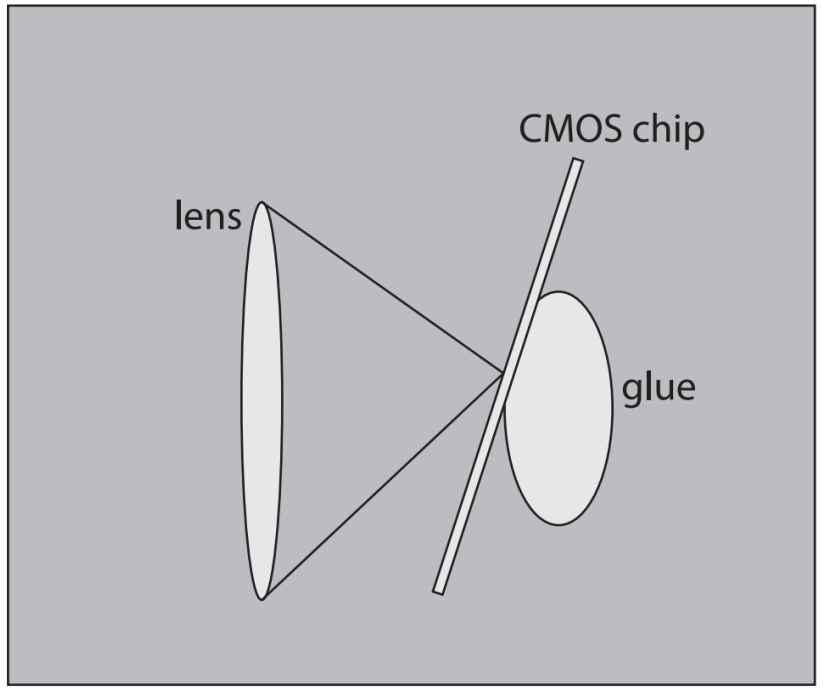
Image is compressed as a function of radius

Calibration will measure the center and strength of the curvature

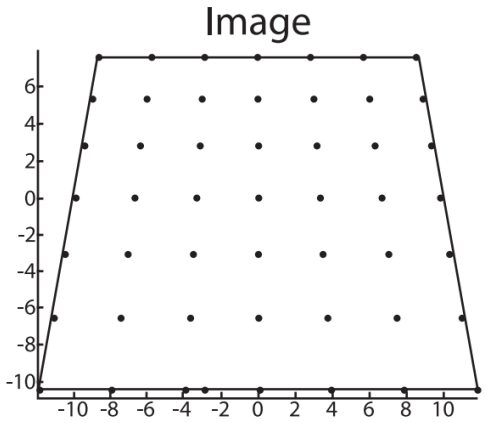
180° fisheye lens capture

Tangential Distortion

Tangential distortion is caused by tiny differences in angle due to lens mounting. Calibration measures this skewness



Extreme Example



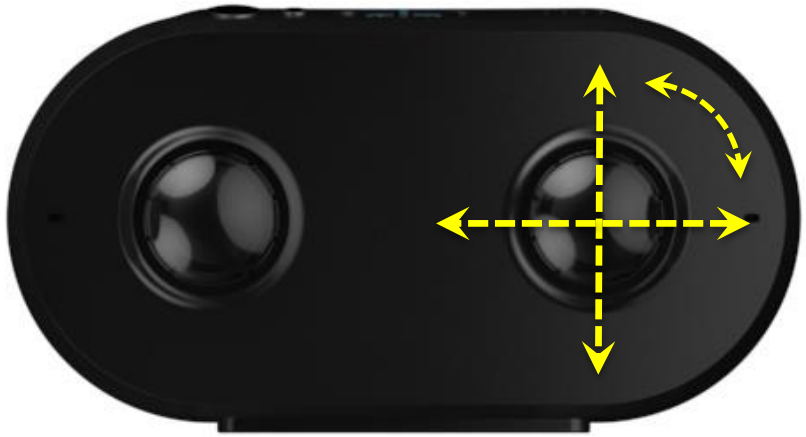
Each camera's calibration parameters may be unique

