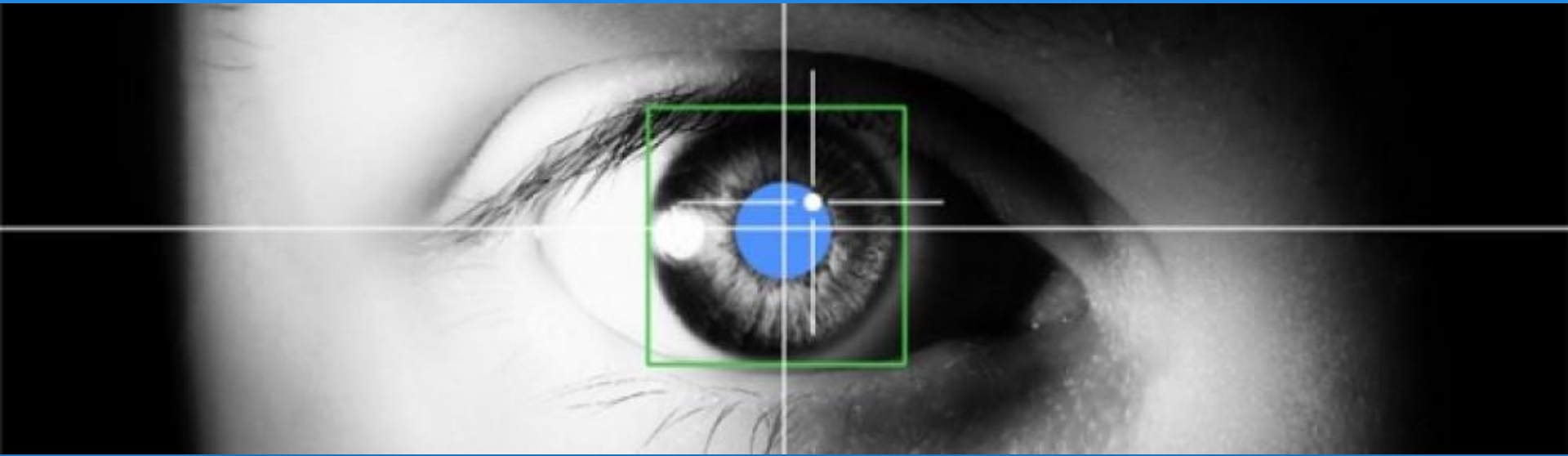


# Eye gaze tracking technologies



Ali Riza Özoguz  
Mohammad Razavi

# Part I

Ali Riza Özoguz

# Eye Gaze Tracking

Article about Eye Gaze Tracking for Human Computer Interaction:

[http://edoc.ub.uni-muenchen.de/11591/1/Drewes\\_Heiko.pdf](http://edoc.ub.uni-muenchen.de/11591/1/Drewes_Heiko.pdf)

Interesting to read, but a bit long :-)

# History of Eyetracking

1800's there were studies through observation

Then in the end of the 19's Century questions about reading came up because of an observation concerning the saccades of the eyes

(Btw.) What are Saccades?

Saccades are short and fast motions of the eye to get another point of view in focus

In the middle of the 20th century the research in this field raised up

-> Increase of Research in the field of "Human Computer Interaction"

And also the eyes are now a field of research to improve HCI

# Eyes and their Output

Example:

Many People are standing in a row

I ask the same question many times

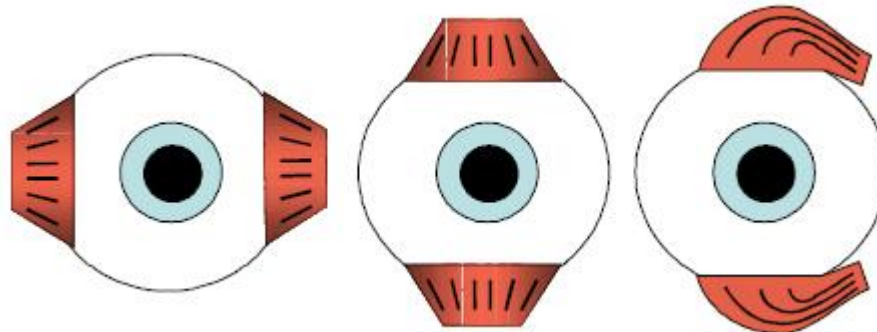
From where do I know who I talked with when I don't say names...

# Anatomy of the Eye

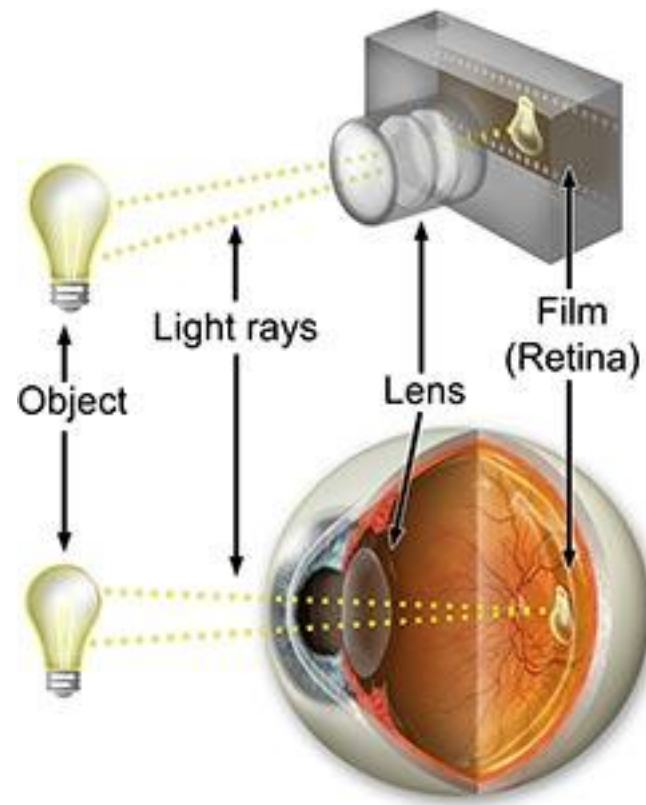
*"The eye and its muscles can be seen as a camera with image stabilization"*

There are 6 muscles:

1 pair for horizontal, 1 pair for vertical and 1 pair for rotational movement control



# Anatomy of the Eye (Camera)



# Eye vs. Camera

The Eye is like a camera but there are Differences:

The Eye sees 3d - The Camera sees in 2D (Today there are already Cameras which generate 3D pictures)

The eye sees only sharp on the fixation point, while you can modify the sharp zones of the camera through different properties

In the night you need to wait for a while when you just saw light until you see something / the camera needs to get more light input for its picture

I read an article where someone praised the camera because it's not so breakable

# Part II

Mohammad Razavi

# Gaze tracking systems categories

Depending on hardware they use:

- Head-mounted systems
- Non intrusive systems



# Gaze tracking systems categories

Depending on the kind of light they use:

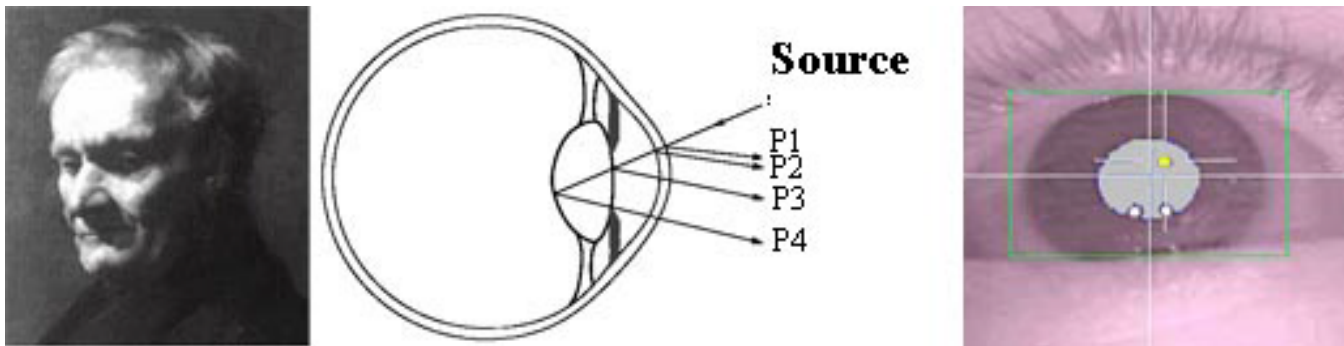
- Ambient light
- Infrared or near infrared light



# Four Purkinje images analysis

Purkinje images are reflections of objects from structure of the eye. There are at least four Purkinje images that are visible when looking at an eye.

