Mapping and Localization from a Panoramic Vision Sensor

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which can be expressed in matrix form as

\[ \Lambda = \Phi^T \Sigma \Phi, \]  

(A.5)

where \( \Lambda \) is a \( D \times D \) diagonal matrix containing the eigenvalues \( \lambda_i \) and \( \Phi \) is a \( D \times D \) matrix whose columns constitute the Eigenvectors \( b_i \). After sorting the Eigenvectors in descending order of corresponding eigenvalues, the first \( K \ll D \) Eigenvectors are used to project an image vector \( z \) into the \( K \)-dimensional eigenspace

\[ y = \Phi^T \left[ z - \bar{z} \right]. \]  

(A.6)

The calculation of the Eigenvectors of a large matrix is computationally expensive. Several methods have been developed to compute the Eigenvectors efficiently. Singular value decomposition (SVD) [73] is numerically the most accurate way to compute the Eigenvectors. Singular value decomposition can be directly applied to decompose the covariance matrix \( \Sigma \) as \( \Sigma = U \Lambda V^T \), where \( V \) is a \( D \times D \) orthonormal matrix whose columns are the Eigenvectors \( b_i \). Using SVD, \( \Lambda \) contains the eigenvalues \( \lambda_i \) in increasing order. Often, the number of training vectors is much smaller than the dimensionality of the training vectors, i.e. \( L \ll D \). In [49] it is shown that the Eigenvectors and eigenvalues of \( \Sigma \) can also be derived via an SVD decomposition of the implicit covariance matrix defined by \( \tilde{\Sigma} = Z'Z \). If \( L < D \) the implicit covariance matrix is smaller than the covariance matrix and hence its SVD decomposition can be calculated faster. The Eigenvectors and eigenvalues of the covariance matrix can be derived as

\[ \lambda_i = \tilde{\lambda}_i, \]

\[ e_i = \tilde{\lambda}_i^{-1/2} Ze_i, \]

(A.7)

where \( \lambda_i \) and \( \mathbf{e}_i \) denote the \( i \)-th eigenvalue and eigenvector of \( \Sigma \), and \( \tilde{\lambda}_i \) and \( \tilde{\mathbf{e}}_i \) denote the corresponding eigenvalue and eigenvector of \( \tilde{\Sigma} \). We adopt this method.

We would like to inform the reader that more efficient methods have been devised for sets of images which are in-plane rotated realizations of the same image. Such in-plane rotated realizations of a same image can be obtained by our catadioptric vision system is rotated about the mirror axis of symmetry. In [99] it is shown that the Eigenvectors of a set of such rotated images which are obtained from a single image are the basis vectors for the discrete cosine transform of the original image in polar coordinates. As a result, the Eigenvectors of the rotated images can be obtained efficiently. A similar method is developed in [7]. In [44] these methods are extended to the case of rotated images obtained from multiple viewpoints.