Pupil dynamics for presentation attack detection in iris recognition

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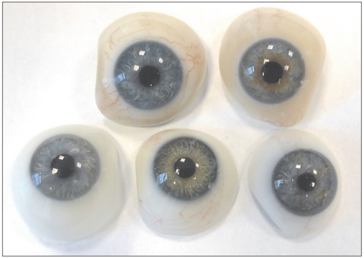
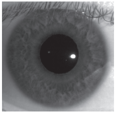
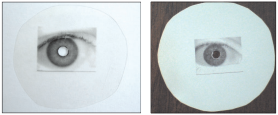
Static eye imitations



Eye models



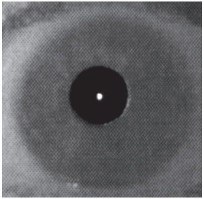
Biometric image of the authentic iris



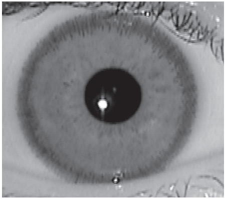
Foil and paper printouts

Biometric images of the artefacts

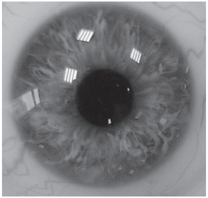
Paper printout



Printed contact lens



Prosthetic eye

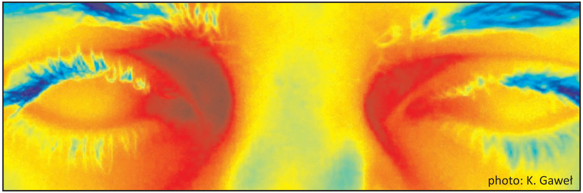


Static eye imitations

1. Static 2D images
   - paper and foil printouts
   - images displayed on a screen (hypothetical)
   - simple but alarming: possible impersonation of a given eye
2. Static 3D objects
   - authentic eye + printed contact lens
   - prosthetic eyes
   - impersonation difficult or impossible; typical aim: disturbing an iris pattern to cause a false rejection

Countermeasures for static eye imitations

1. Passive measurement
   - 2D liveness features: frequency analysis, use of local binary patterns, use of thermal data
   - 3D liveness features: eyeball shape, iris tissue structure, Purkinje reflections
2. Active measurement
   - positions of stimulated NIR reflections
   - tissue absorption for different NIR wavelengths



Example thermal image of the eyes (**left**) and 3D structure of the iris (**right**)

Dynamic eye imitations

1. Deformable objects with printed iris patterns
2. Movies displayed on a screen, off-line or on-line (hypothetical)
3. Image capture under coercion

Dracula (2000)

Minority report (2002)

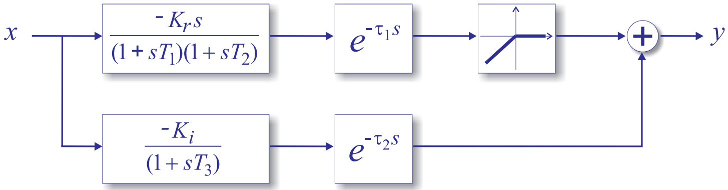
Bad company (2002)

Countermeasures for dynamic eye imitations

1. Passive measurement:
   analysis of involuntary activities of the eye
   - spontaneous oscillations of the pupil size
   - detection of spontaneous blinks
2. Active measurement:
   use of voluntary activities of the eye
   - gaze detection when following moving objects
   - eyeball dynamics (analysis of fixations and saccades)
   - pupil dynamics (modeling of pupil size variations when stimulated by visible light)

Modeling of pupil dynamics
Clynes-Kohn nonlinear model

Liveness features: channel gains (K_i, K_r), time constants (T_1, T_2, T_3) and delays (τ_1, τ_2)



x - visible light intensity

y - pupil size

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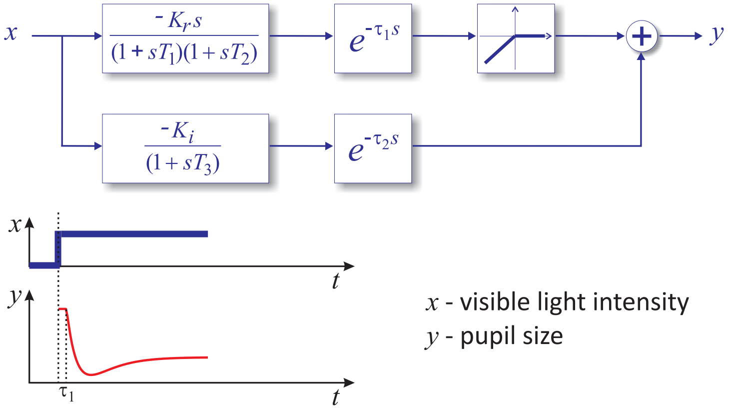