Using light emitting diodes on head mounted system, it is possible to record several images which represent the reflects of emitted light in the eyes



The Czech anatomist **Jan Evangelista Purkyně** (1787-1869) and his four images.

# Four Purkinje types

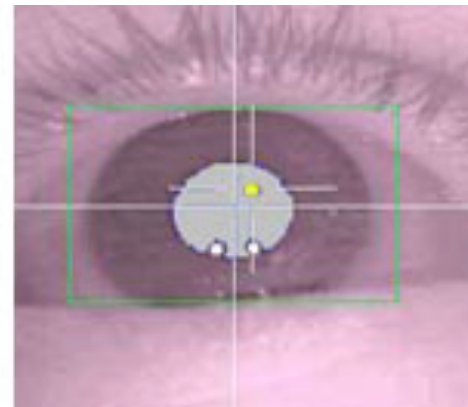
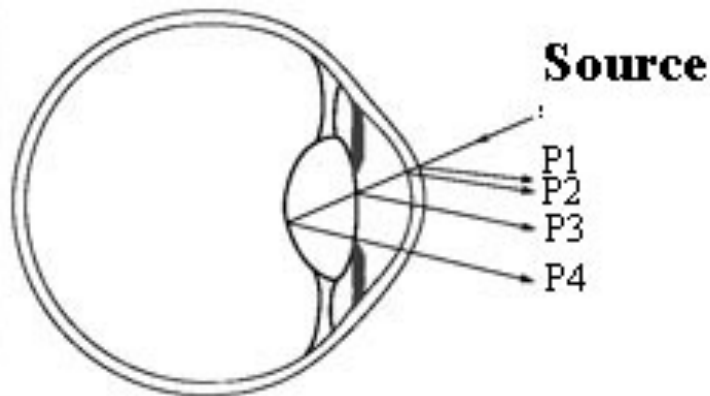
## Purkinje types:

(P1) is the reflections from the **outer** surface of the **cornea**.

(P2) is the reflections from the **inner** surface of the **cornea**.

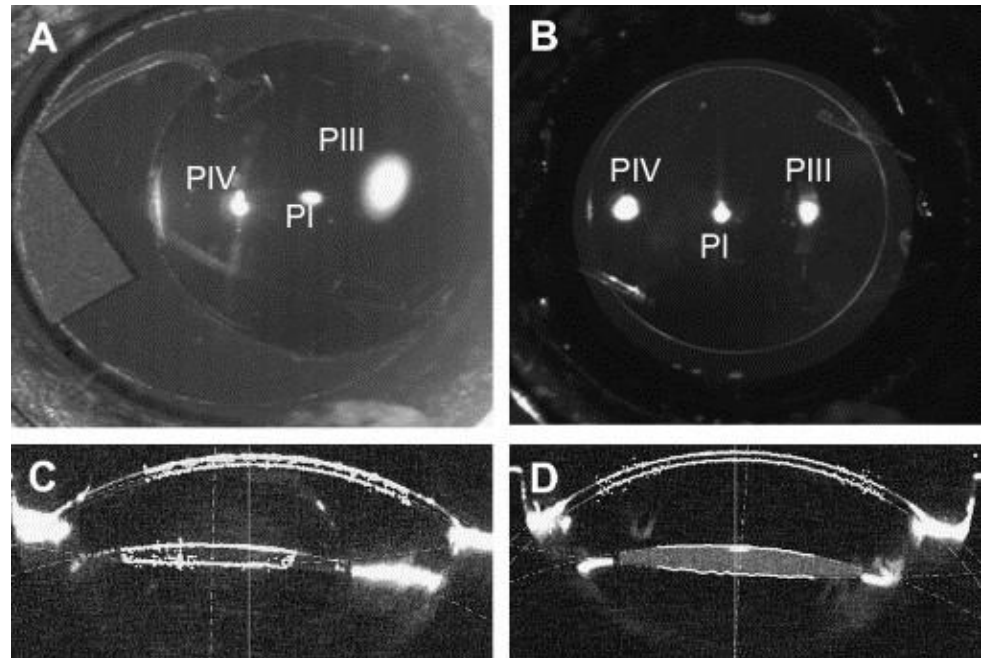
(P3) is the reflections from the **anterior** surface of the **lens**.

(P4) is the reflections from the **posterior** surface of the **lens**



# Four eye Purkinje images

The principle of almost all head mounted systems is to measure and compare P1 cornea or pupil images (or P2) with P3 retinal images



(P4 images is quite difficult to follow but used in the Dual Purkinje Image method)

If the illumination is coaxial with the optical path then it produces a bright pupil effect similar to **red eye**.



# Pupil tracking

If the illumination source is offset from the optical path, then the pupil appears dark.

## Bright Pupil tracking

- Creates greater iris/pupil contrast
- More robust eye tracking and more reliable tracking

Bright pupil techniques are not effective for tracking outdoors as extraneous infrared sources interfere with monitoring.

# Eye Capturing

Regarding technology

- Some eye tracking systems require the head to be **stable**
- Some function remotely and automatically track the head **during motion**.

Sampling rate of at least **30 - 50/60 Hz**.

In the field of neurobiology, in order to capture the detail during reading **240/350 -1000/1250 Hz**.

## Advantages of the non intrusive eye and gaze tracking system compared to the head-mounted ones

- Should allow natural head movements;
  - Should be able to perform with a wide variety of eye shapes, contact lenses or glasses;
  - Should be portable.
- Should be real time.

# Main approaches to detect and measure in a non invasive system

1. The glint;
2. A 3D-model;
3. A local linear map network.

# The glint method

Calculate the angle of the **visual axis** and the location of the **fixation point** on the display surface by tracking the relative position of the **pupil** and a point of light reflected from the **cornea**, i.e. the glint.

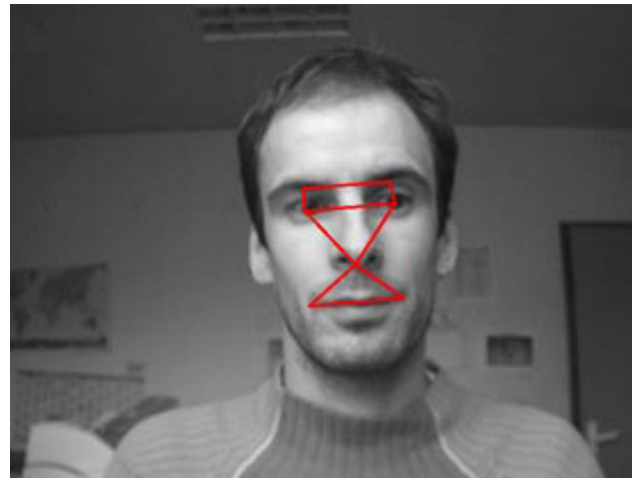
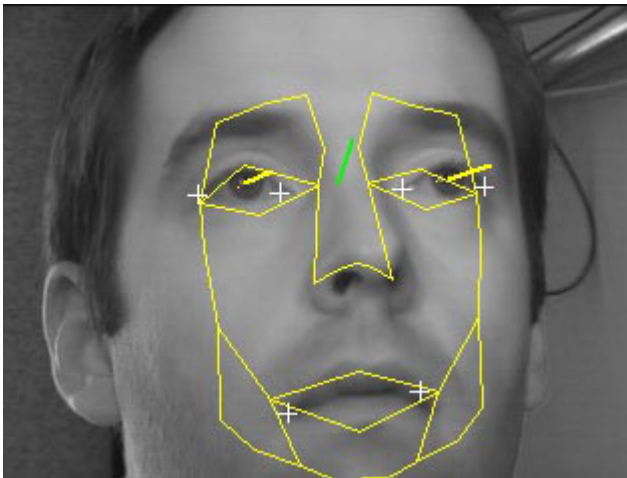
Infrared light enhanced measures take advantage of the bright pupil effect

This is the most commonly used approach.



