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Evaluation of Presentation Attack Detection: An Example

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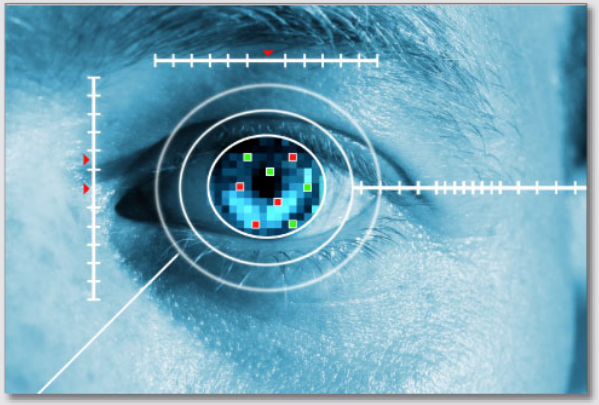
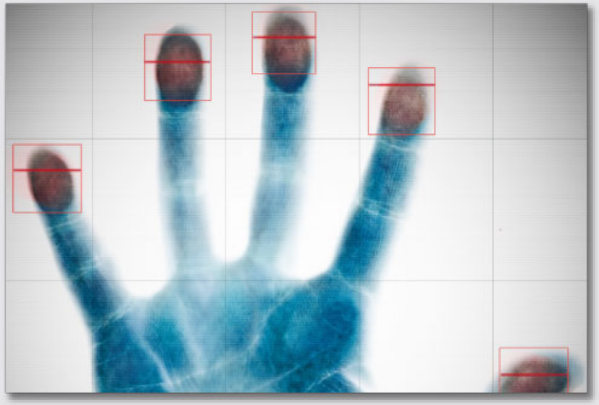
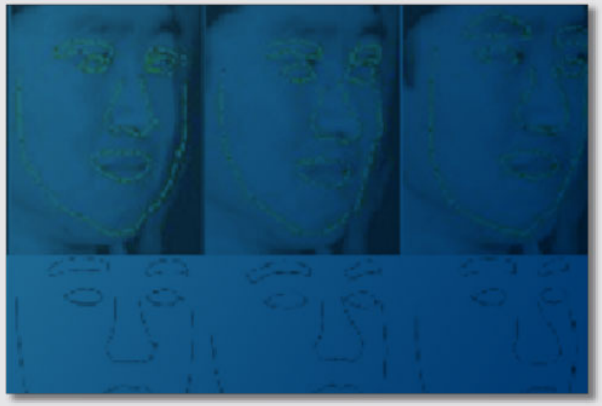

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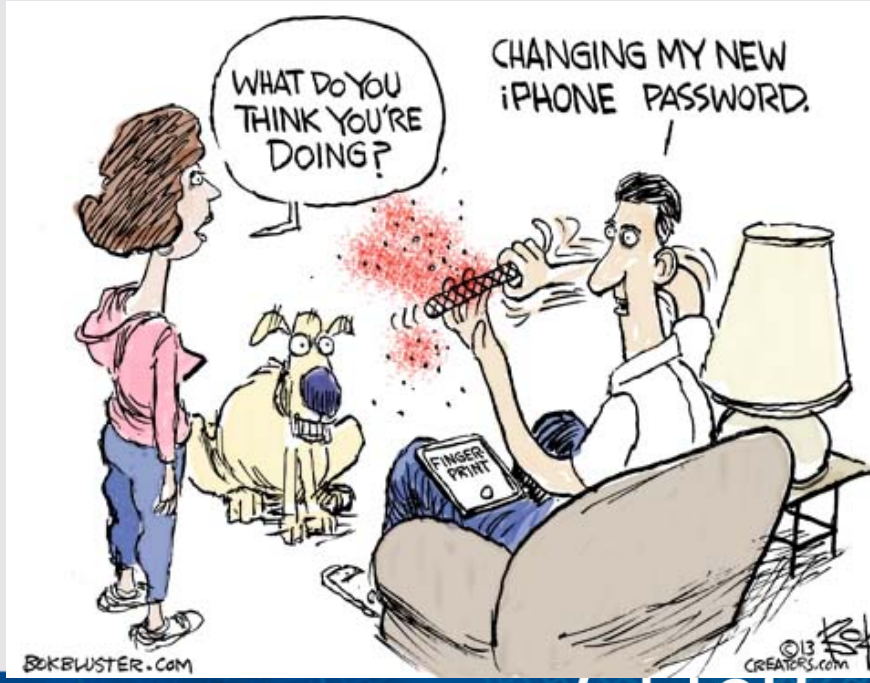
Presentation Attacks

- Spoofing is common term used most in past decade.
- ISO Standards underway:
  - **Presentation Attack** Definition: Presentation of an artefact or human characteristic to the biometric capture subsystem in a fashion that could interfere with the intended policy of the biometric system*

- Why?

  Posing as another individual
  - Positive ID applications

  Hiding your identity
  - Negative ID applications
  - May form 'new' identity for positive ID



*from: ISO/IEC CD 30107-1, Information Technology — Biometrics -- Presentation Attack Detection

Fingerprint Presentation Attacks

- Cooperative

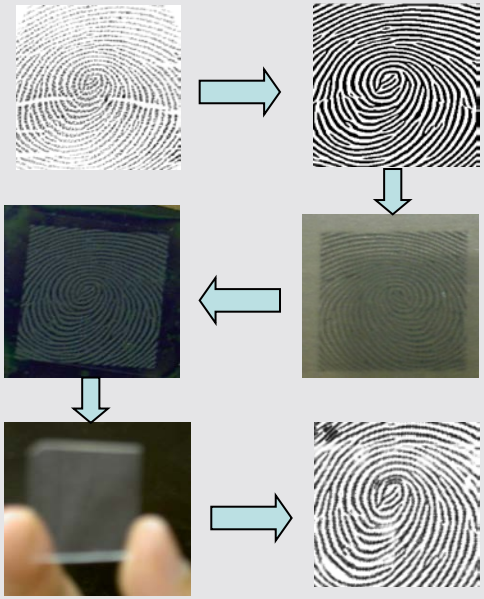
  Characteristic captured directly from individual with assistance (e.g. finger mold)

