# Perceptron Images: The Camera and Models

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The Perceptron [1] range camera recovers depth by computing the phase shift between an outgoing laser beam and its returned (bounced back) signal. A detailed description of the workings of the camera can be found in [2, 3], from which the following equations are taken. Each pixel in a Perceptron range image $r[i][j], 0 <= i, j <= 512$ is converted to Cartesian coordinates (in centimeters) as follows:

$$
\begin{array}{ll}
x[i,j] = dx + r_3 \cdot sin(\alpha) & \alpha = \alpha_{\mathbf{0}} + \mathbf{H}(255.5 - j)/512.0 \\
y[i,j] = dy + r_3 \cdot cos(\alpha) sin(\beta) & \beta = \beta_{\mathbf{0}} + \mathbf{V}(255.5 - i)/512.0 \\
z[i,j] = dz + r_3 \cdot cos(\alpha) cos(\beta) &
\end{array}
$$

$$
\begin{array}{ll}
r_1 = (dz - \mathbf{h_2})/\delta & dx = (\mathbf{h_2} + dy) tan(\alpha) \\
r_2 = \sqrt{(dx)^2 + (\mathbf{h_2} + dy)^2}/\delta & dy = dz \cdot tan(\theta + \frac{1}{2}\beta) \\
r_3 = (r[i,j] + \mathbf{r_0} - (r_1 + r_2))\delta & dz = -\mathbf{h_1}(1.0 - cos(\alpha))/tan(\gamma)
\end{array}
$$

The specific values of $\mathbf{h_1}$, $\mathbf{h_2}$, $\gamma$, $\theta$, $\alpha_{\mathbf{0}}$, $\beta_{\mathbf{0}}$, $\mathbf{H}$, $\mathbf{V}$, $\mathbf{r_0}$ and $\delta$ are obtained through calibration before imaging. For the 40 images used in this project, the calibrated values are:

$$
\begin{array}{l}
\mathbf{h_1} = 3.0, \quad \mathbf{h_2} = 5.5, \quad \gamma = \theta = 45.0^\circ, \quad \alpha_{\mathbf{0}} = \beta_{\mathbf{0}} = 0.0 \\
\mathbf{H} = 51.65, \quad \mathbf{V} = 36.73, \quad \mathbf{r_0} = 830.3, \quad \delta = 0.20236
\end{array}
$$

Figure 1 shows the six objects used in imaging. CAD descriptions of these objects, in the form of vertex and face lists, are included at the end of this write-up for the sake of completeness. Scale is in centimeters. Table 1 lists which objects appear in each of the 40 images.

## References

[1] LASAR Hardware Manual, Perceptron Inc., 23855 Research Drive, Farmington Hills, Michigan 48335, 1993.

[2] O. H. Dorum, A. Hoover and J. P. Jones, "Calibration and control for range imaging in mobile robot navigation", in *Proc. Vision Interface '94*, Banff, Alberta, Canada; May 18-20, 1994.

[3] O. H. Dorum, A. Hoover and J. P. Jones, "Calibration and control for range imaging in mobile robot navigation", in Research in Computer and Robot Vision, edited by C. Archibald and P. Kwok; World Scientific Press, Singapore, In Press.

