Auto-Calibration for Screen Correction and Point Cloud Generation

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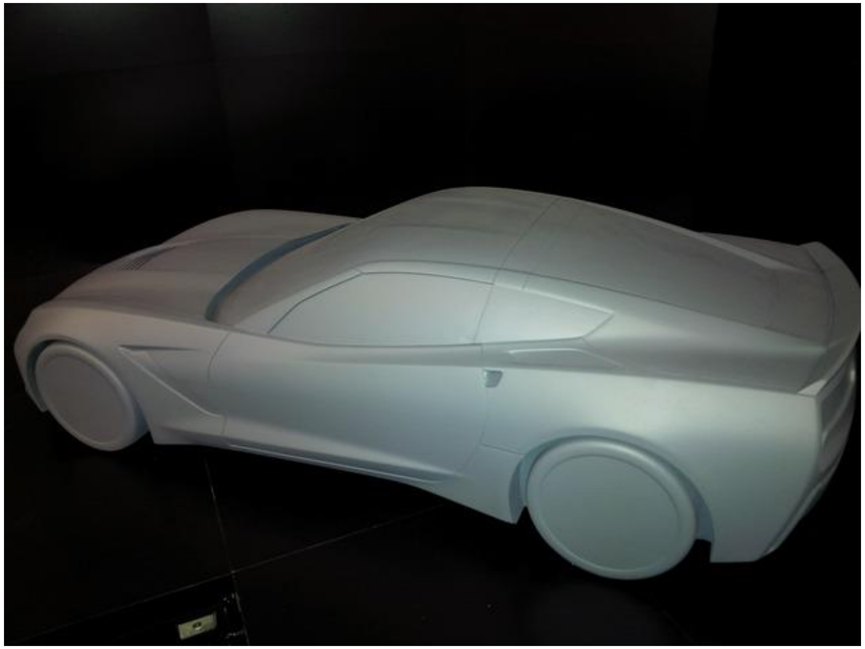
Background

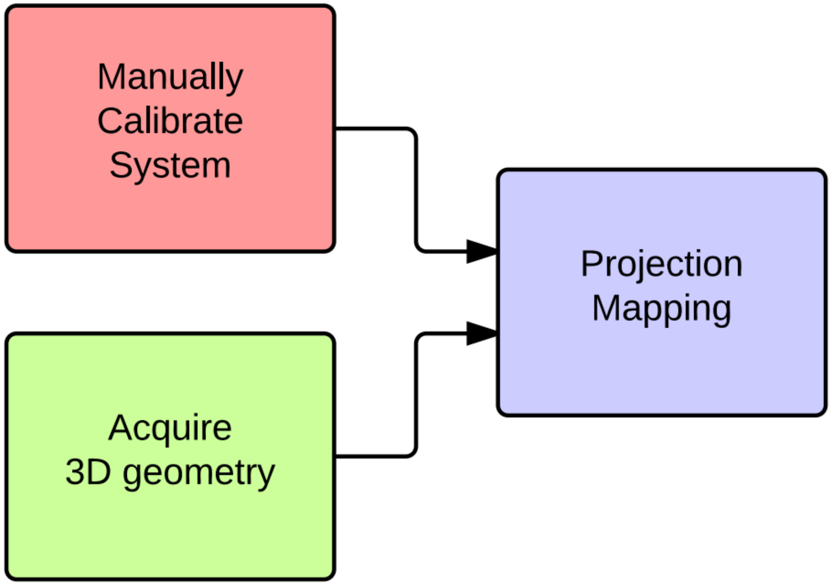
- Projection mapping is projecting an image onto a 3D surface to change the appearance of that surface.
  - Large scale: buildings
  - Small scale: model cars, mannequins



Projection mapping used for altering the appearance of a grey car.