Image Credit: Bradski and Kaehler, *Learning OpenCV*

Stereoscopic Calibration

We also need to align the left and right images to each other

This will correct for any differences in **horizontal, vertical, or rotational disparity** between the two image sensors



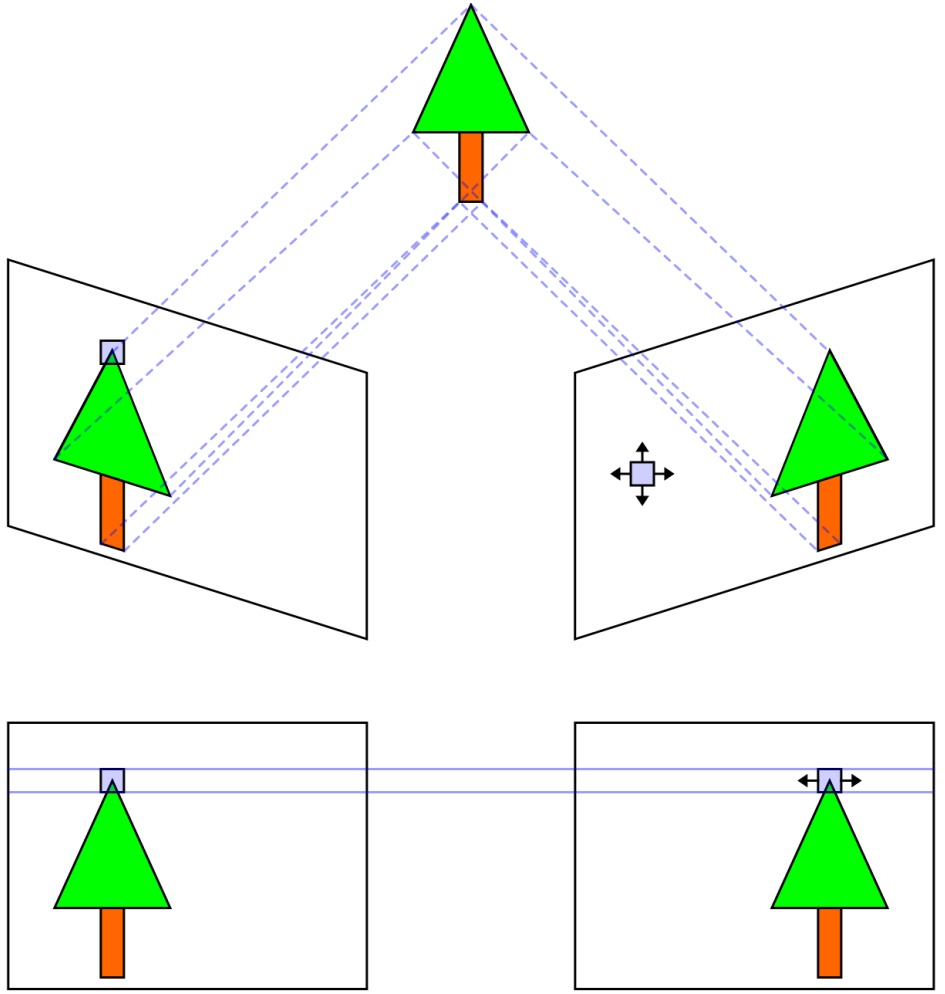


Image Credit: Bart van Andel (CC BY-SA 3.0)

