Role of motion inertia in dynamic motion integration for smooth pursuit

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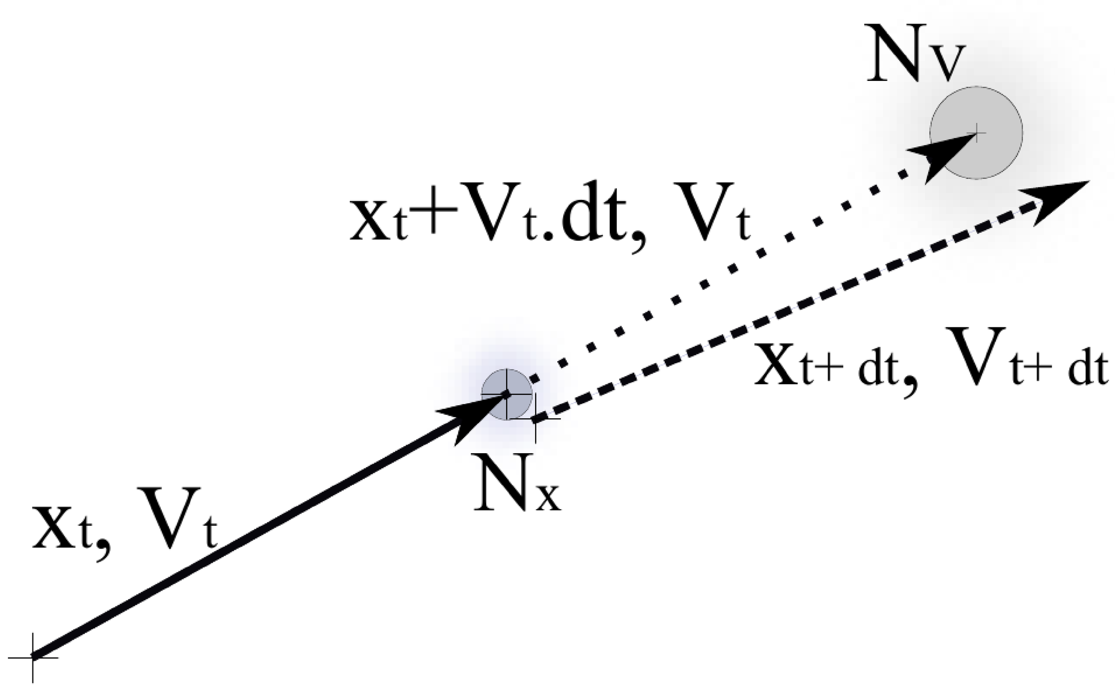
Introduction

Due to the aperture problem, the initial direction of tracking responses to a translating tilted bar is biased towards the direction orthogonal to the orientation of the bar. This directional error is progressively reduced during the initial 200ms of pursuit because of dynamic motion integration. In this work, we have studied dynamics of motion integration at different stages of pursuit by perturbing the translation: Subjects (n=6) were asked to track the center of a 45 degree tilted bar moving horizontally at a constant speed, while bar disappears for 200 ms (blank) at different times during initial and steady state phases of smooth pursuit. Results suggest that the role of prediction for motion integration is higher in initial phase compared to steady state. We have conducted the same experiments on a probabilistic, motion-based prediction model. The observed dynamic suggests a form of motion inertia in the modeled response which affects error at different stages of prediction. This inertia favors smooth pursuit trajectories path. We have studied how motion inertia changes at different stages of pursuit with respect to blank time and compared it with behavioral results.

Keywords: Motion integration, probabilistic representation, predictive field, emergence, smooth pursuit, motion inertia

Probabilistic representations of motion: prediction using the Navier-Stokes equations



$$I(x + V(x,t) \cdot \delta t, t + \delta t) = I(x,t) + \mathcal{N}_I \quad (1)$$
$$V(x + V(x,t) \cdot \delta t + \mathcal{N}_x, t + \delta t) = V(x,t) + \mathcal{N}_V \quad (2)$$

FIGURE 1: We use the prior knowledge that in natural scenes, motion as defined by its position and velocities (x_t and V_t), is following smooth trajectories [Burgi et al,2000]: position and velocity is conserved at time $t + dt$, with a small perturbation on position and velocity (respectively $\mathcal{N}_x$ and $\mathcal{N}_V$).
In a probabilistic representation of local motion, knowing measurements as the likelihood of the observation process $P(I_t|\vec{x}_t, V_t)$ parameterized by $\mathcal{N}_I$, one can perform inference as a Hidden Markov Model. The dynamical system consisting of the flow of incoming and predictive information controls the evolution of the motion representation, dynamically propagating the local information to the whole field.