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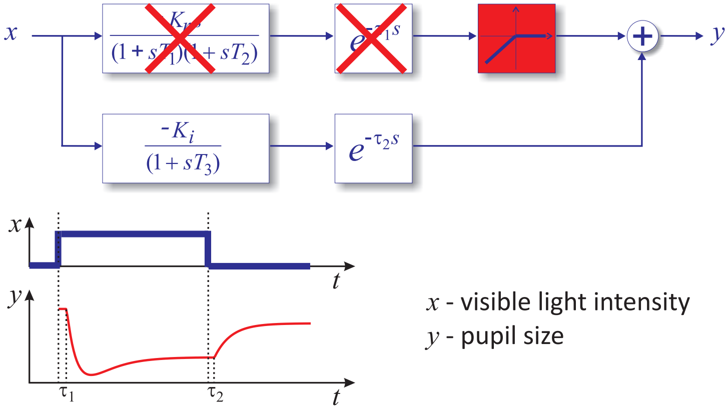

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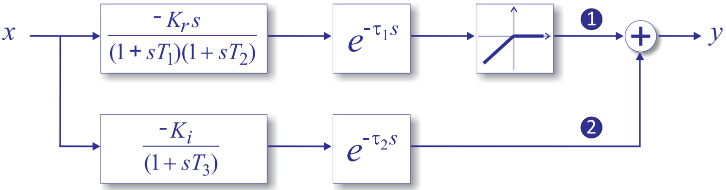
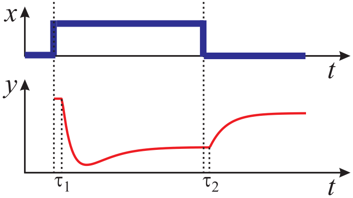
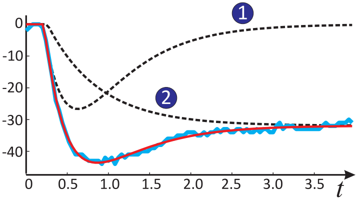






Model identification (finding a best fit)

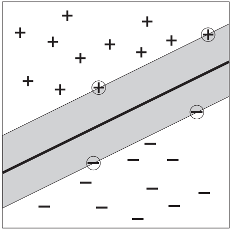
$$\widehat{\phi} = \underset{\phi \in \Phi}{\operatorname{argmin}} \sum_{i=1}^{N} (\widehat{y}_{i;\phi} - y_i)^2$$

where:

$\phi = [K_r, K_i, T_1, T_2, T_3, \tau_1, \tau_2]^T$ – liveness features
Φ – set of possible values of ϕ
$\widehat{\phi}$ – identified liveness features
$\widehat{y}_{i;\phi}$ – model output given the liveness features ϕ
y_i – actual (observed) change of the pupil size
N – length of the observed sequence

Processing of the modeling outcomes

1. Classification
   - use of Support Vector Machine to classify samples in ϕ-space
   - SVM maximizes the gap between samples of different classes
   - SVM may solve linear and non-linear problems (use of 'kernel trick')



2. Goodness of fit
   - use of normalized root mean square error

$$\text{GoF} = 1 - \frac{\|\widehat{y}_\phi - y\|}{\|\widehat{y}_\phi - \bar{y}\|}$$

where $\bar{y}$ is an average of y.

Questions

Question 1: How to simulate odd reactions of the eye?

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Question 3: How long shall we observe the eye?

- larger times give better modeling, but decrease usability

Database of eye reactions to light changes

Re: Question 1 (How to simulate odd reactions of the eye?)

1. Collection of samples
   - involuntary pupil oscillations under no light changes
   - pupil reaction to positive and negative jumps in light intensity
   - $N = 25$ volunteers $\times$ 2 eyes $\times$ $K = 4$ samples = 200 samples
2. Representatives of actual and odd reactions
   - involuntary pupil oscillations as odd reactions
   - stimulated changes in pupil size as actual reactions
   - pupil modeled as a circle; pupil size = circle radius
3. Division of dataset into training and testing subsets
   - leave-one-out cross-validation
   - 'one' relates to the person, not a single sequence
   - N divisions; in each division: $2(N-1)K$ training samples and $2K$ testing samples

