Eye Tracking

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The eye contact plays important role in everyday communication between humans.
It has also wide range of possible applications as natural interface between man and computer or machine.
Although during the last 20 years different systems for detection of line of sight have been designed, they have found only limited use mainly in the medical and military sector. The reason is, that all known systems achieve low reliability in environment with bright and changing illlumination, such as in a office or a vehicle. Another drawback is complexity and cost of existing commercial systems.

In this contribution a reliable low cost eye detection system, using embedded computer technology will be presented.

The basis of all methods for gaze detection is the detection of the eye pupil position.
Once the pupil position is known, it is possible to calculate the gaze direction as well.

This contribution deals with a improved method for reliable eye pupil detection.

In the Fig. 1 the well known eye structure is shown (from Tuerpitz).

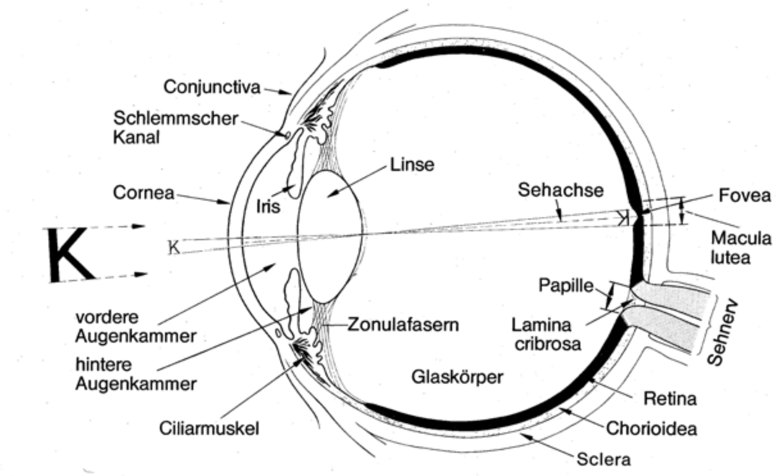

Fig. 1 , The Eye

The optical system of the eye produces a number of optical reflections.
The cornea front surface reflects ca. 4% at all wevelegth.
Reflections from the surfaces inside of the optical system, known as Purkynie reflections, have intensity less than 1%.
The reflection of the retina dependes on the wavelength, in the near IR achieves up to 30 %.
The transmission and reflection characteristic of the eye is shown on Fig.2

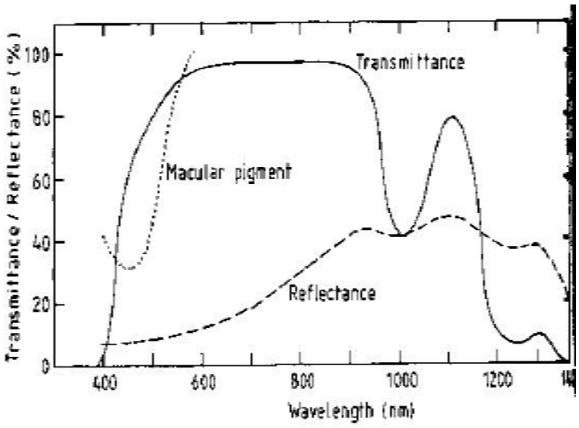

Fig. 2, Transmission and reflection of the eye

The reflection of the retina in the near infrared can be easily detected, it is much stronger than diffuse reflection from the face or from the surroundings.

When the eye is illuminated with a light source, the light is focused on the retina and reflected back in the direction of the light source. The eye acts as retroreflector, which also causes the well known red eye effect.

The smallest possible size of a reflected spot with 50% of the total intensity in the plane of the light source can be calculated using the diffraction limit formula:

$$Q = 1.22 \cdot 0.424 \cdot f \cdot \frac{\lambda}{D}$$

Given distance f=1000 mm, pupile size D= 3 mm ad wavelength 810 nm, the smalles spot size is 140µm.
The optical qualityof the eye is alternating significantly from person to person.
W. J. Donnelly III and A. Roorda state that the lateral resolution of the eye can vary between 6µm and 43µm.
Due to aberations and scattering, the reflected spot will always be larger than the size of the light source.

