Real-Time Mapping of the Visual Field using Random Stimulus Presentation

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Introduction: For clinical fMRI applications, it is desirable that parameter estimates and statistical results be displayed in real-time. An fMRI retinotopy experiment was conducted using a random visual field excitation paradigm. Real-time mapping of the visual field was simulated, post-experiment, using recursive, multi-parameter Kalman filter estimation of the visual field sensitivity profile for each voxel.

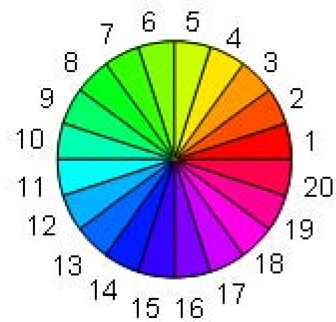

Fig.1: Color Coding of Visual Field

Theory: The system (i.e., voxel) *state vector* **x**, was modeled by:

$$\mathbf{x}_k^T = \left[b_k \quad \tfrac{db}{dt} \quad a_k(1) \quad a_k(2) \quad \cdots \quad a_k(20) \right], \qquad (1)$$

where k = time index, b_k = baseline, db/dt = drift rate, $a_k(j)$ = amplitude of response to jth wedge. The state was propagated forward in time according to the *system model*:

$$\mathbf{x}_k = \mathbf{F}_{k-1}\mathbf{x}_{k-1} + \mathbf{w}_{k-1}, \qquad \mathbf{w}_k \sim N(0, \mathbf{Q}_k). \qquad (2)$$

The *measurement vector* **h** mapped the state vector to the fMRI measurement:

$$\mathbf{h}_k^T = \left[1 \quad 0 \quad u_k(1) \quad u_k(2) \quad \cdots \quad u_k(20) \right]. \qquad (3)$$

Here, $u_k(j)$ = hemodynamic response to the jth wedge, was modeled by:

$$u_k(j) = f_k(j) \otimes g_k, \qquad j = 1,\ldots,20, \qquad (4)$$

where $f_k(j)$ = indicator function for jth wedge, and g_k = canonical IRF.
The fMRI *measurement* z_k, at time k, was modeled by:

$$z_k = \mathbf{h}_k^T \ \mathbf{x}_k + v_k, \qquad v_k \sim N(0, \mathbf{R}_k). \qquad (5)$$

Using Eqns.(1)-(5), a discrete-time Kalman filter [1] was implemented for recursive estimation of voxel sensitivity to different wedge locations in the visual field.

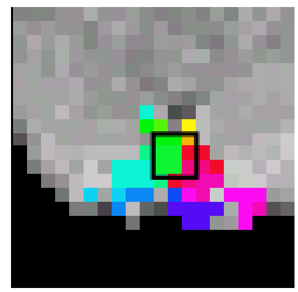

Fig. 2: Visual Field Sensitivity Map

Materials and Methods: An 8 Hz flickering, black & white checkerboard visual stimulus was presented to the subject during a 240 sec. run. This flashing pattern was limited to a subset of the full visual field, consisting of 20 wedges (Fig.1). Approx. half of the 20 wedges were active at any one time. The timing sequence of wedge activation was randomized. fMRI data were collected at TR = 1 sec. A Matlab program was used, post-experiment, to simulate real-time parameter estimation and display of the visual field sensitivity map (Fig.2). Approx. 900 Kalman filters were set up to run in parallel, one for each voxel in the masked region. Each acquisition of a single slice of imaging data was input to the bank of Kalman filters at rate = 1/TR. The color of a voxel was determined by the wedge having the highest z-score, thresholded at z_{thr} = 2.25. For the 9 voxels inside the square in Fig.2, the individual voxel visual field sensitivity profiles are presented in Fig.3. For each voxel sub-plot, the horizontal axis represents wedge location; the vertical axis is the z-score obtained from the real-time Kalman filter output. Both the visual field sensitivity map and the voxel visual field sensitivity profiles were updated once per TR.

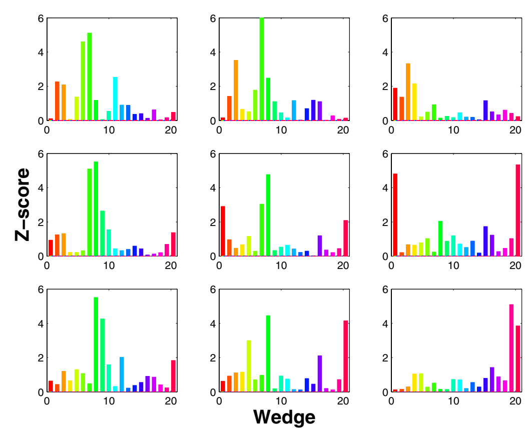

Fig. 3: Voxel Visual Field Sensitivity Profiles

Results and Discussion: Activation is primarily in the visual cortex, as expected (Fig.2). In general, the set of active voxels grows gradually during the run, although the colors of the active voxels (i.e., the most sensitive wedge locations) tend to constant values. Most of the visual field can be detected in this single slice through the visual cortex. However, Fig.3 shows that the results are more subtle than the simple "winner-take-all" map of Fig.2. That is, Fig.3 shows the partial-voluming that occurs within a voxel. Also, we see the gradual shift in visual field sensitivity from voxel-to-voxel.

References [1] Gelb A. (ed.) 1974. *Applied Optimal Estimation*, M.I.T. Press.