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

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 \((\tau_1, \tau_2)\)

\[
\begin{align*}
    x & \quad \xrightarrow{-K_r s} \quad \frac{-K_r s}{(1 + s T_1)(1 + s T_2)} \\
    & \quad \xrightarrow{e^{-\tau_1 s}} \\
    & \quad \xrightarrow{-K_i} \quad \frac{-K_i}{(1 + s T_3)} \\
    & \quad \xrightarrow{e^{-\tau_2 s}} \\
    & \quad \xrightarrow{+} \\
    y & \quad \xrightarrow{x \text{- visible light intensity}} \\
    & \quad \xrightarrow{y \text{- pupil size}}
\end{align*}
\]
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time constants \((T_1, T_2, T_3)\) and delays \((\tau_1, \tau_2)\)

\[
\begin{align*}
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& \rightarrow \frac{-K_i}{(1 + sT_3)} \\
& \rightarrow e^{-\tau_2 s} \\
& \rightarrow y
\end{align*}
\]

\(x\) - visible light intensity
\(y\) - pupil size
Liveness features: channel gains ($K_i$, $K_r$),
time constants ($T_1$, $T_2$, $T_3$) and delays ($\tau_1$, $\tau_2$)

$x$ - visible light intensity 
$y$ - pupil size
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 \((\tau_1, \tau_2)\)
Modeling of pupil dynamics
Model identification (finding a best fit)

\[ \hat{\phi} = \arg\min_{\phi \in \Phi} \sum_{i=1}^{N} (\hat{y}_{i;\phi} - y_i)^2 \]

where:

\( \phi = [K_r, K_i, T_1, T_2, T_3, \tau_1, \tau_2]^T \) – liveness features
\( \Phi \) – set of possible values of \( \phi \)
\( \hat{\phi} \) – identified liveness features
\( \hat{y}_{i;\phi} \) – model output given the liveness features \( \phi \)
\( y_i \) – actual (observed) change of the pupil size
\( N \) – length of the observed sequence
1. Classification
   - use of Support Vector Machine to classify samples in $\phi$-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
     \[
     \text{GoF} = 1 - \frac{\| \hat{y}_{\phi} - y \|}{\| \hat{y}_{\phi} - \bar{y} \|}
     \]
     where $\bar{y}$ is an average of $y$. 

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- simulation of the coerced use → not really feasible
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- misclassifications always happen, so what about other metrics, e.g. goodness of fit?

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

[Images of eye reactions to light changes]

[pupil radius (pixels)]

[time (seconds)]
Classifier: linear SVM. Observation time: 5 sec.

- Correct reaction of the eye
- Odd (or no) reaction of the eye

Goodness of fit: normalized root mean square error (NRMSE)
Decisions of linear SVM + goodness of fit
Re: Question 2 (Should we uncritically rely on classifier output?)

Classifier: linear SVM. Observation time: 5 sec.

Correct reaction of the eye
Odd (or no) reaction of the eye

Goodness of fit: normalized root mean square error (NRMSE)
Modeling horizon (observation time)

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

Modeling horizon: 2 seconds

Modeling horizon: 3 seconds

Modeling horizon: 4 seconds

Modeling horizon: 5 seconds
FerrLive and FerrFake vs. observation time
Linear SVM, goodness of fit not considered
FerrLive and FerrFake vs. observation time
Linear SVM, goodness of fit considered

Classifier: linear SVM

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

Classifier: SVM with nonlinear kernel (RBF)
FerrLive and FerrFake vs. observation time
SVM with Gaussian kernel, goodness of fit considered

Classifier: SVM with nonlinear kernel (RBF)

- FerrLive
- FerrFake with goodness of fit
- Regression for FerrLive
- Regression for FerrFake with goodness of fit
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 ($\geq 3$) while capturing the iris may provide *almost perfect recognition* of actual and odd behavior of the pupil
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