Applying the Calibration

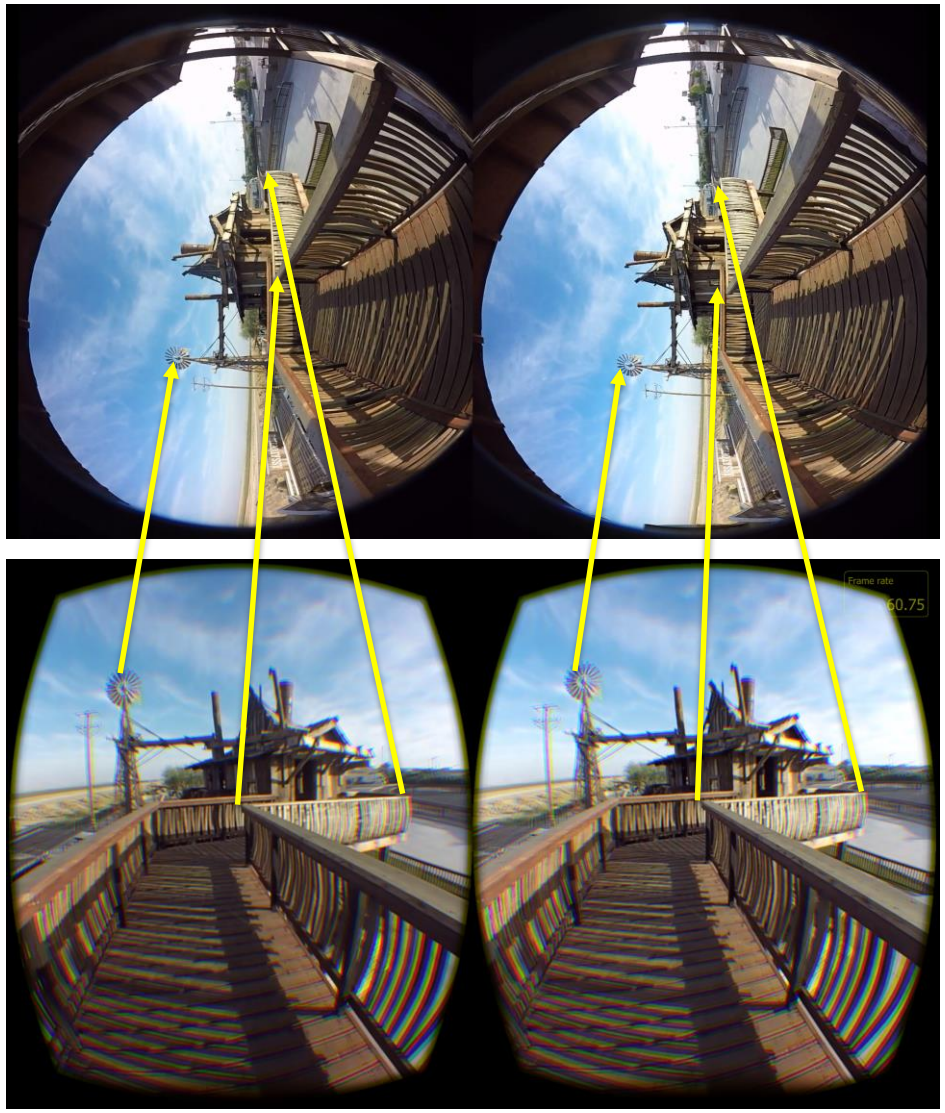
We can apply the calibration in real-time at playback:

1. **Measure VR headset orientation**

2. **For each pixel in the VR headset, determine its latitude/longitude**

3. **Map each VR headset pixel to a point in the raw video frame**
   - Calibration gives us enough information to do this accurately
   - Use radial, tangential, and stereo calibration parameters