$$P(x_t, V_t|I_{0:t}) = P(I_t|x_t, V_t)P(x_t, V_t|I_{0:t-\delta t})/P(I_t|I_{0:t}) \quad (3)$$

with

$$P(x_t, V_t|I_{0:t-\delta t}) = \int P(x_t, V_t|x_{t-\delta t}, V_{t-\delta t})P(x_{t-\delta t}, V_{t-\delta t}|I_{0:t-\delta t})dx_{t-\delta t}, dV_{t-\delta t} \quad (4)$$

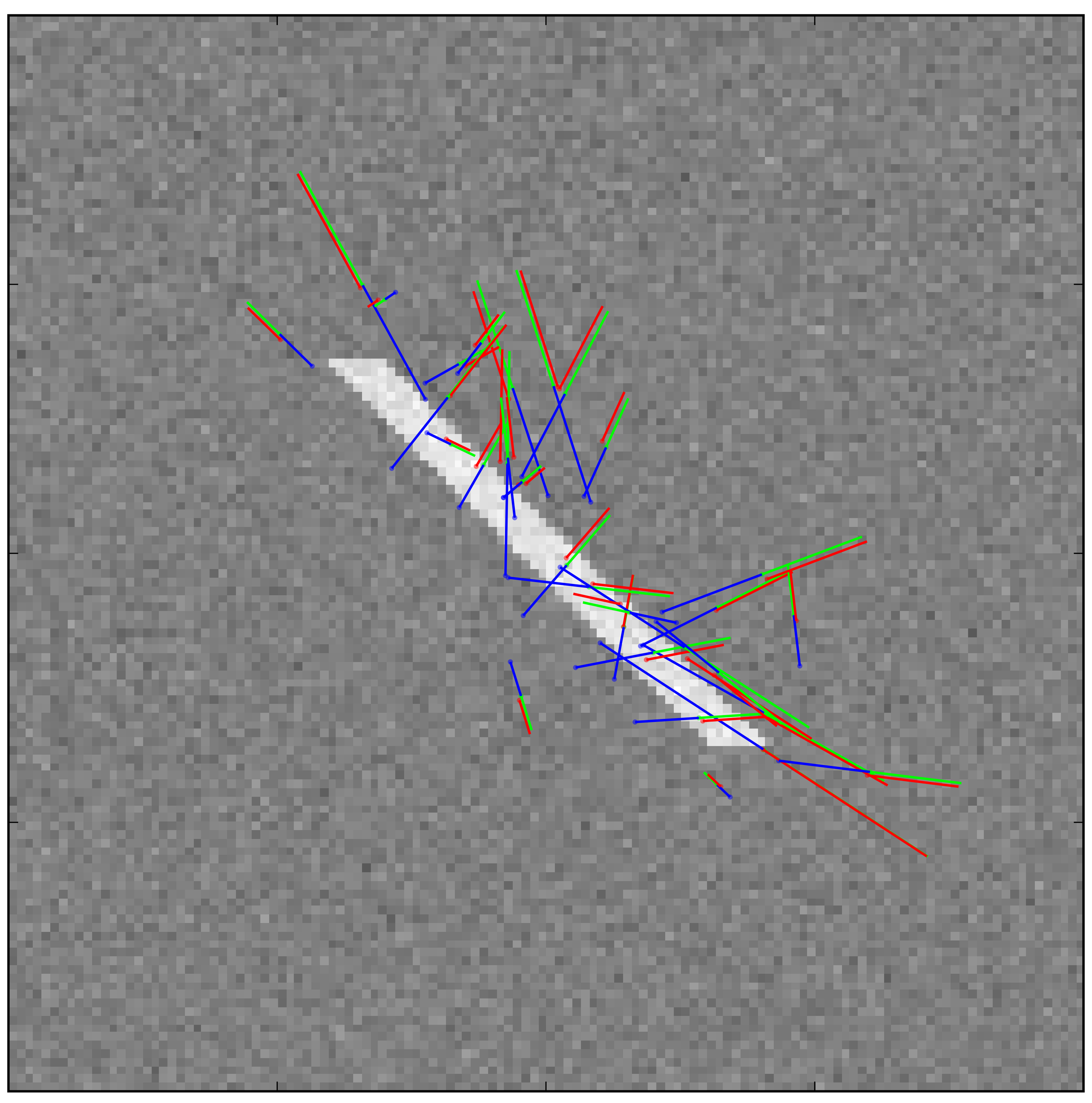


FIGURE 2: Particle filtering. The idea behind Sequential Monte Carlo algorithms is to simplify dynamical probabilistic equations by representing the probability using a finite set of weighted samples, as in the CONDENSATION algorithm [Isard and Blake,1998]. In the case of probabilistic motion these samples correspond each to a position (x^i, y^i) with a given velocity (u^i, v^i) (blue vectors). Using Eq. (2), one can predict the position of these samples (green vectors). The blurred approximation (red vectors) implements the prediction error., as defined by Eqs. (3-4).