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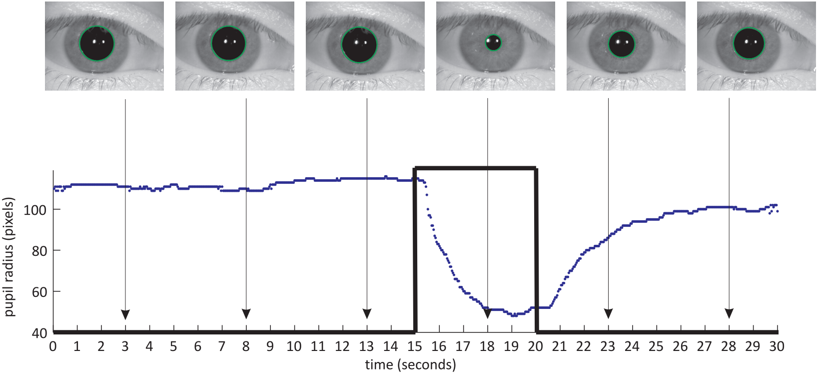
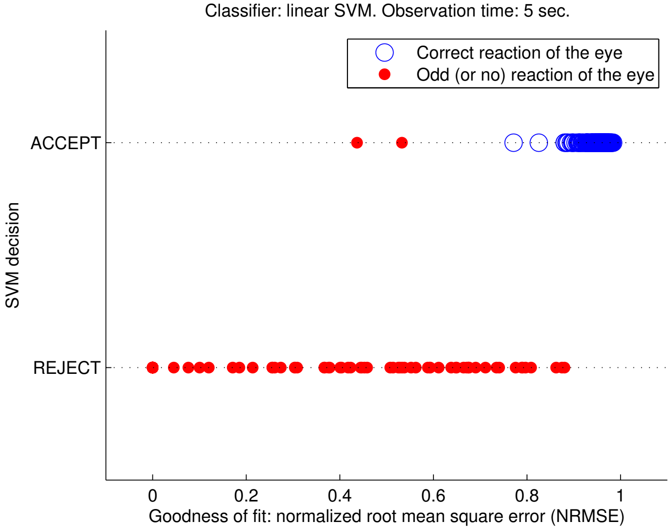
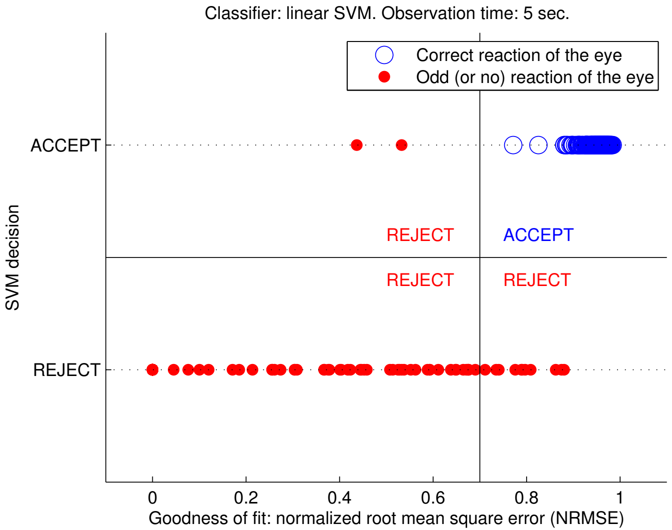


Decisions of linear SVM
Observation time: 5 seconds



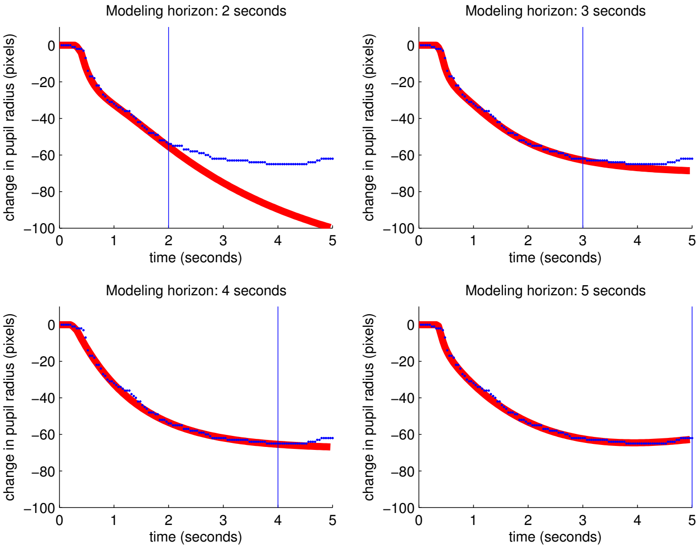
Decisions of linear SVM + goodness of fit

Re: Question 2 (Should we uncritically rely on classifier output?)