This whole process can run on the **GPU** to be really fast



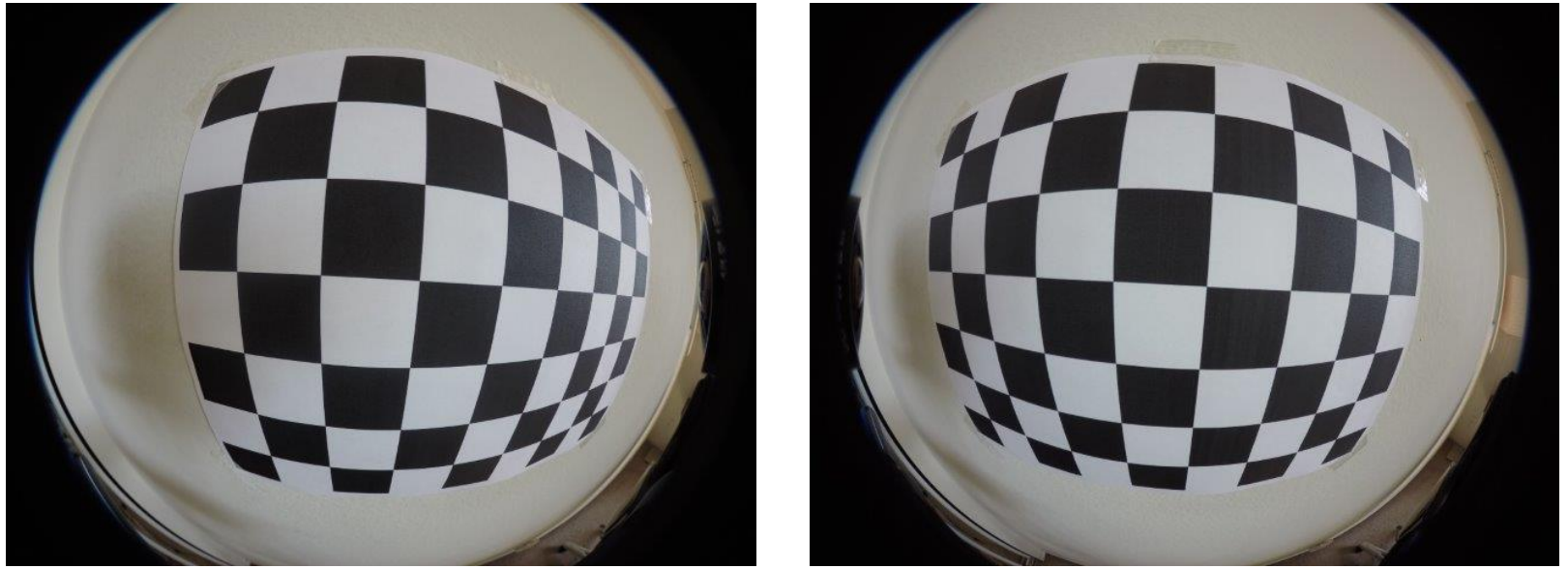
How do we obtain all of the calibration parameters?

