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Passive Forensic Analysis for Anti Piracy

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Technicolor at a Glance

Who We Are

Technicolor, a worldwide technology leader in the media and entertainment sector, is at the forefront of digital innovation.

Our world class research and innovation laboratories and our creative talent pool enable us to lead the market in delivering advanced services to content creators and distributors.

We also benefit from an extensive intellectual property portfolio focused on imaging and sound technologies, supporting our thriving licensing business.

Our Mission

Developing, creating and delivering immersive augmented digital life experiences that ignite our imagination.

C. 350
RESEARCHERS AND EXPERTS

OSCAR® NOMINATIONS
FOR 25 FILMS SERVED BY TECHNICOLOR

6,000+
FILM & ADVERTISING VISUAL EFFECTS SHOTS

3
RESEARCH CENTERS:
RENNES
HANOVER
LOS ALTOS

300
MILLION DIGITAL HOME DEVICES SHIPPED TO DATE

80 %
OF CONSUMER ELECTRONICS MANUFACTURERS INTEGRATE OUR IP

7+%
OF PATENT PORTFOLIO RENEWED EVERY YEAR

TOUCHING
75 %
OF BLOCKBUSTERS WORLDWIDE IN 2013

1.47
BILLION
DVD AND BLU-RAY™ SHIPPED TO 40,000 DESTINATIONS IN 2013

265,000+
DIGITAL CINEMA DELIVERIES

#1
IN GATEWAYS

#2
IN SET-TOP BOXES

WORLDWIDE
IN TERMS OF SHIPMENTS

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Agenda

Acknowledgements: Séverine Baudry, Bertrand Chupeau, Antoine Robert, Mario de Vito, *Xavier Rolland-Nevière*, *Adi Hajj-Ahmad*, *Omar Alvarez*, *Cherif Ben Zid*

Piracy of Entertainment Content

Piracy Modality Characterization

Luminance Flicker Analysis

Pirate Devices Identification

Questions and Answers

Piracy of Entertainment Content

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The Challenging Transition to Digital

Key specificities of digital content

- Clones rather than copies i.e. no more generational degradation
- Assets can be tangible or intangible
- Ease of dissemination i.e. the world is at your doorstep

Apparition of a bestiary of pirates (Courtesy: Irdeto)

On the cost of piracy…

CNBC's Crime Inc #10: Hollywood Robbery (August 2012)

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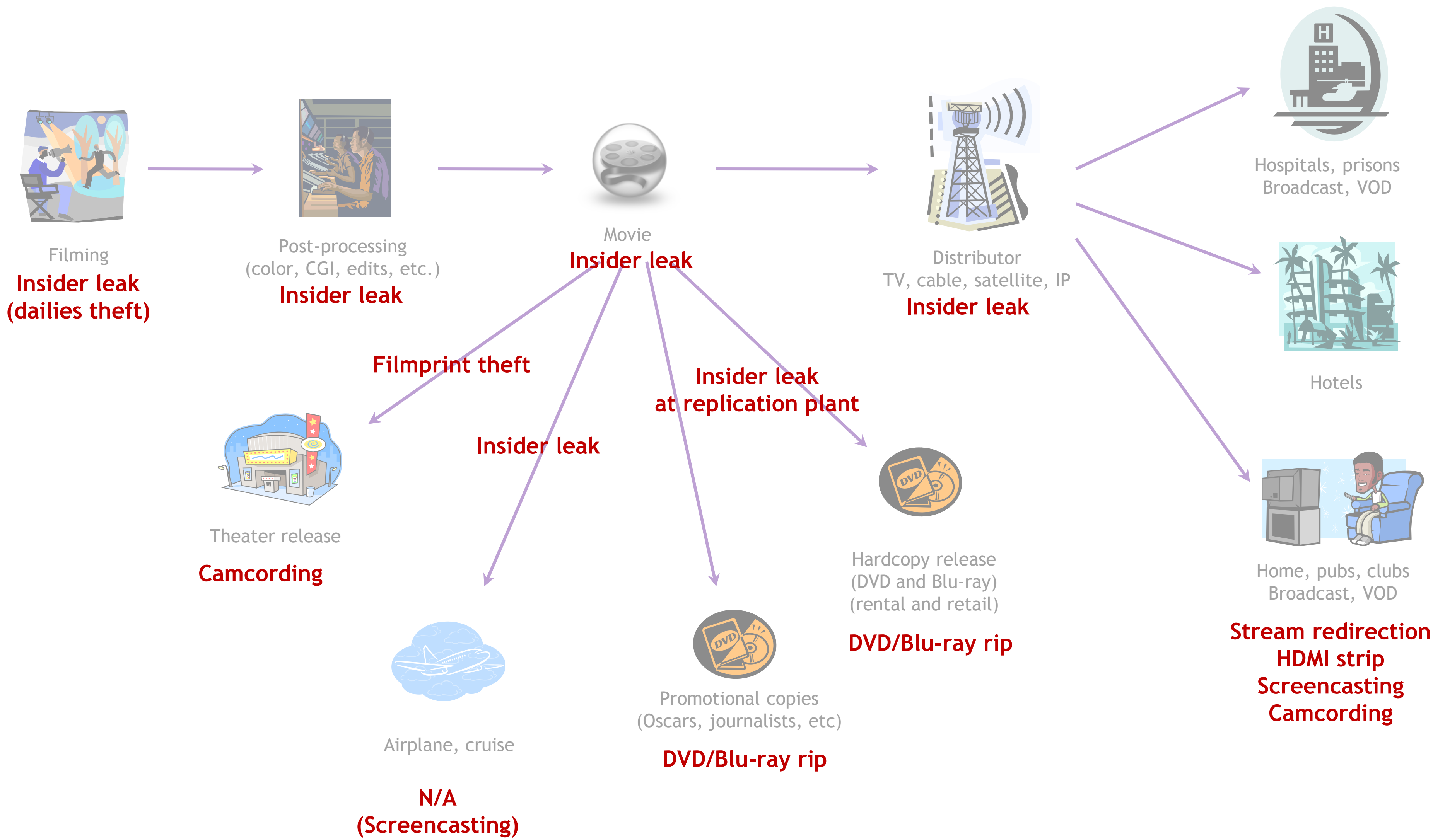
Threat Analysis



Anti-Piracy Arsenal

Regulate
- WIPO 1996 (DMCA, EUCD, Hadopi, etc.)
- SOPA/PIPA

Inform / Educate
- FA©T anti-piracy information campaigns
- Hard-to-counterfeit security features
  - Intaglio, color-shifting inks, holograms, CDIs

Prevent
- Content encryption aka. CAS and DRM
- Anti rip
- Playback/record control

