Single View 3D Reconstruction for Grain Inspection

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Introduction

In the US, grain grading is mainly done with inspector looking at grain kernels from directly above. There are great interests in using imaging technique to speed up the grading process. In hyperspectral imaging for grains, grains are not always falling in the optimal position with camera at various angles. Using single view 3D reconstruction, we tried to reconstruct the directly above view of grain kernels to recover their correct dimensions. Majority of this project is based on the work by Horry, Anjyo, and Arai, in 1999 and Criminisi, Reid, and Zisserman in 2000.

Procedures and results

Image collection

Corn, pinto bean (PB), sunflower seed (SF), and wheat kernels were selected for this experiment. Sample dimensions were measured using a caliper (figure 1) and recorded in table 1.

Figure 1: Sample dimension measurement setup.

Table 1: Sample kernels dimensions.

	Pinto bean	Sunflower seeds	Wheat
Length (mm)	12.54	14.14	7.30
Width (mm)	7.28	6.84	3.98
Height (mm)	4.81	4.90	3.40

To capture images at different angle, each kernel was placed at the center of a grid paper, and pictures were taken at 90° (up right), 60°, and 30° angles (figure 1). Distance between the grain kernel and the camera center was kept at 48cm for all angles. Both distance and angle were measured using the angle meter shown in the figure 2.

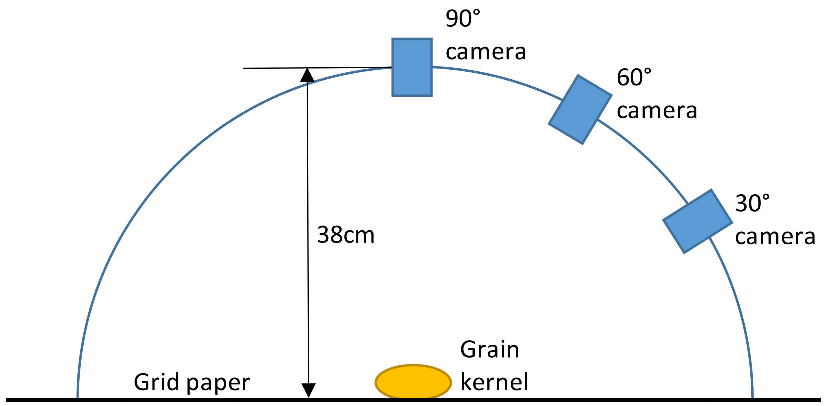


Figure 1: Setup diagram.

Figure 2: Camera and grain kernel setup.

Finding Vanishing Points

For instance, there are four points on x axis, which form 2 parallel lines ($line_{x_1}$ and $line_{x_2}$). They will meet at the vanishing point. For point P_1 and P_2, the line in homogenous coordinate is calculated using equation 1 (figure 3). For only two line, the vanishing point is callused using equation 2.

$$line_{x_1} = P_1 \times P_2 \tag{1}$$

$$vanishing\ point_x\ (V_x) = line_{x_1} \times line_{x_2} \tag{2}$$

We need to understand the homogenous coordinate to image coordinate which is shown in equation 3.

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} \frac{u}{w} \\ \frac{v}{w} \\ 1 \end{bmatrix} \tag{3}$$

Then, pictures of pinto bean are obtained and vanishing lines are drawn (figure 3).