# 3D-model method

Consists in the use of **serialized image** processing methods to detect face, pupils, mouth and nostrils, Once these treatments are done, a 3D model is used to evaluate **face orientation** and finally gaze direction is estimated using eyes images



[Link to the Example](#)

<http://www.google.com/patents/US7197165>

# A local linear map network.

Consists in the use of a **neural networks** of the local linear map type which enables a computer to identify the head orientation of a user by learning from examples.



[Link to the Example](#)

# Some important points about all methods

1. Infrared light may facilitate results
2. Calibration is a real problem
  - Either a model is adapted in real time
  - or is build before the tracking and adapted for a single person.
3. The price range of most commercially available eye-trackers is between \$5000 and \$60.000.

# Eye and gaze tracking applications

## 1. User interface design:

- Knowing where people are looking at is really important to **design devices**, cockpits, cars...
- Many publications can be found relating to this field

The studies are based on the ***eye-mind hypothesis***:

- what a person is looking at is assumed to indicate the **thought** on top of the stack of **cognitive** processes.

The results of findings can be used to improve the design of the interface.

# Eye and gaze tracking applications

## 2. The human-computer interaction (HCI)

- Currently very few applications have been implemented for consumer products.

The main reason for the slow emergence of attentive interfaces utilizing eye gaze is what is called

**Midas touch problem** :

- The application should not react every time the target of the gaze changes, only in ***appropriate*** situations, and at the ***right*** moment, very complex notions for a computer.

# Eye and gaze tracking applications

## **3. Enabling people with severe physical disabilities to communicate and/or interact with computer devices.**

- Simply by looking at control keys displayed on a computer monitor screen, the user can perform a broad variety of functions including speech synthesis, control, playing games, typing.

COGAIN network (Communication by GAZE INteraction [www.cogain.org](http://www.cogain.org))

# Additional applications

**4. Administration of intelligence and psychological tests**

**5. The cognitive and behavioural therapy**

- A branch of psychotherapy specialized in the treatment of anxiety disorders like phobias

# Additional applications

## 6. Military weapon control

- To aid pilots to observe and select targets with their eyes while **flying** the plane and **firing** the weapons with their hands.



[Video link](#)

# Additional applications

## 7. Remote robotics.

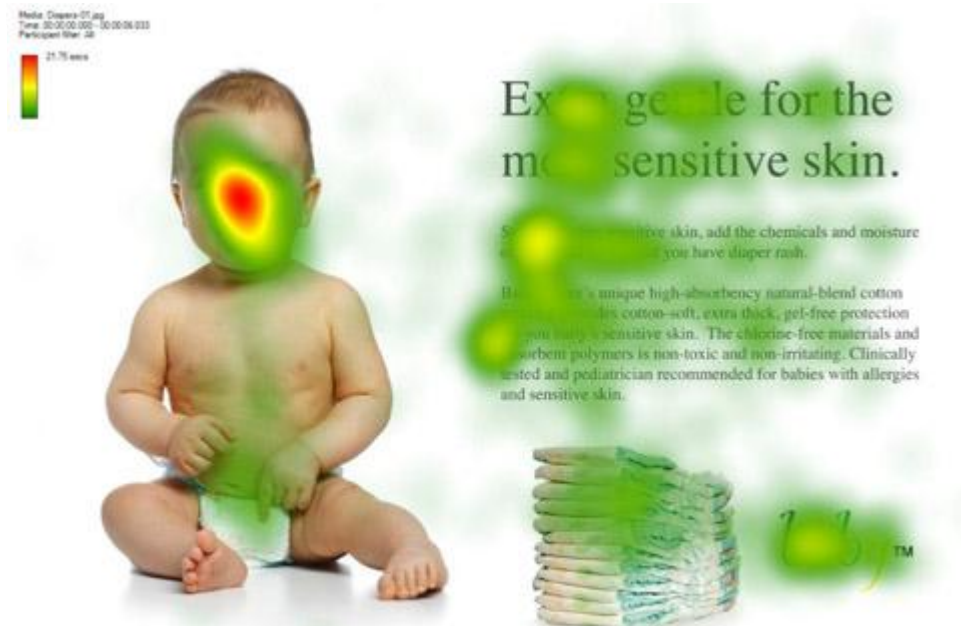
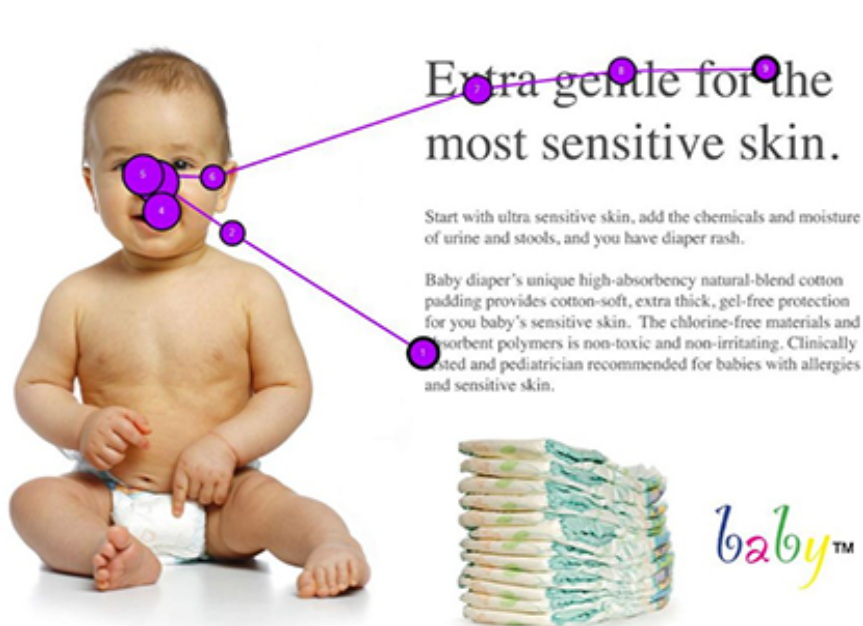