Interfere / Jam
- Anti-recording e.g. Macrovision
- Anti-camcording

Monitor / Scout
- Data loss prevention systems
- Content fingerprinting

Trace
- Digital watermarking
- Passive forensics

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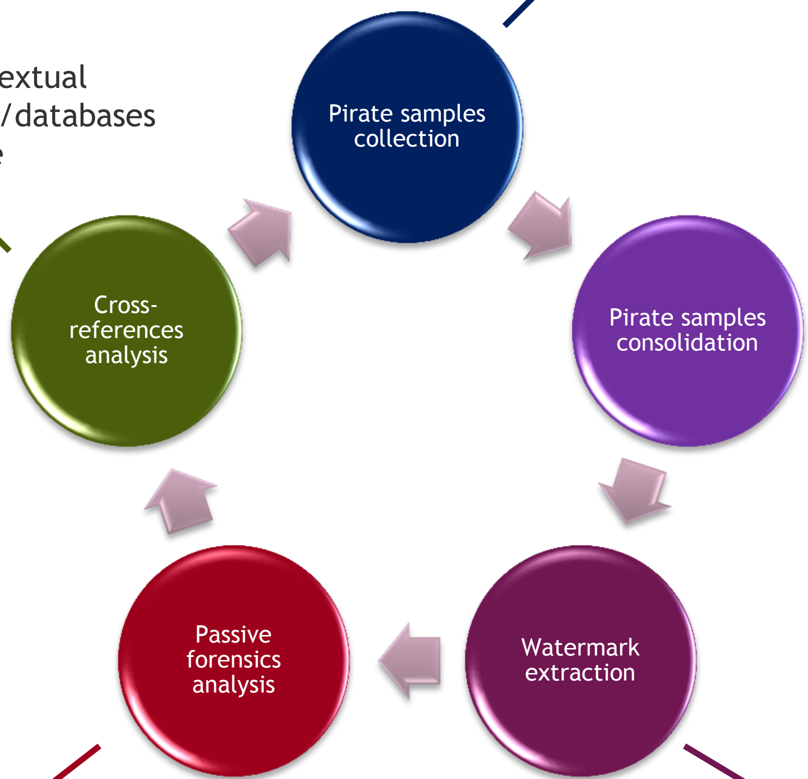
The Forensics Landscape

Outsourced
Internet Crimes Group, Deluxe (WEBWatch), Irdeto (Bay TSP), private investigators, blueSpike

Operated by MPAA
Manual process mostly relying on textual metadata collated in spreadsheets/databases e.g. the pirate release group name

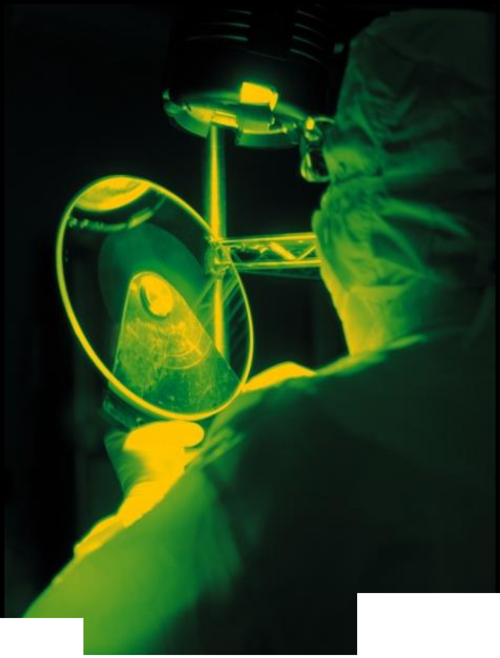


Outsourced
Manual Process?

Mostly operated by Deluxe/Technicolor
Manual process typically involving tedious audio-visual inspection

Mostly operated by Deluxe/Technicolor
with detectors bought/licensed from WM vendors e.g. Civolution, Verimatrix, Irdeto, Verance, (Technicolor) or through web portals

Piracy Modality Characterization



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Motivation

Different delivery channels $\Rightarrow$ different piracy behaviors

- Camcorder theft in (digital) cinemas
- Ripping of optical disks
- HDMI stripping/screencasting of streamed content

Different delivery channels $\Rightarrow$ different forensic watermarks

- Cinema vs. disk vs. broadcast vs. OTT

Objective: isolate statistical discrepancies from pirated audio visual content to infer its piracy modality (and thus its delivery channel) to optimize watermark detection costs

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Prior Works

Camcording

- Combing artifacts due to video interlacing [Lee:JIVP2012]
- Global motion jitter [Visentini:MMSP2013]
- Ghosting artifacts [Bestagini:ICIP2013]

Optical disk rip

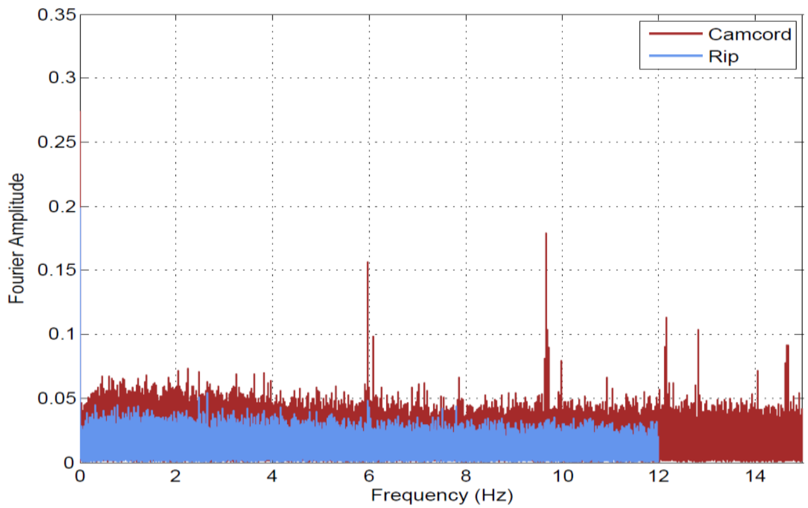
- Double compression detection [...]
  - Holes in histograms of DCT modes
  - Occasional Unexpected large prediction error

Piracy classification [Technicolor]

- Legacy cinema vs. digital cinema [Rolland-Nevière:SPIE2012]
- DVD rip vs. digital cinema [Moreira-Pérez:WIFS2013, Chupeau:WIFS2014]

Luminance Flicker Feature

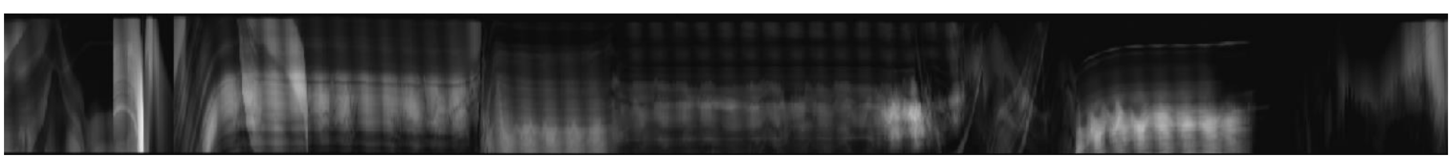
Interplay between the projector and the camcorder



Periodical high-frequency frame refresh (at 96 fps or higher) captured at 25 or 29.97 fps translates into low frequency aliased components

Feature vector

- Reduce the video into a 1-D temporal signal (luminance row average)