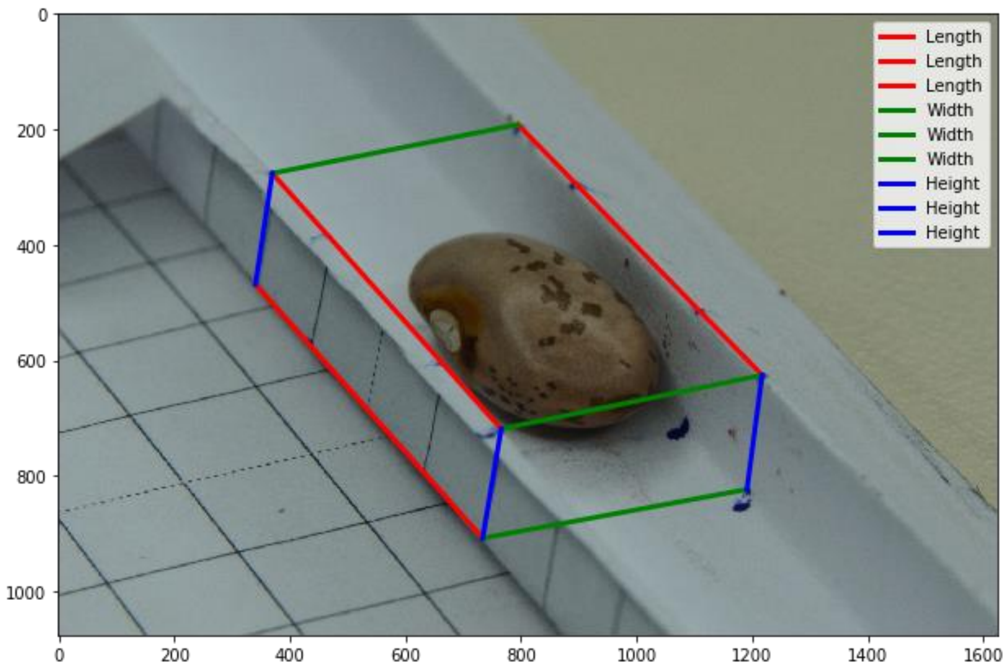


Figure 3: Camera and grain kernel setup.

Finding projection matrix

A point in world coordinate is equal to $\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$. Therefore, the projection matrix is equal to $\begin{bmatrix} a\,V_x \\ b\,V_y \\ c\,V_z \\ w_o \end{bmatrix}$, where w_o is the world origin.

For a reference point on x axis $\begin{bmatrix} x \\ 0 \\ 0 \\ 1 \end{bmatrix}$, the distance between origin and the reference is $dist_x$. Therefore,

$$\begin{bmatrix} a\,V_{x1} & b\,V_{y1} & c\,V_{z1} & w_{o1} \\ a\,V_{x2} & b\,V_{y2} & c\,V_{z2} & w_{o2} \\ a & b & c & 1 \end{bmatrix} \begin{bmatrix} dist_x \\ 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} w\,ref_{x1} \\ w\,ref_{x2} \\ w \end{bmatrix} \tag{4}$$

$$\begin{pmatrix} a\,V_{x1}\,dist_x \;+\; w_{o1} = w\,ref_{x1} \\ a\,V_{x2}\,dist_x +\; w_{o2} = w\,ref_{x2} \\ a\,dist_x + 1 = w \end{pmatrix} \tag{5}$$

$$\begin{pmatrix} a\,V_{x1}\,dist_x +\; w_{o1} = (a\,dist_x + 1)\,ref_{x1} \\ a\,V_{x2}\,dist_x +\; w_{o2} = (a\,dist_x + 1)\,ref_{x2} \end{pmatrix} \tag{6}$$

$$\begin{pmatrix} a\; = \dfrac{ref_{x1} - w_{o1}}{dist_x\,(V_{x1} -\; ref_{x1})} \\ a\; = \dfrac{ref_{x2} - w_{o2}}{dist_x\,(V_{x2} -\; ref_{x2})} \end{pmatrix} \tag{7}$$

Since $dist_x$, point V_x, and point ref_x are known, we can calculate a. Similarly, we can calculate a, b, and c using equations 4 to 7.

The projection matrix is shown below:

$$P = \begin{bmatrix} \dfrac{ref_{x1} - w_{o1}}{dist_x\,(V_{x1} -\; ref_{x1})} V_x \\ \dfrac{ref_{x1} - w_{o1}}{dist_y\,\left(V_{y1} -\; ref_{y1}\right)} V_y \\ \dfrac{ref_{z1} - w_{o1}}{dist_z\,(V_{z1} -\; ref_{z1})} V_z \\ w_o \end{bmatrix}$$

Product of matrix P and M was perform translation and rotation using equation 8 below

$$\underbrace{\begin{bmatrix} x' \\ y' \\ w' \end{bmatrix}}_{\mathbf{p}'} = \left(\underbrace{\begin{bmatrix} 1 & 0 & tx \\ 0 & 1 & ty \\ 0 & 0 & 1 \end{bmatrix}}_{T(t_x,t_y)} \underbrace{\begin{bmatrix} \cos\Theta & -\sin\Theta & 0 \\ \sin\Theta & \cos\Theta & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{R(\Theta)} \underbrace{\begin{bmatrix} sx & 0 & 0 \\ 0 & sy & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{S(s_x,s_y)} \right) \underbrace{\begin{bmatrix} x \\ y \\ w \end{bmatrix}}_{\mathbf{p}} \tag{8}$$

Then, perspective transformation was applied to an image (cv2.warpPerspective). XY, YZ, and ZX transformations are obtained and shown in figures 4, 5, and 6. The transformed images are cropped based on the bean box shown in figure 3.