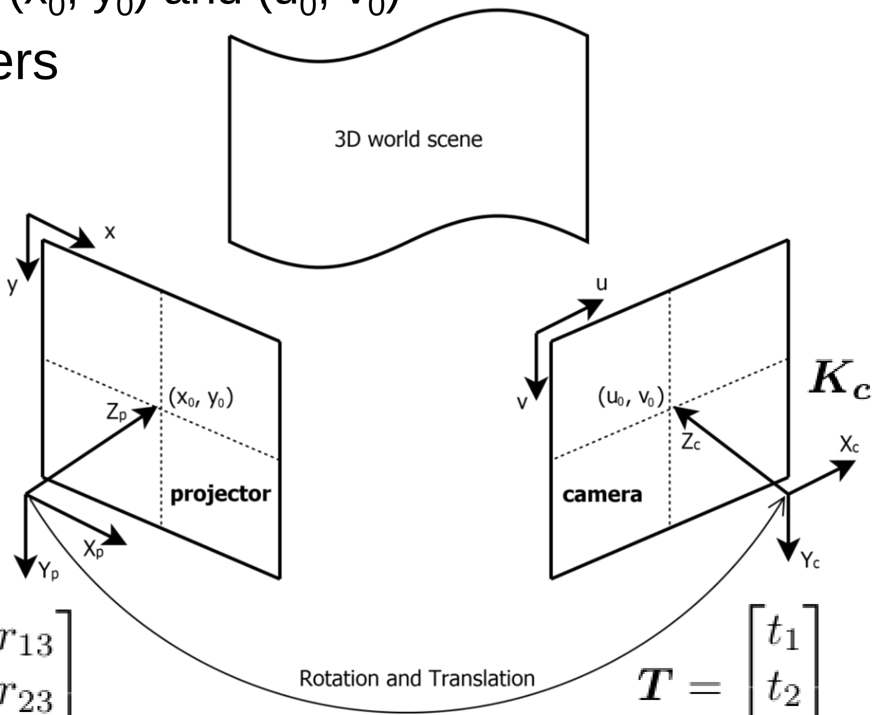
Motivation

- In order to project content onto an object's surface two steps must occur:
  1. The projector and camera must be calibrated.
  2. The 3D geometry of the surface must be known.



Calibration of Projector Camera System

- A calibrated system requires knowing the following:
  1. Intrinsic parameters: K_p and K_c
     - Focal lengths: f_p and f_c
     - Principal points: (x_0, y_0) and (u_0, v_0)
  2. Extrinsic parameters
     - Rotation (R)
     - Translation (T)



$$\boldsymbol{K_p} = \begin{bmatrix} f_p & 0 & x_0 \\ 0 & f_p & y_0 \\ 0 & 0 & 1 \end{bmatrix}$$

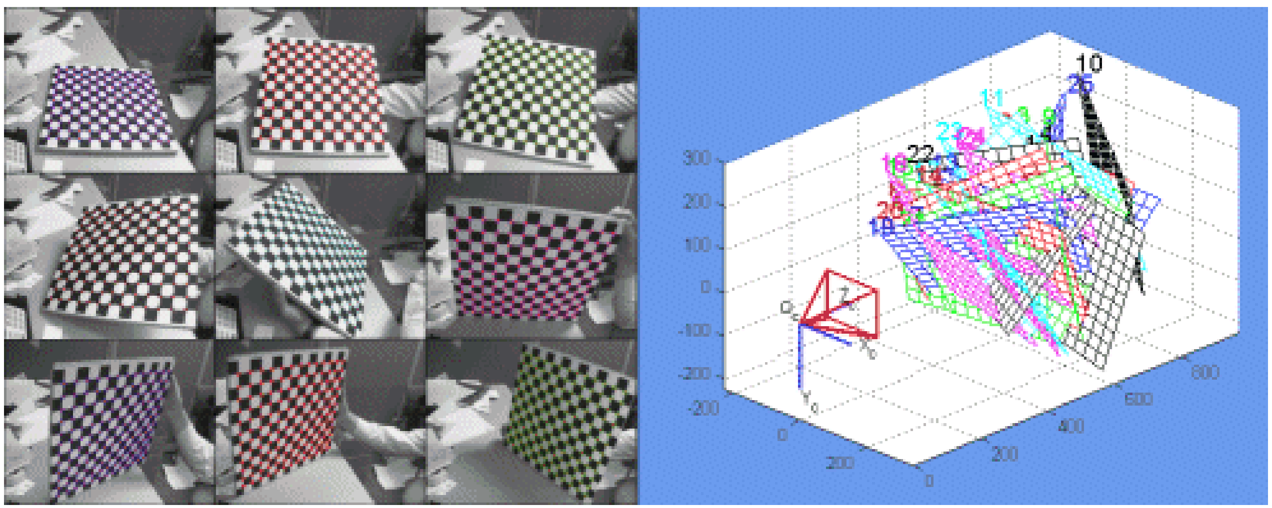
$$\boldsymbol{K_c} = \begin{bmatrix} f_c & 0 & u_0 \\ 0 & f_c & v_0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\boldsymbol{R} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$