Results: Dynamic motion integration affected by blinking stimulus

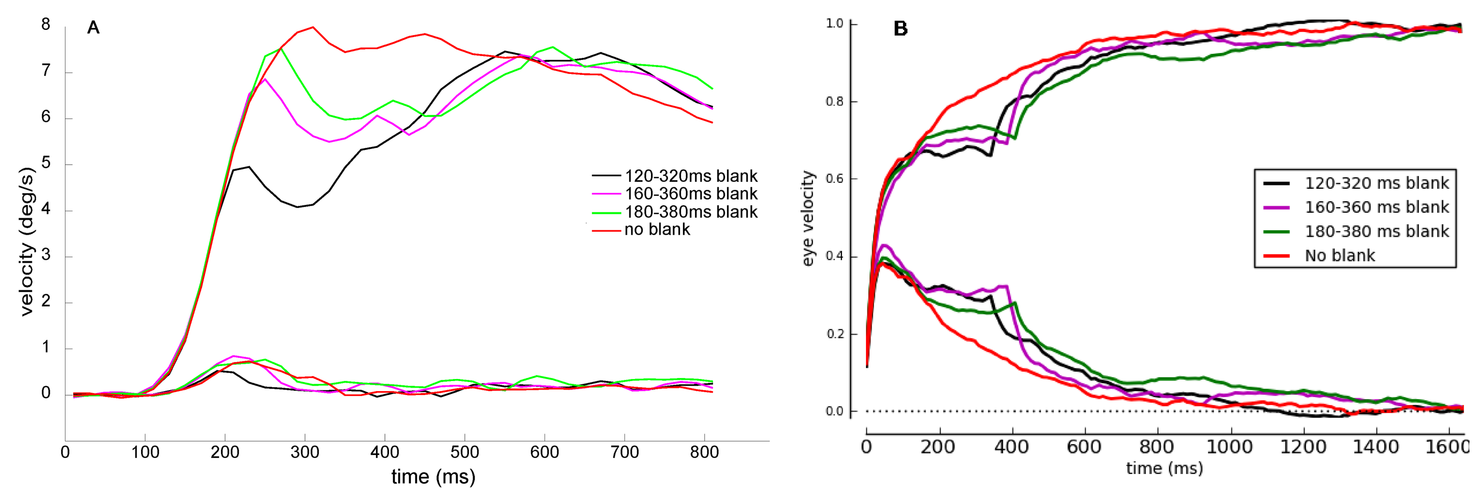


FIGURE 3: According to behavioral experiments, when the subject begins to follow a horizontally moving bar, eye movement is started after a 80 ms delay, afterwards the horizontal component of eye velocity rises gradually and it takes 200-300 ms to reach a stable velocity which is velocity of stimulus. (red trace in figure A) These 2 phases of smooth pursuit are called respectively: initial state and steady state. The vertical component of velocity has a bump right after 80 ms delay and then gradually goes to zero. This deviation indicates strength of aperture problem, because for a short while eye goes in a direction perpendicular to orientation of bar which includes a vertical component as well as horizontal one. But rapidly, eye takes the horizontal route and vertical component is strongly diminished. *(A)* Shows the eye velocity traces for blanking in the initial stages of smooth pursuit.The stimulus in all experiments shown above is a 17 degree long bar with a tilt of 45 degree, moving at constant speed of 8.4deg/s against a Grey background with full contrast.Each trial starts with fixation for a variable duration(400 - 600ms) followed by a 100ms fixed blank screen after which the stimulus starts moving(step-ramp paradigm).Subjects are asked to track the center of the bar.The stimulus was blanked at 120,160 and 180ms for 200ms during the initial stages of smooth pursuit.*(B)* We have simulated a blinking tilted bar with the same physical specifications as behavioral experiment. This figure shows averaged velocity traces of all particles in probabilistic prediction model over 20 trial. Main difference of to plots is in velocity drop after blank. We observe a kind of Inertia in response of model to blinking stimulus. As we have tried to model sensory level, then shown traces would be equivalent of input to oculomotor. During blank, system does not receive any stimulus and keeps latest information. Interestingly, after reappearance of stimulus, we don't have aperture problem anymore which is matched to behavioral results.

