Passive Forensic Analysis for Anti Piracy

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### 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.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
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<tbody>
<tr>
<td>Researchers and Experts</td>
<td>350</td>
</tr>
<tr>
<td>Research Centers</td>
<td>3</td>
</tr>
<tr>
<td>Film &amp; Advertising Visual Effects Shots</td>
<td>6,000+</td>
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<tr>
<td>Consumer Electronics Manufacturers Integrating Our IP</td>
<td>80%</td>
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<tr>
<td>Touching Every Year Of Patent Portfolio Renewed</td>
<td>7%</td>
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<tr>
<td>Blockbusters Worldwide in 2013</td>
<td>75%</td>
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<tr>
<td>Digital Home Devices Shipped To Date</td>
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</tr>
<tr>
<td>DVD and Blu-ray™ Shipped To 40,000 Destinations In 2013</td>
<td>1.47B</td>
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<td>Digital Cinema Deliveries</td>
<td>265,000+</td>
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<tr>
<td>Gateways Worldwide In Terms Of Shipments</td>
<td>#1</td>
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<tr>
<td>Set-Top Boxes Worldwide In Terms Of Shipments</td>
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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
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)

The Piracy Continuum™

On the cost of piracy...
CNBC’s Crime Inc #10: Hollywood Robbery (August 2012)
Threat Analysis

Filming
Insider leak (dailies theft)

Post-processing (color, CGI, edits, etc.)
Insider leak

Movie
Insider leak

Filmpint theft

Insider leak
at replication plant

Distributor
TV, cable, satellite, IP
Insider leak

Hospitals, prisons
Broadcast, VOD

Hotels

Airplane, cruise

Camcording

Theater release
Camcording

Insider leak

Promotional copies
(Oscars, journalists, etc)

DVD/Blu-ray rip

Hardcopy release
(DVD and Blu-ray)
(rental and retail)

Insider leak

Insider leak at replication plant

Insider leak

N/A (Screencasting)

Stream redirection
HDMI strip
Screencasting
Camcording
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
The Forensics Landscape

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

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

Outsourced Manual Process?

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

Pirate samples consolidation

Cross-references analysis

Passive forensic analysis

Watermark extraction

Pirate samples collection

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
Motivation

Different delivery channels ⇒ different piracy behaviors
- Camcorder theft in (digital) cinemas
- Ripping of optical disks
- HDMI stripping/screencasting of streamed content

Different delivery channels ⇒ 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
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

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

Periodical high-frequency frame refresh (at 96 fps or higher) captured at 25 or 29.97 fps translates into low frequency aliased components
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 $C_bC_r$ plane at all luminance levels.

**Color feature behavior (DB mean)**
Sequential Feature Selection

17 components in total (out of 768)
- Color saturation: 5 (out of 256)
- Color bias: 12 (out of 512)

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

Observation: camcorder recapture induces planar perspective distortion

- Distribution of straight edges impacted

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

\[ f(o) = \frac{\beta}{2\alpha \Gamma(1/\beta)} \exp \left( \frac{|o - \mu|}{\alpha} \right)^\beta \]
Feature Sensitivity Synthetic Validation

- **Standard deviation**
  - 0° Peak
  - 90° Peak

- **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
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)*
Luminance Flicker Analysis
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]

\[ f(x, y, t) = (A \cdot c(x, y, t) + B) \cdot \cos (\omega_t t + \omega_y y + \varphi) \]

- **Camcorded flicker**
- **Content luminance**
- **Flicker amplitude parameters**
- **Flicker temporal frequency**
- **Flicker vertical frequency**
- **Phase**

- **x** column index
- **y** row index
- **t** frame index

\[ t = 1, y = 1 \ldots H \quad \text{idle} \quad t = 2, y = 1 \ldots H \]
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 \( \omega_t \)
- Phase of Fourier coefficients at \( \omega_t \) for all rows → linear slope equal to \( \omega_y \)

Amplitude parameters

- Near replicate in the spectrum at 0 and \( \omega_t \)
- Least means square minimization

\[
(\alpha, \beta) = \arg \min \sum_{\varepsilon < \rho} \left( Y(\omega_t + \varepsilon) - \frac{e^{i\psi}}{2} (\alpha Y(\varepsilon) + \beta \delta(\varepsilon)) \right)^2
\]
Estimation Accuracy with Synthetic Flicker

