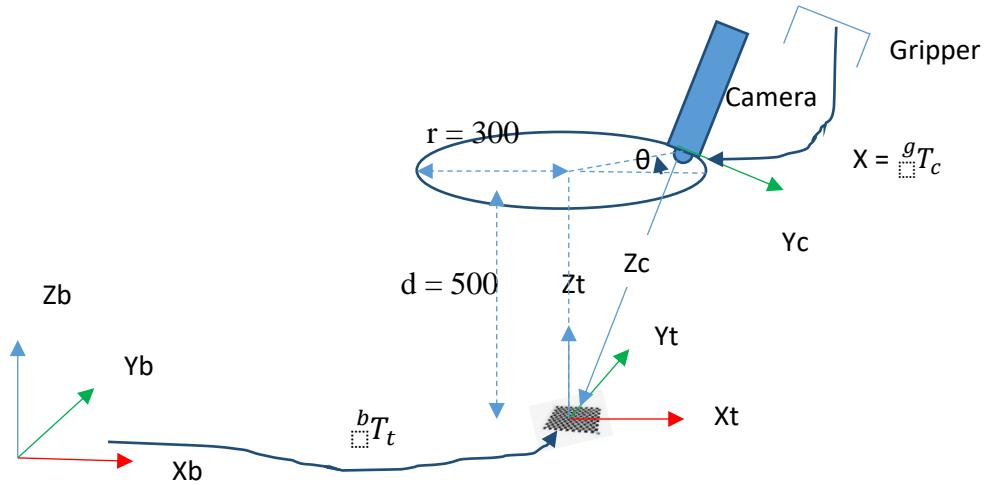


Simulation of the Hand-Eye

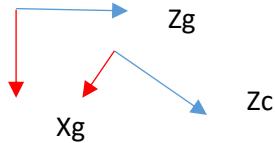


If we look at the Figure, we define a calibration plate defined by $\{X_t, Y_t, Z_t\}$, placed at ${}^b T_t$ with respect to the base of the robot $\{X_b, Y_b, Z_b\}$. The camera is placed at a vertical distance $d = 500$ mm, and at the circumference of a circle of radius $r = 300$ mm at different angles, with the Z_c axis pointing at the origin of frame $\{t\}$, and X_c parallel to the plane $\{X_t, Y_t\}$.

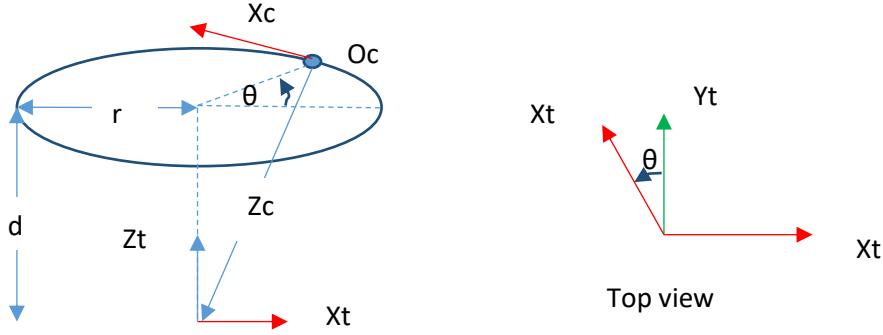
Suppose that the plate is parallel to the base of the robot, and at 500 mm in X_b , 0 mm in

Y_b and 200mm in Z_b , i.e. ${}^b T_t = \begin{bmatrix} I & 500 \\ 0 & 0 \\ 0 & 200 \\ 0 & 1 \end{bmatrix}$. Also, suppose that the axis Y_c and Y_g are aligned, and that the axis Z_c is tilted 45° downwards respect to the axis Z_g , i.e. ${}^g T_c =$

$$\begin{bmatrix} c45^\circ & 0 & s45^\circ & 100 \\ 0 & 1 & 0 & 200 \\ -s45^\circ & 0 & c45^\circ & 300 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$



Suppose also, that the camera is situated at n equally space positions in the circle above the plate, with the Z_c pointing at the origin of $\{t\}$, and that we add some randomness to the position and orientation of the camera.



From the Figure, we realize that ${}^tO_c = \begin{bmatrix} r * c\theta \\ r * s\theta \\ d \end{bmatrix}$,

$${}^tZ_c = \frac{{}^0 - {}^tO_c}{\| {}^tO_c \|} = - \frac{\begin{bmatrix} r * c\theta \\ r * s\theta \\ d \end{bmatrix}}{\sqrt{r^2 + d^2}}, \quad {}^tX_c = \frac{\begin{bmatrix} -r * s\theta \\ r * c\theta \\ 0 \end{bmatrix}}{r}, \quad {}^tY_c = {}^tZ_c \times {}^tX_c,$$

$${}^tR_c = [{}^tX_c \quad {}^tY_c \quad {}^tZ_c], \quad {}^cT_t = \begin{bmatrix} {}^tR_c^T & -{}^tR_c^T * {}^tO_c \\ 0 & 1 \end{bmatrix}$$

Finally, the positions of the gripper can be calculated from ${}^bT_t = {}^bT_g * {}^gT_c * {}^cT_t$:

$${}^bT_g = {}^bT_t * {}^cT_t^{-1} * {}^gT_c^{-1}$$

In the simulation in Matlab, we have to add randomness to the position and orientations of the camera, because on the other case the solution does not have enough differences.