Multiscale Image Representations for Ultrasound Visual Servoing

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We present a novel approach to visual servoing, in which the feature vector used to guide the visual servoing process is obtained by considering the coefficients of wavelet- and shearlet-based transforms of the image currently observed by an imaging device, such as an ultrasound probe.

Two- and three-dimensional ultrasound imaging devices are widely used in medicine for non-invasive observations of inner organs. In this context, robotic systems have been developed to automatically compensate for patient movements in order to keep the observed ultrasound image as stable as possible. This is typically achieved by continuously adjusting the position of an ultrasound probe such that the error between a currently observed set of features $\mathbf{s} \in \mathbb{R}^N$ and a desired set of features $\mathbf{s}^* \in \mathbb{R}^N$

$$\mathbf{e} = \mathbf{s} - \mathbf{s}^*,$$

is minimized by applying the Levenberg-Marquardt algorithm

$$\mathbf{v} = -\lambda \left((\mathbf{L_s}^\intercal \mathbf{L_s} + \mu \, \mathrm{diag}(\mathbf{L_s}^\intercal \mathbf{L_s}) \right)^{-1} \mathbf{L_s}^\intercal \mathbf{e},$$

where the movement of a robot with k degrees of freedom is expressed via the velocity vector $\mathbf{v} \in \mathbb{R}^k$ and $\mathbf{L_s} \in \mathbb{R}^{N \times k}$ denotes a so-called interaction matrix encoding how the observed features $\mathbf{s}$ change with respect to $\mathbf{v}$.

We show how the matrix $\mathbf{L_s}$ corresponding to a shearlet- or wavelet-based feature vector $\mathbf{s}$ can be explicitly computed at a given point in time and present experimental evidence that shearlet- and wavelet-based methods can increase the reliability of visual servoing systems in the presence of external disturbances such as varying lighting conditions.