Results: Segmentation

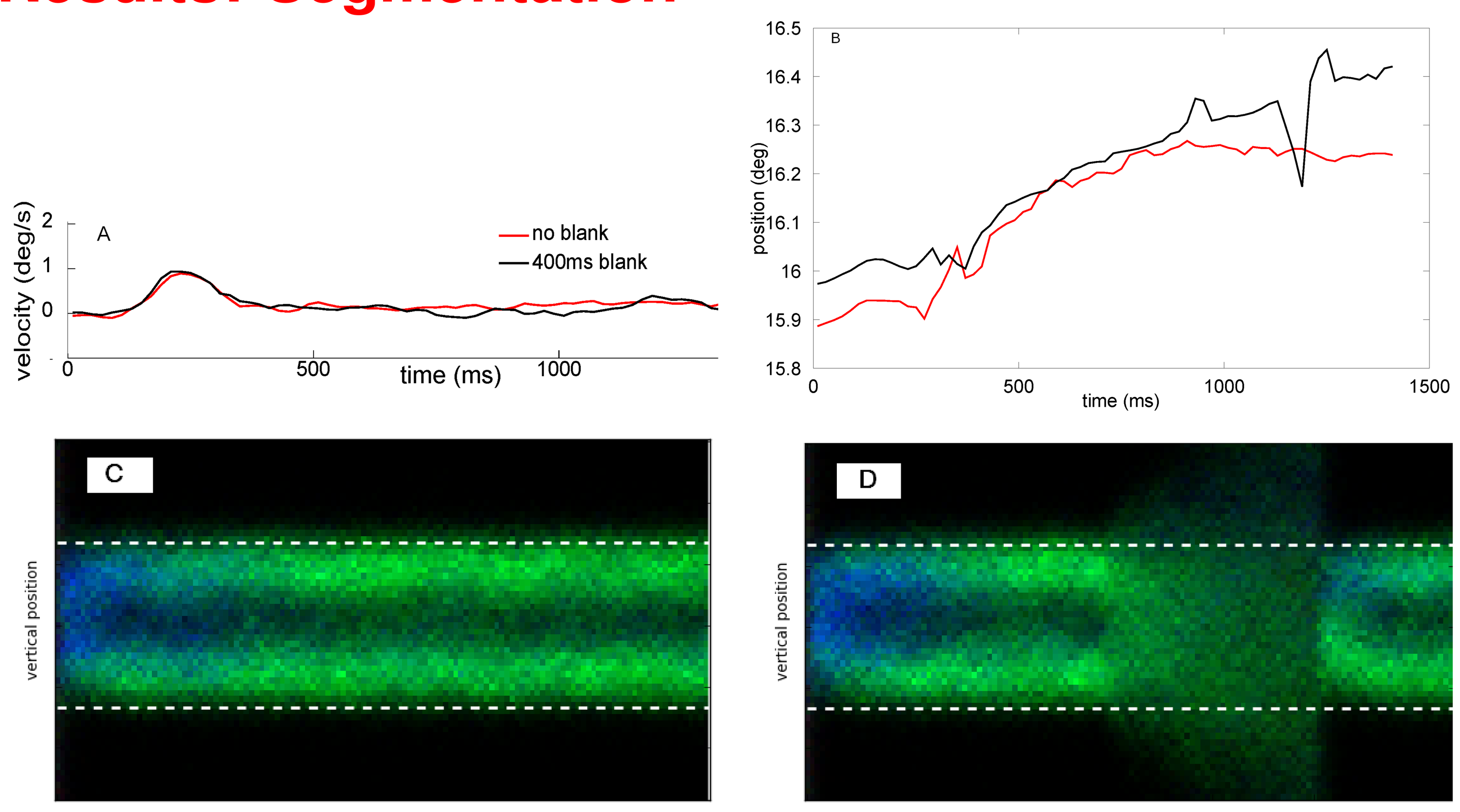


FIGURE 4: Behavioral experiments suggest that while having a blank at steady state of smooth pursuit, eye starts to do some vertical movements from the center of stimulus.*(A)* Vertical velocity of eye during smooth pursuit under no blank and blank at steady state condition. *(B)* Vertical position of eye during smooth pursuit under no blank and blank at steady state condition. There is a considerable fluctuation in vertical position of eye. *(C)* To highlight the propagation of detected velocity in model over the bar, we plot as a function of time (horizontal axis) the histogram of the detected motion marginalized over vertical positions (vertical axis) while direction of velocity is given by the hue. The green color represents a disambiguated motion to the right while blueish colors correspond to the diagonal. The plot shows that motion is disambiguated by progressively explaining away incoherent motion. *(D)* Averaged velocity histogram of model in response to a blank between 600-1000 ms.As its obvious, we have a scattering at vertical position of particles. In absence of stimulus velocity information are less concentrated on position of stimulus.

Acknowledgments

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