Structured light – gray codes

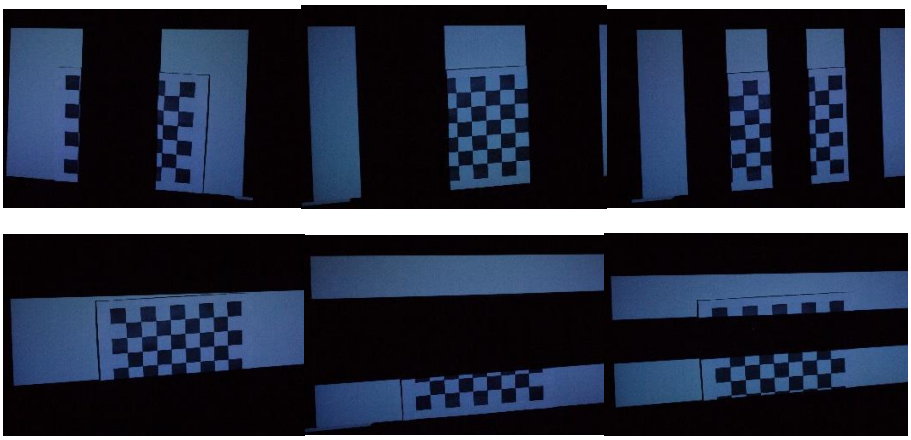
One of the techniques we explored to estimate depth is to use structured light. It is similar to stereo vision, but one camera is replaced by a structured light illumination source. Especially for uniform targets that do not have much salient features to match across two views, a structured light pattern is used to encode the images to find correspondences. There are different categories of structured light: Sequential projections, Continuous varying, Stripe Indexing, Grid indexing and hybrid approaches. We tried a sequential projection pattern using a gray code. A sequence of gray codes is projected on the target and a camera captures the projected images. Each pixel gets encoded by a unique sequence and is matched from the camera to the projection source. The setup is calibrated beforehand to know its intrinsic and extrinsic parameters. The matched points are then projected and triangulated to find depth of the target. To make it easily reproducible, we took a regular display as our projection source (Reference: Francken set up) and tried to estimate depth of the test object.

Top-left: Camera-display setup, Top-right: Projected gray-code and captured images, Bottom: Gray Code samples

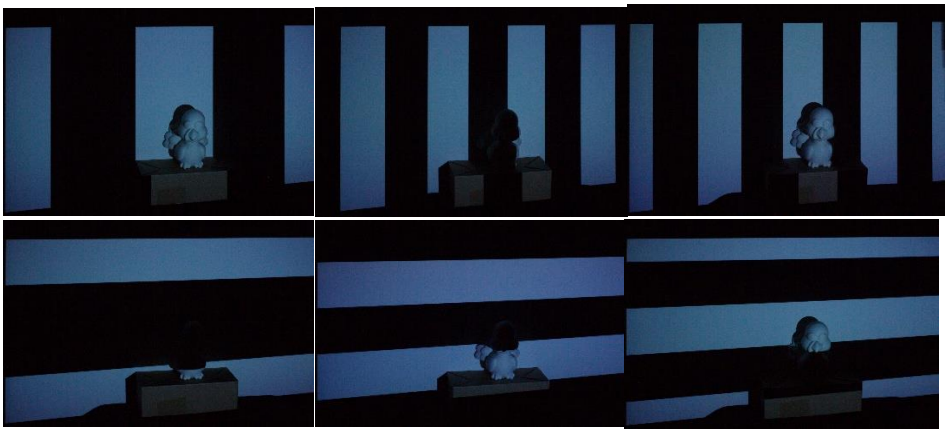
Problems and Conclusion:

The display did not turn out to be a good projection source as can be seen from the images. The projection patterns were not displayed to be strong enough to get deformed and captured on the target's surface. We decided to replace the display by a projector as the projection source.

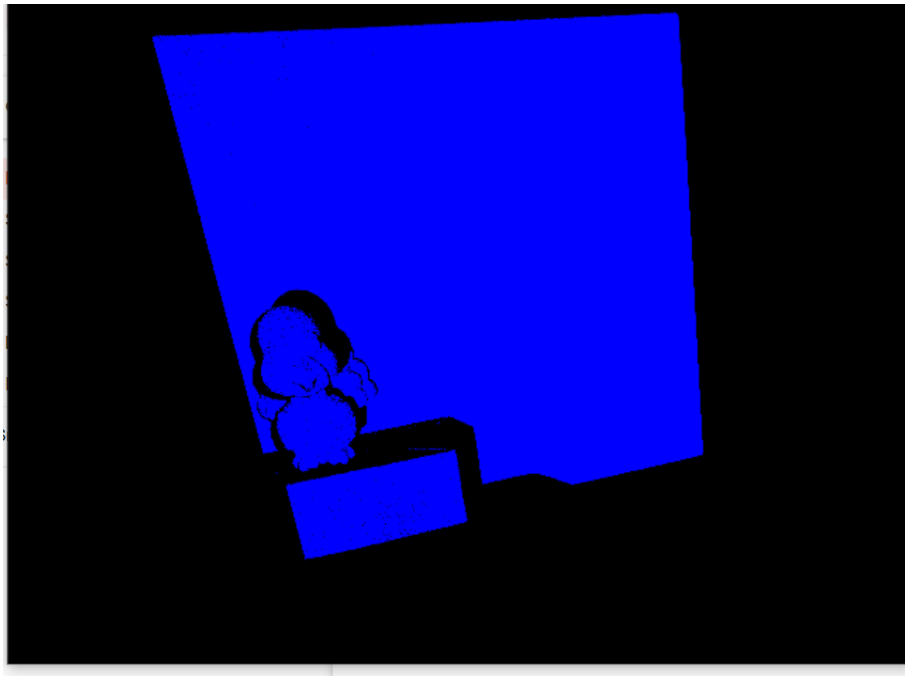
Replacing the projection source to a digital projector solved the illumination problem. We performed projector-camera calibration using gray codes. Gray codes are projected on a printed checkerboard and the camera captures images of such encoded checkerboard. The camera calibration is performed by standard checkerboard technique and corresponding checkerboard corners are identified/matched with the projector's pixel through decoding the gray code. The projector calibration then is also carried the same way as the camera. After calculating the intrinsic and extrinsic parameters, we capture the target illuminated by the gray codes and then decode them to find projector-camera correspondences and finally use these matches to triangulate and find depth of the target.



Calibration: Gray code projected checkerboard images



Target Object: Gray code projected checkerboard images



Initial depth reconstruction

Problems and Conclusions:

The depth estimation using gray codes looked promising, but it still required 40+ images (depending on the projector resolution) to estimate depth of the target object. Additionally, the projector- camera matches is dependent on projector resolution. We decided to opt for a structured light technique that overcomes these problems.

Other Points:

OpenCV python calibration API to find checkerboard corners do not work for a plain black background. We need to put a white reference plane in order to make it work.