AN INTRODUCTION TO MULTIMEDIA FORENSICS

Audio, Image and Video

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- Outline

Introduction - What is this about?

- Multimedia content is found everywhere
- “Everyone” has recording equipment
- People tend to trust something we see more than something we read
- Multimedia:
  - Audio
  - Image
  - Video
- Data related to the multimedia content
  - Metadata
- ENFSI has general and best practices guides on their webpage: `https://enfsi.eu/`

Introduction - Learning outcomes

- Understand some of the possibilities and challenges in multimedia forensics
- Understand metadata
- Know the process that craetes multimedia and the artifacts that is created
- Understand a few methods that are used in multimedia forensics
- What makes deepfakes “deep”, and how to detect it

Metadata - What is *metadata*?

- “Data about data”
- A description of the content
- Parameters for playing the content
- Description of equipment used for creating content
- Metadata can be found many places
  - In media file
  - Text files
  - In databases
  - Other archives?

Metadata - File system data

- Data about the file itself
- File name
- MAC times
  - Modified, Last accessed, Created/Metadata changed
  - But contemporary operating systems don't update Last accessed times
  - Created is mostly updated to the time the file is created in the file system
  - Modified often survives when unpacked from a zip archive
- Username of owner
- Access rights to file

Metadata - Container file data

- Multimedia file typically contains:
  - Content streams: Video and audio content
  - Information about the content
- EXIF, MP3tags, etc.
- Written by creator and editing processes
- . . . but can also be modified by others

Metadata - EXIF

- Exchangeable image file format
- Set by the camera or image creation program
- Can be updated by other programs
- Includes information about the equipment
- Sometimes also GPS coordinates
- Many programs can print the EXIF data
  - exiv2, exiftool, etc.

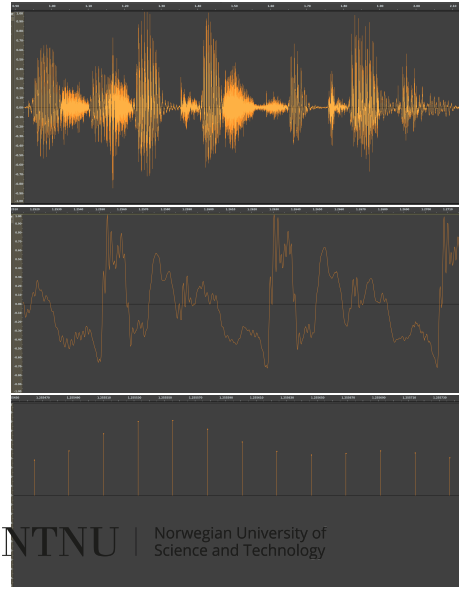
Metadata - EXIF example

```
$ exiftool 20211011/20211011-1806-S10-5851.jpg
ExifTool Version Number         : 12.16
File Name                       : 20211011-1806-S10-5851.jpg
...
File Size                       : 2.4 MiB
File Modification Date/Time     : 2021:10:11 18:06:48+02:00
File Access Date/Time           : 2021:11:04 18:14:17+01:00
File Inode Change Date/Time     : 2021:10:17 22:31:22+02:00
...
Make                            : samsung
Camera Model Name               : SM-G973F
...
GPS Latitude                    : 59 deg 54’ 31.76" N
GPS Longitude                   : 10 deg 48’ 44.12" E
...
```