$$\boldsymbol{T} = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix}$$

Manual Calibration of Projector and Camera

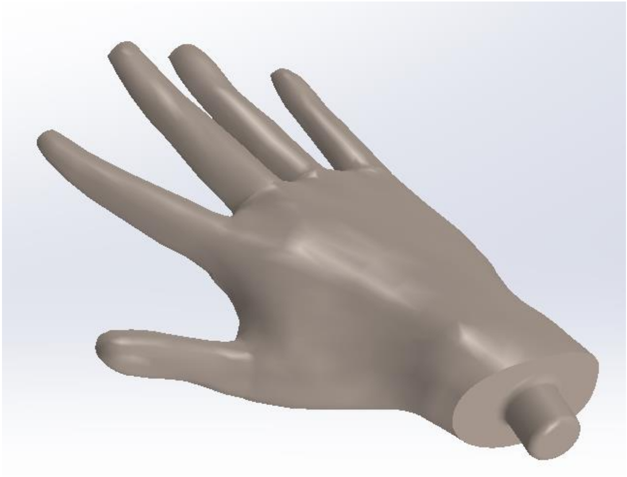
- Involves using a checkerboard target and capturing multiple images.
- Manual calibration can be:
  - Time consuming.
  - Inconvenient and sometimes not possible.

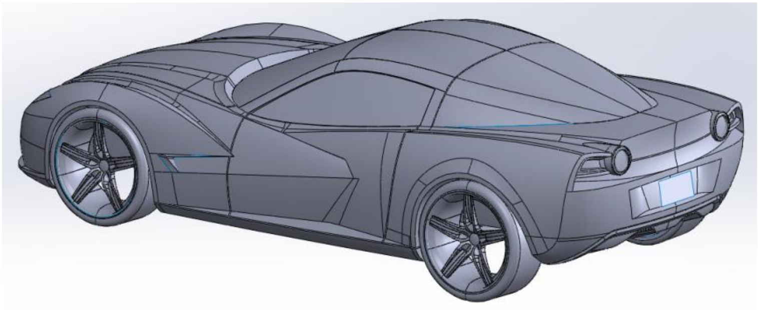


Manual camera calibration using MATLAB toolbox [2, 3].

Finding 3D geometry

- Find the 3D geometry can be accomplished using:
  - CAD model and 3D printing.
  - 3D laser scanning for larger objects like buildings.
  - Structured light or Kinect for smaller objects like a mannequin.
- This step can be both time consuming and expensive.

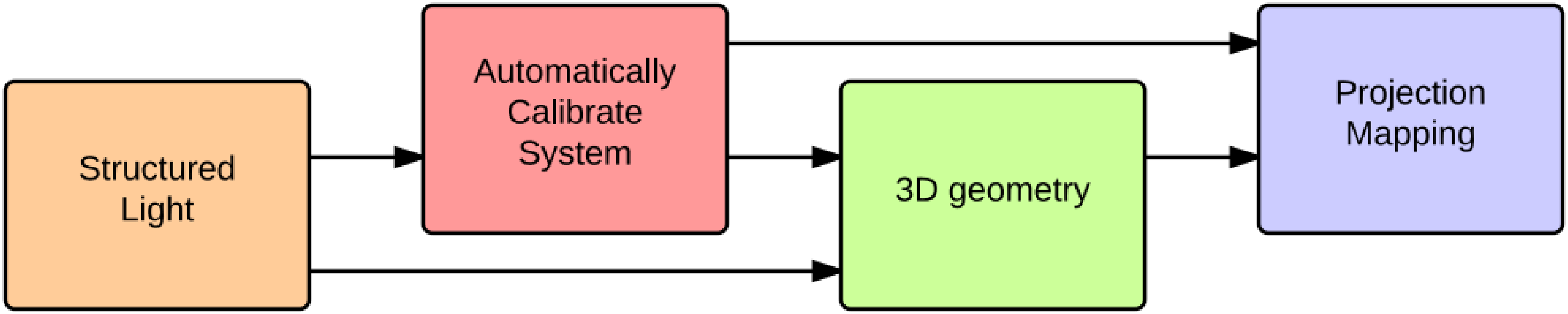




3D models of a hand, corvette and a mannequin.