# Additional applications

## 8. Marketing and advertising

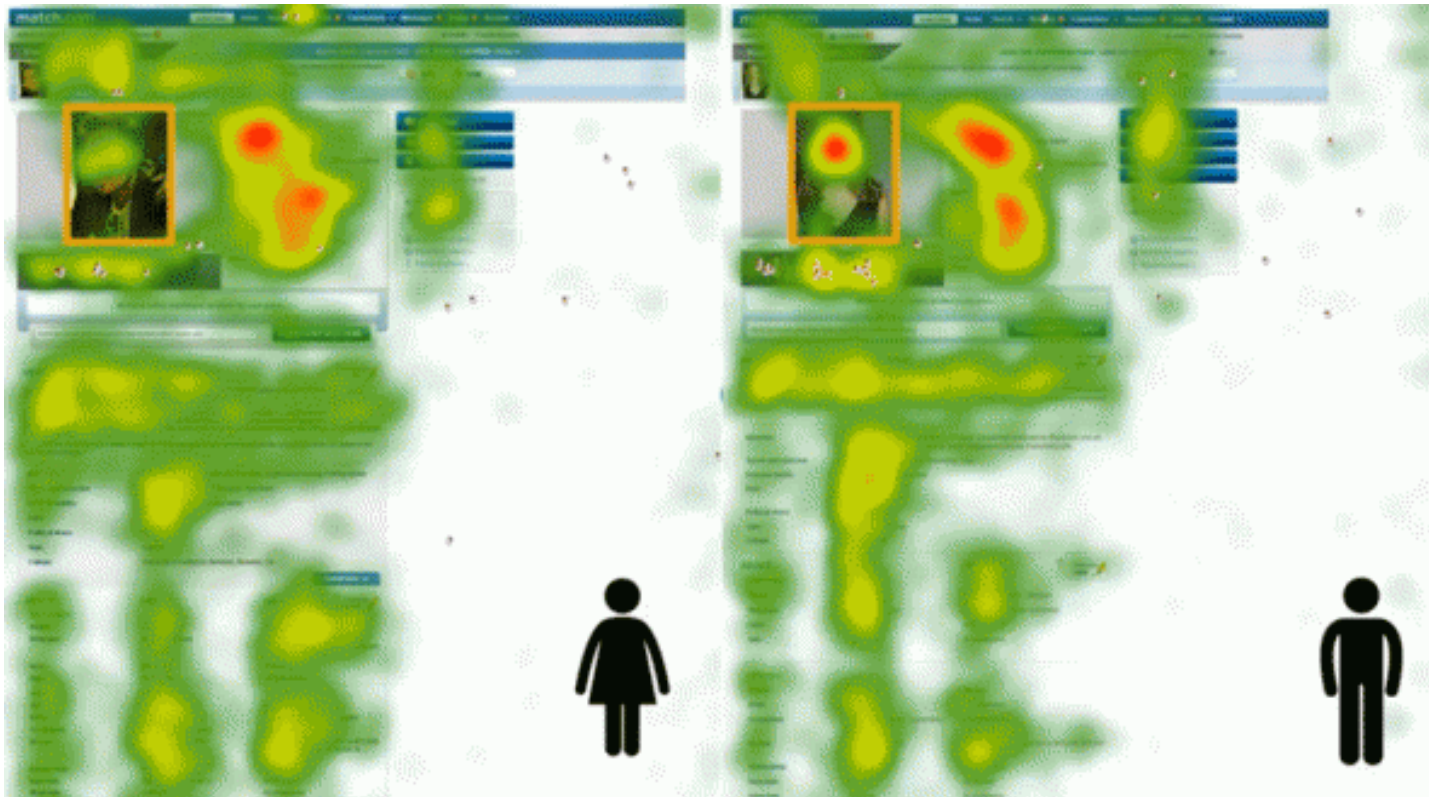
Market researchers want to know what attracts people's attention and whether it is good attention or annoyance.

Advertisers want to know whether people are looking at the right things in their advertisement.



# Additional applications

## 8. Marketing and advertising



How Men And Women Look At Dating Profiles Differently

# Additional applications

## 8. Marketing and advertising



# Additional applications

## 9. Game environment

For rehabilitation, entertainment or edutainment

- The research suggests that action game playing might be a **useful tool** to rehabilitate **visually impaired people** or improve visual attention.
- video-gamers **feel more immersed** and have more fun in virtual environments when they play with commercial **eye tracking** technology.
- Using eye tracking as a **joystick** to play a game and as a **easier-to-use** control

# Additional applications

## 10. Vehicle simulation.



[Video link](#)

# Additional applications

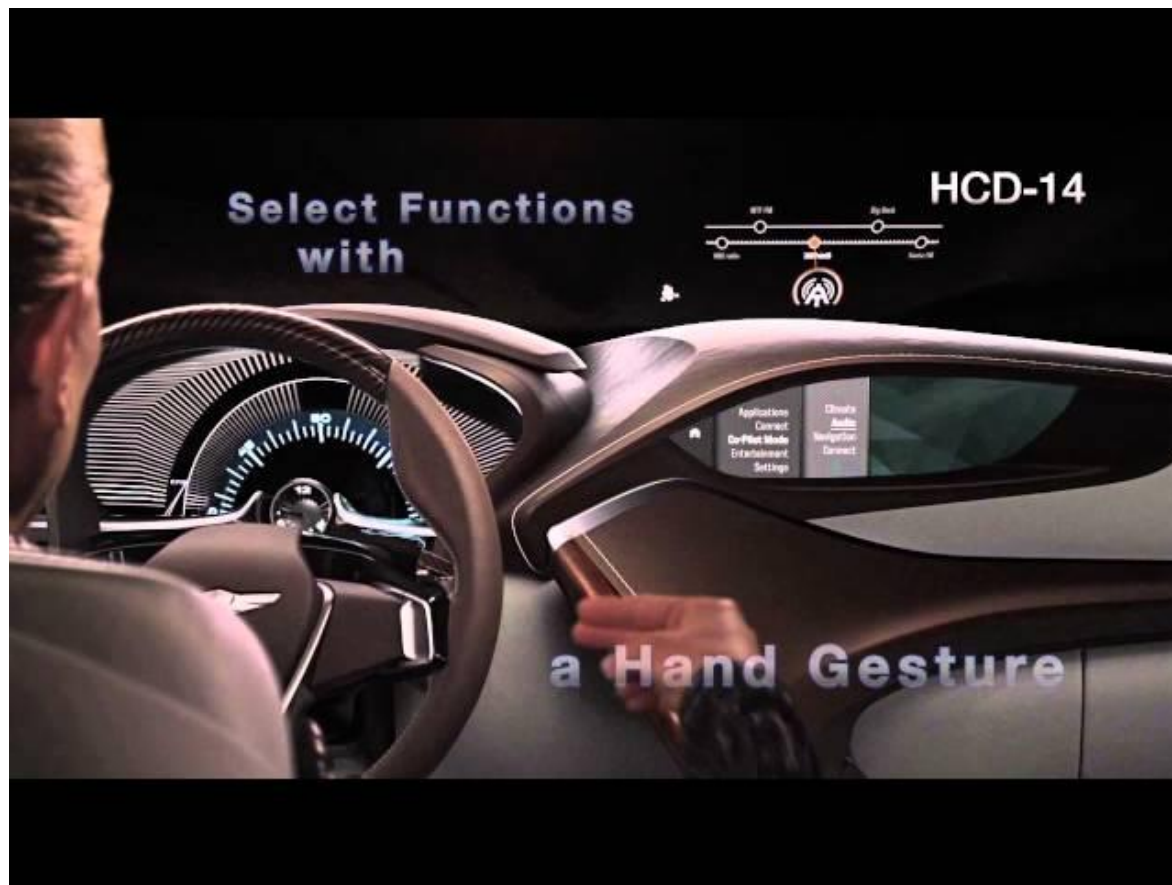
## 11. Detecting driver distraction



[Video link](#)

# Additional applications

## 12. Driver assistant systems



[Video link](#)

Hyundai HCD-14 Genesis Concept Interior Demo

# Additional applications

## 12. Driver assistant systems

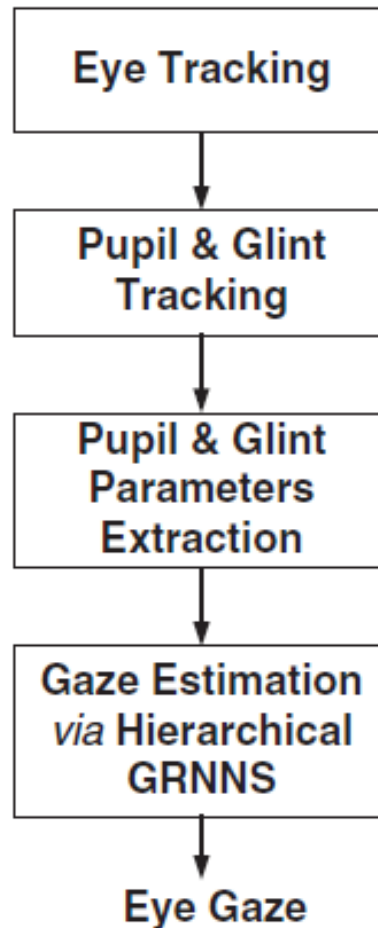


Hyundai HCD-14 Genesis Concept Interior Demo

# Examining two different methods

Zhu, Zhiwei, and Qiang Ji. "**Eye and gaze tracking for interactive graphic display.**" Machine Vision and Applications 15.3 (2004): 139-148.