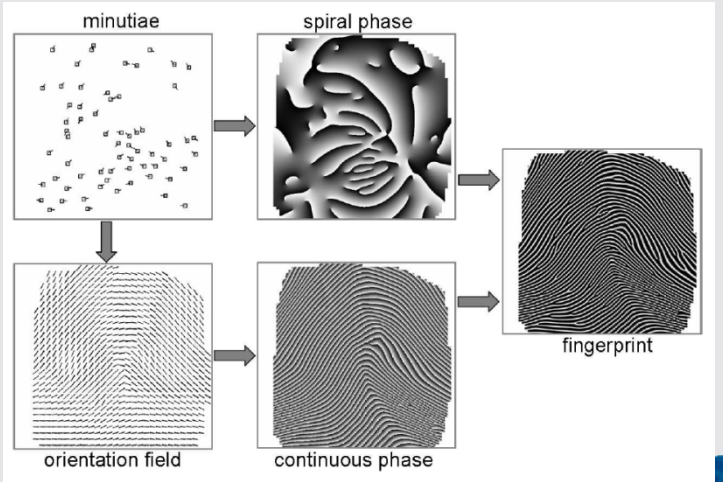
- Latent

  Characteristic captured indirectly through lifting a latent sample

- Synthetic

  Synthetic characteristic, not mapped to real person (e.g. synthetic fingerprint)



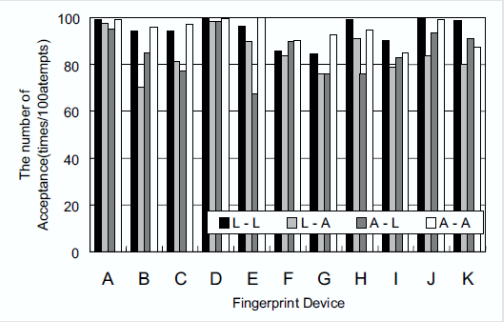


Feng and Jain, Advances in Biometrics article, 2011 [1].

Coli, et al, 2006 [2].

Presentation Attack Testing on Conventional Systems

- Matsumoto et al., 2002 [3]
  - Testing acceptance rate of gelatin and silicone fingers (in terms of matching)
- Thalheim et al., 2002 [4]
  - Tested various techniques for spoofing biometric systems
  - Reactivating latent print and fingerprint on adhesive film
- Galbally et al., 2010 [5]
  - Optical and thermal sweeping sensors shown to be vulnerable to direct (presentation) attacks
- LivDet competitions 2009-13 [6]



Presentation Attack Detection (PAD)

- Presentation Attack Detection (PAD) *

  Automated determination of a presentation attack

- Examples of PAD

  Liveness detection (failure)

  Artefact detection

  Altered biometric detection

  Others terms that have been used: anti-spoofing, biometric fraud, spoof detection, authenticity detection, etc.

*from: ISO/IEC CD 30107-1, Information Technology — Biometrics -- Presentation Attack Detection

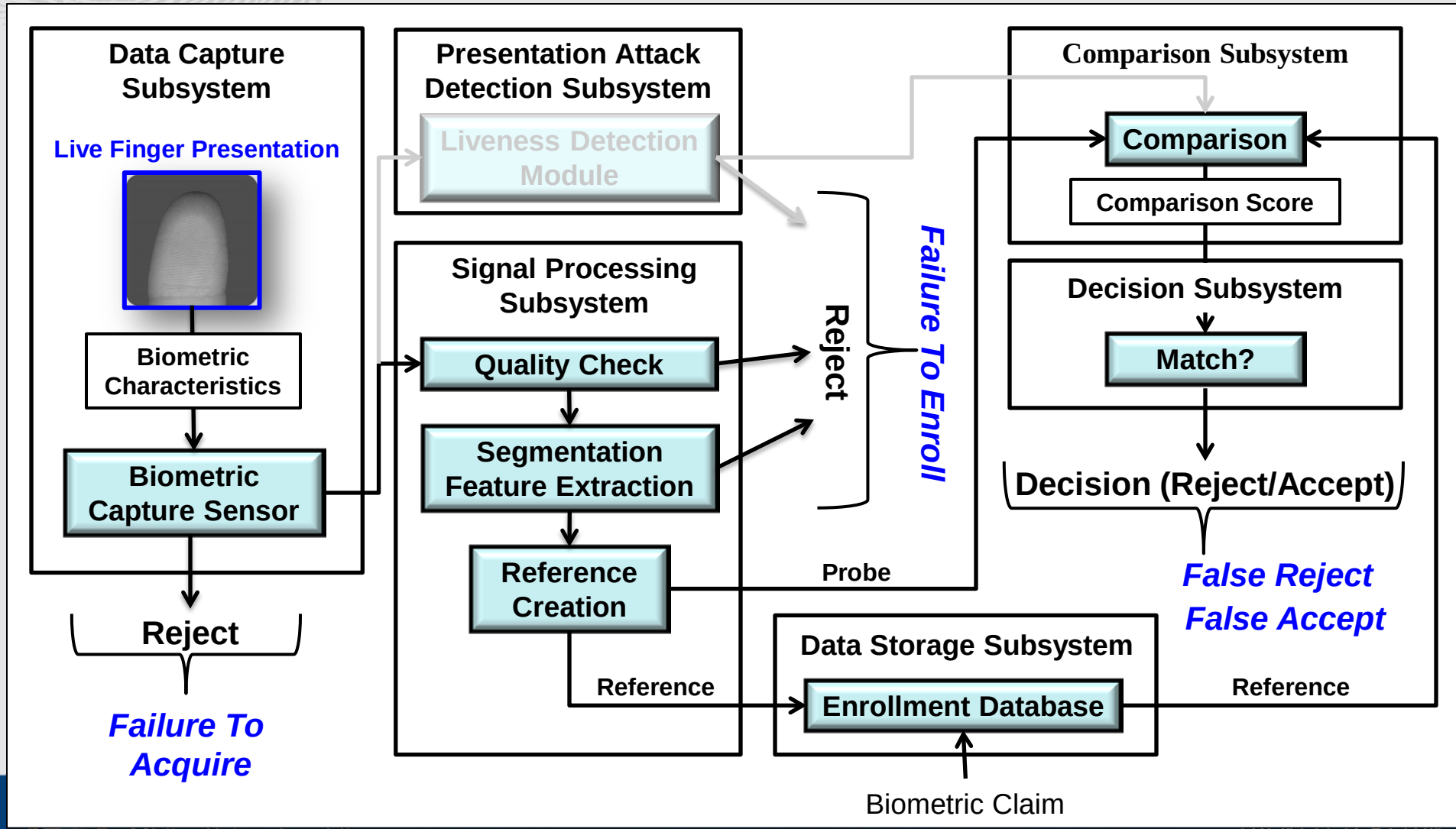
Challenge

- Presentation Attack Detection is a component of biometric system.
- In many applications, a successful presentation attack is an combination of failure of the PAD subsystem and matching a stored biometric
- Previous research on fusion of PAD subsystem and matcher [7]
- Need for common understanding of metrics which measure the fusion of PAD and match scores