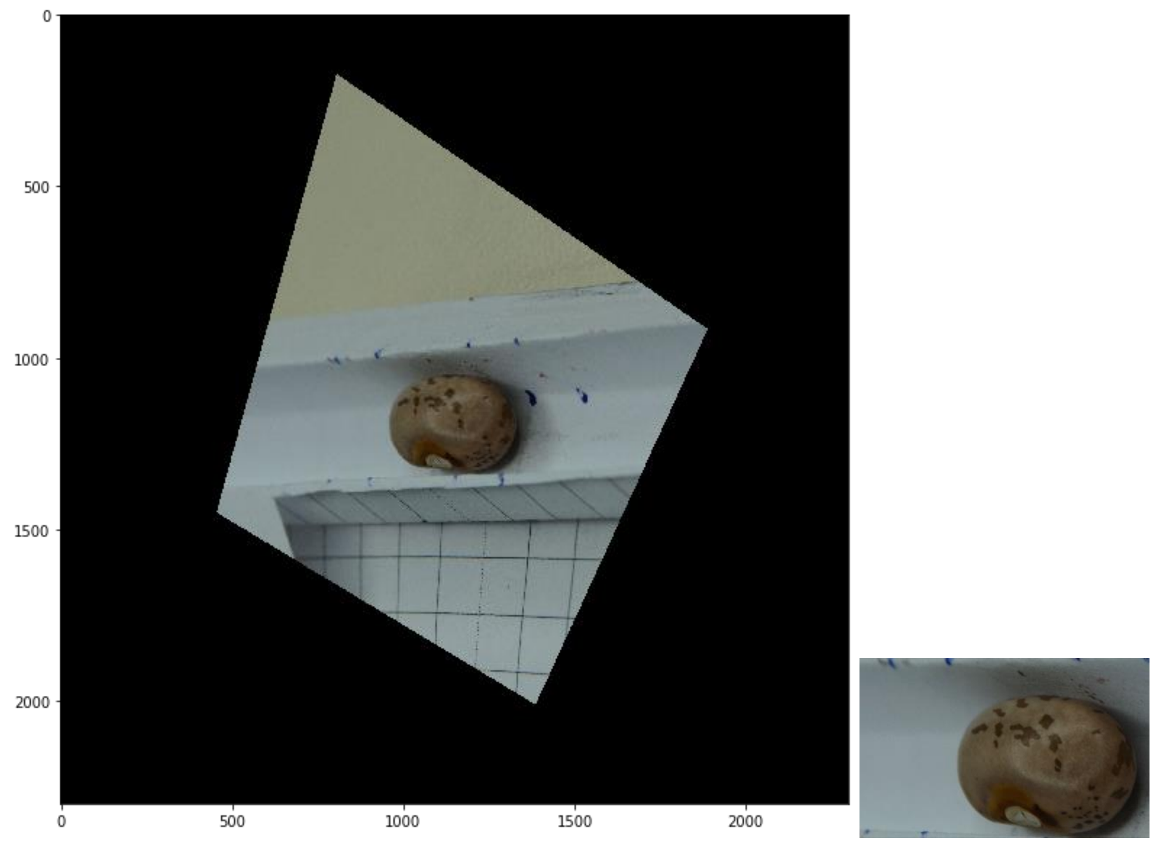


Figure 4: XY transformation result.