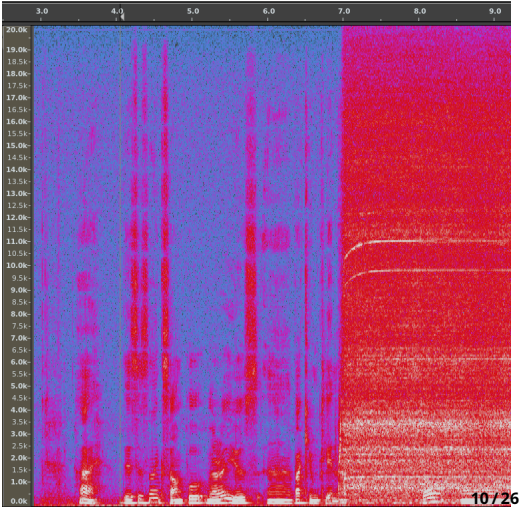
Audio forensics - Audio fundamentals

- Sound waves are pressure waves in a medium (air, solid materials)
- The pressure differences over time is the sound pressure
  - Measured with regard to a reference pressure: dB
- Frequency is the number of pressure tops/bottoms per second
  - Measured in Hz
  - A complex wave can consist of several waves, each with different frequencies
- A microphone convert the sound waves to electrical waves
  - Has a *frequency response* — different sensitivity for different frequencies
- Analogue to Digital Conversion (ADC) introduces noise to the process
- Lossy compression of digital signal also introduces artifacts
  - Lossy: mp3, aac; Lossless: wav, flac

Audio forensics - Visualizing sound



← Waveform ↓ Spectrogram



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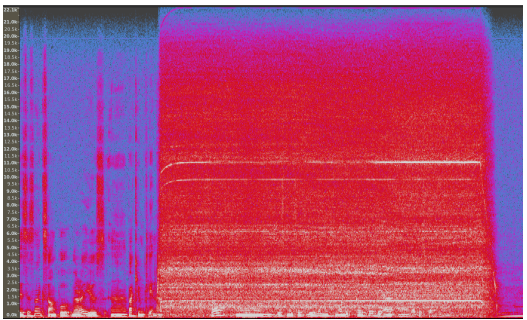
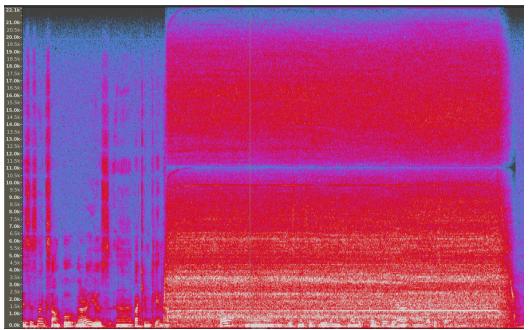
Audio forensics - Cleaning

- Remove noise or other sounds to enhance the sound of interest
- Want to better understand what is happening or being said in the redording
- For speech, a **high risk of bias** when interpreting result
  - We tend to hear what we expect to hear
- Mosty a *subtractive* action
- Remove frequencies that contain noise components
  - But keep most of the speech components
  - Works fairly well for a static noise component
- Be aware that removing parts of the spectrum can make words sound differently
  - e.g. sh $\rightarrow$ s, sharp sounds becoming more “muffled”, etc.

Audio forensics - Notch filter example

- Notch filter will remove only a small range of frequencies
- Other main type of filters are band-pass and -stop filters, high- and low-pass/ -stop filters
- Below is speech interrupted by a vacuum cleaner, to the left using a notch filter for one of the major noise frequencies:



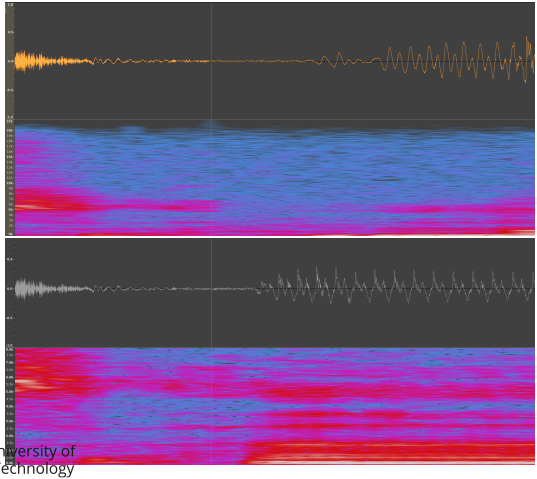


Audio forensics - Authenticity

- Authenticity of a recording is to determine whether:
  - The recording is in its original state
  - The recording is of the described event
- Finding edited areas
  - Cuts, splices
  - Find abrupt changes in the content
  - Noise suddenly changing characteristics
- Does metadata match the content?
- Lack of evidence of manipulation does not guarantee authenticity