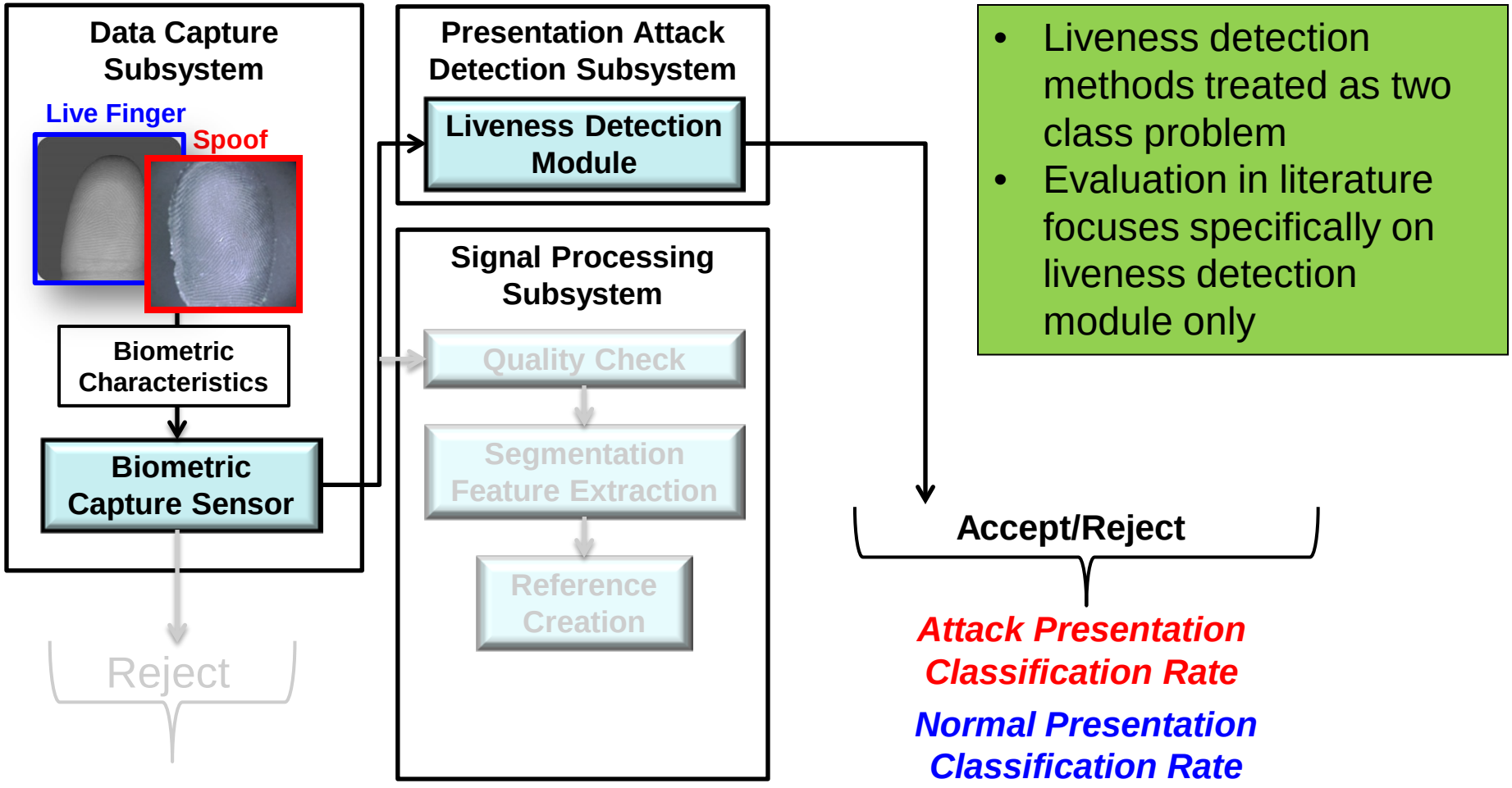
Objective

- Give an example of performance results for
  - -PAD alone
  - -Fusion of PAD and match scores
- Provide dataset of PAD scores and match scores for use in additional research

Traditional Metrics for Biometric Evaluation (Live Finger Input)