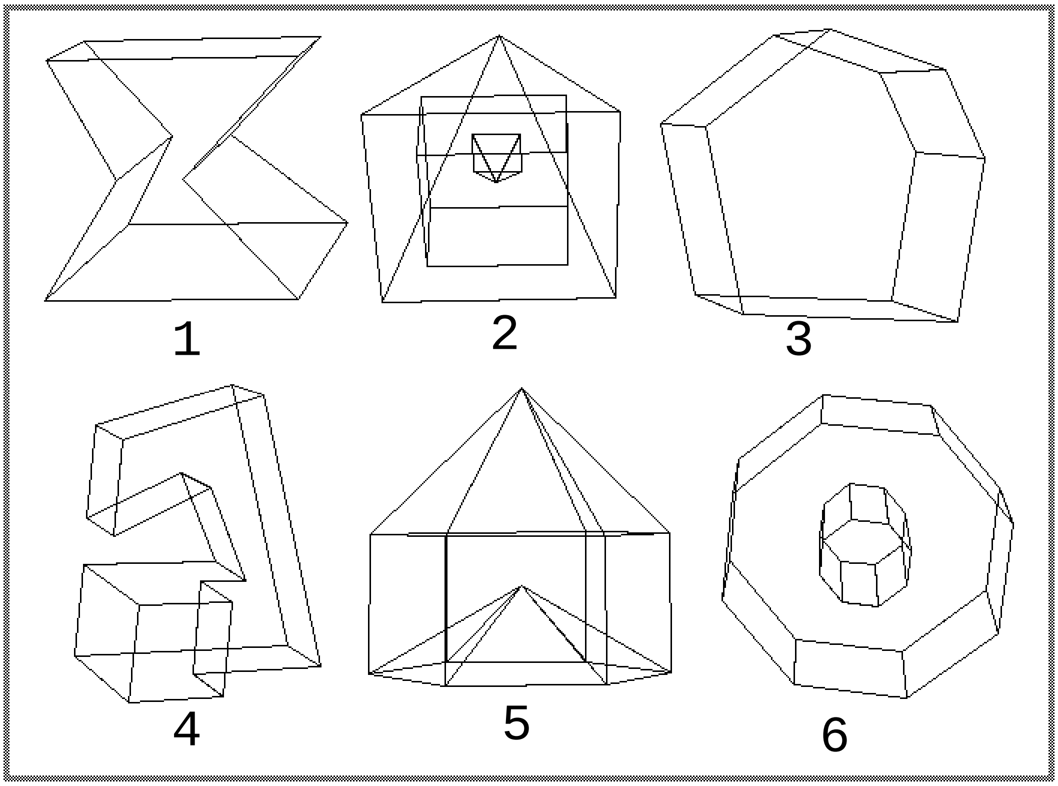


Figure 1: Models of objects used in imaging.

| image name | objects | image name | objects | image name | objects |
|---|---|---|---|---|---|
| perc.train.0 | 1 | perc.test.3 | 2 | perc.test.17 | 2,6 |
| perc.train.1 | 3 | perc.test.4 | 2 | perc.test.18 | 4,5 |
| perc.train.2 | 5 | perc.test.5 | 3 | perc.test.19 | 2,4,6 |
| perc.train.3 | 4 | perc.test.6 | 3 | perc.test.20 | 1,3,6 |
| perc.train.4 | 1,3 | perc.test.7 | 4 | perc.test.21 | 2,5,6 |
| perc.train.5 | 2,3 | perc.test.8 | 4 | perc.test.22 | 1,2,6 |
| perc.train.6 | 4,5,6 | perc.test.9 | 5 | perc.test.23 | 2,4,6 |
| perc.train.7 | 1,3,4 | perc.test.10 | 5 | perc.test.24 | 2,3,5 |
| perc.train.8 | 2,3,5 | perc.test.11 | 6 | perc.test.25 | 1,4,5 |
| perc.train.9 | 1,4,5,6 | perc.test.12 | 6 | perc.test.26 | 2,4,5,6 |
| perc.test.0 | 1 | perc.test.13 | 6 | perc.test.27 | 2,3,5,6 |
| perc.test.1 | 1 | perc.test.14 | - | perc.test.28 | 1,3,4,5,6 |
| perc.test.2 | 2 | perc.test.15 | 4,6 | perc.test.29 | 2,3,4,5,6 |
| | | perc.test.16 | 1,5 | | |

Table 1: Which objects appear in each image.

| x | y | z | | faces |
|---|---|---|---|---|
| 2.00000 | 0.00000 | 0.00000 | | 6 5 4 3 2 1 |
| 78.50000 | 0.00000 | 0.00000 | | 7 8 9 10 11 12 |
| 56.82132 | 33.60889 | 12.75000 | | 1 2 8 7 |
| 78.50000 | 67.21779 | 25.50000 | | 2 3 9 8 |
| 2.00000 | 67.21779 | 25.50000 | | 3 4 10 9 |
| 36.76479 | 33.60889 | 12.75000 | | 4 5 11 10 |
| 2.00000 | 0.00000 | -38.00000 | | 5 6 12 11 |
| 78.50000 | 0.00000 | -38.00000 | | 6 1 7 12 |
| 56.82132 | 33.60889 | -50.75000 | | |
| 78.50000 | 67.21779 | -63.50000 | | |
| 2.00000 | 67.21779 | -63.50000 | | |
| 36.76479 | 33.60889 | -50.75000 | | |

