Programming Project
CAP 6419 - 3D Computer Vision
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1 Background

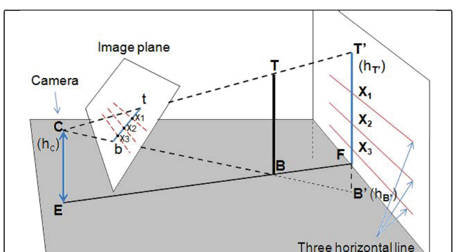
This project is based on the work by Hung & Hartley (2012)[1], in which they present a method to measure human height based on the cross ratio. In their work they compare their method with the vanishing points method used by Criminisi *et al.* (1998)[2], but in this project only the cross ratio approach is used.

For the cross ratio method three elements are required:

1. The camera height (h_C).
2. Three horizontal reference lines (L1, L2 and L3) with known heights (h_1, h_2 and h_3) on the same vertical plane (the *vertical reference plane*).
3. Two vertical lines to identify the vertical vanishing point.

1.1 Computing human height

The following image, taken from Hung & Hartley paper, shows the geometry of the scene:



The geometry of the scene.

In the scene, the top of the human head T and its projection on the ground B correspond to image points t and b, and also correspond with points T' and

[1] N. Hung, R. Hartley. "Height Measurement for Humans in Motion Using a Camera: A Comparison of Different Methods". DICTA2012, 2012.

[2] A. Criminisi, A. Zisserman, L. Van Gool, S. Bramble, and D. Compton. "A new approach to obtain height measurements from video". In *Proc. of SPIE*, vol. 3576, Boston, Massachussets, USA, November 1998.

B' on the vertical reference plane. Having $h_{T'}$ as the height of the point T', $h_{B'}$ as the absolute value of B' height, and h_C as the height of the camera, the human height H can be calculated as:

$$H = \frac{(h_{T'} + h_{B'})h_C}{h_C + h_{B'}} \tag{1}$$

1.2 Computing $h_{T'}$ and $h_{B'}$

The points T', B' and the three horizontal lines all lie on the reference plane, hence the cross ratio can be applied to compute the T' and B' heights. A cross ratio can easily be computed from image points $x1$, $x2$, $x3$ and t. These points correspond to points $X1$, $X2$, $X3$ and T' in the scene. Since cross ratio is preserve under projective transformations, we have:

$$\begin{aligned}
\frac{\overline{tx_2} \times \overline{x_1x_3}}{\overline{x_1x_3} \times \overline{tx_3}} = \frac{\overline{T'X_2} \times \overline{X_1X_3}}{\overline{X_1X_3} \times \overline{T'X_3}} &= \frac{(h_{T'} - h_2)(h_1 - h_3)}{(h_1 - h_2)(h_{T'} - h_3)} \\
\frac{\overline{tx_2} \times \overline{x_1x_3} \times (h_1 - h_2)}{\overline{x_1x_3} \times \overline{tx_3} \times (h_1 - h_3)} &= \frac{(h_{T'} - h_2)}{(h_{T'} - h_3)}
\end{aligned} \tag{2}$$

Since all the values in the left side of equation (2) are known, those values can be replaced with their solved value p, and then we have:

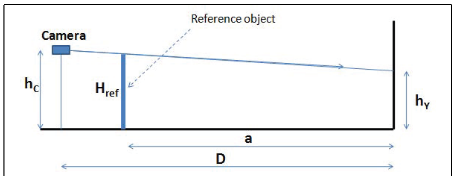
$$\begin{aligned}
p &= \frac{(h_{T'} - h_2)}{(h_{T'} - h_3)} \\
p(h_{T'} - h_3) &= (h_{T'} - h_2) \\
ph_{T'} - ph_3 + h_2 &= h_{T'} \\
h_2 - ph_3 &= h_{T'} - ph_{T'} \\
h_2 - ph_3 &= h_{T'}(1 - p) \\
\frac{h_2 - ph_3}{(1 - p)} &= h_{T'}
\end{aligned} \tag{3}$$

A similar cross ratio can be used to solve $h_{B'}$:

$$\begin{aligned}
\frac{\overline{bx_2} \times \overline{x_1x_3}}{\overline{x_2x_3} \times \overline{bx_1}} = \frac{\overline{B'X_2} \times \overline{X_1X_3}}{\overline{X_2X_3} \times \overline{B'X_1}} &= \frac{(h_{B'} + h_2)(h_1 - h_3)}{(h_2 - h_3)(h_{B'} + h_1)} \\
\frac{\overline{bx_2} \times \overline{x_1x_3} \times (h_2 - h_3)}{\overline{x_2x_3} \times \overline{bx_1} \times (h_1 - h_3)} &= \frac{(h_{B'} + h_2)}{(h_{B'} + h_1)} \\
q &= \frac{(h_{B'} + h_2)}{(h_{B'} + h_1)} \\
q(h_{B'} + h_1) &= (h_{B'} + h_2) \\
qh_{B'} + qh_1 - h_2 &= h_{B'} \\
qh_1 - h_2 &= h_{B'} - qh_{B'} \\
qh_1 - h_2 &= h_{B'}(1 - q) \\
\frac{qh_1 - h_2}{(1 - q)} &= h_{B'}
\end{aligned} \tag{4}$$

1.3 Computing camera height

A reference object with known height is placed between the camera and the reference plane as shown below (image taken from the Hung & Hartley paper):



Camera height calculation.

