EYE MOVEMENT PREDICTION USING STRUCTURED RANDOM WALK WITH INERTIAL CONSTRAINTS

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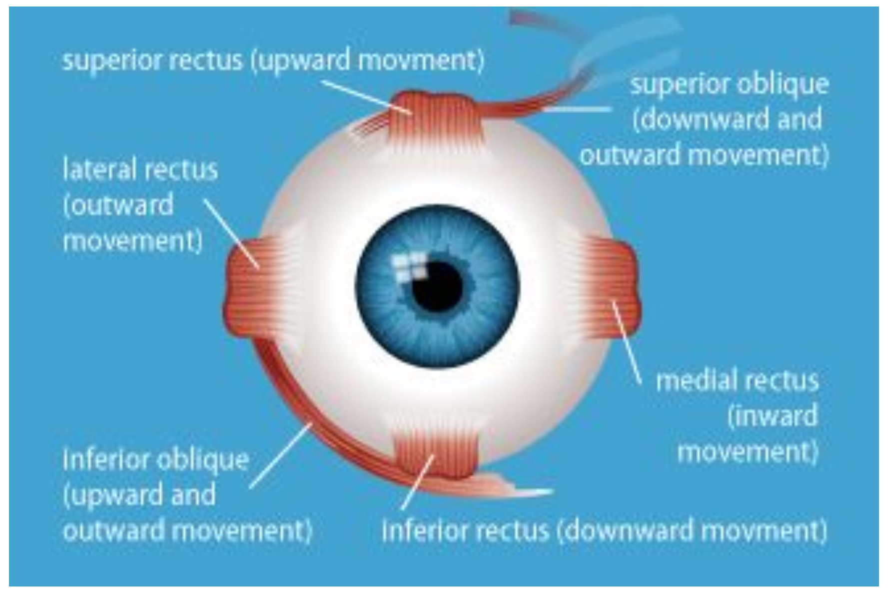
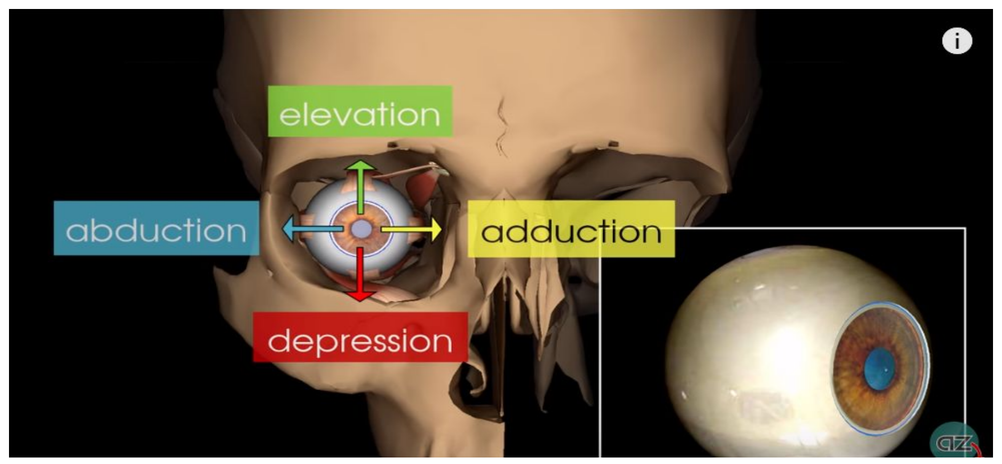
EXTRAOCULAR MUSCLES IN THE HUMAN EYE

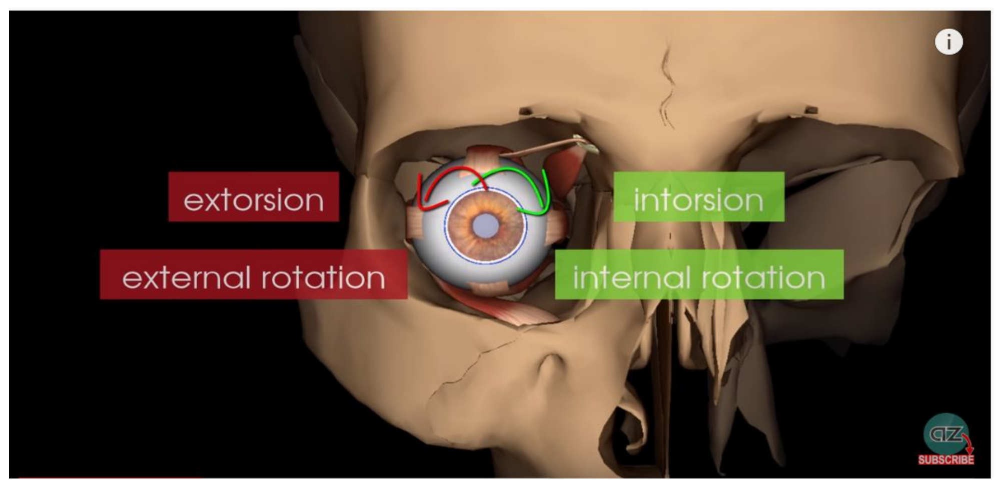
The oculomotor nerve innervates extrinsic eye muscles that perform most movements of the eye and raise the eyelid. The nerve also contains fibers that innervate the intrinsic eye muscles that enable pupillary constriction and accommodation (ability to focus on near objects as in reading). There are six extraocular (extrinsic) muscles that move the globe (eyeball). These muscles are named the superior rectus, inferior rectus, lateral rectus, medial rectus, superior oblique, and inferior oblique.