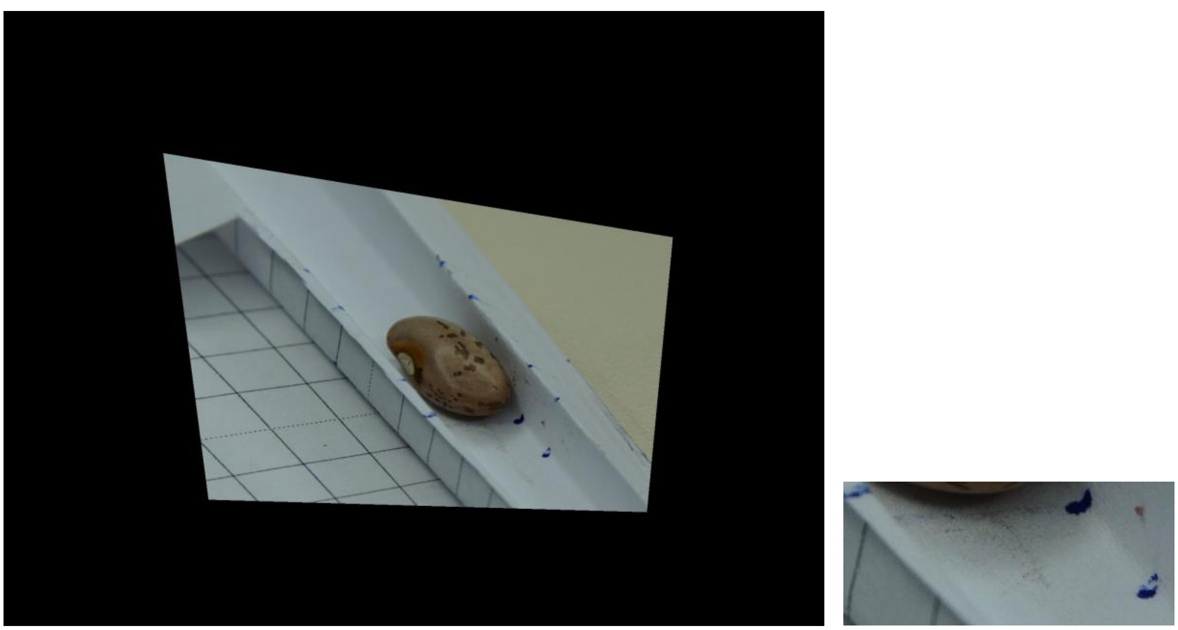


Figure 5: YZ transformation result

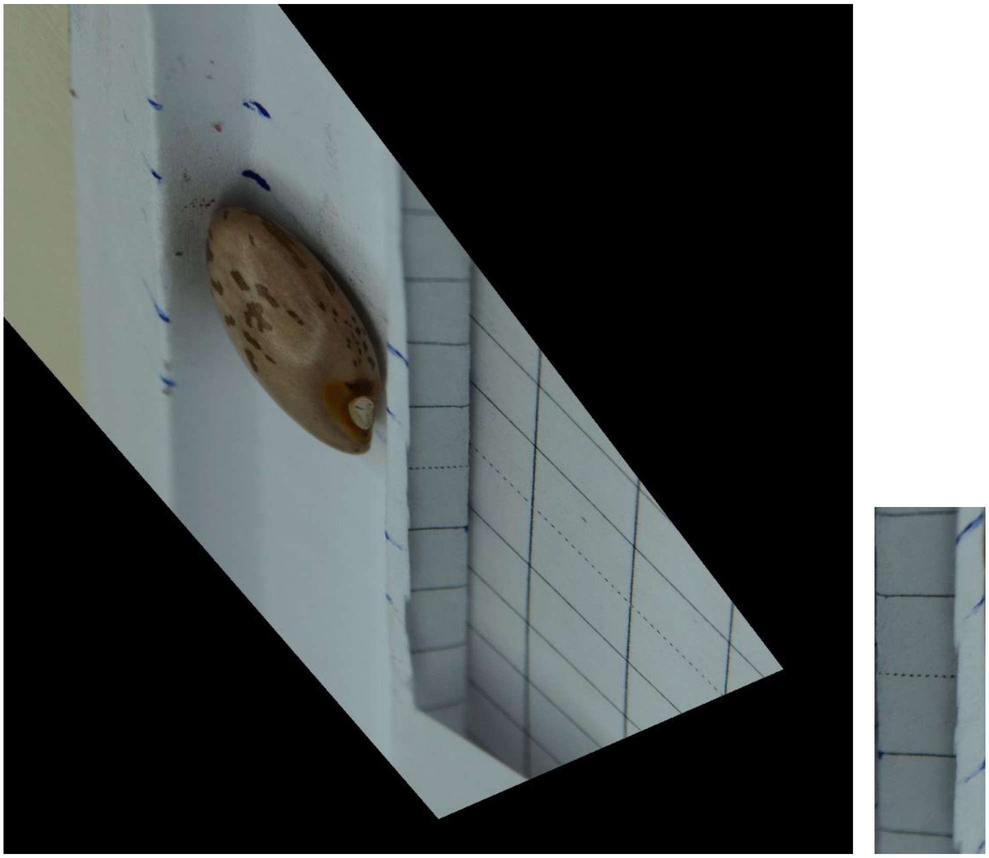


Figure 6: ZX transformation result

To generate 3D VRML model, I modified existing VRML model using text editor.

1. Changed *texture ImageTexture* to cropped images (figures 4, 5, and 6)
2. change *coord Coordinate* of the VRML modelthe actual dimension of the bean box shown in figure 3.
3. view3dscene was used to view the pinto bean VRML model 3D

Result of pinto bean from different 3D angle are generated are shown in figure 7.