The camera height can be computed using the following equation:

$$h_C = h_Y + (H_{ref} - h_Y)\frac{D}{a} \tag{5}$$

The value h_Y can be computed using the same process of measuring $h_{T'}$ and $h_{B'}$.

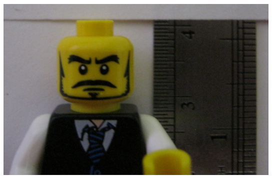
2 Implementation

The function *d()* was implemented in MATLAB to measure the distance between two image points. This function is used to calculate equations (3) and (4), where the segments of lines are needed to estimate cross ratios.

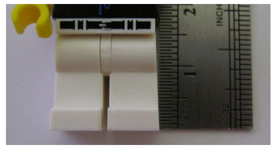
Also a script called *test* was implemented in MATLAB to calculate the human height in an interactive way. Before running the script, the value of h_1, h_2, h_3, a, D, H_{ref} and h_Y must be set manually at the beginning of the script, by opening the script with a text editor and inserting the correct values in the script. When the script is called, the image file named "img.jpg" is loaded and shown. Then, the user must select in the image the points t and b, by clicking over the image. The it must select the three horizontal lines, by choosing two points of each line. After this, the script calculates and displays the human height.

3 Experimental set up

A simple experimental setup was used that mimics experiments by Hung & Hartley. A Lego figure is used as test subject, which measure around $41mm$. For the three horizontal lines, a printed pattern was placed over the ground, with lines L1, L2 and L3 at heights $h_1 = 30mm$, $h_2 = 20mm$ and $h_3 = 10mm$, respectively. A vertical ruler was used as reference object, placed at $100mm$ from the vertical reference plane, and the camera was placed $265mm$ away from the vertical reference plane. The following images illustrate the experimental setup:



Head close up.



Legs aligned with ruler.

Total height.

Experimental setup: L1 (30mm), L2 (20mm) and L3 (10mm) are the horizontal lines. Reference object (the ruler) is placed 100mm in front of the vertical reference plane (in white). The camera is placed 265mm away from the vertical reference plane.

4 Input image and results

The image taken from the camera follows:

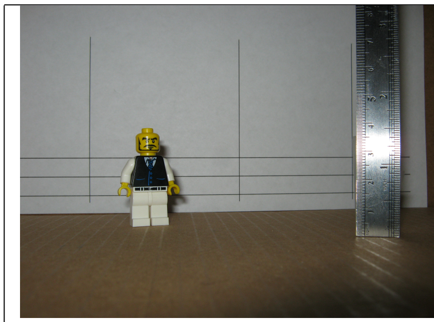
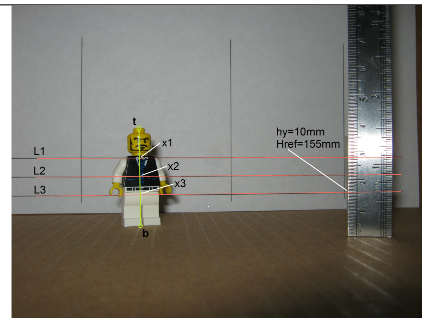


Image taken from the camera.



Reference lines and points.

From the input images, the reference lines L1, L2 and L3 were marked manually, as well as points t and b.

To compute camera height, instead of using and object with known height as H_{ref} and then calculate h_Y, we pick a known h_Y, let's say h_3, and use the ruler to see the matching H_{ref}, in this case $H_{ref} = 15.5mm$. Using equation (5), the camera height was estimated to be $h_C = 24.575mm$.

Using equations (3) and (4), the estimated height of points T' and B' was $h_{T'} = 46.05mm$ and $h_{B'} = 6.61mm$. With those results, and using equation (1), the estimated height of the Lego figure was $41.497mm$, which is 1.2% off the measured height of $41mm$.

5 Conclusions

The cross ratio method seems quite reliable to measure human height, even taking into account all the possible imprecision in setting up the experiment: the errors in measuring the distance between the vertical reference plane and the reference object and the camera, or the errors in manually selecting the horizontal lines and points t and b, not to mention that, as the whole setup was mimic using toys and cardboard materials, archiving high precision was very difficult.