# Major components of the first system

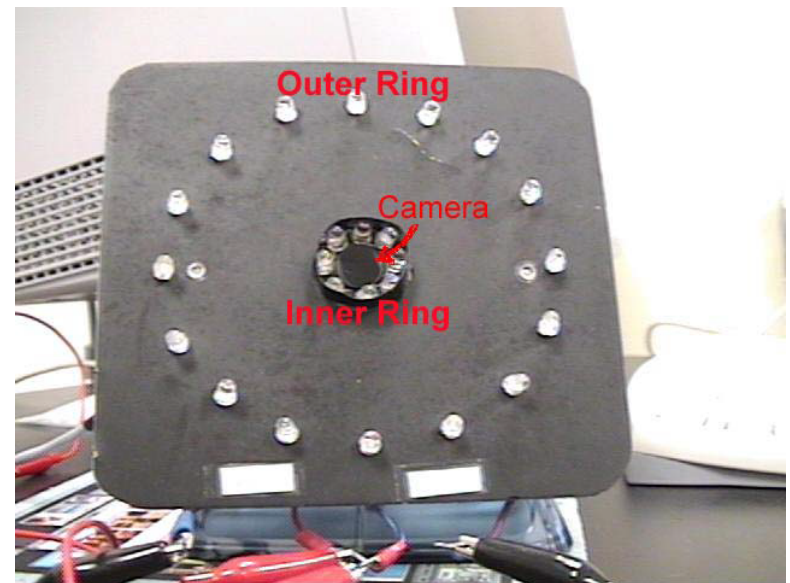


# Eye tracking

Obtaining a dark and a bright pupil image by illuminating the eyes with

- IR LEDs located off (outer IR ring)
- on the optical axis (the inner IR ring), respectively.

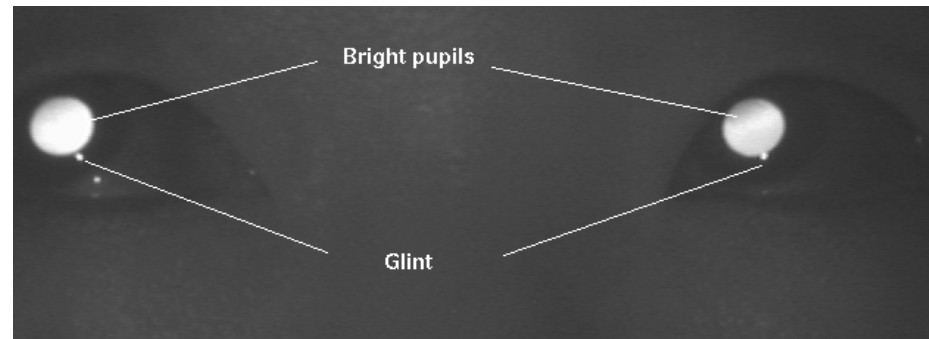
To further improve the **quality** of the image and to minimize **interference** from light sources other than the IR illuminator, they use an **optical bandpass filter**



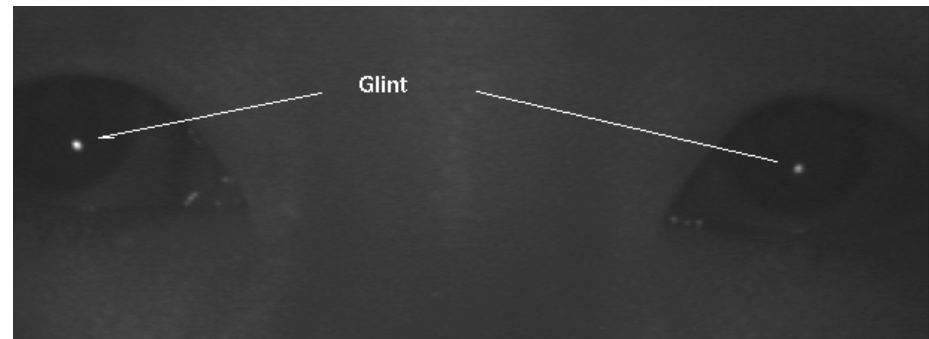
Pupil detection is accomplished based on both

- The intensity of the pupils (the bright and dark pupils)
- On the appearance of the eyes using the support vector machine (SVM).

a



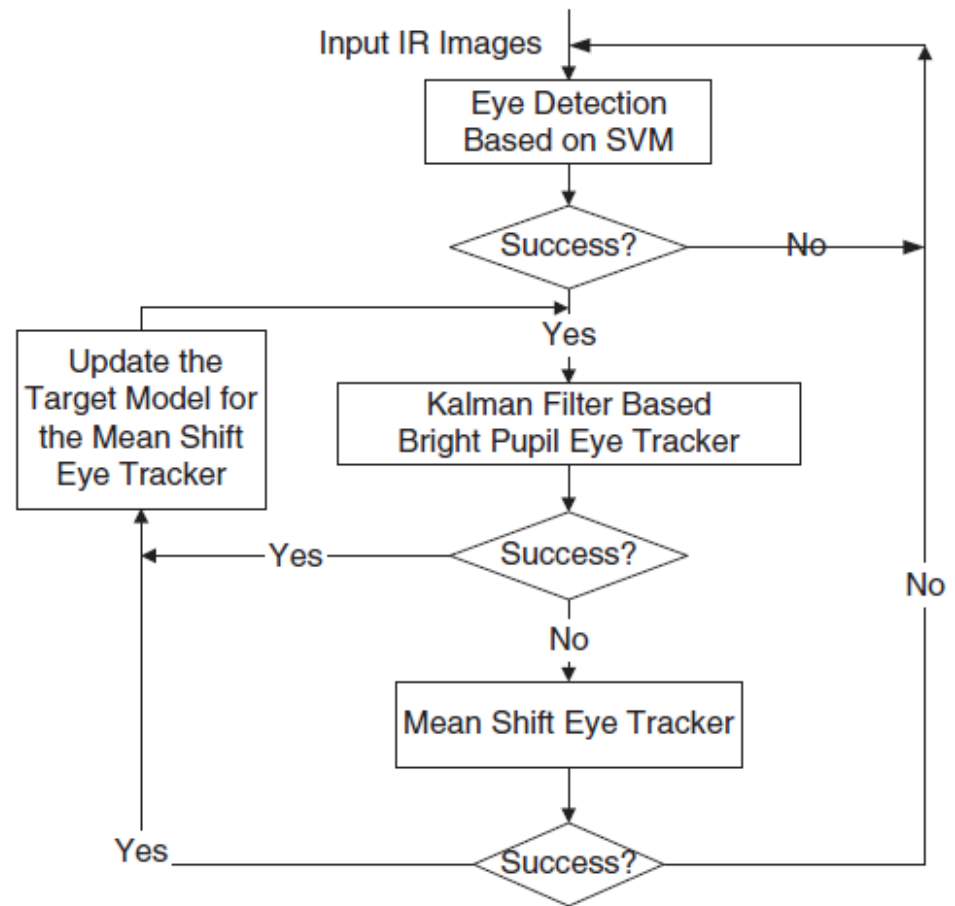
b



Bright (a) and  
dark (b) pupil  
images with glints

# Flowchart of our pupil detection and tracking algorithm

- The use of the SVM **avoids** falsely identifying a bright region as a pupil.
- Kalman filtering is used since it allows pupil positions in the previous frame to **predict pupil positions** in the current frame, thereby greatly limiting the search space.
- To avoid Kalman filtering going awry due to the use of intensity only, Kalman filtering is augmented by mean shift tracking, which **tracks an object** based on its intensity