If the light source is sufficiently small, most of the light will pass to the objective and to the camera.
The drawback of using small light source is limited light power.
This problem could be solved using a laser, but then the power density must not exceeed 5µW/cm², which is not sufficient for good illumintion and also difficult to ensure.

Another possibility is using a number of small light sources, which are placed inside of the aperture of the optical system.
Such an array can be implemented by mounting LEDs on a transparent substrate, or by using light conducting elements as applied in this embedded device.

The light conducting elements used are legated on two high power LEDs with 35mW to circumvent the issues of a low factor at ca. 5%. A schematic image of the setup is shown Fig. 3.

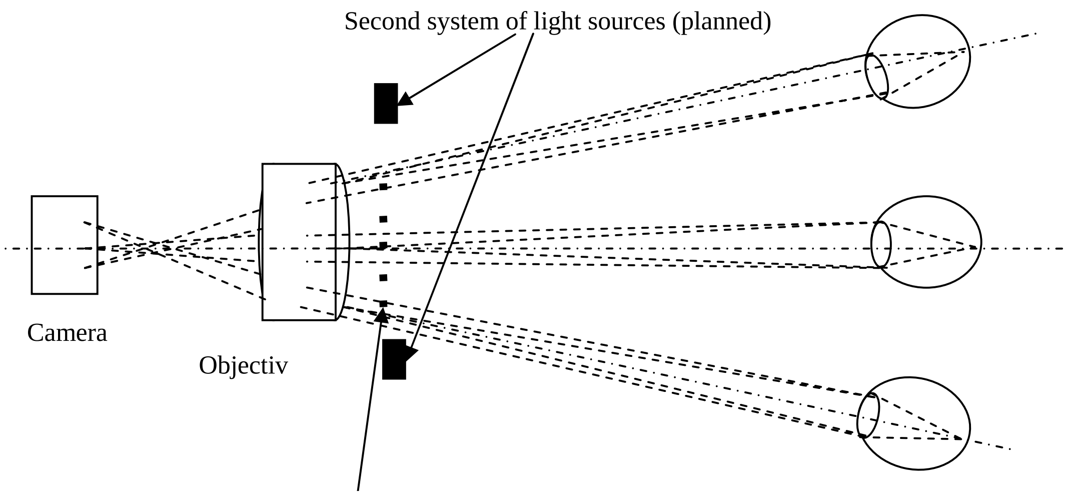

Fig 3 shows the optical layout of the detector.

Image 4.: Retina reflexes of the eye.

A second light system is planned to achieve the same results seen in image 4, even under irregular conditions.
This light system is designed to have the same light intensity density at the eye as the first, however no light reflected by the retina should be visible to the camera.
It is intended to substract images taken with different illumination, to detect the retina reflexes even more reliable.

The system was designed on a VIA embedded motherboard and a VGA resolution Philips webcam.
One aim for this embedded system was to implement it using only open source software.
This could be achieved using a modified Debian Linux, the sound library Libao, and the computer vision library OpenCV.
The two channel sound interface triggers the light system and provides a warning tune in case the eye cannot be found for given period of time.

At the beginning of each capture cycle two images are taken, to be able to subtract interfering background light.

Fig. 4 shows a simplified diagram of the software used in the device.
Using a region of interest a frame rate of 15fps could be achieved.