THE MOVEMENTS IN HUMAN EYE

As the eye globe rotates in a fluid inside of an eye socket, the eye has the capability of moving much faster than limbs that are burdened by bones. Here we have consider the various voluntary eye movements. The figures below explain the various kinds of movements the human eye performs



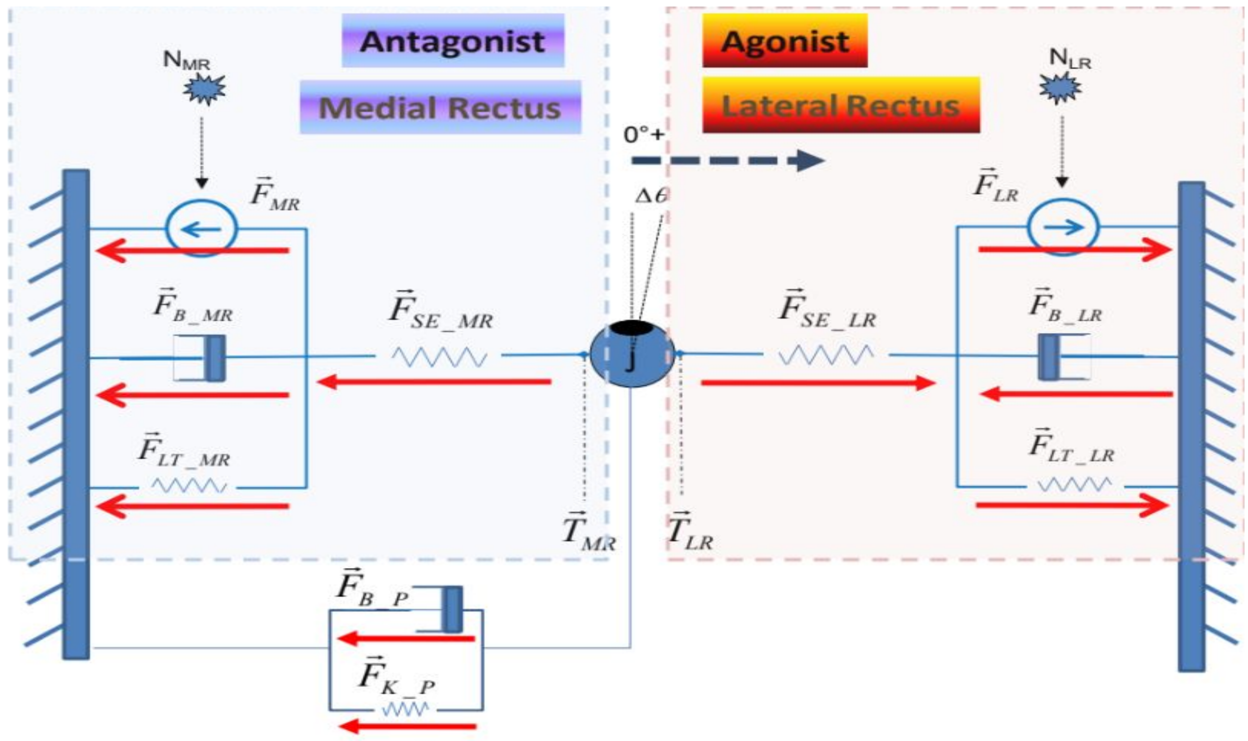


OCULOMOTOR PLANT MECHANICAL MODEL

With great simplification, we can describe the various movements as :