# Gaze determination and tracking

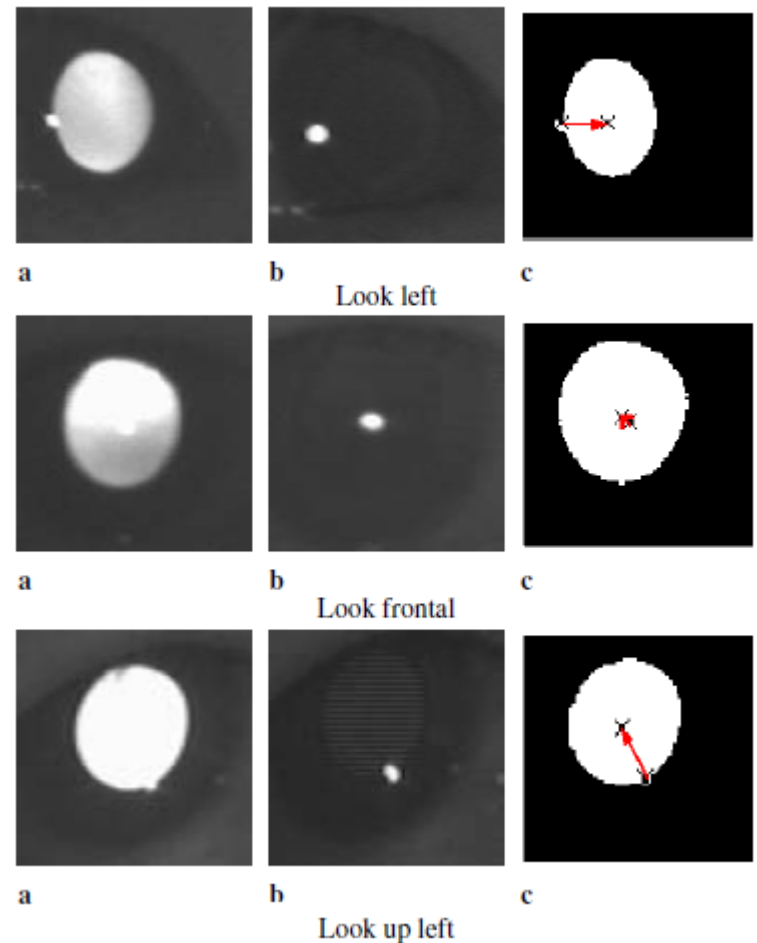
- **Pupil and glint detection and tracking**

The two rings of IR illuminator are turned on and off **alternately** to produce the so-called **bright and dark pupil effect**

- **Local gaze calibration**

Relative spatial relationship between **glint** and **bright** pupil center used to determine eye **gaze position**.

- **Gaze mapping to a function**



a. Bright pupil images. b. Glint images. c. Pupil–glint relationship generated by superimposing glint to the thresholded bright pupil images

# Direction of a person's gaze

The direction of a person's gaze is determined by two factors:

- **Face** orientation (face pose)
  - Determines the **global direction** of the gaze (head-based approach)
- **Eye** orientation (eye gaze).
  - Determines the **local direction** of the gaze (ocular-based)

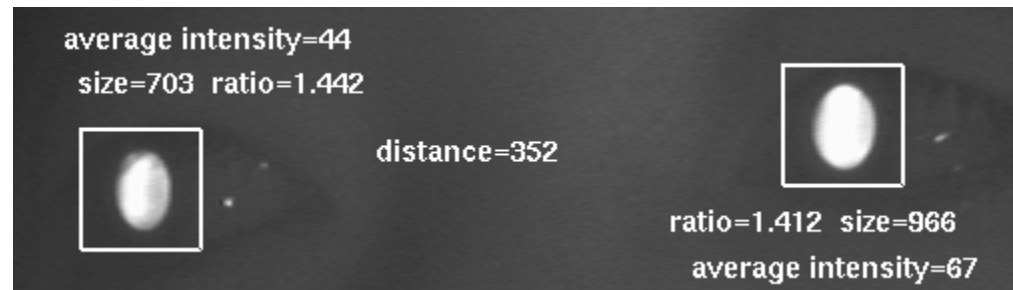
Global gaze and local gaze together determine the final gaze of the person.

(combined head- and eye-based approach)

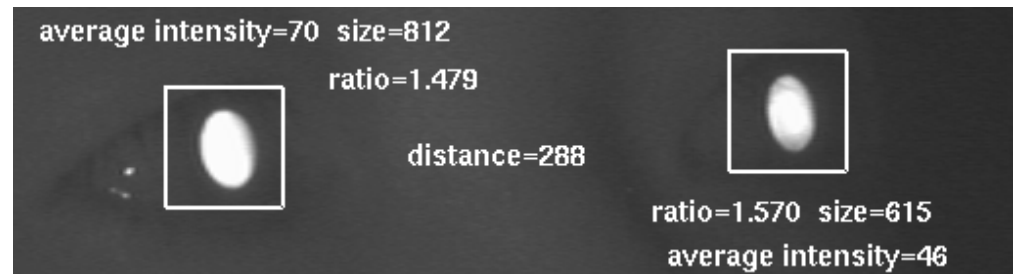
# Changes of pupil images under different face orientations

The study shows that there exists a direct correlation between 3D face pose and properties such as pupil size, inter pupil distance, pupil shape, and pupil ellipse orientation.

Look right



Look left



Look front



# Changes of pupil images under different face orientations

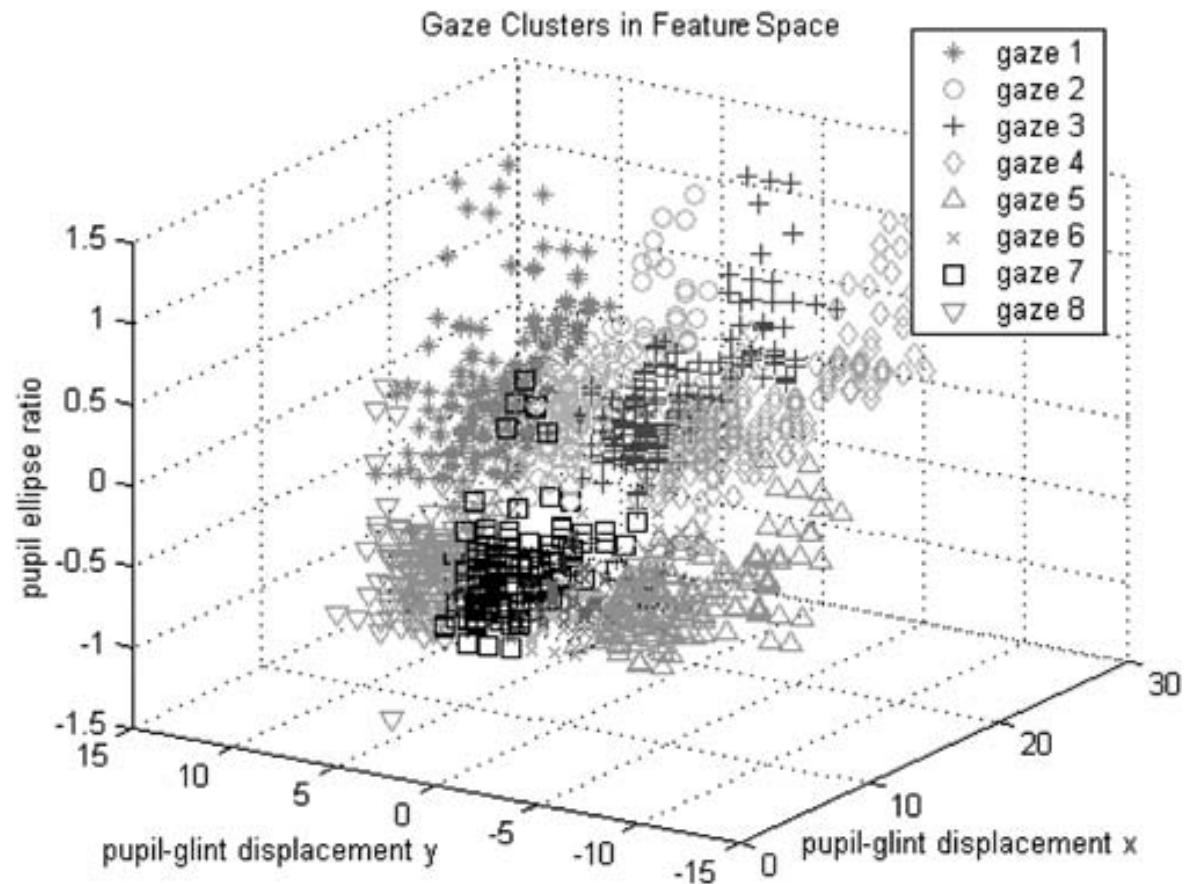
It is apparent from these images that:

1. The inter pupil distance decreases as the face rotates away from the frontal orientation.
2. The ratio between the average intensity of the two pupils either increases to over one or decreases to less than one as the face rotates away.
3. The shapes of the two pupils become more elliptical as the face rotates away or rotates up/down.
4. The sizes of the pupils also decrease as the face rotates away or rotates up/down.
5. The orientation of the pupil ellipse will change as the face rotates around the camera optical axis.

