



# Multiple View Geometry: Solution Sheet 4

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Wednesdays 16:00–18:15 at Hörsaal 2, "Interims I"  
(5620.01.102), and on RBG Live

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## Part I: Theory

### 1. Image Formation

- (a) Compute  $\lambda$  and show that (2) is equivalent to

$$u = \frac{fX}{Z} + o_x, \quad v = \frac{fY}{Z} + o_y.$$

Performing the matrix multiplication in (2), one obtains

$$\begin{pmatrix} \lambda u \\ \lambda v \\ \lambda \end{pmatrix} = \begin{pmatrix} fX + o_x Z \\ fY + o_y Z \\ Z \end{pmatrix}$$

From the third row, it directly follows that  $\lambda = Z$ . Substituting  $Z$  for  $\lambda$  and dividing the equation by  $Z$ , one immediately obtains the result.

- (b) A classic ambiguity of the perspective projection is that one cannot tell an object from another object that is exactly *twice as big but twice as far*. Explain why this is true. Let  $\tilde{\mathbf{X}}_1 = (X_1 \ Y_1 \ Z_1)^\top$  be a point on the smaller object and  $\tilde{\mathbf{X}}_2 = (X_2 \ Y_2 \ Z_2)^\top$  a point on the larger object. Since  $\tilde{\mathbf{X}}_2$  is twice as far away, we have  $Z_2 = 2Z_1$ , and since it is twice as big we have  $X_2 = 2X_1$  and  $Y_2 = 2Y_1$ . Thus,

$$u_2 = \frac{fX_2}{Z_2} + o_x = \frac{2fX_1}{2Z_1} + o_x = \frac{fX_1}{Z_1} + o_x = u_1$$

and analogous for  $v_2 = v_1$ .

- (c) For a camera with  $f = 540$ ,  $o_x = 320$  and  $o_y = 240$ , compute the pixel coordinates  $u$  and  $v$  of a point  $\tilde{\mathbf{X}} = (60 \ 100 \ 180)^\top$ .

$$u = \frac{fX}{Z} + o_x = \frac{540 \cdot 60}{180} + 320 = 500$$
$$v = \frac{fY}{Z} + o_y = \frac{540 \cdot 100}{180} + 240 = 540$$

Explain with the help of (b) why the units of  $\tilde{\mathbf{X}}$  are not needed for this task.

Using different units (mm, cm, m, etc.) can be interpreted as scaling the point coordinates by a constant factor (10, 100, ...). The argument of (b) for a factor of 2 can easily be generalized to any factor  $\alpha$ .

Will the projected point be in the image if it has dimensions  $640 \times 480$ ?

No, the point  $(u, v) = (500, 540)$  is not in  $[-0.5, 639.5] \times [-0.5, 479.5]$ .

- (d) Using the generic projection  $\pi$ , show that (3) — and therefore also (1) and (2) — is equivalent to

$$\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = K \begin{pmatrix} \pi(\tilde{\mathbf{X}}) \\ 1 \end{pmatrix}.$$

Insert in the RHS of the equation:

$$\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = K \begin{pmatrix} \pi(\tilde{\mathbf{X}}) \\ 1 \end{pmatrix} = \begin{pmatrix} f & 0 & o_x \\ 0 & f & o_y \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X/Z \\ Y/Z \\ 1 \end{pmatrix} = \begin{pmatrix} fX/Z + o_x \\ fY/Z + o_y \\ 1 \end{pmatrix}$$

## 2. Radial Distortion

- (a) Can this model be used for lenses with a field of view of more than  $180^\circ$ ?  
 No, it can only model points for which the viewing ray intersects the image plane. Since points are first projected on the canonical image plane with  $\pi(\tilde{\mathbf{X}})$  there is a singularity at  $Z = 0$  (which is  $180^\circ$ ).  
*Note:* It is possible to rewrite the FOV model to avoid the division by  $Z$  and apply it to lenses with more than  $180^\circ$  FOV.

- (b) Derive a closed form solution for  $f$  in the undistortion formula

$$\pi(\tilde{\mathbf{X}}) = f \left( \|\pi_d(\tilde{\mathbf{X}})\| \right) \cdot \pi_d(\tilde{\mathbf{X}})$$

using (6) and  $g(r) = g_{\text{ATAN}}(r)$ .

Define  $r := \|\pi(\tilde{\mathbf{X}})\|$  and  $r_d := \|\pi_d(\tilde{\mathbf{X}})\|$ . The norms of (9) and (6) are:

$$r = f(r_d)r_d \quad \text{and} \quad r_d = g(r)r$$

Inserting  $g = g_{\text{ATAN}}$  yields

$$\begin{aligned} r_d &= \frac{1}{\omega r} \arctan \left( 2r \tan \left( \frac{\omega}{2} \right) \right) r = \frac{1}{\omega} \arctan \left( 2r \tan \left( \frac{\omega}{2} \right) \right) \\ &\Rightarrow \tan(r_d \omega) = 2r \tan \left( \frac{\omega}{2} \right) \\ &\Rightarrow r = \frac{\tan(r_d \omega)}{2 \tan \left( \frac{\omega}{2} \right)} = f(r_d)r_d \quad \Rightarrow f(r_d) = \frac{\tan(r_d \omega)}{2r_d \tan \left( \frac{\omega}{2} \right)} \end{aligned}$$