Models of Tracking and Search Eye-Movement Behavior

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Humans interact with visual displays and interfaces not by passively absorbing the information like a fixed camera, but rather by actively scanning the visual image, searching for areas with relevant information, and by following the motion of features of interest. The overall goal of this project is to develop and test computational models of human eye-movement control with particular emphasis on two types of eye movement behaviors: search saccades and smooth pursuit. The specific aim is to incorporate recently acquired empirical knowledge of how eye movements contribute to information gathering and of the relationship between the eye-movement behavior and the associated percept, into computational tools for the design of more effective visual displays and interfaces that are matched to human abilities and limitations.

Most current models of visibility have focussed on the passive human visual ability to detect, discriminate, or identify a target in noise in carefully controlled laboratory conditions in which eye movements are suppressed. When human operators interact with a display in the real-world (e.g. air traffic controller), they move their eyes from one image location to another using rapid eye movements (saccades) that point the fovea, the retinal region of highest resolution, at a region of interest. This active search process greatly enhances human performance. Two major categories of models have been used to measure search performance: guided-search and signal-detection-theory models. We are examining the ability of these two models to predict eye movement performance during search. A first major step was the extension of the guided-search model to a closed-form version that can predict localization performance in search (Eckstein & Beutter, 1998; Eckstein et al., 1998,1999). Drs. Eckstein, Beutter, and Stone are now actively testing both of these models to determine which is the better predictor of human performance.

When humans view displays that contain motion, they generate smooth tracking eye movements (pursuit) that follow the motion of features of interest. This ability is crucial when using a display to perform tasks involving motion estimation (e.g. teleoperation of a robot arm or docking). Current pursuit models implicitly assume that the neural control of pursuit merely attempts to minimize the retinal motion of the target. Drs. Stone, Beutter, & Lorenceau have demonstrated that this view cannot explain the full range of human pursuit behaviors, including the critical ability to track real-world targets, even when they are partially occluded by other objects. Our proposed new control framework for pursuit is consistent with our new behavioral results as well as primate neurophysiology and anatomy. It postulates that pursuit is driven by a cortically constructed estimate of target motion (related to perceived target motion), rather than by retinal error signals (Stone et al., 1996, 1999; Krauzlis & Stone, 1999ab). Drs. Perrone, Krauzlis, and Stone are currently adding to the model, a biologically realistic input stage that uses motion-energy units based on the neurophysiology of primary visual cortex followed by a velocity-estimation stage, consistent with the known neural responses in higher-order cortical areas. The output stage uses positive feedback to achieve compensation for the viscoelastic properties of the eye muscles and orbit (Krauzlis & Lisberger, 1994; Stone et al., 1996).

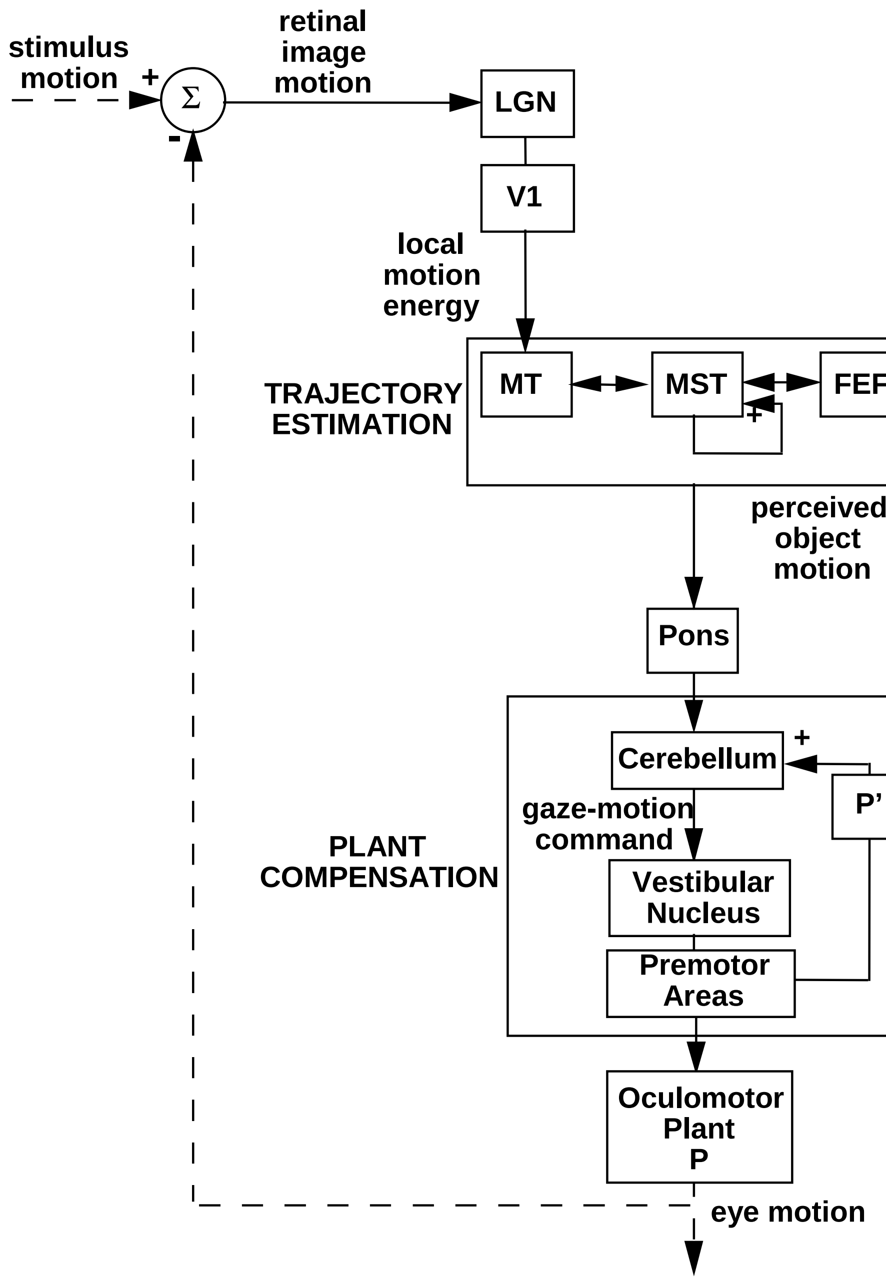

Fig. 1. New control strategy for pursuit (modified from Stone et al., 1999). Rather than raw retinal image motion, the main driving input is perceived object motion, which is computed by the extrastriate visual cortex. The extraretinal pursuit signal in area MST (the medial superior temporal area) could be generated via local internal positive feedback or by true efference copy from the brainstem. Once object motion is computed, the remaining transformation needed to optimize performance is compensation for the dynamics of the oculomotor plant. This can be achieved by positive feedback through the cerebellum (i.e. by setting P'~ P to eliminate the lag associated with the transfer function P) and is consistent with the observed Purkinje cell responses in the cerebellar paraflocculus.

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