Extracting Egomotion from Optic Flow: Limits of Accuracy and Neural Matched Filters

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1. Abstract

In this chapter we review two pieces of work aimed at understanding the principal limits of extracting egomotion parameters from optic flow fields (Dahmen et al. 1997) and the functional significance of the receptive field organization of motion sensitive neurones in the fly’s visual system (Franz and Krapp 1999). In the first study, we simulated noisy image flow as it is experienced by an observer moving through an environment of randomly distributed objects for different magnitudes and directions of simultaneous rotation $\mathbf{R}$ and translation $\mathbf{T}$. Estimates $\mathbf{R}'$, of the magnitude and direction of $\mathbf{R}$, and $\mathbf{t}'$, of the direction of $\mathbf{T}$, were derived from samples of this perturbed image flow and were compared with the original vectors using an iterative procedure proposed by Koenderink and van Doorn (1987). The sampling was restricted to one or two cone-shaped subregions of the visual field, which had variable angular size and viewing directions oriented either parallel or orthogonal with respect to the egomotion vectors $\mathbf{R}$ and $\mathbf{T}$. We also investigated the influence of environmental structure, such as various depth distributions of objects and the role of planar or spherical surfaces. From our results we derive two general rules how to optimize egomotion estimates: (i) Errors are minimized by expanding the field of view. (ii) Sampling image motion from opposite directions improves the accuracy, particularly for small fields of view.

From the iterative algorithm we derived a fast, non-iterative “matched filter” to extract $\mathbf{R}'$ and $\mathbf{t}'$, which under many conditions yields results very similar to those obtained by iteration. Its structure shows striking similarities to the receptive field organization of wide-field motion sensitive neurones in the visual system of the fly (Krapp and Hengstenberg 1996), but there are characteristic differences. To explain these differences, we developed a more elaborate version of this approach in which the statistical properties of the fly’s environment and behaviour, i.e. the distribution of object distances and flight directions, are taken into account. A matched filter was directly derived from an optimization principle that minimizes the variance of the filter output caused by noise and distance variabilities. The optimized filters were then compared to the detailed organization of the receptive fields of the fly’s wide-field neurones. Our analysis suggests that these neurones are not optimal for estimating the magnitude of $\mathbf{R}$ and $\mathbf{t}'$, but rather for consistently encoding the presence and the sign of rotatory or translatory flow fields along a particular set of axes.