Audio forensics - Splicing example

- The upper image is spliced, the bottom is the original
- Note the change in noise at the splice



Audio forensics - Doppler effect

- Sound waves generated while moving will be compressed in the direction of movement and stretched in the opposite direction
- The same is true for a static audio source and a moving recorder
- Compressed waves means a higher frequency, or pitch
- Stretched waves means a lower frequency, or pitch
- Example of the Doppler effect: Sirens passing by, train horn as it passes.

Image forensics - Capture process

- Light enters through lenses — focuses image on sensor
- Color Filter Array (CFA) — each pixel only see one color component
- Sensor — Transform photons to electric current and digitizes the current
- Camera processor:
  - Demosaic — four color pixels from the CFA to one pixel with three colors
  - In-cam processing — Color/ white balance, contrast, saturation adjustments
  - Image encoding — JPEG compression
- Post-processing of image
- Editing

Image forensics - Capture process

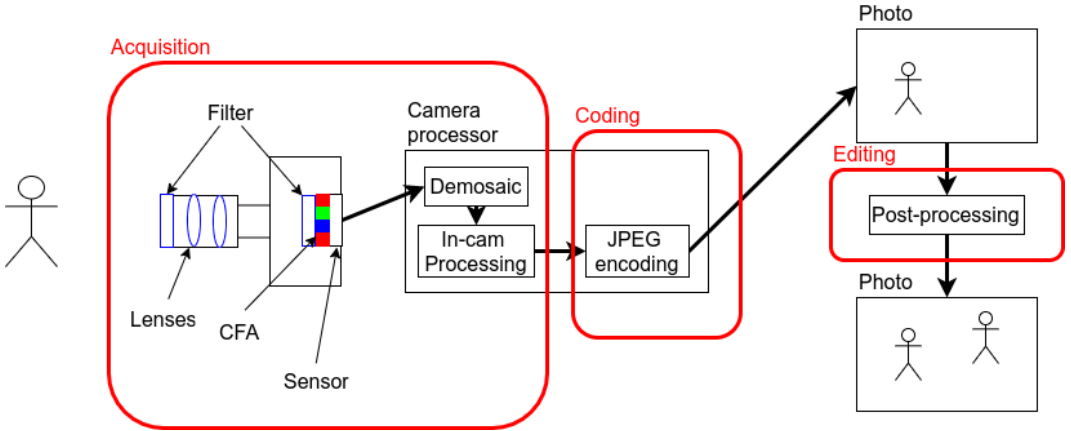


Image forensics - Photogrammetry

- Measure angles, distances, sizes in photos
- Mapping from 2D to 3D space
  - Trigonometry
  - Compare to objects with known sizes
- Need to know the effects lenses have on the photo: Optical distortion
  - Straight lines curving in the photo
  - Barrel distortion — lines curving away from the center
  - Pin-cushion distortion — lines curving toward the center
  - Moustache distortion, a combination of barrel and pin-cushion distortion
  - Photo editing programs often have filters to adjust optical distortions
- Perspective distortion
  - Wide-angle distortion — Objects closer to the camera appear bigger
  - Compression distortion — Objects further away appear bigger, closer

Image forensics - Distortion from wide angle lens

- A grid notebook page, wide angle lens from a phone
- The example shows a pin-cushion distortion
  - Can be from in-camera lens correction