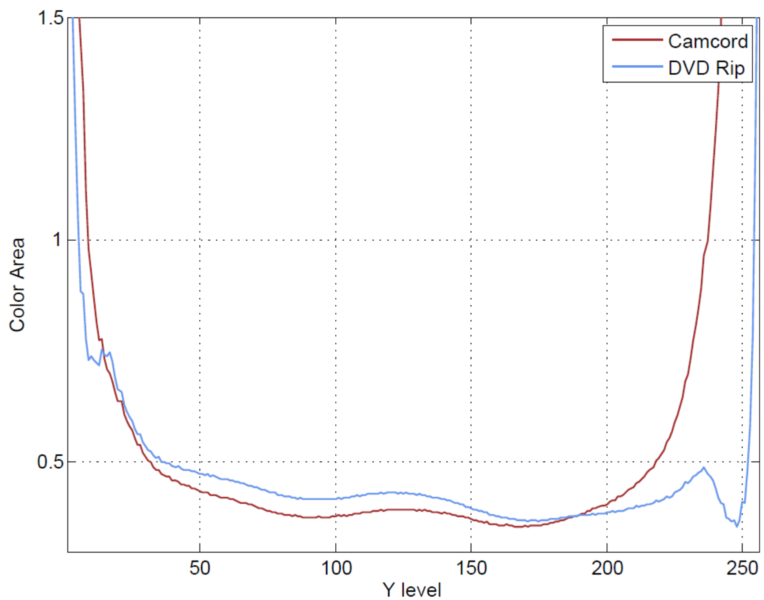


- Record the *P* highest peaks of the magnitude of the temporal FFT

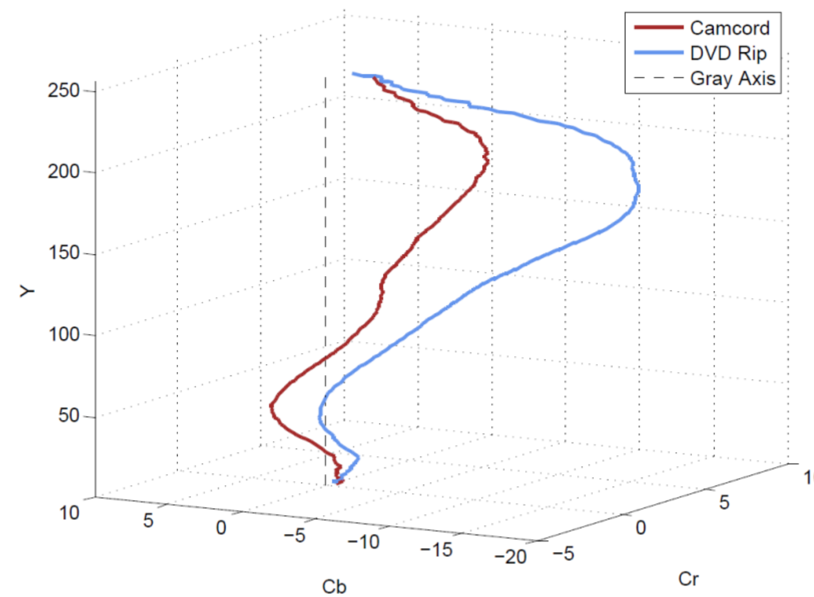
Color Gamut Properties

Color feature vectors

- **Color areas (saturation):** number of colors at all luminance (**Y**) level, normalized by the maximum area of feasible colors at the same level
- **Color centroids (bias):** coordinates of the color centroids in $\mathbf{C_bC_r}$ plane at all luminance levels



Color areas



Color centroids

Color feature behavior (DB mean)

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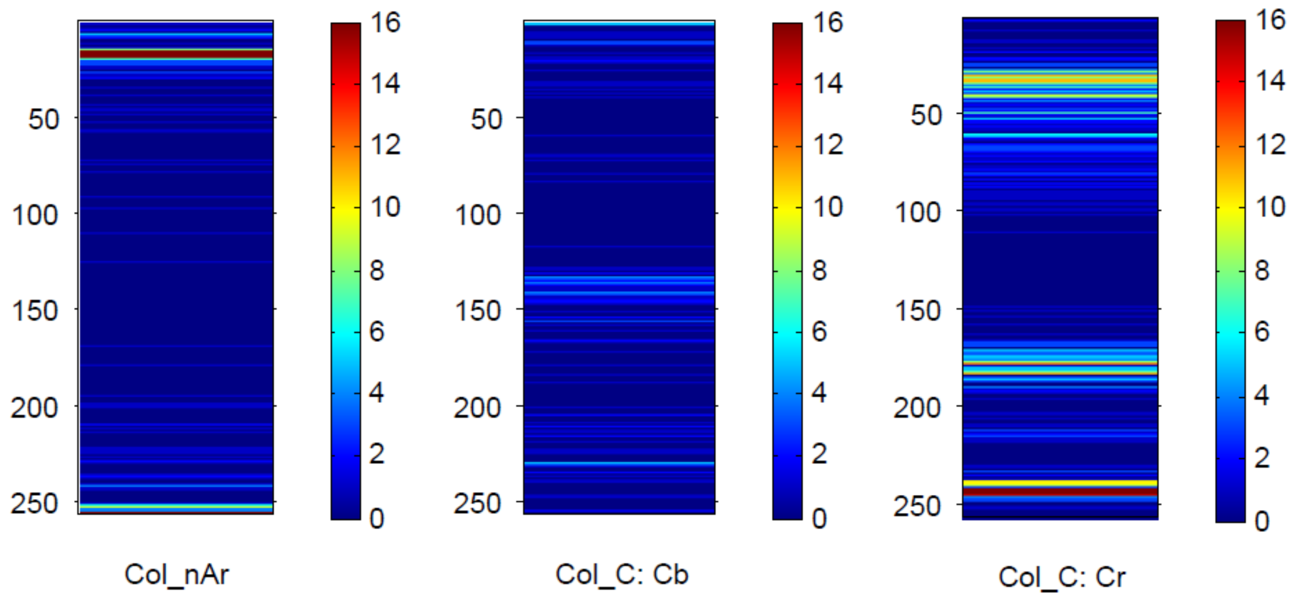
Sequential Feature Selection



Number of time each component has been included into the optimal subset estimated by the SFS algorithm (repeated 100 times)

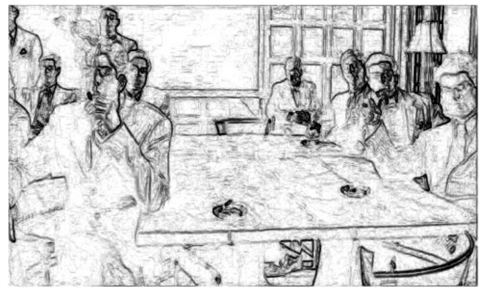
17 components in total (out of 768)

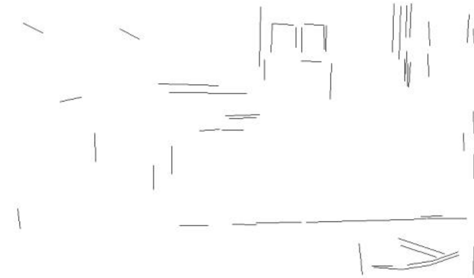
- Color saturation: 5 (out of 256)
- Color bias: 12 (out of 512)