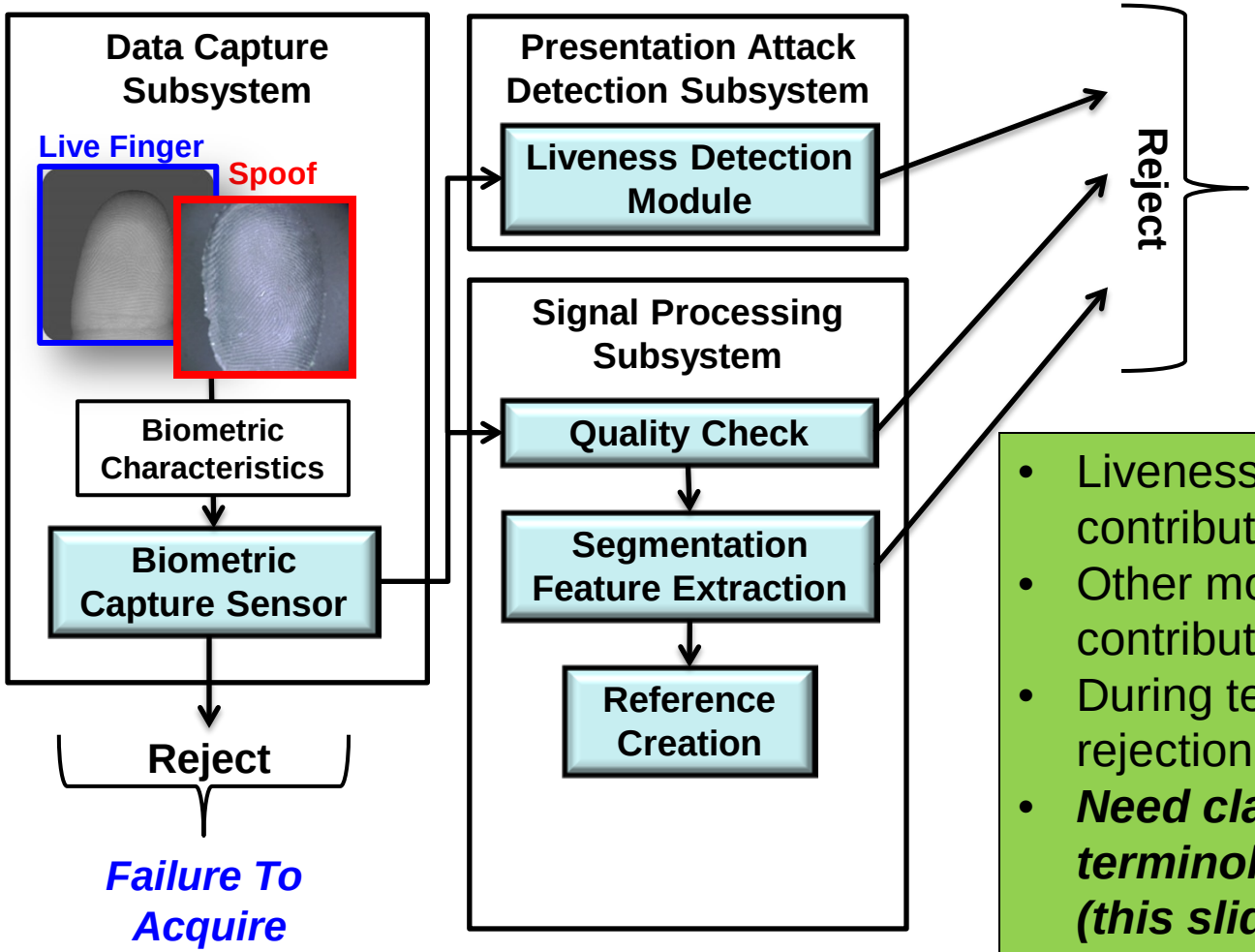


Additional Metrics (Spoof Input)



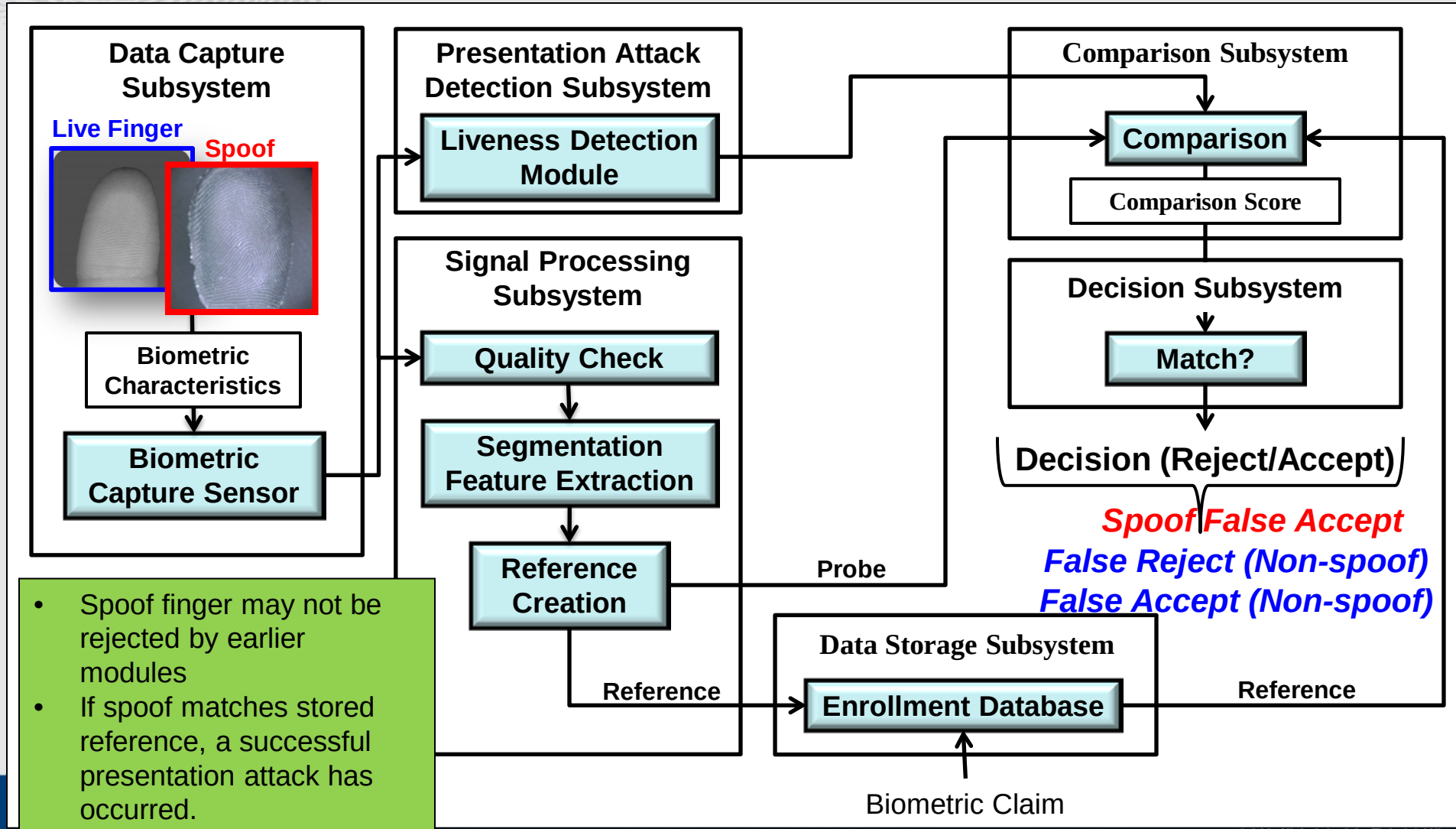
- Liveness detection methods treated as two class problem
- Evaluation in literature focuses specifically on liveness detection module only

Additional Metrics (Spoof Input)



- Liveness detection module will contribute to decision to reject
- Other modules (e.g. quality) may contribute
- During testing specific reason for rejection may not be known
- ***Need clarification in terminology for system testing (this slide) and liveness detection module testing (last slide)***

What about matching? (Spoof Input)



- Spoof finger may not be rejected by earlier modules
- If spoof matches stored reference, a successful presentation attack has occurred.