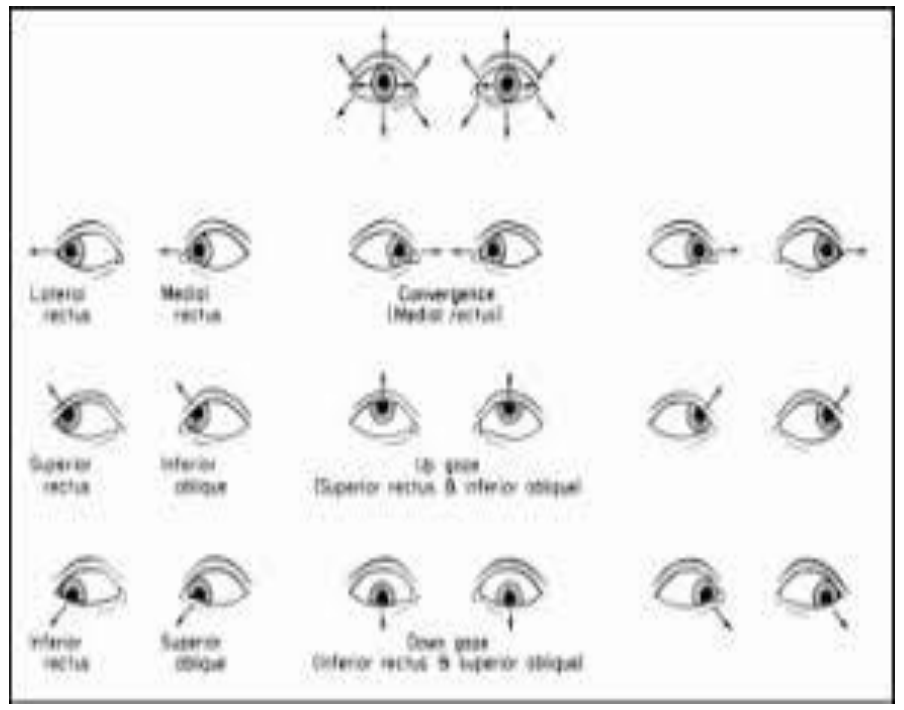
1) fixation – eye movement that keeps an eye gaze stable in regard to a stationary target providing visual pictures with highest acuity,
2) saccade – very rapid eye rotation moving the eye from one point to another.
3) pursuit -stabilizes the retina in regard to a moving object of interest.

The figure presents the OPMM diagram during rightward eye movements. Each individual extraocular muscle is represented by a set of separate components generating a specific force.



These components include:
1) active state tension modeled as an ideal force generator
2) series elasticity and length-tension components, modeled as ideal linear strings with coefficients
3) force velocity relationship components , characterized by damping coefficients and the velocity of muscular contraction

Now we model the saccadic eye movements (eye gaze) as a random walk and try to predict the eye movements using the Kalman filter. Next we try to understand how a Kalman filter works



KALMAN FILTER AND MODELLING THE SACCADIC EYE MOVEMENTS AS A RANDOM WALK

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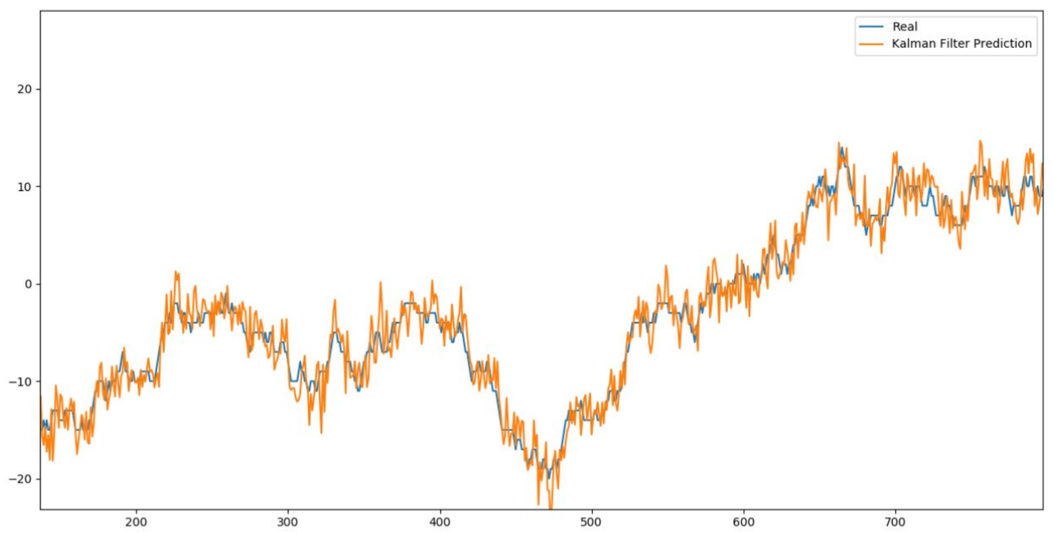
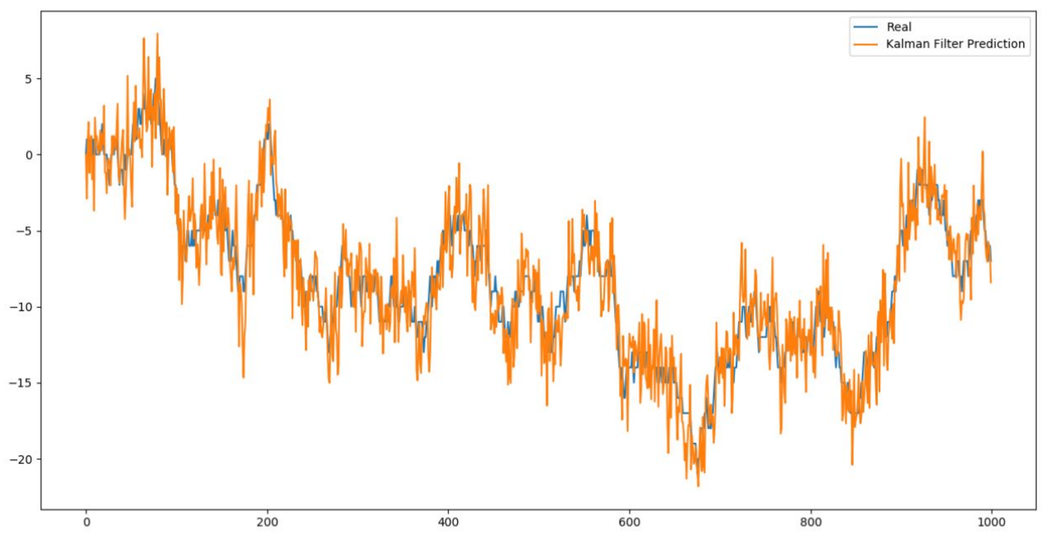