CALIBRATION PROCESS

Performing a Calibration

To calibrate, we need to capture a **set of test images**

These test images are used to **compute calibration parameters**

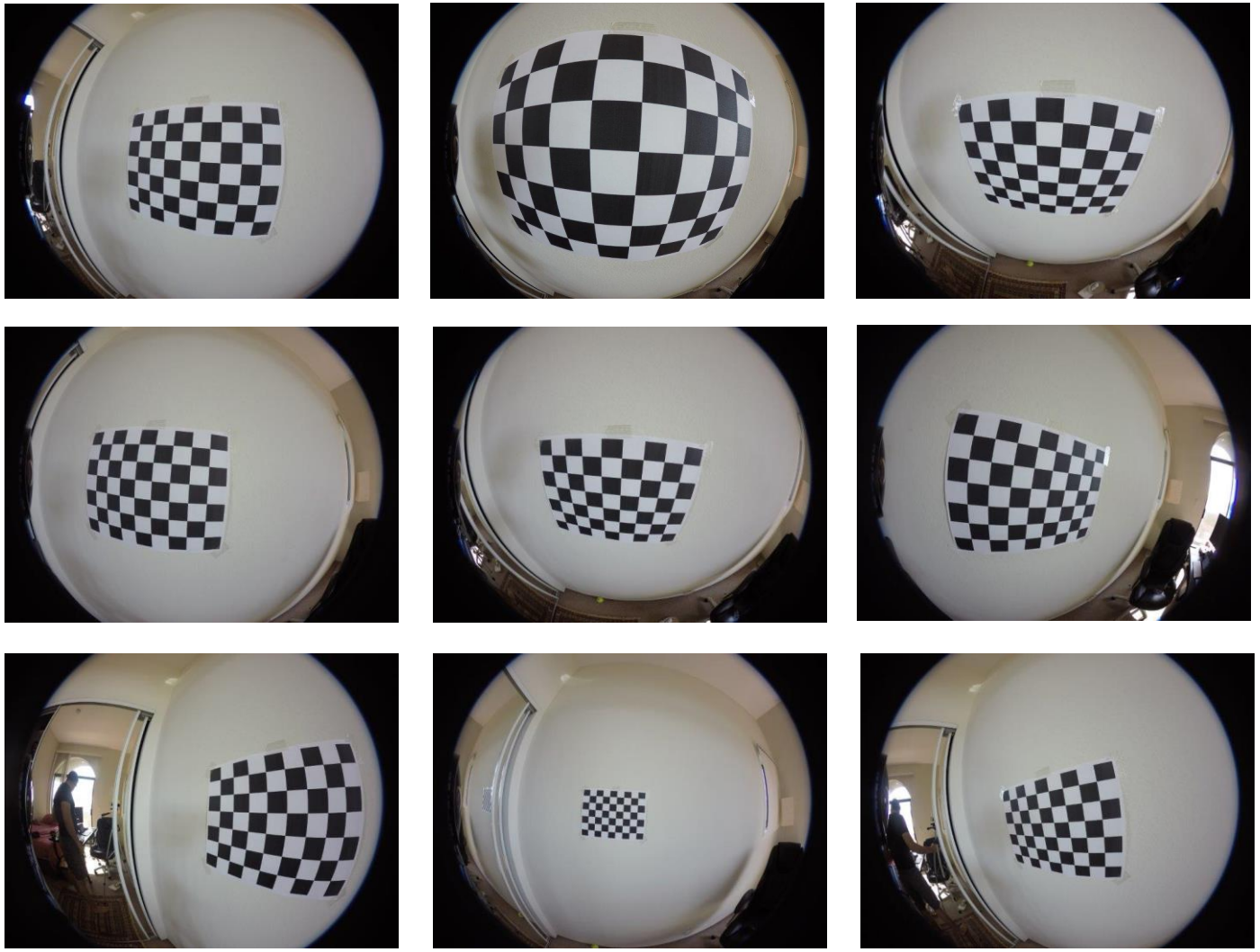


Calibration pattern captured by left and right sensors

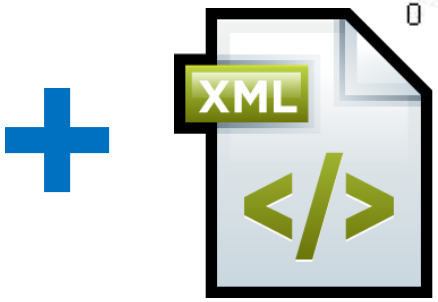
Sample Calibration Images

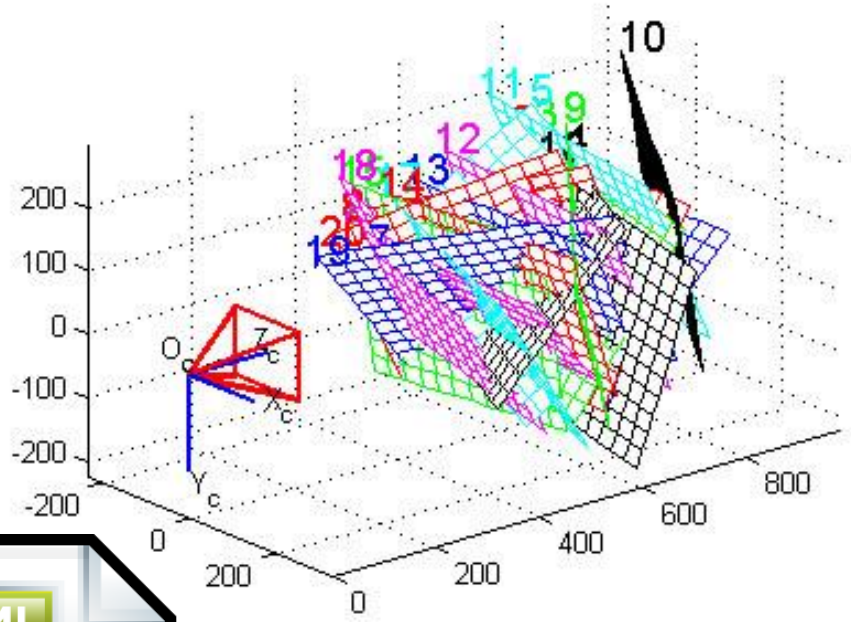
The more images at different distances and orientations the better