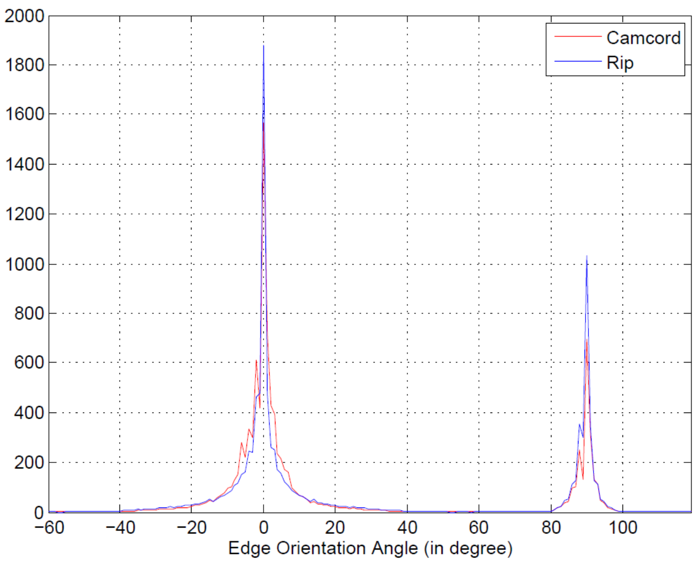
Distribution of Edge Orientations

Observation: camcorder recapture induces planar perspective distortion

- Distribution of straight edges impacted







Histogram of edge orientations (DB mean)

- 180-D histogram $\rightarrow$ 4-D descriptor
  - Standard deviation and shape parameter of the Generalized Gaussian fit around the horizontal and vertical directions

$$f(o) = \frac{\beta}{2\alpha\Gamma(1/\beta)} \exp\left(\frac{|o-\mu|}{\alpha}\right)^{\beta}$$

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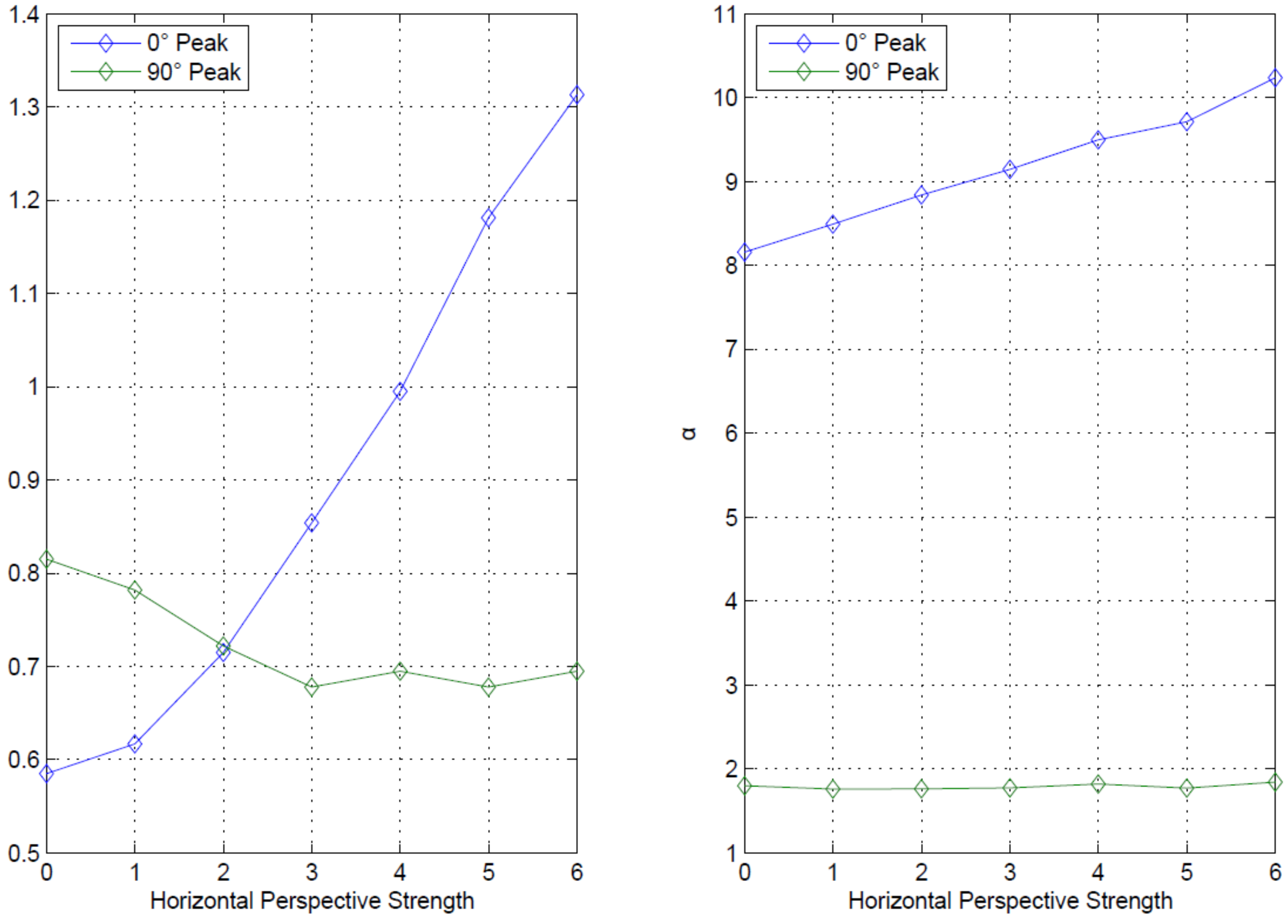
Feature Sensitivity Synthetic Validation



Standard deviation

Shape parameter

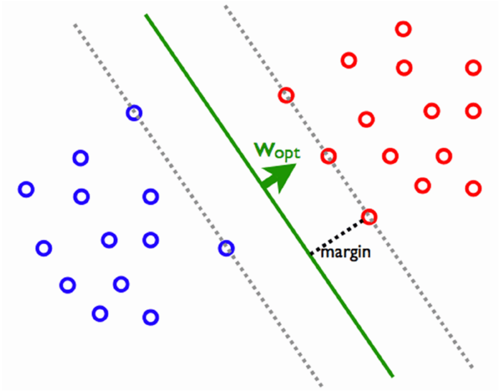
Experimental Setup

Dataset of pirate samples

- 113 real-life camcorded DCI movies from TCH Forensics Operations
- 103 DVD rips: 48 from the web, 55 generated in the lab
- Random 15k frames long extract with no overlap ⇒ ~1.8k samples

SVM-based classifier

- Record AUC for 100 random train (90%) / test (10%) splits
- Score averaging to combine individual classifiers



