

Rubik's Cube – a photogrammetry tutorial.

This tutorial illustrates the basic principles of a photogrammetric measurement by creating a 3D model of a Rubik's Cube.

Experimental setup:

The goal of the tutorial is to illustrate the basic steps of a photogrammetric measurement by creating of a simple 3D model from a series of pictures. For the experiment a color cube was placed on a sheet of paper and pictures taken from all sides using a conventional compact camera. The pictures were taken at a small zoom setting resulting in small image distortions. To create a texture of the bottom face of the cube, one separate image was taken with the cube turned upside down.

In this baseline experiment, we will use the A4 sheet as reference to align the camera pose for the scene. For a real world measurement using a sheet of paper as a reference not a good idea, but for illustrating the basic concepts of photogrammetric and creating a simple qualitative model it is just fine.

Setting up a photogrammetric scene consists of three elemental steps:

- Finding the camera position and orientation,
- coordinate measurement of the corner points,
- camera calibration and minimization of the measurement error.

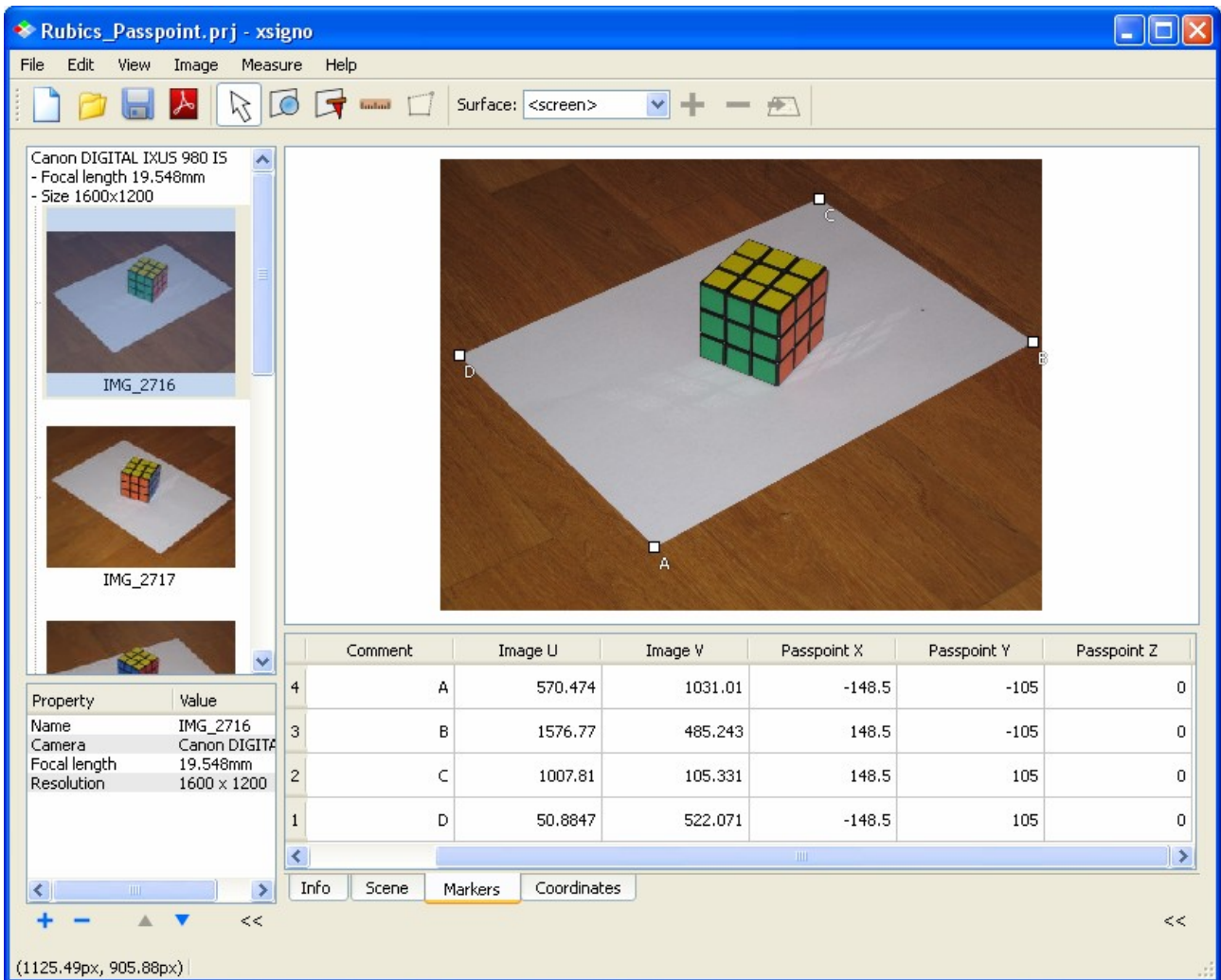
Once the 3D coordinates are found, the next steps are