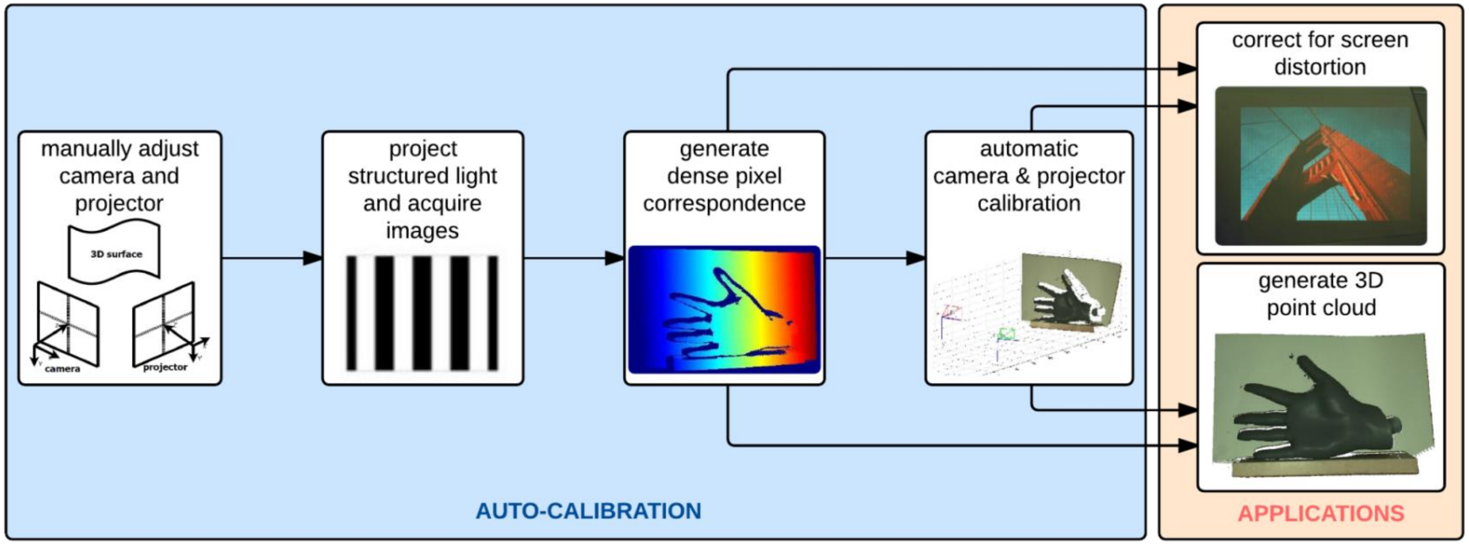
Auto-calibration Overview

- Previously we needed the following before we could accomplish projection mapping:
  1. Fully calibrated system
  2. 3D geometry
- With auto-calibration we combine these steps into one pipeline.
- From auto-calibration we fully calibrated the system and then find the 3D information.



Auto-calibration Pipeline

- The goal is to automatically calibrate a projector camera pair without any checkerboard.
- Use auto-calibration for two applications:
  1. Point cloud generation.
  2. Screen correction.



An overview of the auto-calibration process with two applications.

Experimental Setup

- Projector projects gray code binary pattern sequence.
- Camera captures corresponding images.

The projector-camera setup relative to the 3D scene.

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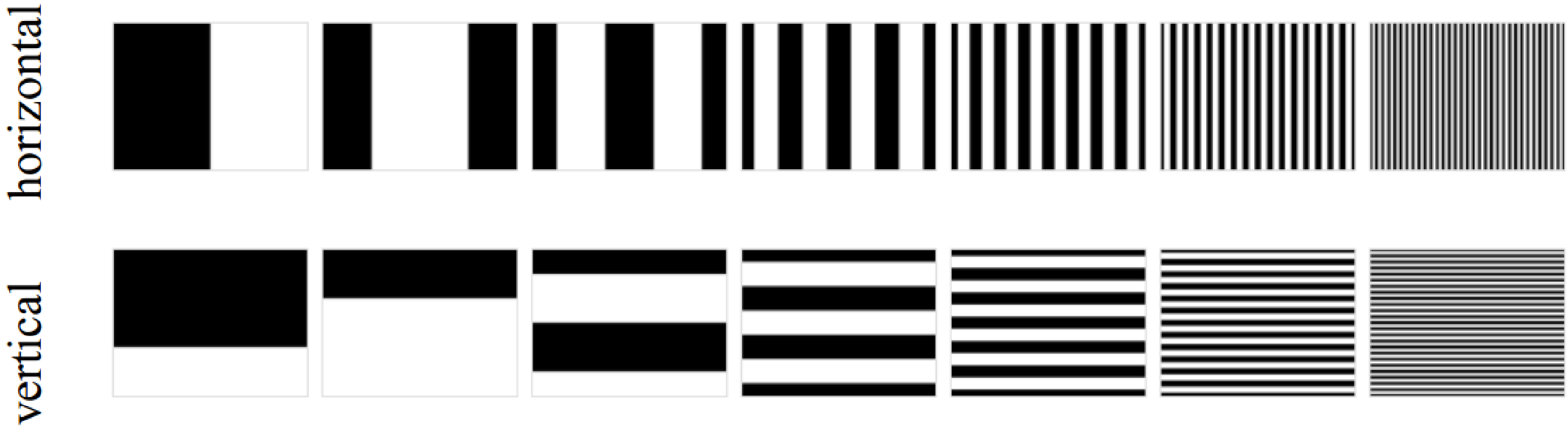
Structured Light for Dense Pixel Correspondence