Presentation Attack Detection Dataset

- Algorithms are often referred to as **liveness detection** algorithms
- Dataset includes scores from two PAD algorithms

  Algorithm 1: Intensity analysis of fingerprint image [8]

  Algorithm 2: Combination of multiple algorithms
    - Intensity [8]
    - Valley noise analysis [9]
    - Ridge signal analysis [10]
- A PAD score is determined for the probe image of each pair of fingerprints that is matched

Fingerprint Matching

- Fingerprint matching was conducted using the VeriFinger fingerprint matching SDK [11]
- Genuine match scores:
  - Matching of two different fingerprint images from the same subject and same finger
  - Every match score was calculated from a pair of fingerprint images that were collected on different days
- Imposter match scores:
  - Matching of two different fingerprint images from two different subjects and same finger
- Spoof match scores:
  - Matching of two different fingerprint images from the same subject and same finger
  - Gallery image is from a live finger and probe image is from a spoof finger

Fingerprint Score Dataset

- A fingerprint dataset consisting of 50 subjects, two fingers each is used for the following analysis
  - The dataset is split into two subsets: 25 subjects for training and 25 subjects for testing
  - 8019 total live images
  - 2705 total spoof images
  - Images collected from right thumb (R1) and right index finger (R2) for each subject
- Dataset is available by request on the CITeR website: http://www.clarkson.edu/citer/research/collections/index.html

Subset	Number of Subjects	Number of Live Images	Number of Spoof Images	Normal Presentation—Genuine	Normal Presentation—Imposter	Presentation Attack (Genuine)
Training	25	R1: 2,187 R2: 1,896	R1: 724 R2: 491	519,198	911,476	106,943
Testing	24	R1: 2,153 R2: 1,783	R1: 749 R2: 561	381,182	976,161	132,075

Performance Metrics – Matching

- Performance Metrics:

  False match rate (FMR): percentage of fingerprint pairs from different people (imposters) that match

  False non-match rate (FNMR): percentage of fingerprint pairs from the same person/finger (genuine) that do not match

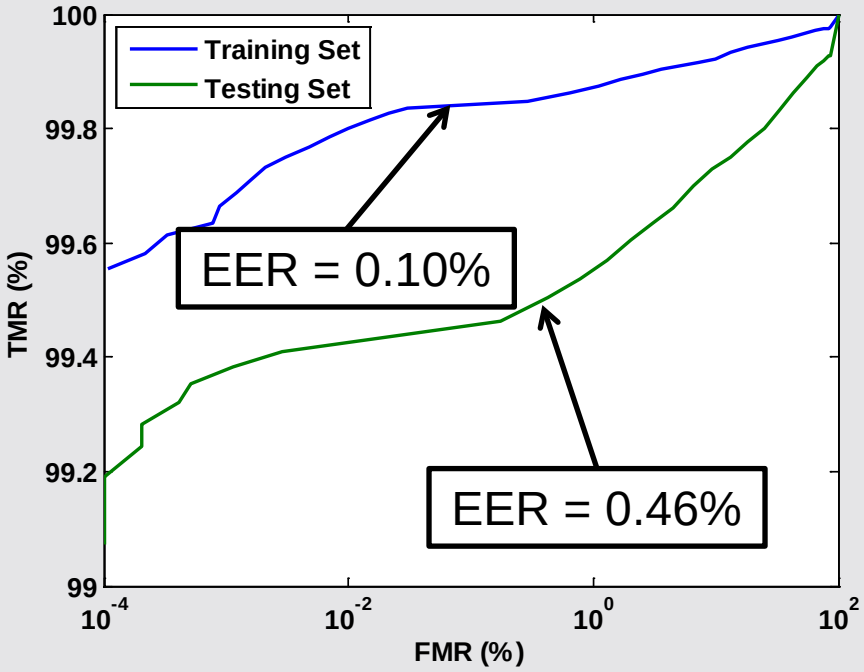
  True match rate (TMR): TMR = 100 – FNMR

- Matching threshold is selected from training set performance and tested on the testing set