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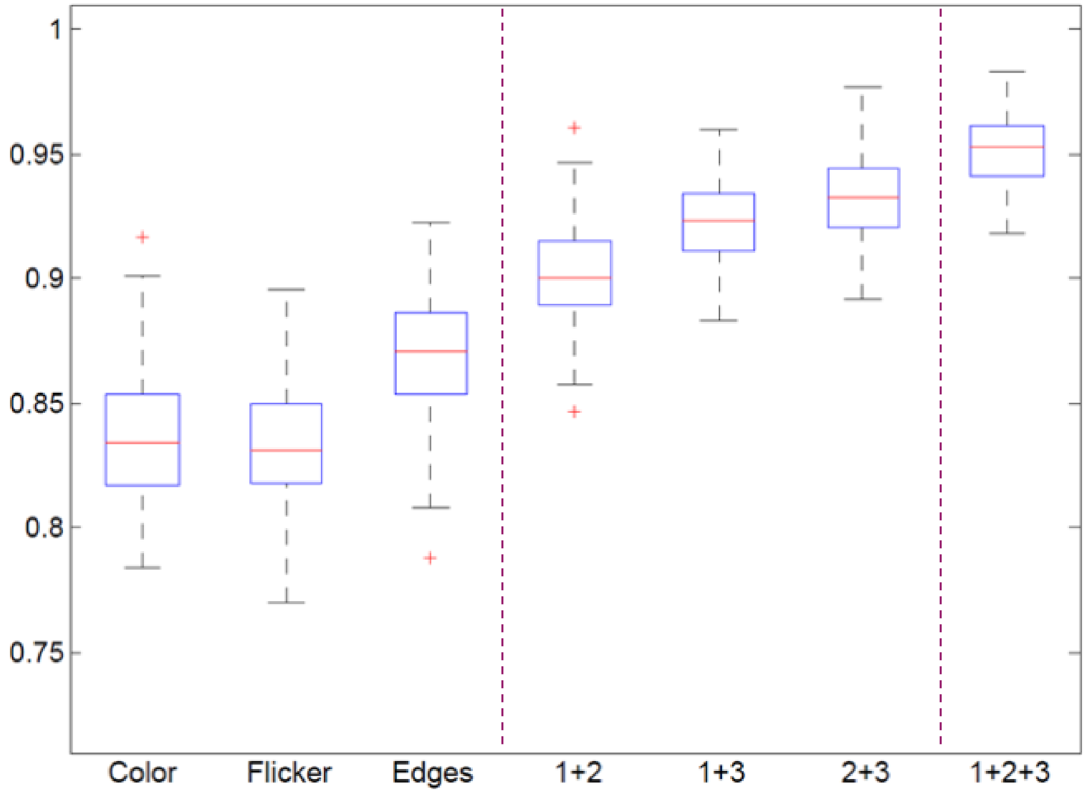
Experimental Results



Take-away lessons

1. Good performance of individual classifiers
2. Boost of performances by combining features
3. Increased stability when combining features (reduced boxplot width)

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Luminance Flicker Analysis

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Motivation

Early piracy has a drastic impact on revenues

- Poor quality camcord of new released movies in cinema
- Good quality camcord of premium VoD movies at home

Tell-tale visual artifact = small and periodic spatio-temporal variations of the luminance in the pirate sample e.g. dark/bright stripes rolling down/up the frames

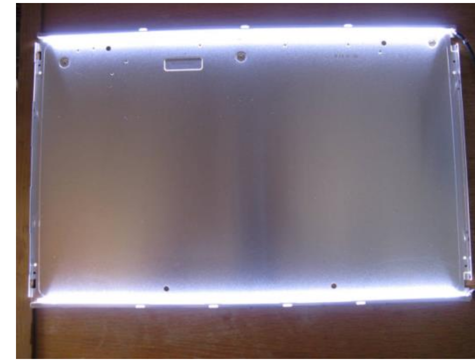
Objective #1: model the flicker signal, estimate the parameters of the model and compensate for this effect to improve watermark detection

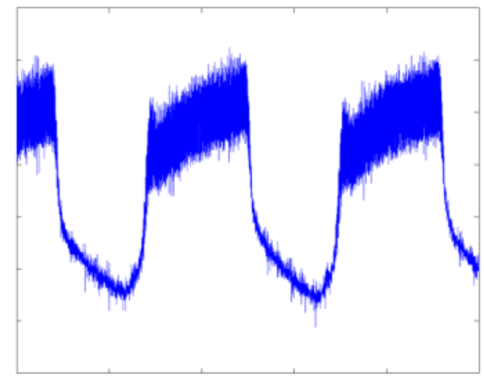
Objective #2: model the flicker signal to be able to synthesize distortion introduced by camcorder recapture for efficient benchmarking

Camcording an LCD Screen

LCD screen backlight

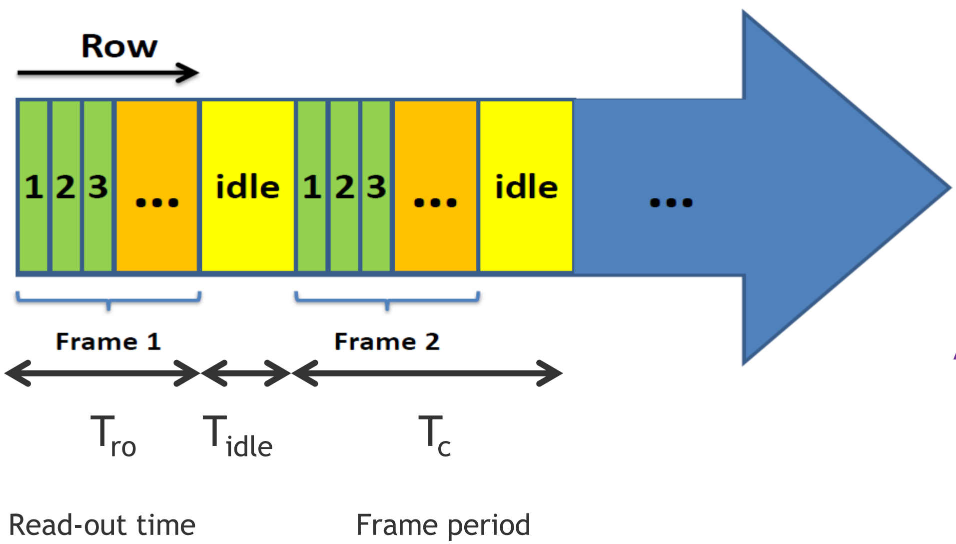
- Light source LCD luminance level
- Typical frequency: 120-1000 Hz





Camcorder shutter

- Global shutter (CCD) vs. rolling shutter (CMOS)
- Typical frequency: 25-50 fps



Aliasing due to the backlight signal being sampled below Nyquist frequency

Recapture Flicker Modeling [Baudry:WIFS2014]