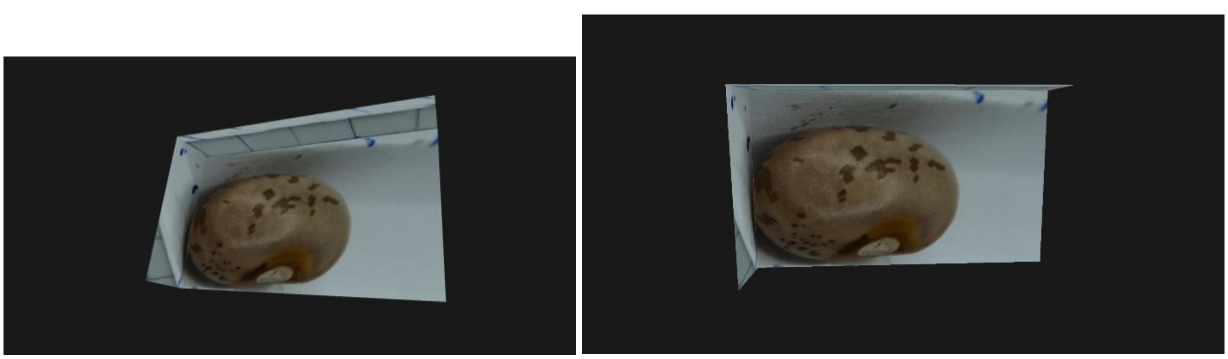
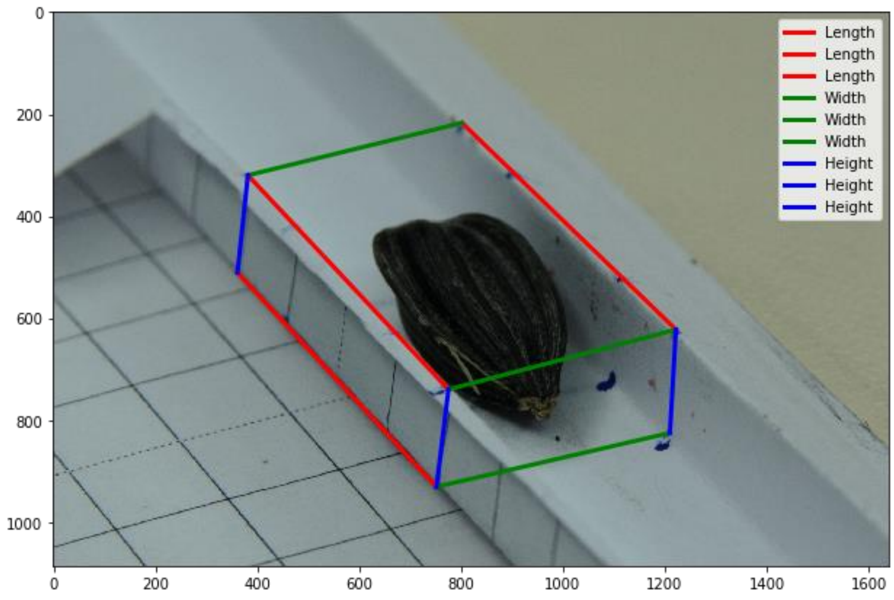


Figure 7: 3D generated images based on VRML model and view3dscene

Figure 8: Actual 90 degree image.

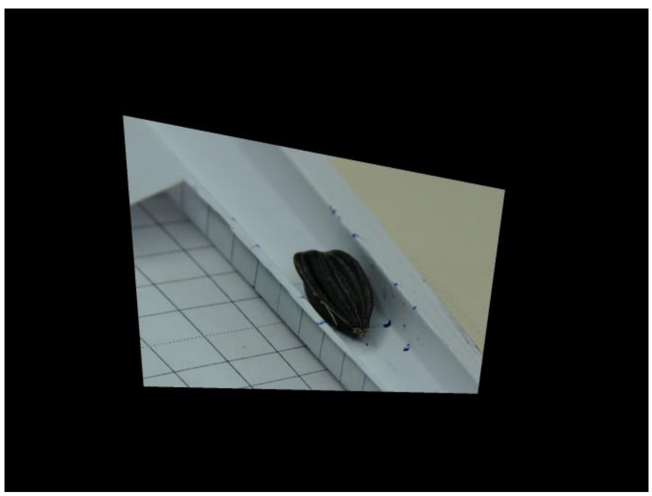
Simple-view 3D models of sunflower seed and wheat kernel were also completed.

Sunflower seed:



Vanishing lines

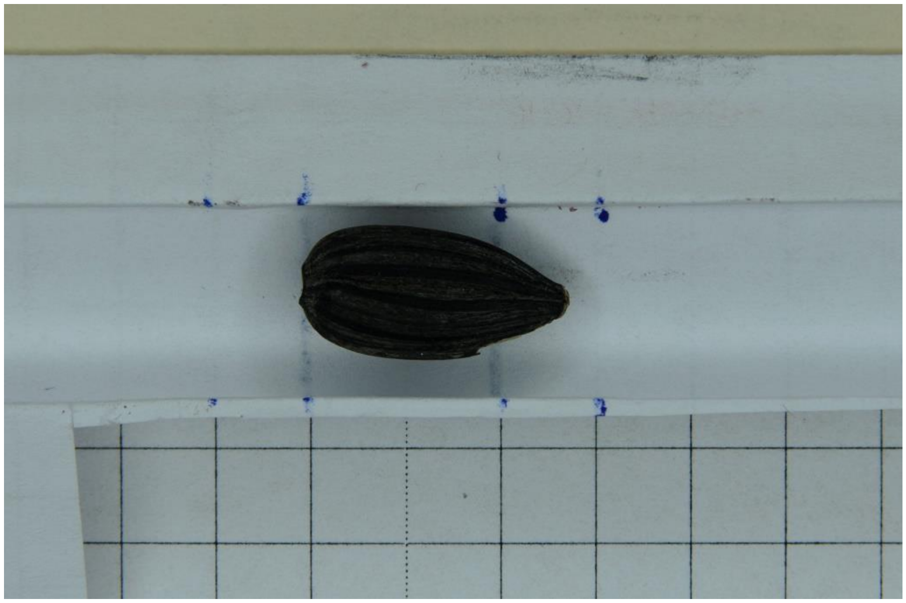
XY figure



YZ figure

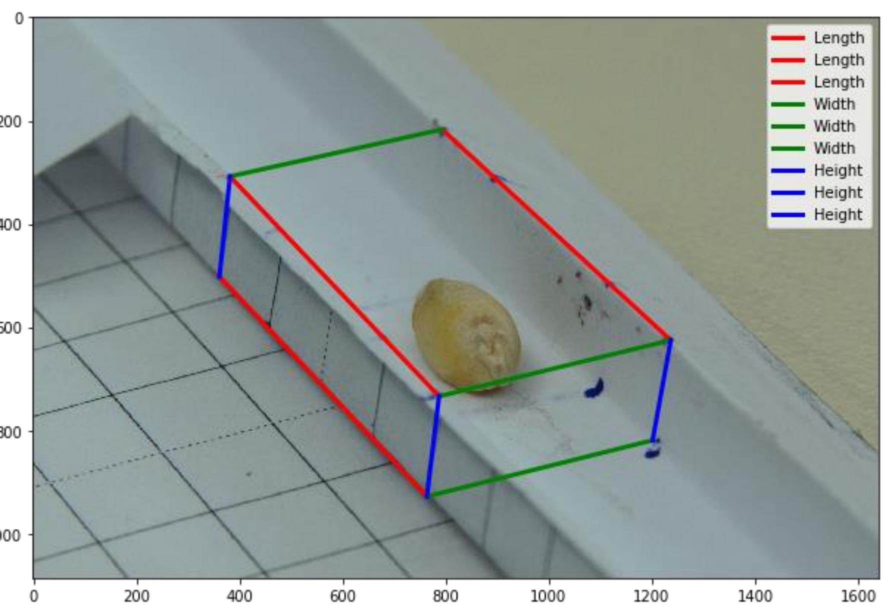
ZX figure

Sunflower 3D generated