  Matching threshold = 30

  FRR = 0.59%

  FAR = 0.003%



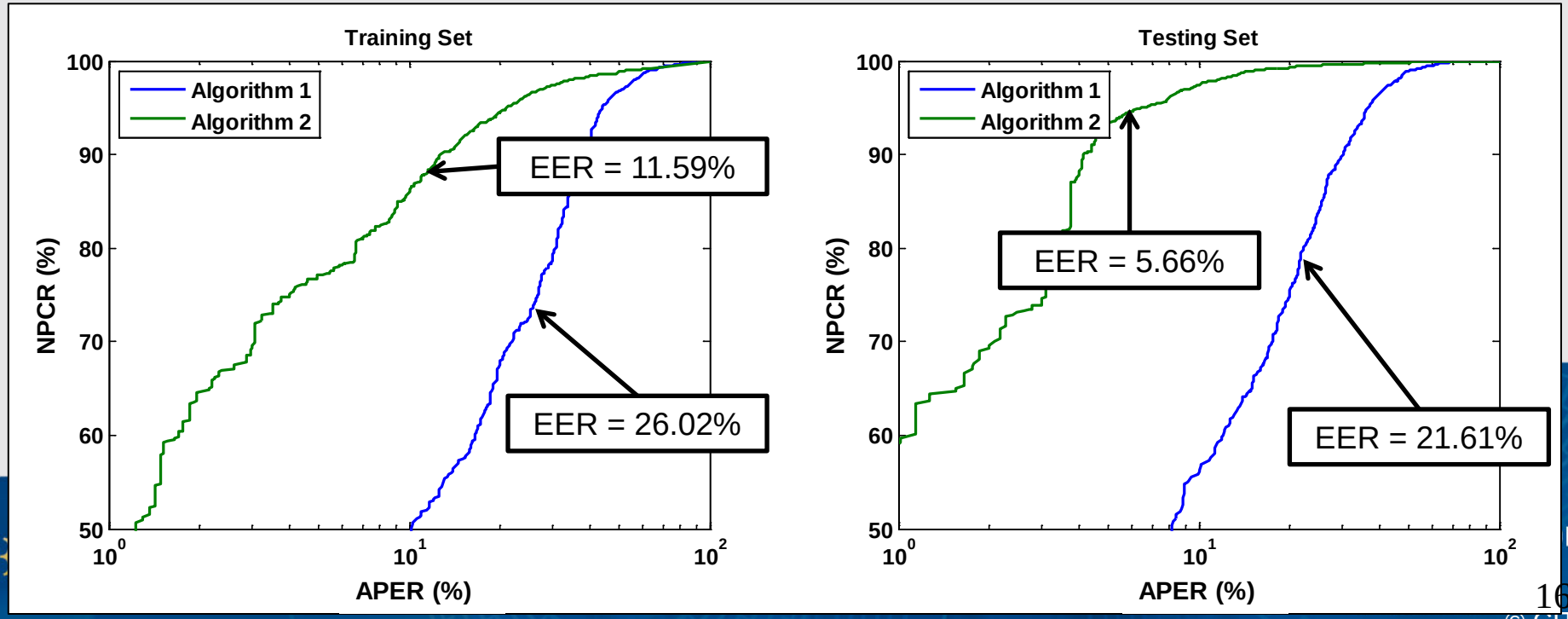
Performance Metrics – PAD

- Performance Metrics:

  Normal Presentation Classification Rate (NPCR): percentage of normal presentations (live fingerprints) that are accepted as normal presentations

  Attack Presentation Classification Rate (APCR): percentage of attack presentations (spoof fingerprints) correctly classified as attack presentations

  Attack presentation error rate (APER): percentage of attack presentations that are accepted as normal presentations (100 – APCR)



Performance Metrics – System Level

- The biometric system combines the Comparison Subsystem (matching) with the Presentation Attack Detection Subsystem (liveness)

  The system needs to be able to utilize information passed from both modules to make a single decision (accept or reject)

  New error terms must be applied with the addition of Presentation Attack Detection

- Performance Metrics:

  False accept rate (FAR): Percentage of imposters accepted by the system

  False reject rage (FRR): Percentage of genuine users rejected by the system

  True accept rate (TAR): TAR = 100 – FRR

  Spoof false accept rate (SFAR): Percentage of spoof samples that are accepted by the system (i.e. by matching and PAD)