- **Graphs**
  - Title: Estimation Accuracy with Synthetic Flicker
  - X-axis: \( \alpha \) with values 0.1, 0.15, 0.2, 0.25
  - Y-axis: Estimation error
  - X-axis: \( \beta \) with values -3, -2, -1, 0, 1
  - Y-axis: Estimation error
  - X-axis: \( f_t \) with values 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.39, 0.4
  - Y-axis: Estimation error
  - X-axis: \( f_y \) with values -0.42, -0.34, -0.26, -0.18, -0.1
  - Y-axis: Estimation error
Watermark Detection after Flicker Removal

![Graph showing the WM score against the number of payload for flickered and deflicker cases.](image)

- **Flickered** line
- **Deflicker** line

**# Payload**

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<th>Payload</th>
<th>WM Score</th>
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<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
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<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
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</table>
Pirate Devices Identification
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

\[ f(x, y, t) = (A \cdot c(x, y, t) + B) \cdot \cos(\omega_t t + \omega_y y + \varphi) \]

\[ \omega_t = 2\pi \frac{f_t}{f_c} \]

\[ f_t = |f_{BL} - k f_c| \]

Can be seen as rate of change of flicker signal over different frames
Flicker Parameters vs. Devices Parameters

\[ f(x, y, t) = (A \cdot c(x, y, t) + B) \cdot \cos(\omega_t t + \omega_y y + \varphi) \]

\[ \omega_t = 2\pi \frac{f_t}{f_c} \]

\[ \omega_y = 2\pi \frac{f_{BL}}{H/T_{ro}} = \frac{2\pi}{H} f_{BL} T_{ro} \]

- \( x \) column index
- \( y \) row index
- \( t \) frame index

Frame read-out time (10–35 ms)

Backlight frequency (120-1000 Hz)

Can be seen as back-light frequency divided by sampling frequency \( \frac{H}{T_{ro}} \) (in lines/sec)
Flicker-Based Pirate Device Identification

Piracy identity

\[
\frac{\omega_y H}{2\pi} = f_{BL} \cdot T_{ro}
\]

Forensic protocol

1. Estimate \( \omega_y \) 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 $\Rightarrow f_{BL}$

Read-out time of suspect camcorders

- Record a short video of a still gray image on a screen with known $f_{BL}$
- Estimate $\omega_y$ (cf. before)
- $T_{ro} = \frac{\omega_y H}{2\pi f_{BL}}$
Blind Identification Results [HajjAhmad:IHMMSec2015]

<table>
<thead>
<tr>
<th>Screens</th>
<th>F_BL (Hz)</th>
<th>T_ro (ms)</th>
<th>JVC 50 fps</th>
<th>Panasonic 50 fps</th>
<th>Sony 25 fps</th>
<th>Toshiba 29.97 fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen 1</td>
<td>240.06</td>
<td>13.5</td>
<td>J–1 ✓</td>
<td>P–1 ✓</td>
<td>S–1 ✓</td>
<td>T–1 ✓</td>
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<tr>
<td>Screen 2</td>
<td>180.43</td>
<td></td>
<td>S–3 ✗</td>
<td>P–2 ✓</td>
<td>S–2 ✓</td>
<td>T–2 ✓</td>
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<tr>
<td>Screen 3</td>
<td>159.98</td>
<td></td>
<td>J–3 ✓</td>
<td>P–3 ✓</td>
<td>P–5 ✗</td>
<td>T–3 ✓</td>
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<tr>
<td>Screen 4</td>
<td>120.00</td>
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<td>J–4 ✓</td>
<td>P–1 ✓</td>
<td>J–4 ✗</td>
<td>T–4 ✓</td>
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<tr>
<td>Screen 5</td>
<td>146.61</td>
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<td>J–5 ✓</td>
<td>S–5 ✗</td>
<td>S–5 ✓</td>
<td>T–5 ✓</td>
</tr>
<tr>
<td>Screen 6</td>
<td>226.70</td>
<td></td>
<td>J–6 ✓</td>
<td>P–6 ✓</td>
<td>S–6 ✓</td>
<td>T–6 ✓</td>
</tr>
<tr>
<td>Screen 7</td>
<td>172.80</td>
<td></td>
<td>P–5 ✗</td>
<td>P–7 ✓</td>
<td>S–7 ✓</td>
<td>T–7 ✓</td>
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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
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