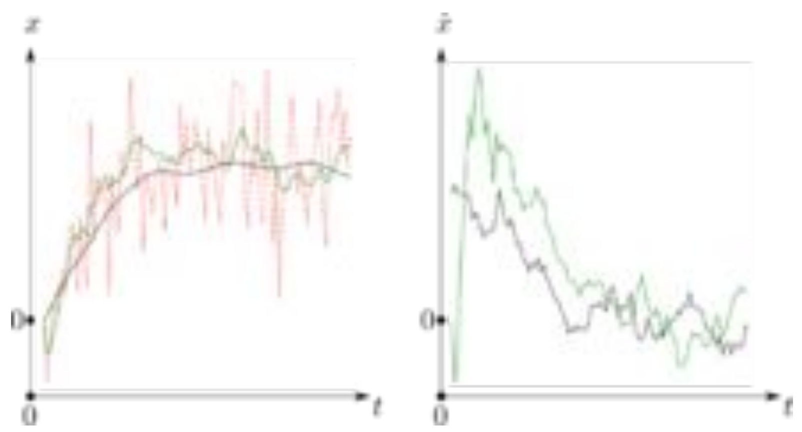
For our convenience, we developed a miniature model of a simple random walk problem in two dimensions that resembles the motion of the eye, and apply Kalman filtering algorithms on it to get a prediction of the path of the eye. The predicted path however, closely matches the observed path as is evident from the graphs.

KALMAN FILTERING

In statistics and control theory, Kalman filtering, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more accurate than those based on a single measurement alone, by estimating a joint probability distribution over the variables for each timeframe.

$$\mathbf{x}_k = \mathbf{F}_k \mathbf{x}_{k-1} + \mathbf{B}_k \mathbf{u}_k + \mathbf{w}_k$$

The Kalman Filter uses a recursive algorithm to estimate measurements over time and eliminate noise, involving two steps : predict and update. The final output after multiple iterations will be close to actual output and will give us a more accurate result.



Two State Kalman Filter (TSKF) models an eye as a system with position, velocity, and white noise acceleration. The TSKF is capable of predicting eye movement trajectories continuously, but it has low accuracy of prediction during saccades. The Oculomotor Plant Kalman Filter (OPKF) predicts eye movement trajectory for the duration of the saccade after it is detected by the TSKF.

APPLICATIONS

The core issue related to the human computer interaction is reducing the delay introduced by auxiliary inputs to computer systems (such as a mouse). The accurate eye movement can considerably minimize size of the high quality *Region of Interest,* thereby reducing overall bandwidth or computational requirements.

The main application of eye-tracking are:

Market research: To evaluate the shopping behaviour of customers, measure attention to brand, advertising, designs,etc.

Psychology research: Visual attention can be measured and correlated with other measures such as how the brain works

Medical research: Eye tracking in combination with conventional research can help in diagnosing ADHD, Autism, OCD, etc.

Human Factors and Simulation: Automotive research has embraced eye tracking glasses for a long time to gauge driver's visual attention.

PC and Gaming Research: Assures better understanding of the game so that it is possible to create features that push the boundaries of reality even more.