- Measurement of distances,
- defining surfaces and textures and
- generation of a 3D model.

Setting up a photogrammetric scene

The size of a A4 sheet of paper is approximately 297mm x 210 mm. To center the coordinate origin in the middle of the sheet, we place four corner markers labeled “A” to “D” and enter the corner coordinates in the passpoint fields as shown in the figure below. By selecting “Measure > Camera Pose” the software will setup the orientation of the image and a small green tripod marks the origin of the scene. It is necessary to enter the 3D passpoint coordinates only for the first image, for the remaining images it is just necessary to ensure a consistent labeling. When looking at the scene from a different angle, it can be confusing the place the markers in the correct order.

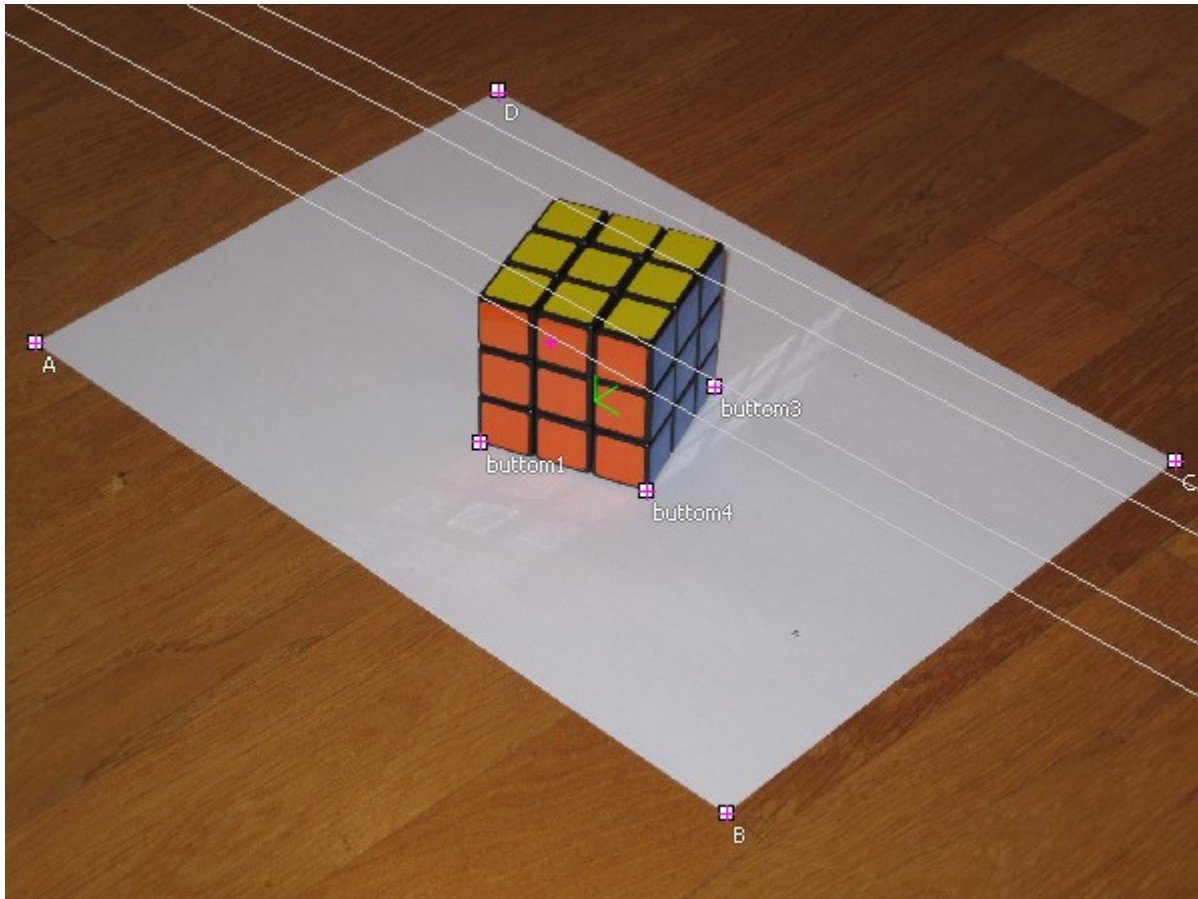
The estimation of the camera pose depends strongly on the image distortion. If you have a calibrated camera or know the coefficient of the distortion from previous measurements, you can enter the coefficient for the camera setting before doing the pose estimation. Otherwise you can fine tune the scene later by doing an automatic calibration after setting up all scenes.