- Gray code binary pattern was used for our structured light.
  - Encode both horizontal and vertical information of the scene.
- This results in a dense pixel correspondence between the projector and camera.



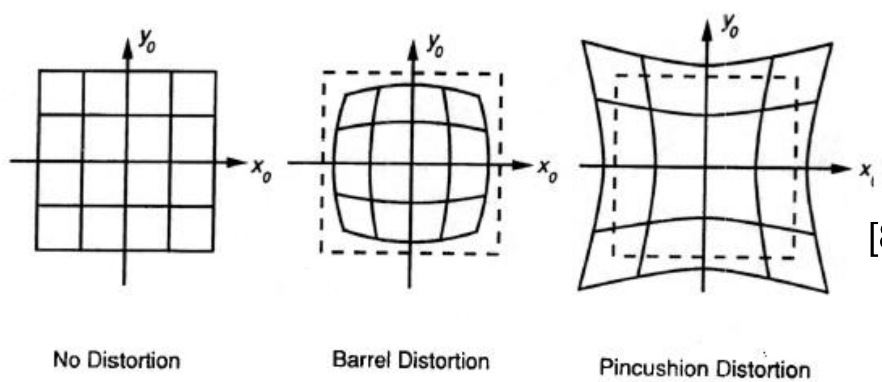
Horizontal and vertical gray code structured light [5, 6].

Distortion Model

- The radial lens distortion of the projector and camera can be represented by the division model [5]:
- The division model is an alternative to the conventional polynomial distortion model.

$$
\begin{aligned}
(u', v') &= \frac{1}{1 + d_p|\boldsymbol{r}_p|^2}\boldsymbol{r}_p + (a_p, b_p) \\
(x', y') &= \frac{1}{1 + d_c|\boldsymbol{r}_c|^2}\boldsymbol{r}_c + (a_c, b_c),
\end{aligned}
$$

- Here $\boldsymbol{r}_p = (u, v) - (a_p, b_p)$, $\boldsymbol{r}_c = (x, y) - (a_c, b_c)$



[8]

Optimization: Initialization

- Reliable points were chosen using RANSAC [5].
- The following 15 parameters were then initialized:
  - Principal points: (x_0, y_0) and (u_0, v_0)
  - Distortion coefficients: d_p and d_c
  - Fundamental Matrix, F: 3x3 matrix
- Choosing a good starting point is imperative to ensure that the optimization converges to the correct answer.

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Optimization: Cost Function

- A mathematical model is used to create a cost function which is minimized to estimate the intrinsic and extrinsic camera parameters.
- The main data term in the cost function is known as the Sampson reprojection error [5, 6, 8]:

$$\sum_{i=1}^{n} \frac{(\boldsymbol{u_i}^T \boldsymbol{F} \boldsymbol{x_i})^2}{(\boldsymbol{F}\boldsymbol{x_i})_1{}^2 + (\boldsymbol{F}\boldsymbol{x_i})_2{}^2 + (\boldsymbol{F}^T\boldsymbol{u_i})_1{}^2 + (\boldsymbol{F}^T\boldsymbol{u_i})_2{}^2}$$

- This 15 dimensional cost function was optimized using the Levenberg-Marquardt algorithm.