Decision Matrix & Metrics

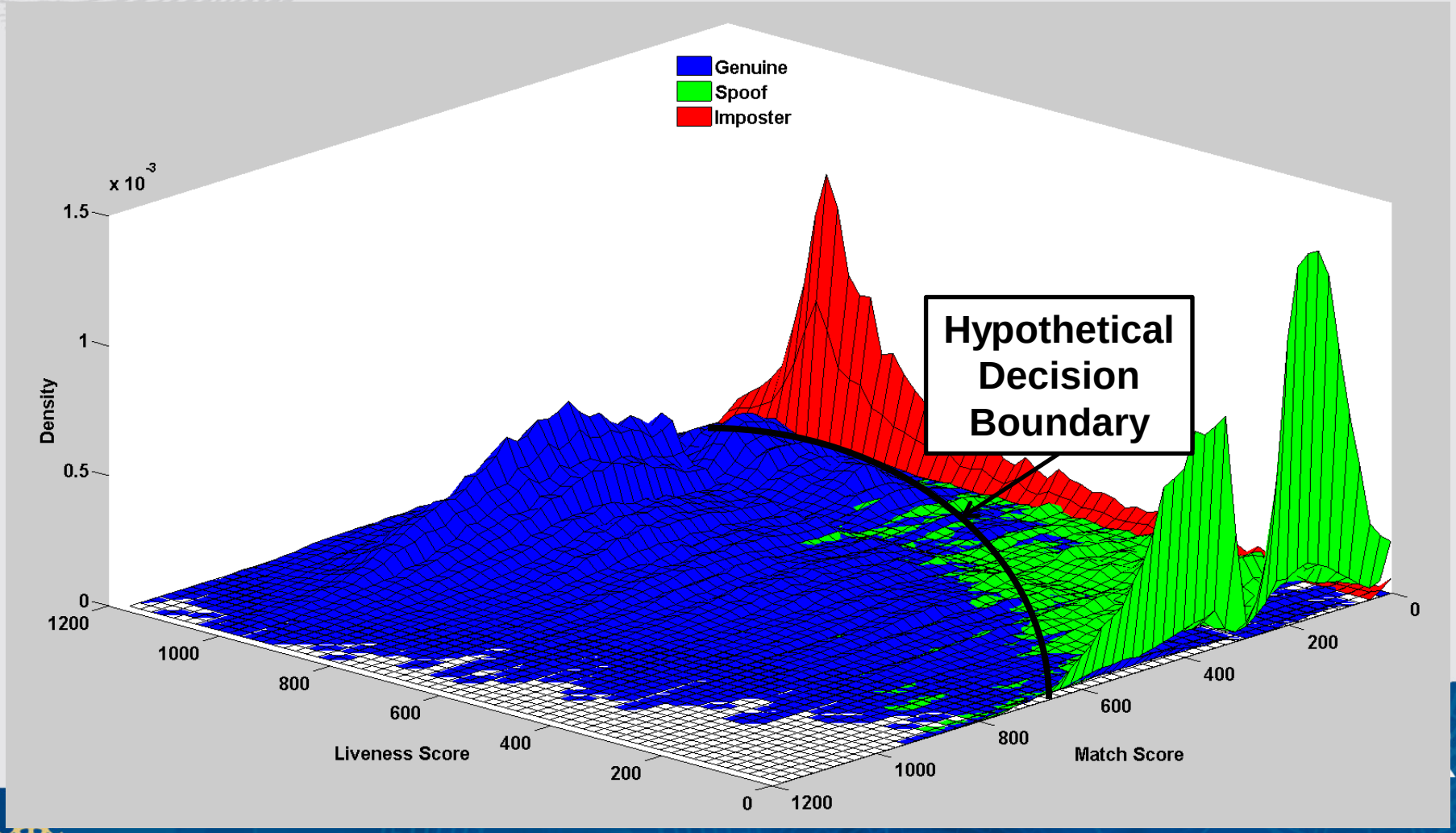
TYPE OF TEST

DECISION

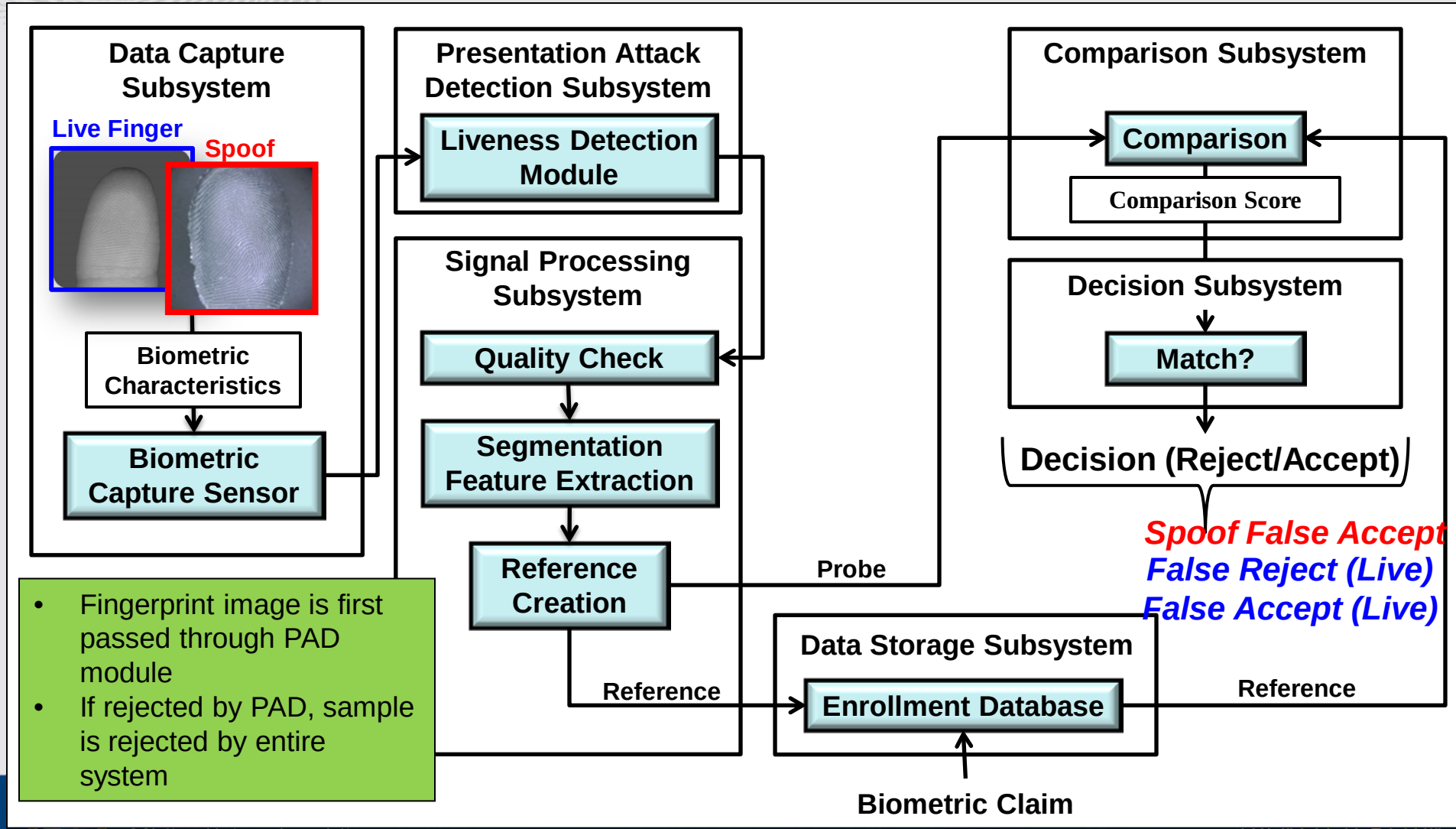
	Presentation Attack Genuine	Normal Presentation Genuine	Normal Presentation Imposter
Presentation Attack Match		**FRR***	**
Presentation Attack Non-Match		**FRR***	
Normal Presentation Non-Match		**FRR***	
Normal Presentation Match	**SFAR**		**FAR**

*Incorrectly rejected by PAD OR Matcher
**Correctly rejected but for the wrong reason (PAD)

Joint Distributions of Match and PAD (Liveness) Scores (Liveness Algorithm 2)