Camcorded flicker

Content luminance

Phase

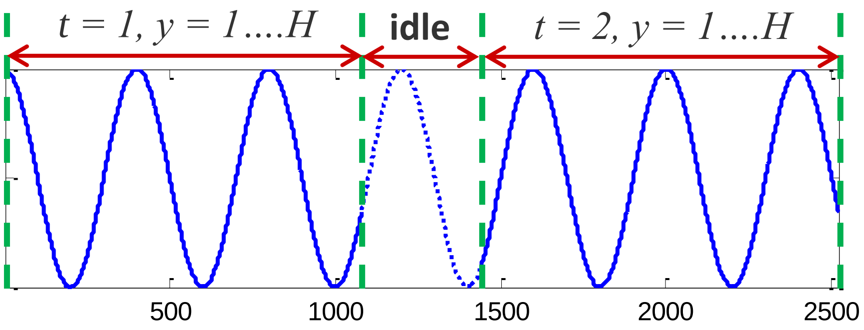
$$\mathbf{f}(x,y,t) = (A.\,\mathbf{c}(x,y,t) + B).\cos\,(\omega_t t + \omega_y y + \varphi)$$

Flicker amplitude parameters

Flicker temporal frequency

Flicker vertical frequency

x column index
y row index
t frame index



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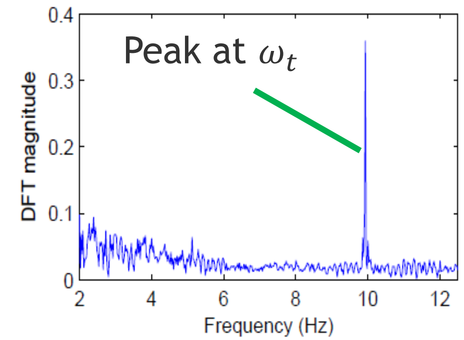
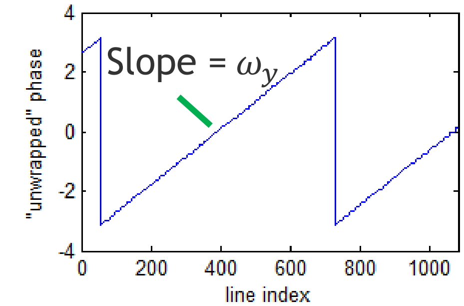
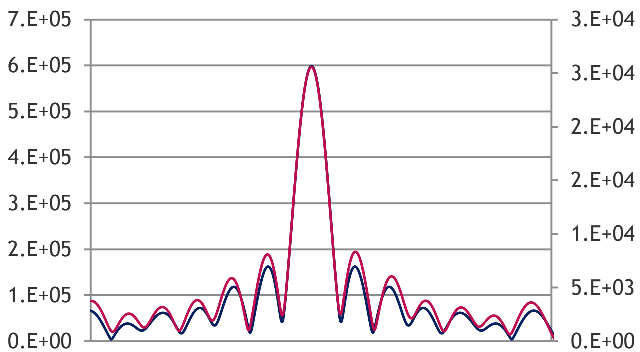
Parameters Estimation [Baudry:WIFS2014]

Periodicity parameters

- Video frame → row luminance average (1-D vector)
- Temporal Fourier transform analysis *for a single row* → spectral peak at ω_t
- Phase of Fourier coefficients at ω_t for all rows → linear slope equal to ω_y







Amplitude parameters

- Near replicate in the spectrum at 0 and ω_t
- Least means square minimization

$$(\alpha, \beta) = \arg\min \sum_{\varepsilon > -\rho}^{\varepsilon < \rho} \left(\mathbf{Y}(\omega_t + \varepsilon) - \frac{e^{i\psi}}{2} \left(\alpha \mathbf{Y}(\varepsilon) + \beta \delta(\varepsilon) \right) \right)^2$$