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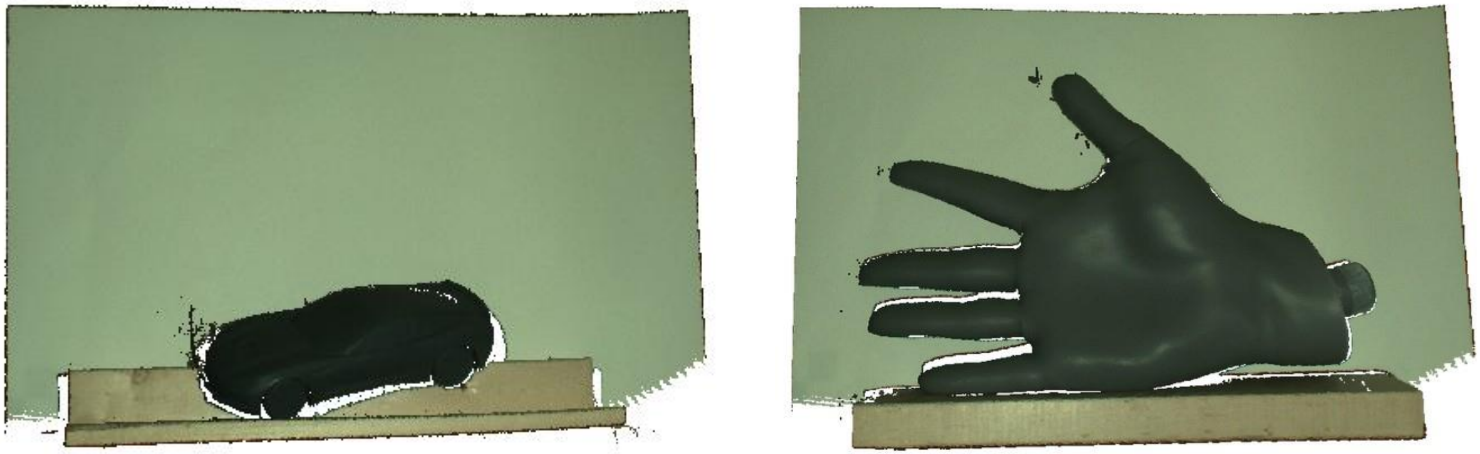
Application: 3D Point Cloud Generation

- Using this auto-calibration process we can create 3D point clouds by triangulating the 3D point from the pixel correspondences.



3D point clouds of a car and a hand.

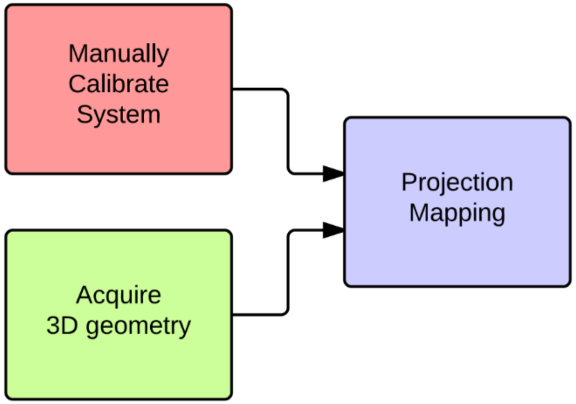
Application: Screen Correction

- Using the auto-calibration we are apply to apply keystone correction to the projector image.

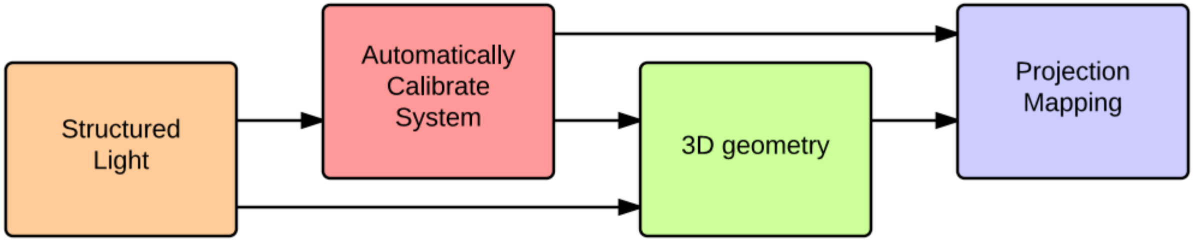
The distorted image on the left and the corrected image on the right.

Summary

- In order to projection map onto an object two steps must occur:



- Auto-calibration combines these steps using structured light:



- Auto-calibration can be used for generating a dense 3D point cloud as well as screen correction.

Questions

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