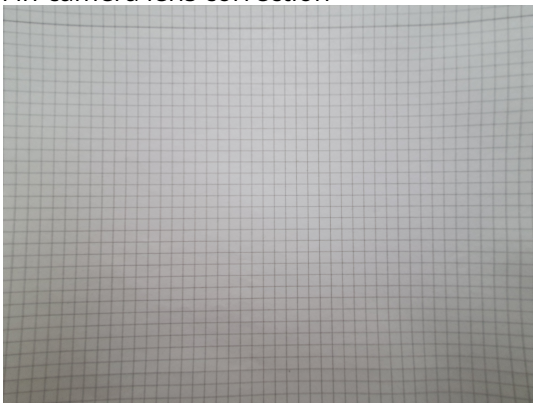


Image forensics - Editing detection

- Malicious editing operations change the perceived meaning of the image
  - Copy part of an image to another location in the same image
  - Copy part of another image into the image
  - Remove part of an image, change perspective, etc.
- Analysis of the encoded data
  - Anomalies in blocking of JPEG images
  - Error Level Analysis
  - Anomalies in histogram of JPEG DCT coefficients
- Analysis of the scene
  - Lighting/shadow anomalies
  - Detection of similar areas in the photo
  - Perspective anomalies

Image forensics - Equipment identification

- Each sensor consist of millions of pixels, each have slight variations due to production imprecision
- Photoresponse Non-uniformity (PRNU)
  - Unique for each photosensor
  - The PRNU can be suppressed by strong compression
  - Experiments show that this is stable over the lifetime of the chip
  - Exist python libraries for extracting and comparing the PRNU
- Color Filter Array / demosaicing artifacts
  - Don't uniquely identify device
  - Identify type of device, camera model

Image forensics - Deepfakes

- Term from AI — Deep learning
- Most generators today use Generative Adversial Networks (GAN)
  - One deep learning module generate images
  - The other tries to detect which is generated
  - Result fed back to generator that tries to improve the generated image
  - Many iterations
- Sometimes the generated image have details that don't make sense for a human eye
- Often lack PRNU, but this can be synthetically created (if implemented in generator)
- Machine learning detection
  - By adjusting GAN or compressing image: detection rate drops
  - Don't trust AI/ML detection methods more than at an advisory level

Video forensics - Different than images?

- One image per frame plus audio
- Videos are typically more compressed than images
  - Removes PRNU, demosaicing artifacts
- Less standardized, more configurable encoding steps
  - Also a temporal component to the encoding and compression
  - Parameters for encoding can be used for identifying models of equipment
- Harder to hide evidence of editing operations, as every frame need to be undetectable
- Some operations
  - Remove noise, encoding and compression artifacts
  - Find editing operation such as greenscreen
  - Detect deepfakes

Video forensics - Audio/ video correlation

- Speed of light is different from the speed of sound
  - 299 792 458 m/s vs. 343 m/s (at 20 °C, dry air)
- One second difference between visual source of sound and audible sound means that the event was 343 meters from the camera
- Can be hard to know exactly when a visible event generates the sound
- Have to find the offset between video and audio from close events
  - Check that the audio/video offset is stable throughout the video

Video forensics - Deepfakes

- Videos can be generated from scratch, but this is resource demanding
- Add a face to the body of someone else
  - Face swapping apps
- Make a person say something different
  - Change the audio to something else
  - Change the face to give new expression, mouth movements to match the audio
  - Can also generate deepfake audio
- Video deepfakes are often easier to detect, as the generation is harder and leaves more anomalies
  - E.g. blinking, eye movements, but many deepfake generators implement this now
- Anomalies can be hidden by harder compression
- A search on Youtube on “deepfake” shows many examples of face swaps

Video forensics - Other sources

- Also use external sources:
  - OSINT
  - Interpretation of the recorded scene (audio, photo, video)
- Does the content fit the broader picture, or is it inconsistencies between the content and the broader context?
- As deepfake technology gets better and more accessible, this will be used for all types of information
  - Elections
  - Polarized topics
  - +++

Thank you for your attention