Table 2: CAD description of Object 1: 12 vertices, 8 faces.

| x | y | z | | faces |
|---|---|---|---|---|
| 19.00000 | 0.00000 | 0.00000 | | 1 2 3 4 |
| 109.00000 | 0.00000 | 0.00000 | | 5 6 7 8 |
| 109.00000 | 90.00000 | 0.00000 | | 2 1 18 |
| 19.00000 | 90.00000 | 0.00000 | | 4 3 18 |
| 37.00000 | 18.00000 | 0.00000 | | 1 4 18 |
| 91.00000 | 18.00000 | 0.00000 | | 3 2 18 |
| 91.00000 | 72.00000 | 0.00000 | | 12 11 10 9 |
| 37.00000 | 72.00000 | 0.00000 | | 16 15 14 13 |
| 37.00000 | 18.00000 | 32.99655 | | 9 10 6 5 |
| 91.00000 | 18.00000 | 32.99655 | | 10 11 7 6 |
| 91.00000 | 72.00000 | 32.99655 | | 11 12 8 7 |
| 37.00000 | 72.00000 | 32.99655 | | 12 9 5 8 |
| 55.00000 | 36.00000 | 32.99655 | | 13 14 17 |
| 73.00000 | 36.00000 | 32.99655 | | 14 15 17 |
| 73.00000 | 54.00000 | 32.99655 | | 15 16 17 |
| 55.00000 | 54.00000 | 32.99655 | | 16 13 17 |
| 64.00000 | 45.00000 | 16.49827 | | |
| 64.00000 | 45.00000 | 107.23881 | | |

Table 3: CAD description of Object 2: 18 vertices, 16 faces.

| x | y | z | | faces |
|---|---|---|---|---|
| 2.00000 | 0.00000 | 0.00000 | | 6 5 4 3 2 1 |
| -2.88072 | 55.78690 | 0.00000 | | 7 8 9 10 11 12 |
| 13.61927 | 84.36574 | 0.00000 | | 1 2 8 7 |
| 54.67112 | 95.36555 | 0.00000 | | 2 3 9 8 |
| 94.88845 | 61.61920 | 0.00000 | | 3 4 10 9 |
| 78.00000 | 0.00000 | 0.00000 | | 4 5 11 10 |
| 2.00000 | 0.00000 | 64.00000 | | 5 6 12 11 |
| -2.88072 | 55.78690 | 64.00000 | | 6 1 7 12 |
| 13.61927 | 84.36574 | 64.00000 | | |
| 54.67112 | 95.36555 | 64.00000 | | |
| 94.88845 | 61.61920 | 64.00000 | | |
| 78.00000 | 0.00000 | 64.00000 | | |

Table 4: CAD description of Object 3: 12 vertices, 8 faces.

| x | y | z | | faces |
|---|---|---|---|---|
| -17.00000 | 0.00000 | 0.00000 | | 6 5 4 3 2 1 |
| 73.00000 | 0.00000 | 0.00000 | | 1 2 7 8 9 10 11 12 |
| 73.00000 | 59.50000 | 0.00000 | | 5 6 13 14 15 16 20 17 |
| 37.00000 | 59.50000 | 0.00000 | | 12 13 6 1 |
| 37.00000 | 29.75000 | 0.00000 | | 19 18 17 20 8 7 |
| -17.00000 | 29.75000 | 0.00000 | | 2 3 19 7 |
| 73.00000 | 0.00000 | 36.00000 | | 3 4 18 19 |
| 19.00000 | 0.00000 | 36.00000 | | 4 5 17 18 |
| 37.00000 | 0.00000 | 72.00000 | | 20 16 9 8 |
| 73.00000 | 0.00000 | 54.00000 | | 16 15 10 9 |
| 73.00000 | 0.00000 | 90.00000 | | 15 14 11 10 |
| 19.00000 | 0.00000 | 108.00000 | | 14 13 12 11 |
| 19.00000 | 29.75000 | 108.00000 | | |
| 73.00000 | 29.75000 | 90.00000 | | |
| 73.00000 | 29.75000 | 54.00000 | | |
| 37.00000 | 29.75000 | 72.00000 | | |
| 37.00000 | 29.75000 | 36.00000 | | |
| 37.00000 | 59.50000 | 36.00000 | | |
| 73.00000 | 59.50000 | 36.00000 | | |
| 19.00000 | 29.75000 | 36.00000 | | |