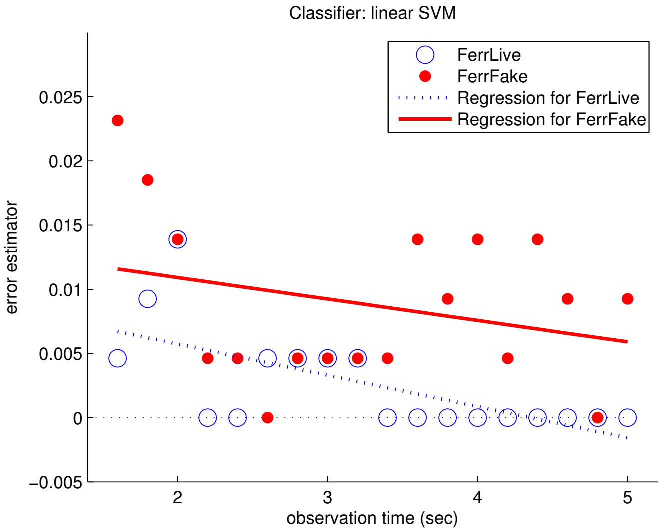
Modeling horizon (observation time)

Re: Question 3 (How long shall we observe the eye?)



FerrLive and FerrFake vs. observation time

Linear SVM, goodness of fit not considered



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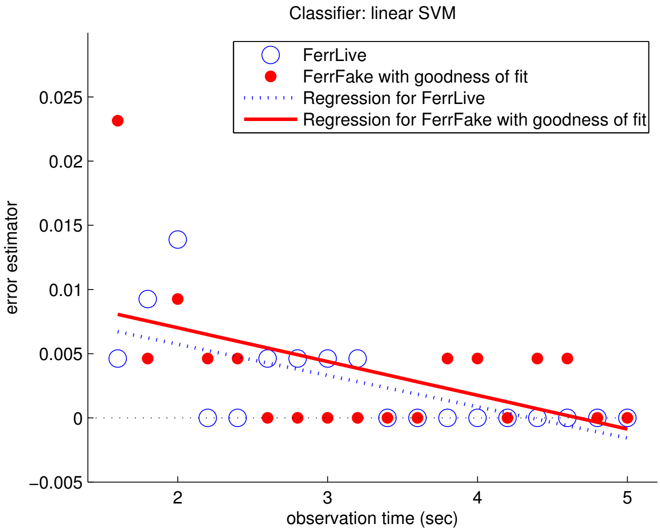
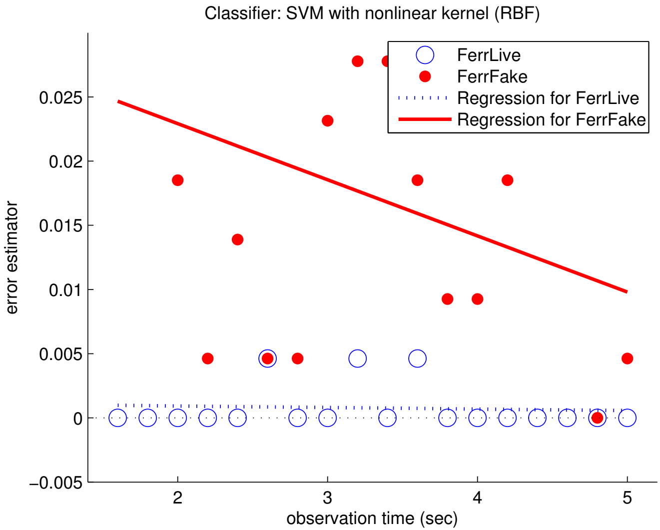


FerrLive and FerrFake vs. observation time
SVM with Gaussian kernel, goodness of fit not considered



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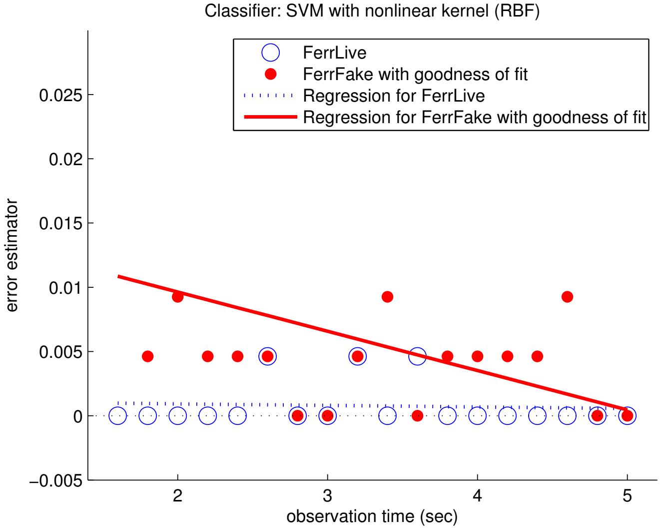

Conclusions

1. Dynamics of the pupil delivers interesting liveness features
2. Depending on the assumed dynamics of fake objects, linear classification seems to be sufficient to recognize artefacts
3. Having a few additional seconds ($\geqslant 3$) while capturing the iris may provide almost perfect recognition of actual and odd behavior of the pupil

Contact

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