Chapter 16
Applications of Machine Vision to Industrial Systems

Abstract. Applications of vision-based industrial robotic systems are rapidly expanding due to the increase in computer processing power and low prices in machine vision hardware. Visual servoing over a network of synchronized cameras is an example where the significance of machine vision and distributed filtering for industrial robotic systems can be seen. A robotic manipulator is considered and a cameras network consisting of multiple vision nodes is assumed to provide the visual information to be used in the control loop. A derivative-free implementation of the Extended Information Filter is used to produce the aggregate state vector of the robot by processing local state estimates coming from the distributed vision nodes. The performance of the considered vision-based control scheme is evaluated through simulation experiments.

16.1 Machine Vision and Imaging Transformations

16.1.1 Some Basic Transformations

In Chapter 1 the kinematics of a multi-link robot were analyzed. In the following, several important transformations used in machine vision for robotic applications will be discussed. It will also be explained how a camera model can be derived and how one can treat the stereo imaging problem. The basic imaging transformations are [107]:

(i) Translation: The objective is to translate a point with coordinates \((X,Y,Z)\) to a new location by using displacements \((X_0,Y_0,Z_0)\). The translation is easily accomplished by using the following equation:

\[
\begin{pmatrix}
X^* \\
Y^* \\
Z^*
\end{pmatrix} = \begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix} + \begin{pmatrix}
X_0 \\
Y_0 \\
Z_0
\end{pmatrix}
\] (16.1)
where \((X^*, Y^*, Z^*)\) are the coordinates of the new point. Eq. (16.1) can be also written in the form

\[
\begin{pmatrix}
X^* \\
Y^* \\
Z^* \\
1
\end{pmatrix} =
\begin{pmatrix}
1 & 0 & 0 & X_0 \\
0 & 1 & 0 & Y_0 \\
0 & 0 & 1 & Z_0 \\
0 & 0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
X \\
Y \\
Z \\
1
\end{pmatrix}
\] (16.2)

It is often useful to concatenate several transformations to produce a composite result, such as translation, followed by scaling, and then rotation. Eq. (16.2) can be written as

\[v^* =Tv\] (16.3)

where \(T\) is a \(4\times4\) transformation matrix, \(v\) is a column vector containing the original coordinates and \(v^*\) is a column vector whose components are the transformed coordinates:

\[
v =
\begin{pmatrix}
X \\
Y \\
Z \\
1
\end{pmatrix}, \quad v^* =
\begin{pmatrix}
X^* \\
Y^* \\
Z^* \\
1
\end{pmatrix}
\] (16.4)

while the matrix used for translation is given by

\[
T =
\begin{pmatrix}
1 & 0 & 0 & X_0 \\
0 & 1 & 0 & Y_0 \\
0 & 0 & 1 & Z_0 \\
0 & 0 & 0 & 1
\end{pmatrix}
\] (16.5)

(ii) **Scaling**: Scaling by factors \(S_x\), \(S_y\) and \(S_z\) along the \(X\), \(Y\) and \(Z\) axes is given by the transformation matrix

\[
S =
\begin{pmatrix}
S_x & 0 & 0 & 0 \\
0 & S_y & 0 & 0 \\
0 & 0 & S_z & 0 \\
0 & 0 & 0 & 1
\end{pmatrix}
\] (16.6)

(iii) **Rotation**: Rotation of a point about the \(Z\) coordinate axis by an angle \(\theta\) is achieved by using the transformation

\[
R_\theta =
\begin{pmatrix}
\cos(\theta) & \sin(\theta) & 0 & 0 \\
-\sin(\theta) & \cos(\theta) & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{pmatrix}
\] (16.7)

The rotation angle \(\theta\) is measured clockwise. Similarly, rotation of a point about the \(X\) axis by an angle \(\alpha\) is performed by using the transformation