Typically a dozen or more orientations are used



Applying the Calibration





Recorded .mp4 video file + Calibration .xml file

Calibration Program

The calibration image set is passed to our calibration program

The program estimates the optimal stereoscopic calibration settings to explain the distortion in all of the images

- We get back a left and right calibration vector
- Each vector consists of about 10 parameters, to describe the stereoscopic distortion

We use **OpenCV** and other image processing APIs to help perform calibration

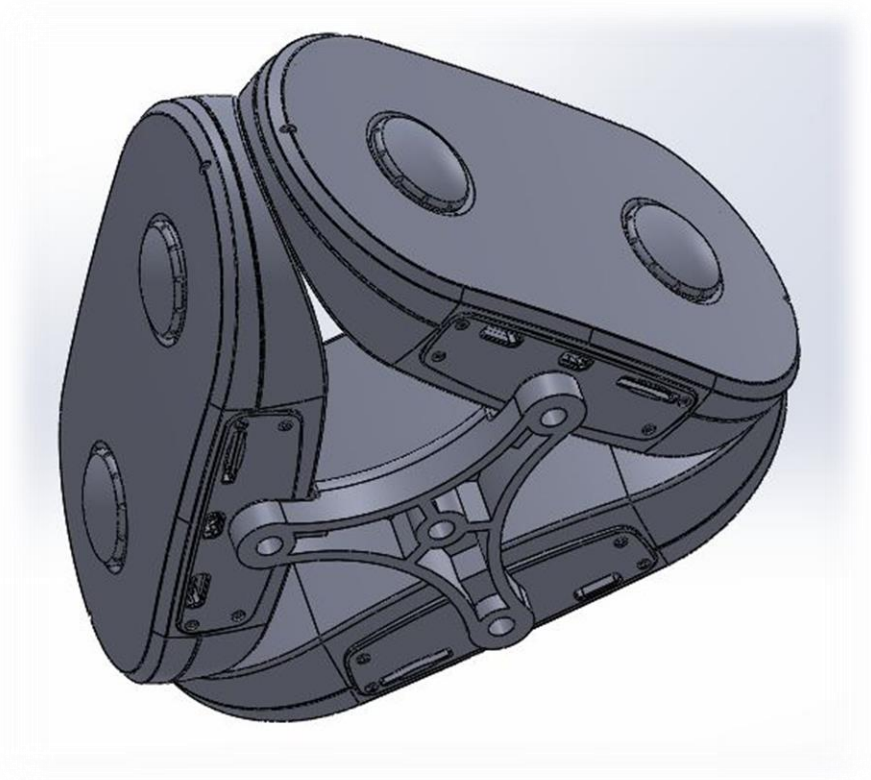
360 DEGREE STEREO STITCHING

Video Stitching

Using **3 LucidCams**, we can record 360 degree videos

We need to stitch the **3 left eye** images and the **3 right eye** images

How can we preserve the 3D effect?