# Parameters for gaze calibration

## Gaze mapping and classification

An average of gaze classification accuracy of (85% accuracy) was achieved for 480 testing data



# Parameters for gaze calibration

Further analysis of this result shows significant misclassification occur between neighboring gaze regions. For example,

- About 18% of the gaze in region 1 are misclassified to gaze region 2
- About 24% gazes for region 3 are misclassified as gaze region 4.

Conclusion:

Misclassification almost exclusively occur among **neighboring gaze regions.**

# Hierarchical gaze classifier

To reduce misclassification among neighboring gaze classes, we need additional classification.

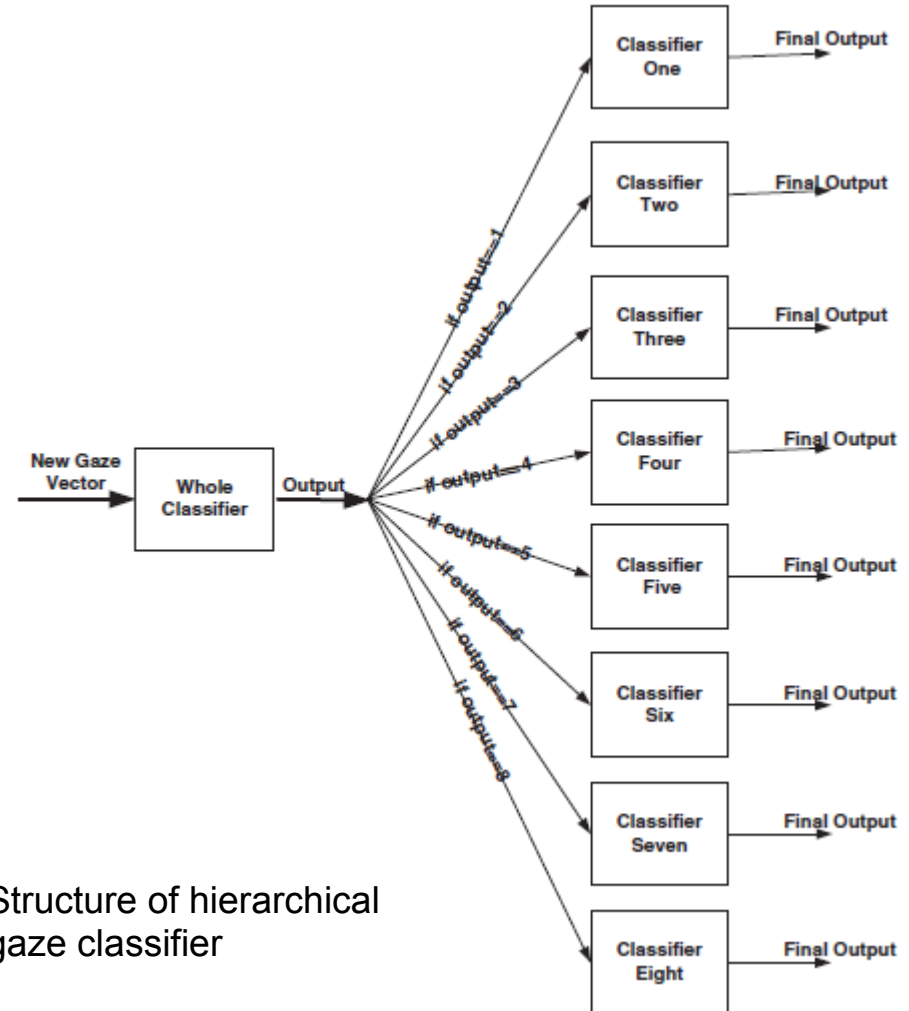
A classifier for each gaze region has been designed to perform the neighboring classification again.

1. Region 1: neighbors: 2,8
2. Region 2: neighbors: 1,3,7
3. Region 3: neighbors: 2,4,6
4. Region 4: neighbors: 3,5
5. Region 5: neighbors: 4,6
6. Region 6: neighbors: 3,5,7
7. Region 7: neighbors: 2,6,8
8. Region 8: neighbors: 1,7

# Hierarchical gaze classifier

These sub classifiers are then trained by GRNN method using the training data consisting of the neighbors' regions only.

The sub classifiers are subsequently combined with the whole classifier to construct a hierarchical gaze classifier



Structure of hierarchical gaze classifier

# Final results

The hierarchical gaze classifier can achieve an average of around **95% accuracy** for a different subject, which improves the accuracy by **around 10%** over the existing one-level gaze classifier method.

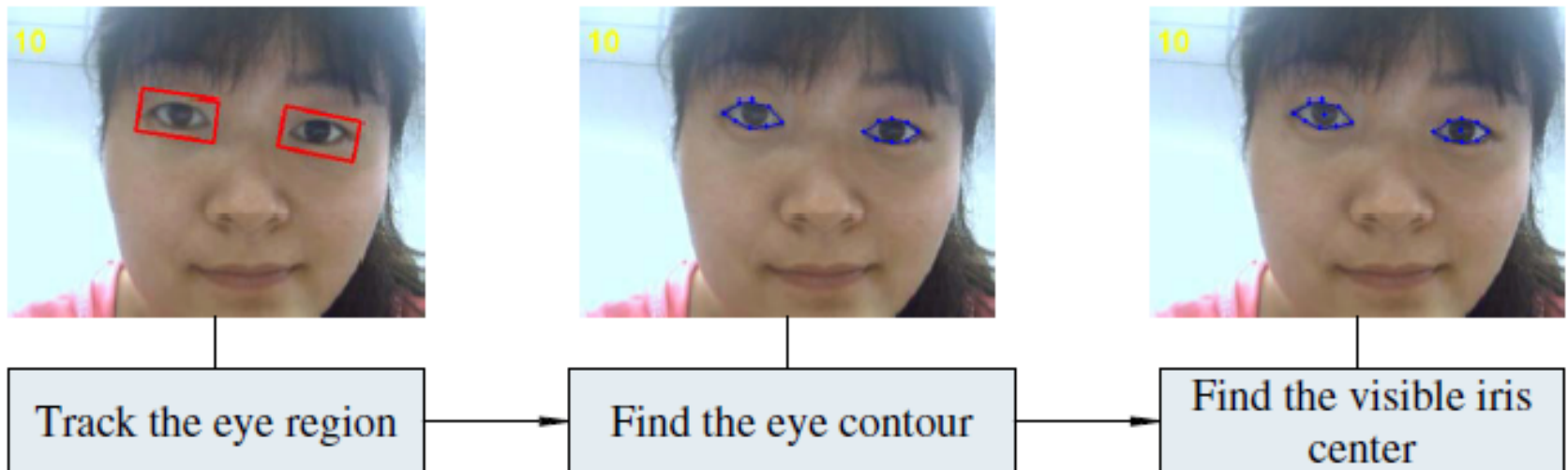
Specifically,

- The misclassification rate between neighbors 1 and 2 has decreased from 18% to about 8%,
- The misclassification rate between gaze regions 3 and 4 has decreased to about 5% from the previous 24%

LU, HUCHUAN, SHIPENG LU, and GANG YANG.  
**"ROBUST EYE TRACKING IN VIDEO SEQUENCE."**  
Journal of Circuits, Systems, and Computers 21.01 (2012).