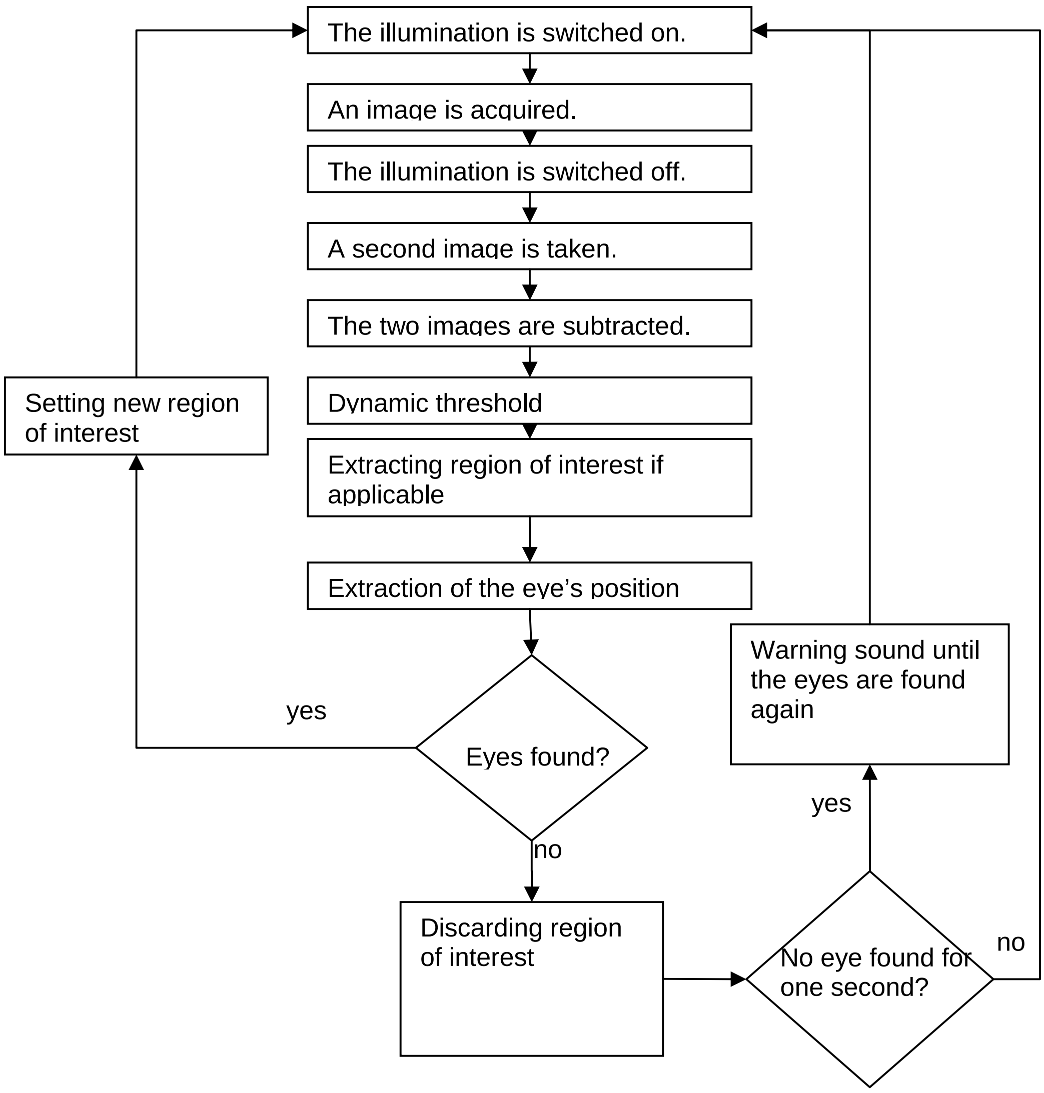

Fig 5. Simplified software diagram

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2. W. J. Donnelly III and A. Roorda, "Optimal pupil size in the human eye for axial resolution", J. Opt. Soc. Am. A/Vol. 20, No. 11/November 2003
3. Eugene Hecht, „Optik" ,Addison-Wesley, 1992, p.444
4. Robert R. Shannon and James C. Wayne, "Applied Optics and Optical Engineering", Vol. 7, Academic Press, 1980, p.209