120 degrees between each camera

2D Video Stitching

We have tools and software to do 2D stitching

Getting the stereo effect right is the hard part

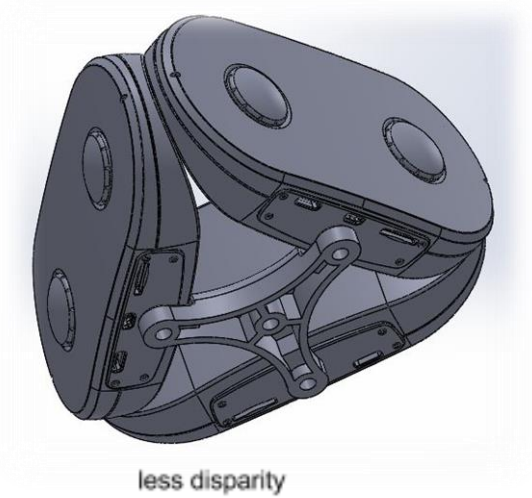
Stereo Video Stitching

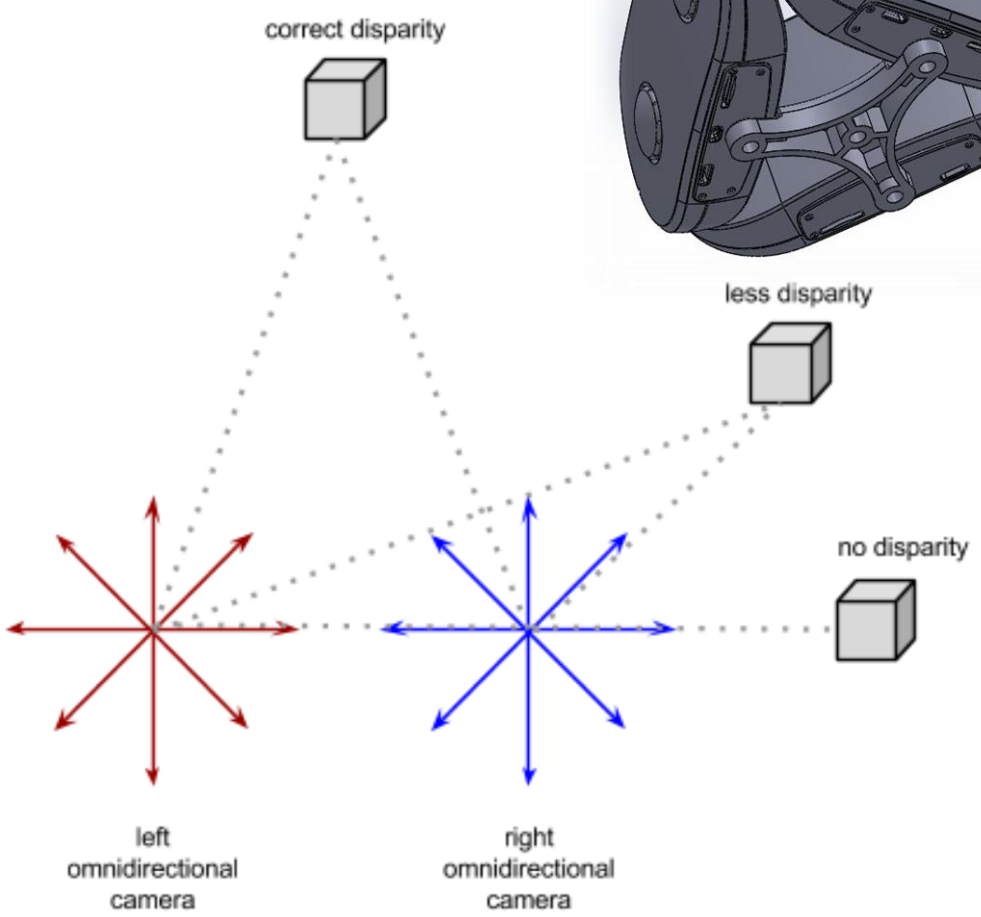
Stereo video stitching is hard!

3 different camera calibrations

We need to resolve the different lens angle disparities at the seams

There is lots of ongoing research in this field that we're following





THANK YOU

STEREOSCOPIC 3D CAMERA