Passpoint markers defining the scene origin and camera pose.

Once the orientation is setup for the images, the next step is the measurement of the 3D coordinates of the cubes corners. It is possible to use any naming, but I choose the naming top1 to top4 for the top face and bottom1 to bottom4 for the cubes bottom face.

For finding the 3D points, it is necessary to mark the coordinates consistently in the remaining images. Manually marking coordinates can be a very tedious and error-prone task. Fortunately the software has some features making the correct placement of labels a very simple task. Activate the visualization of epipolar rays from the menu "View > Display" and switch to a different image having a valid orientation. You will see an overlay of a set of gray lines, each line corresponding to the projection of a marker in your first image view. As you marked the corners of the cube, the rays are touching the corners in your second image view. By activating the marker placement tool from the tool-bar and placing a marker at vicinity of a epipolar, the epipolar will vanish as you have now defined its point in space. Instead of the epipolar you will see a small magenta cross showing the projected position of the point in 3D. By moving the marker, you will see how the position of the 3D coordinate changes as you move the marker. With the aid of epipolar rays and point projections, the correct labeling of all corners is finished quickly.



*Determining 3D coordinates by placing markers in multiple image views.
Marker projection lines (epipolar rays) assist in finding point correspondences.*

The final step of a 3D scene setup is the calibration of the image and camera distortions. The camera calibration step will change the image distortion and orientation to give the best measurement accuracy. A good camera characterization is a very critical step for accurate measurements and requires to take a lot of measurement points covering the whole the field of view. In the example picture of this tutorial, there are not enough points for doing a good calibration but it will give you a reasonable guess.