Table 5: CAD description of Object 4: 20 vertices, 12 faces.

| x | y | z | | faces |
|---|---|---|---|---|
| 26.25000 | 0.00000 | 0.00000 | | 1 2 14 |
| 76.75000 | 0.00000 | 0.00000 | | 2 3 14 |
| 102.00000 | 43.73428 | 0.00000 | | 3 4 14 |
| 76.75000 | 87.46856 | 0.00000 | | 4 5 14 |
| 26.25000 | 87.46856 | 0.00000 | | 5 6 14 |
| 1.00000 | 43.73428 | 0.00000 | | 6 1 14 |
| 26.25000 | 0.00000 | 46.00000 | | 2 1 7 8 |
| 76.75000 | 0.00000 | 46.00000 | | 3 2 8 9 |
| 102.00000 | 43.73428 | 46.00000 | | 4 3 9 10 |
| 76.75000 | 87.46856 | 46.00000 | | 5 4 10 11 |
| 26.25000 | 87.46856 | 46.00000 | | 6 5 11 12 |
| 1.00000 | 43.73428 | 46.00000 | | 1 6 12 7 |
| 51.50000 | 43.73428 | 95.41913 | | 8 7 13 |
| 51.50000 | 43.73428 | 29.07803 | | 9 8 13 |
| | | | | 10 9 13 |
| | | | | 11 10 13 |
| | | | | 12 11 13 |
| | | | | 7 12 13 |

Table 6: CAD description of Object 5: 14 vertices, 18 faces.

| x | y | z | | faces |
|---:|---:|---:|---|---|
| 27.50683 | 0.00000 | 0.00000 | | 1 2 3 4 5 6 7 8 |
| 64.99316 | 0.00000 | 0.00000 | | 24 23 22 21 20 19 18 17 |
| 91.50000 | 26.50683 | 0.00000 | | 16 15 14 13 12 11 10 9 |
| 91.50000 | 63.99316 | 0.00000 | | 25 26 27 28 29 30 31 32 |
| 64.99316 | 90.50000 | 0.00000 | | 2 1 9 10 |
| 27.50683 | 90.50000 | 0.00000 | | 3 2 10 11 |
| 1.00000 | 63.99316 | 0.00000 | | 4 3 11 12 |
| 1.00000 | 26.50683 | 0.00000 | | 5 4 12 13 |
| 27.50683 | 0.00000 | 45.00000 | | 6 5 13 14 |
| 64.99316 | 0.00000 | 45.00000 | | 7 6 14 15 |
| 91.50000 | 26.50683 | 45.00000 | | 8 7 15 16 |
| 91.50000 | 63.99316 | 45.00000 | | 1 8 16 9 |
| 64.99316 | 90.50000 | 45.00000 | | 17 18 26 25 |
| 27.50683 | 90.50000 | 45.00000 | | 18 19 27 26 |
| 1.00000 | 63.99316 | 45.00000 | | 19 20 28 27 |
| 1.00000 | 26.50683 | 45.00000 | | 20 21 29 28 |
| 40.34745 | 31.00000 | 0.00000 | | 21 22 30 29 |
| 52.15254 | 31.00000 | 0.00000 | | 22 23 31 30 |
| 60.50000 | 39.34745 | 0.00000 | | 23 24 32 31 |
| 60.50000 | 51.15254 | 0.00000 | | 24 17 25 32 |
| 52.15254 | 59.50000 | 0.00000 | | |
| 40.34745 | 59.50000 | 0.00000 | | |
| 32.00000 | 51.15254 | 0.00000 | | |
| 32.00000 | 39.34745 | 0.00000 | | |
| 40.34745 | 31.00000 | 45.00000 | | |
| 52.15254 | 31.00000 | 45.00000 | | |
| 60.50000 | 39.34745 | 45.00000 | | |
| 60.50000 | 51.15254 | 45.00000 | | |
| 52.15254 | 59.50000 | 45.00000 | | |
| 40.34745 | 59.50000 | 45.00000 | | |
| 32.00000 | 51.15254 | 45.00000 | | |
| 32.00000 | 39.34745 | 45.00000 | | |

Table 7: CAD description of Object 6: 32 vertices, 20 faces.