LissEYEjous Tracker

In the optical imaging scanning systems, the most commonly used scanning pattern is raster. The raster scanning process involves moving a beam of light across the scanned object in a horizontal line, then moving it down slightly and scanning the next line, and so on, until the entire area of interest has been scanned. Raster scanning can produce images with high resolution, enabling detailed visualization of the scanned object. Raster patterns are commonly used in ophthalmic imaging in techniques such as optical coherence tomography (OCT) or scanning laser ophthalmoscopy (SLO). In these cases, the scanned object is the human retina.

The human eye is never still. Small involuntary movements of the eye such as microsaccades frequently shift the eye position even for trained people with very stable fixation. When the eye moves during image acquisition it creates imaging artifacts. The effect on the image is very similar to what one would obtain with an office flatbed scanner if the scanned document was shifted during the work of the scanner (although the working principle is different here).

One of the disadvantages of the raster scanning is that its speed is limited by the mechanical constraints of the scanning mirrors. Motion of the eye is faster and can happen several times before the full picture is takes. Additionally, raster scanning is highly anisotropic in time. What it means is that the top part of the picture is always taken earlier than the bottom part of the picture.

Motion artifacts that happen during imaging can be corrected in several different ways. In many cases, knowing the motion of the eye that happened during the acquisition allows to use software techniques and correct these errors in the image. Techniques that allow the imaging device to follow the eye to avoid these errors also exist, but they are not perfect. Also, if the images are magnified, for example to see the retinal cells, the effects of motion also become magnified. Accurate measurements of the eye motion are therefore essential. But there are more reasons than optical imaging.

It is often said that human eye is a window to the brain. This is usually in context of photoreceptor cells, that are part of the nervous system and may be directly observed through the eye. However, the oculomotor system also carries essential information about the brain intricate mechanisms. It turns out that many neurological diseases, such as Parkinson disease, Huntington disease, or Alzheimer's disease, manifest in abnormalities of the eye motion. Retinal eye tracking systems may provide speed and resolution that is not available for commercial video eye trackers and therefore have the potential to tackle the diagnosis of such diseases at early stages.

Currently, the most popular method for retinal eye tracking is so called strip-based registration method. The method divides retinal images acquired using raster scanning into several strips. Comparing consecutive strips to a reference frame allows to retrieve the eye motion with significantly higher amount of measurement points in time than in case of comparing frame to frame, since the acquisition of a full frame is too slow. However, current methods have limitations, for example, dividing the image into strips reduces the detection possibilities of vertical eye motion. New solutions are being developed to improve the accuracy and robustness of the retinal eye tracking methods.

In this project a new method is proposed that has the potential to push the retinal eye tracking limits. New scanning paradigms, based on Lissajous curves, will replace traditionally used raster scanning. This innovative approach, combines two micro-scanners with similar high resonant frequencies (19—23 kHz). The approach leverages the speed of both scanners to achieve dense, isotropic sampling that cannot be achieved with raster-scanning at proposed frame rates. Although dense Lissajous scanning is becoming more popular, for example, in microscopic applications, it was never reported at the frame rates of up to 500—4000 frames per second. Innovative approach with a specially designed optical setup that accommodates two perpendicularly oriented ultrafast micro-electromechanical systems (MEMS) resonant scanners, was first proposed and demonstrated by the PI of this project.

In this project, the MEMS-based ultrafast Lissajous scanning will be deeply investigated to achieve the most accurate and robust eye tracking methodology. It is predicted that the use of high-speed system in combination with the properties of Lissajous curves will allow for the design of algorithms that are resistant to imperfections of other systems, such as dependence on the reference frame, while also solving the acquisition problem of strongly non-uniform spatial sampling.