# CAMERA CALIBRATION

DepthSenseSDK

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| **Project Name – Reference** | Camera Calibration |
| **Ordering Part number** | |
| **Version** | V2.0 |
| **Last Change - Revision** | 13.03.2015 |
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*CONFIDENTIALITY*

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# 1 Introduction

This document describes the camera model used in DepthSenseSDK and assumes that the DepthNode::coordinateSystemType is set to COORDINATE_SYSTEM_TYPE_RIGHT_HANDED.

The coordinate system is as follow:

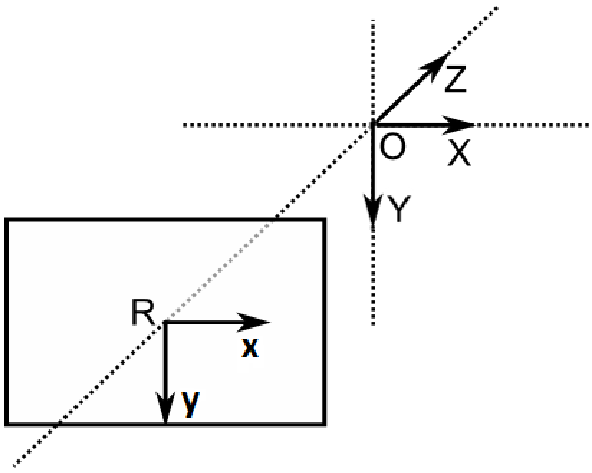


**Figure 1 DepthSenseSDK Right-Handed Coordinate System**

Note that the default coordinate system used in DepthSenseSDK is a left-handed coordinate system. It is highly recommended to change the coordinate system to the right-handed coordinate system.

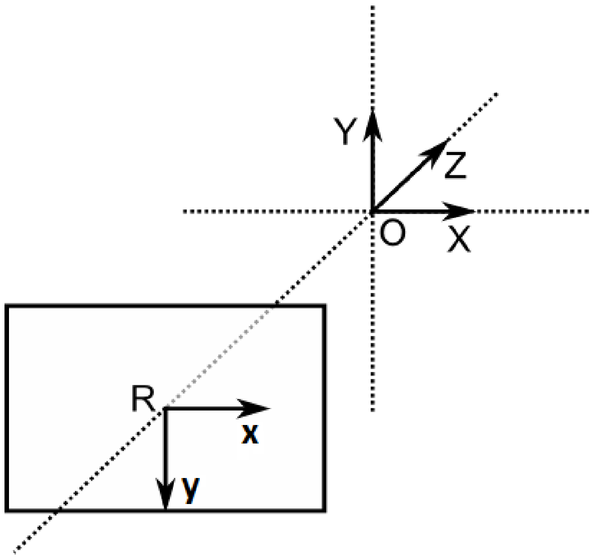


**Figure 2 DepthSenseSDK Left-Handed Coordinate System**

## 1.1 Definitions, acronyms and abbreviations

**DSSDK**: DepthSenseSDK

## 2 Matrix of intrinsic parameters

Each color or depth node is modeled by the following matrices:

$$A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \text{ and } [k_1 \quad k_2 \quad p_1 \quad p_2 \quad k_3]$$

Where:

- $f_x$, $f_y$ are respectively the focal length in pixel-related units along the x and y axis
- $c_x$, $c_y$ are respectively the principal point of the camera along the x and y axis
- $k_1$, $k_2$, $k_3$ are the radial distortion coefficients
- $p_1$ and $p_2$ are the tangential distortion coefficients

The A matrix is the pinhole camera model of the camera and the distortion coefficients are used to correct the distortion of the lenses.

These parameters will vary depending on the frame format in use for the node.

# 3 Matrix of extrinsic parameters

The following matrices are used to describe the relative positions of the color and depth cameras in the system.

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \text{ and } t = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix}$$

Where:

- R is a rotation matrix
- t is the translation matrix expressed in meters

These matrices are used to convert 3D coordinates from the depth coordinate system to the color coordinate system.

These matrices are frame format invariant and do not depend on the contents of the scene.

Note that in case the Left-Handed coordinate system is used, the sign of the Y component of the vertices, $r_{21}$, $r_{22}$, $r_{23}$ and $t_2$ should be inverted before applying the transformation. Note that the resulting coordinates will be expressed in a Right-Handed coordinate system.

## 4 Projecting a 3D point into the depth camera plane

Let ($X_D$, $Y_D$, $Z_D$) be the coordinates of a 3D point in the world coordinate space expressed in the depth coordinate system and ($x_D$, $y_D$) the coordinates of the projection point in pixels in the depth camera plane. The intrinsic parameters to be used are the one of the depth camera.

The projection point can be computed with the following formula:

$$x_D = f_{xD} * x'' + c_{xD}$$

$$y_D = f_{yD} * y'' + c_{yD}$$

Where:

$$x'' = x'(1 + k_{1D}r^2 + k_{2D}r^4 + k_{3D}r^6) + 2p_{1D}x'y' + p_{2D}(r^2 + 2x'^2)$$

$$y'' = y'(1 + k_{1D}r^2 + k_{2D}r^4 + k_{3D}r^6) + 2p_{2D}x'y' + p_{1D}(r^2 + 2y'^2)$$

Where:

$$x' = \frac{X_D}{Z_D}$$

$$y' = \frac{Y_D}{Z_D}$$

$$r^2 = x'^2 + y'^2$$

# 5 Projecting a 3D point into the color camera plane

Let ($X_D$, $Y_D$, $Z_D$) be the coordinates of a 3D point in the world coordinate space expressed in the depth coordinate system and ($x_C$, $y_C$) the coordinates of the projection point in pixels in the color camera plane. The intrinsic parameters to be used are the one for the color camera.

The projection point can be computed with the following formula:

$$x_c = f_{xC} * x'' + c_{xC}$$

$$y_C = f_{yC} * y'' + c_{yC}$$

Where:

$$x'' = x'(1 + k_{1C}r^2 + k_{2C}r^4 + k_{3C}r^6) + 2p_{1C}x'y' + p_{2C}(r^2 + 2x'^2)$$

$$y'' = y'(1 + k_{1C}r^2 + k_{2C}r^4 + k_{3C}r^6) + 2p_{2C}x'y' + p_{1C}(r^2 + 2y'^2)$$

Where:

$$x' = \frac{X_C}{Z_C}$$

$$y' = \frac{Y_C}{Z_C}$$

$$r^2 = x'^2 + y'^2$$

Where:

$$\begin{bmatrix} X_C \\ Y_C \\ Z_C \end{bmatrix} = R \begin{bmatrix} X_D \\ Y_D \\ Z_D \end{bmatrix} + t$$