images based on VRML model and view3dscene

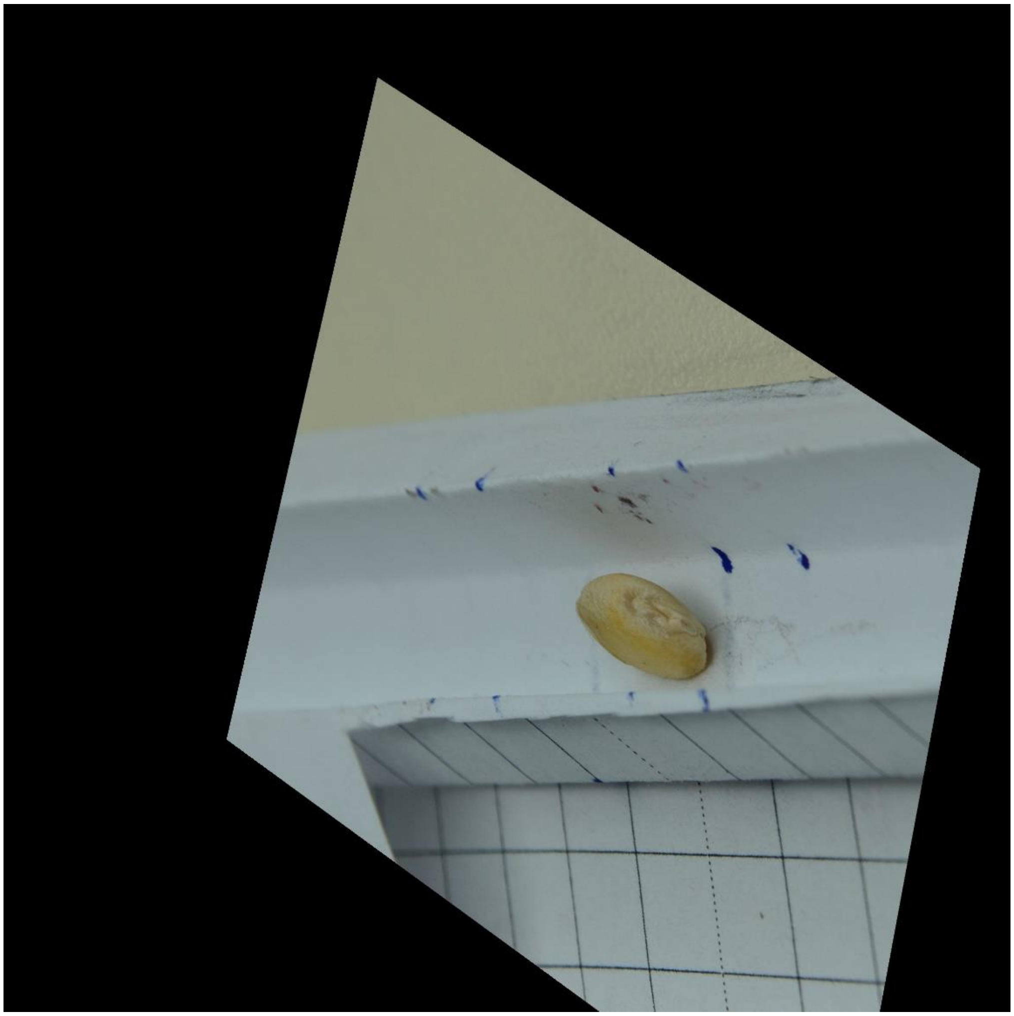


Actual 90-degree view

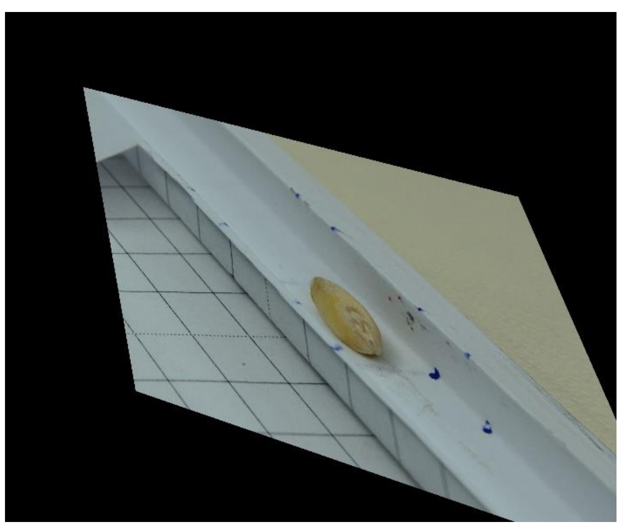
Wheat:



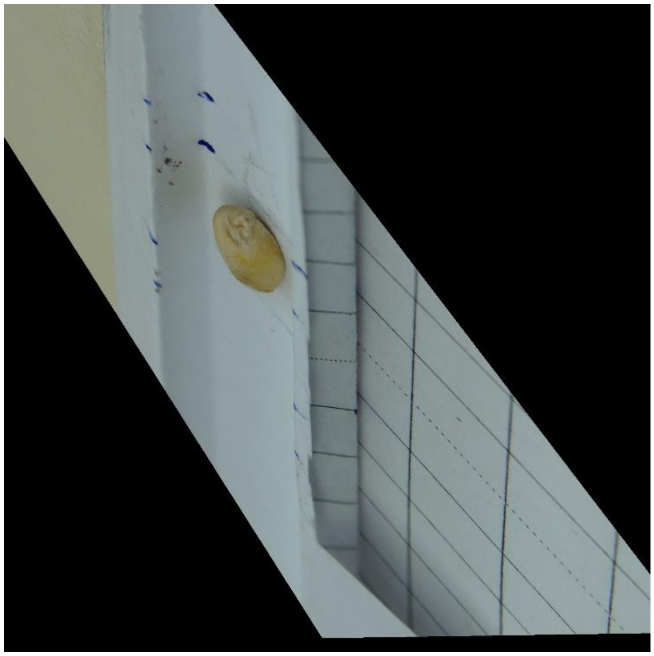
Vanishing lines



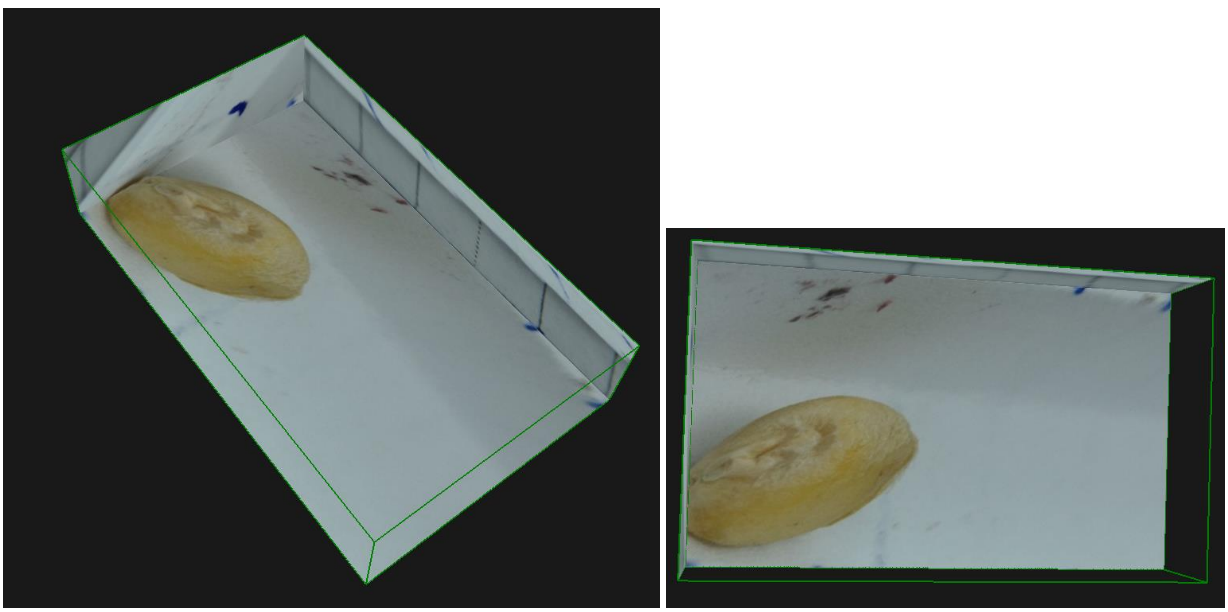
XY figure



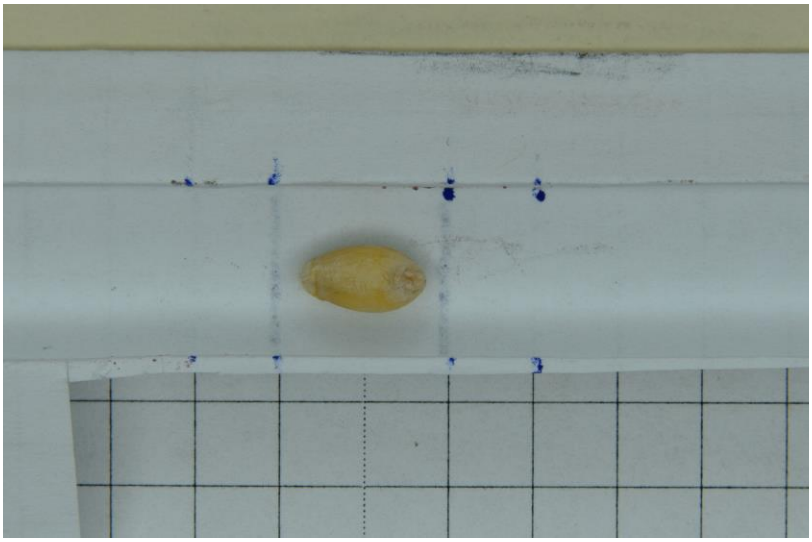
YZ figure



ZX figure



Wheat single view 3D generated images based on VRML model and [view3dscene]



Actual 90-degree view

Discussions and Future Studies

Single view 3D reconstruction for grain kernels was performed in this project. Comparing the 3D generated images to actual images (figures 7 and 8), we can see that the patterns and shapes of two grains are significantly different. The reason is that this model only consider the object as a flat surface, and the object itself doesn't change its shape as the camera positon changes.

To perform 3D reconstruction of grain kernels more precisely, a kernel mask needs to be built. Following methods will be interested to look into in the future:

- Multiple-view 3D reconstruction (Choy et al., 2011).
- Distance sensors such as LADAR (LAser Detection And Ranging) or IR distance sensors (Kinect) to gather the shape of the object.

Reference:

Choy, C. B., Xu, D., Gwak, J., Chen, K., & Savarese, S. (2016, October). 3d-r2n2: A unified approach for single and multi-view 3d object reconstruction. In *European conference on computer vision* (pp. 628-644). Springer, Cham.

Criminisi, A., Reid, I., & Zisserman, A. (2000). Single view metrology. *International Journal of Computer Vision*, *40*(2), 123-148.

Horry, Y., Anjyo, K. I., & Arai, K. (1997, August). Tour into the picture: using a spidery mesh interface to make animation from a single image. In *Proceedings of the 24th annual conference on Computer graphics and interactive techniques* (pp. 225-232).

https://inst.eecs.berkeley.edu/~cs194-26/fa17/Lectures/SingleView.pdf

https://inst.eecs.berkeley.edu/~cs194-26/fa16/upload/files/projFinalUndergrad/cs194-26-abv/

https://github.com/pjrambo/Single-View-Model/tree/master/realimage

https://castle-engine.io/view3dscene.php