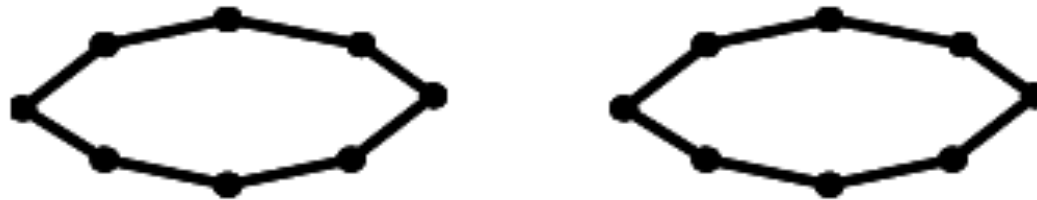
# System overview

## Online affine manifold model



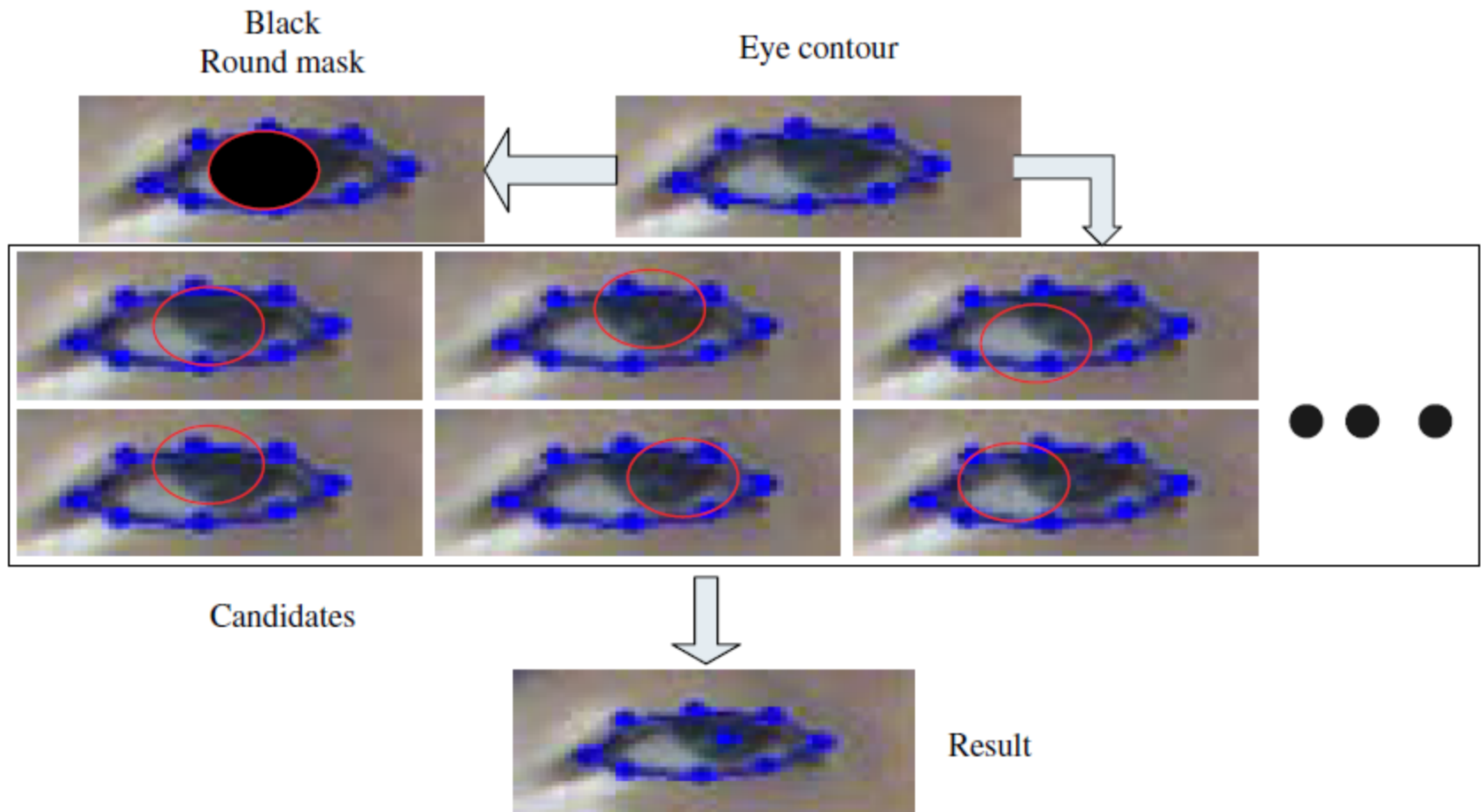
# Eye contour template

Eye contour template.



- A set of eight points are placed on the eye contour,
- Two of which correspond to the eye corners
  - The rest are equidistant on the contour

# Mask matching



Procedure of the adaptive black round mask matching

# System eye detections



Pose change



Eye change

# Conclusions

- The IVT tracker is used to extract the images of eyes
- The online affine manifold model that deals with the continuously changed data in the tracking video is used to find the eye contour points.
- A simple varying black round template matching method is brought forward to locate the visible iris center, which could offer some rough valuable information for gaze tracking.
- The whole system is empirically showed to work well in videos with significant head and eyeball motions.

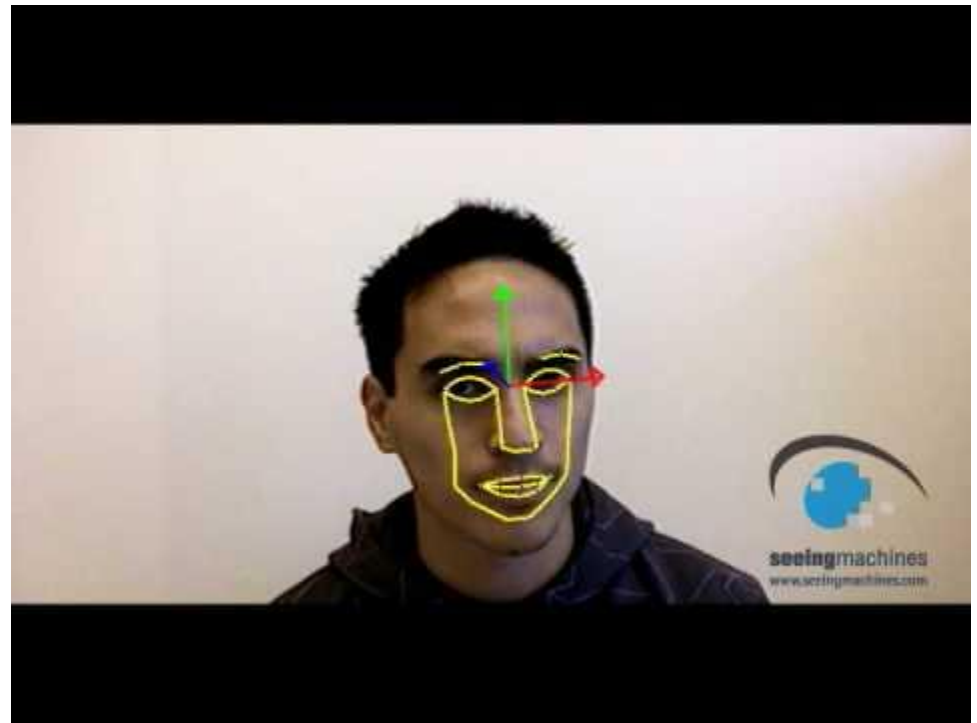
# FaceAPI

A suite of image-processing modules created specifically for tracking and understanding faces and facial features

faceAPI is available under Non-Commercial, Development and Production licenses.

[www.faceapi.com](http://www.faceapi.com)

[Video link](#)



# Part III

Just that you see this

# Practical Use in our Project

We thought about where is Eye-controlled Human Computer Interaction in our Project of importance:

There are different questions:

What are our eyes looking for in a car?

Example: put down the window, start the motor?

What can happen if we are controlling important parts of the car with our eyes?

Example: The wheel (there I don't want to go)

**How far is it allowed to put in HCI for the eyes and which objects are allowed to be included in this Interaction?**

**(Example: Backseats to lay them down, and while you are looking back...)**

**How can we start a command through the eyes?**

**(possibly like Humphry Bogart who said in a film:**

**"Schau mir in die Augen, Kleines" - Look into my Eyes Baby)**

**How can we end a command through the eyes?**

**(Example: Close the eyes for about 10 seconds? )**

**Can we combine different types of HCI to get a command including gaze tracking?**

**(gesture on my eyes to symbolize follow them...)**