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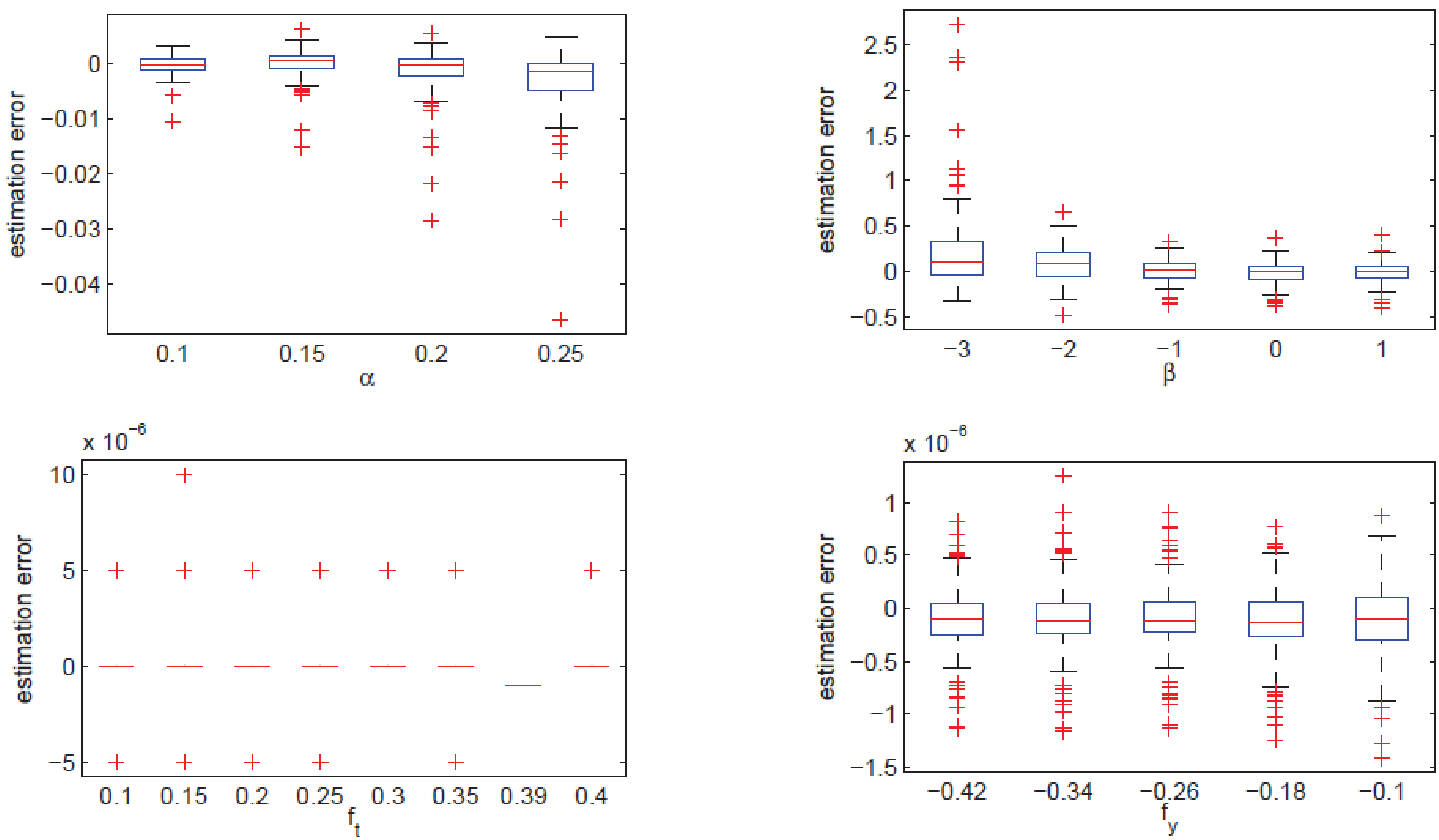
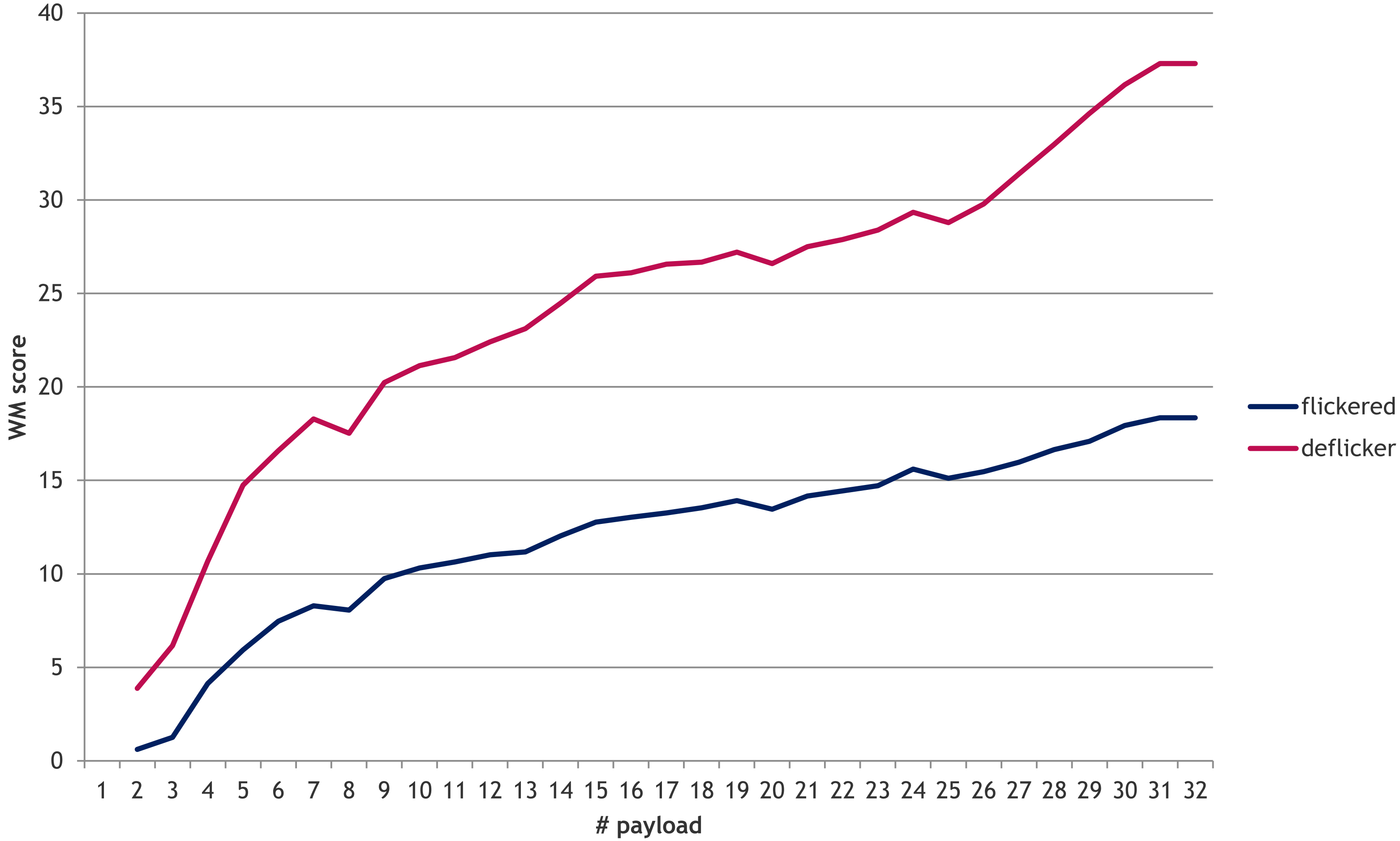
Estimation Accuracy with Synthetic Flicker



Watermark Detection after Flicker Removal



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Pirate Devices Identification

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Motivation

Forensic scenario

- Traitor-tracing analysis points to a suspect individual
- Camcorders/screens are seized at the home the suspect
- Assess if the pirate's flicker can be produced by a pair of these devices

Cross-referencing scenario

- Information about the piracy workflow is extracted from pirate samples
- Cross-reference such metadata to isolate piracy trends / hot spots

Objective: infer information about the intrinsic parameters of the pirate devices used to produce the pirate samples from the analysis of the induced underlying statistical anomaly

Flicker Parameters vs. Devices Parameters

$$\mathbf{f}(x,y,t) = (A.\mathbf{c}(x,y,t) + B).\cos(\omega_t t + \omega_y y + \varphi)$$

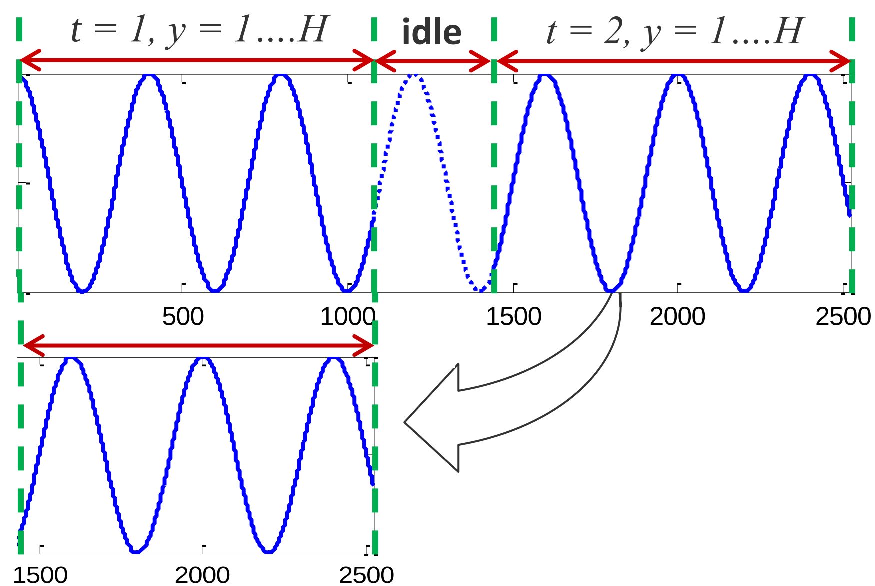
x column index
y row index
t frame index

$$\omega_t = 2\pi \frac{f_t}{f_c}$$

Aliased backlight frequency

Camera frame rate

$$f_t = |f_{BL} - k f_c|$$



Can be seen as rate of change of flicker signal over different frames

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Flicker Parameters vs. Devices Parameters

$$\mathbf{f}(x, y, t) = (A.\mathbf{c}(x, y, t) + B).\cos(\omega_t t + \omega_y y + \varphi)$$