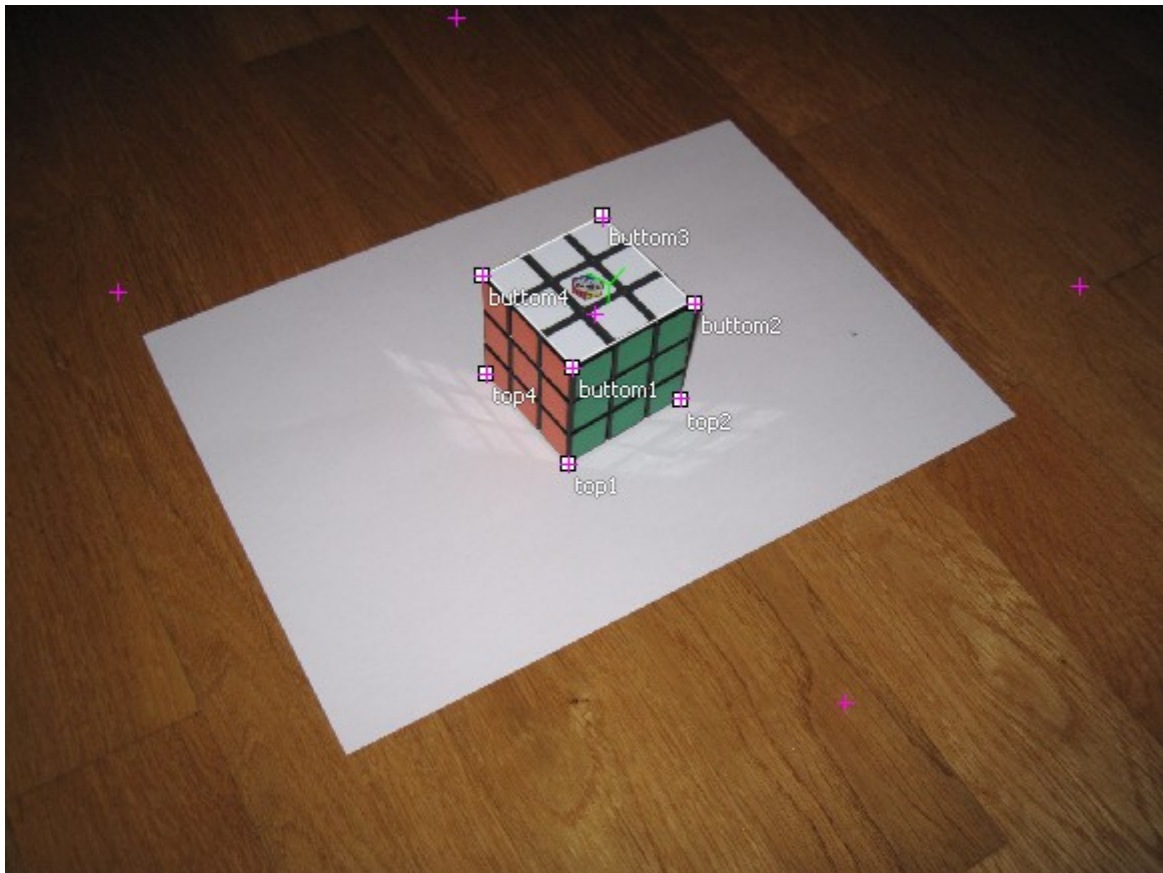
Modeling surfaces and textures

Once the basic scene is setup and the coordinates for the corner points of the cube are marked and calculated, the next step is to use this coordinates for measurement and modeling. To measure the size of the cube, you activate the ruler tool and draw a line between the corner points. As the ruler measures coordinate differences, it is actually attached to the 3D coordinate and not to the 2-dimensional marker. When moving the marker, the ruler's tip follows the projection of the 3D coordinate.

A model is created by defining planar surfaces from the corner points and then drawing a polygonal contour on the surface. In this way you define a textured surfaces for each visible face of the cube and you can export the resulting model to a 3D PDF model.

The last picture shows an image of the cube turned upside down, to complete the model, we add the bottom face of the cube from this image. As the cube was moved, one cannot use the paper sheet for alignment of the camera pose. Instead, it is necessary to use the corner points as alignment references.

Using object points as auxiliary references in alignment is a common technique not only when the object is moved, but also for the measurement of a larger room or object, when it is not possible to capture the alignment points in the field of view.



*Alignment of the camera pose using the cube's corners as auxiliary points.
The floating 3D markers are the corner coordinates of the original reference sheet.*

Summary

In this tutorial the basic steps of a photogrammetric measurement for modeling are covered. For finding the image pose, one technique is to use passpoints to setup a local coordinate system. Once object points are measured, they can be used as auxiliary reference for aligning further images.

The XSIGNO photogrammetry software supports the manual placement of markers by using marker projections – epipolar rays – to assist in finding point correspondences. The projection of a marker in an initial view results in a line projection when changing the view.

The software exports textured models in Collada format, which is an open standard for exchanging 3D data between CAD applications. A format which is supported by popular CAD applications and interior- and home planning software.