x column index
y row index
t frame index

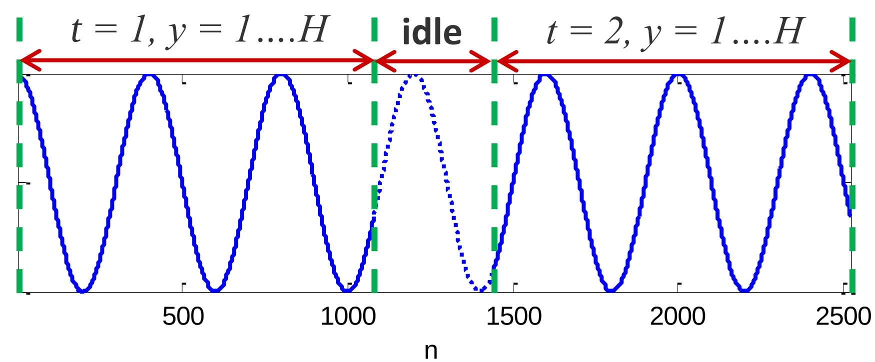
$$\omega_t = 2\pi \frac{f_t}{f_c}$$

$$\omega_y = 2\pi \frac{f_{\mathrm{BL}}}{H/T_{\mathrm{ro}}} = \frac{2\pi}{H} f_{\mathrm{BL}} T_{\mathrm{ro}}$$

Frame read-out time (10—35 ms)

lines/frame (500—1000)

Backlight frequency (120-1000 Hz)



Can be seen as back-light frequency divided by sampling frequency ${}^{H}/_{T_{ro}}$ (in lines/sec)

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Flicker-Based Pirate Device Identification

Piracy identity

$$\frac{\omega_y H}{2\pi} = f_{\mathrm{BL}} . T_{\mathrm{ro}}$$

Flicker vertical frequency

Screen identifier

Camcorder identifier

Forensic protocol

1. Estimate ω_y from the pirate video incl. variant for corner cases
2. Extract ground truth f_{BL} and T_{ro} from suspect's devices
3. Assess if a pair of devices matches the piracy identity

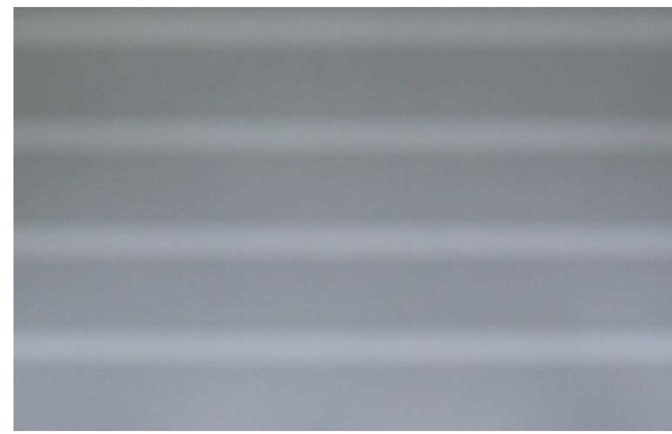
Ground Truth Values Measurements

Backlight frequency of suspect screens

- Record the backlight signal with a photo-detector (for a still gray image)
- Peak of signal's FFT $\Rightarrow f_{\mathrm{BL}}$

Read-out time of suspect camcorders

- Record a short video of a still gray image on a screen with known f_{BL}
- Estimate ω_y (cf. before)
- $T_{\mathrm{ro}} = \frac{\omega_y H}{2\pi . f_{\mathrm{BL}}}$



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Blind Identification Results [HajjAhmad:IHMMSec2015]

	Camcorders	JVC 50 fps	Panasonic 50 fps	Sony 25 fps	Toshiba 29.97 fps
Screens	T_{ro} (ms) / f_{BL} (Hz)	13.5	16	15	32.65
Screen 1	240.06	J–1 ✓	P–1 ✓	S–1 ✓	T–1 ✓
Screen 2	180.43	S–3 ✗	P–2 ✓	S–2 ✓	T–2 ✓
Screen 3	159.98	J–3 ✓	P–3 ✓	P–5 ✗	T–3 ✓
Screen 4	120.00	J–4 ✓	P–1 ✗	J–4 ✗	T–4 ✓
Screen 5	146.61	J–5 ✓	S–5 ✗	S–5 ✓	T–5 ✓
Screen 6	226.70	J–6 ✓	P–6 ✓	S–6 ✓	T–6 ✓
Screen 7	172.80	P–5 ✗	P–7 ✓	S–7 ✓	T–7 ✓

✗ Screen-camcorder pairs are reduced to the product $\Pi = T_{ro} \times f_{BL}$ resulting in more errors, e.g. pairs J–2, J–7, S–3, and P–5 all have $\Pi \approx 2480 \pm 50$

✓ 22/28 = 79% Identified correctly

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Conclusions

Passive forensics beyond content authentication

- Infringement analysis, quality control, context adaptation
- Complement the anti-piracy arsenal
  - Piracy modality identification for watermark detection budget optimization
  - Piracy path modeling for compensation and/or simulation
  - Pirate device characterization for attribution and/or cross-referencing

Flicker forensics

- Interplay between the backlight of the screen and the shutter of the camcorder
- Low-power periodic spatio-temporal signal
- Efficient estimation techniques: detection, cancellation, intrinsic parameters inference

Future work

- Flicker shape estimation
- Screencaster piracy

References

[Rolland-Nevière:SPIE2012] X. Rolland-Nevière, B. Chupeau, G. Doërr, and L. Blondé, "*Forensic Characterization of Camcorded Movies: Digital Cinema versus Celluloid Film Prints*", in Media Watermarking, Security, and Forensics XIV, Proceedings of SPIE 8303, pp. 83030R, 2012

[Moreira-Pérez:WIFS2013] J.J. Moreira-Pérez, B. Chupeau, G. Doërr and S. Baudry, "*Exploring Color Information to Characterize Camcorder Piracy*", in Proceedings of the IEEE International Workshop on Information Forensics and Security, pp. 132-137, 2013

[Chupeau:WIFS2014] B. Chupeau, S. Baudry, and G. Doërr, "*Forensic Characterization of Pirated Movies: Digital Cinema Cam vs. Optical Disc Rip*", in Proceedings of the IEEE Workshop on Information Forensics and Security, pp. 155-160, 2014

[Baudry:WIFS2014] S. Baudry, B. Chupeau, M. de Vito, and G. Doërr, "*Modeling the Flicker Effect in Camcorded Videos to Improve Watermark Robustness*", in Proceedings of the IEEE Workshop on Information Forensics and Security, pp. 42-47, 2014

[Hajj-Ahmad:IHMMSec2015] A. Hajj-Ahmad, S. Baudry, B. Chupeau, and G. Doërr, "*Flicker Forensics for Pirate Devices Identification*" [Best Student Paper Award], in Proceedings of the ACM International Workshop on Information Hiding and Multimedia Security, pp. 75-84, 2015

Questions

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