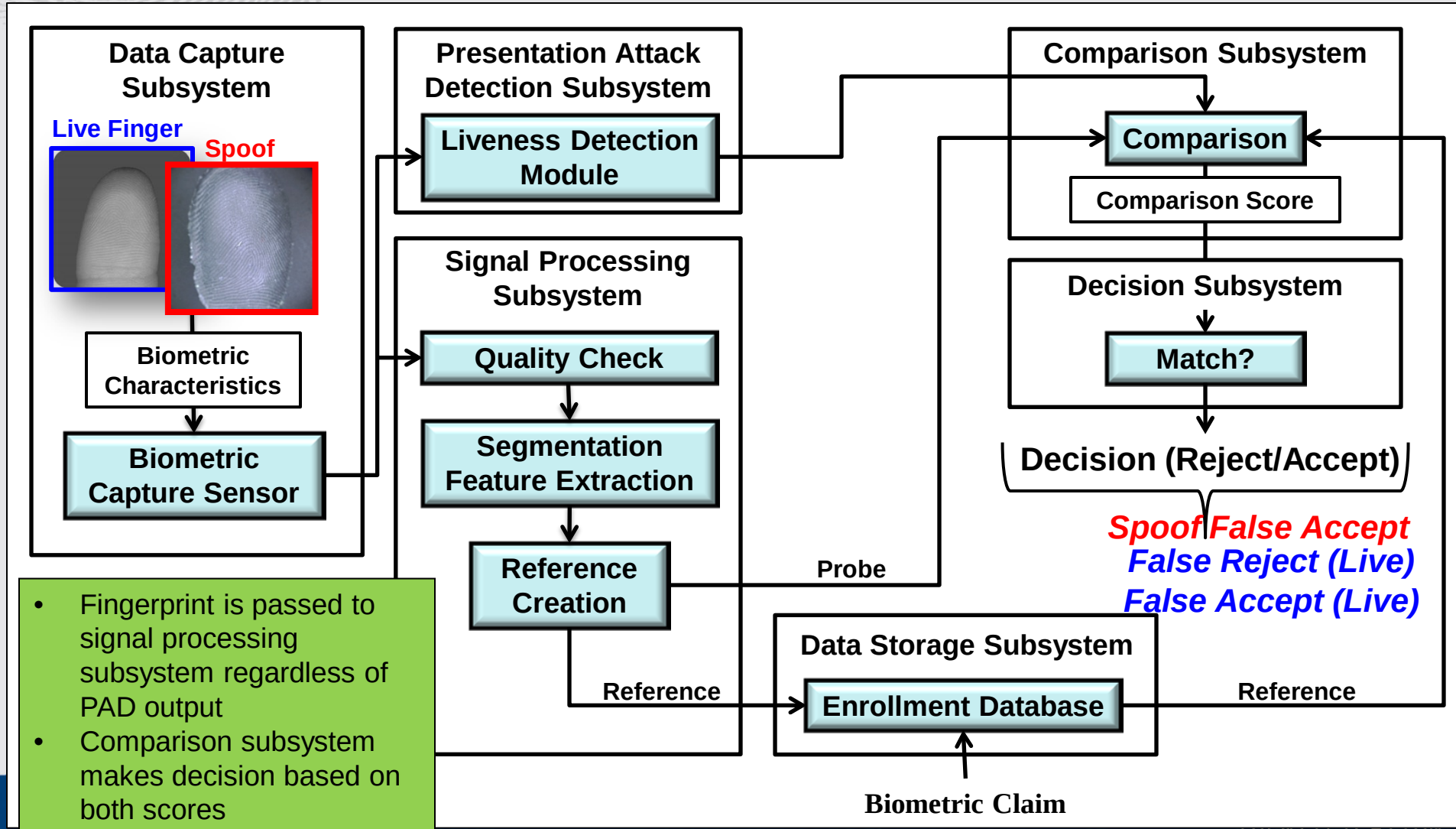


Fingerprint System with Presentation Attack Detection (PAD) – Series Implementation



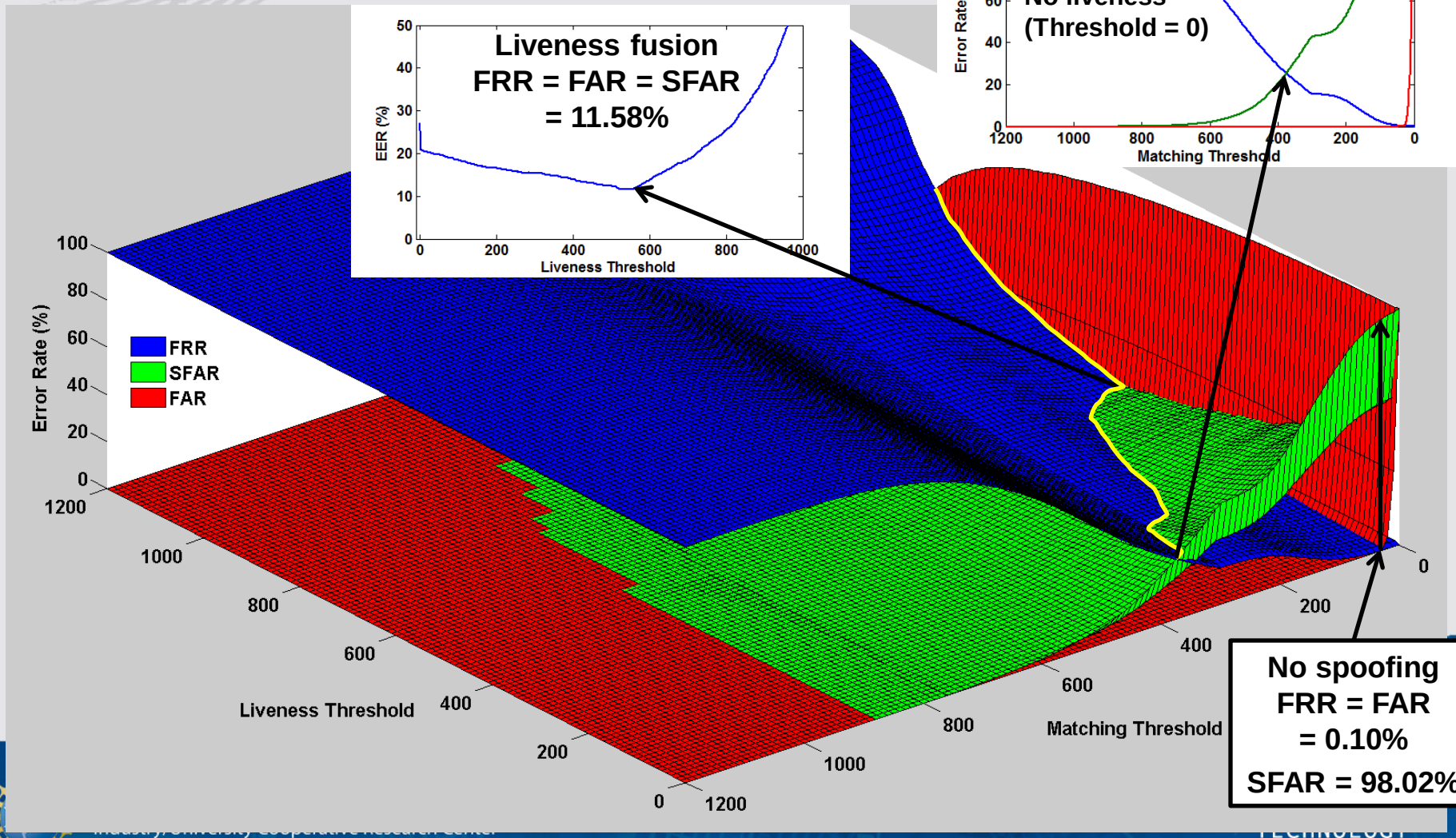
- Fingerprint image is first passed through PAD module
- If rejected by PAD, sample is rejected by entire system

Fingerprint System with Presentation Attack Detection (PAD) – Parallel Implementation

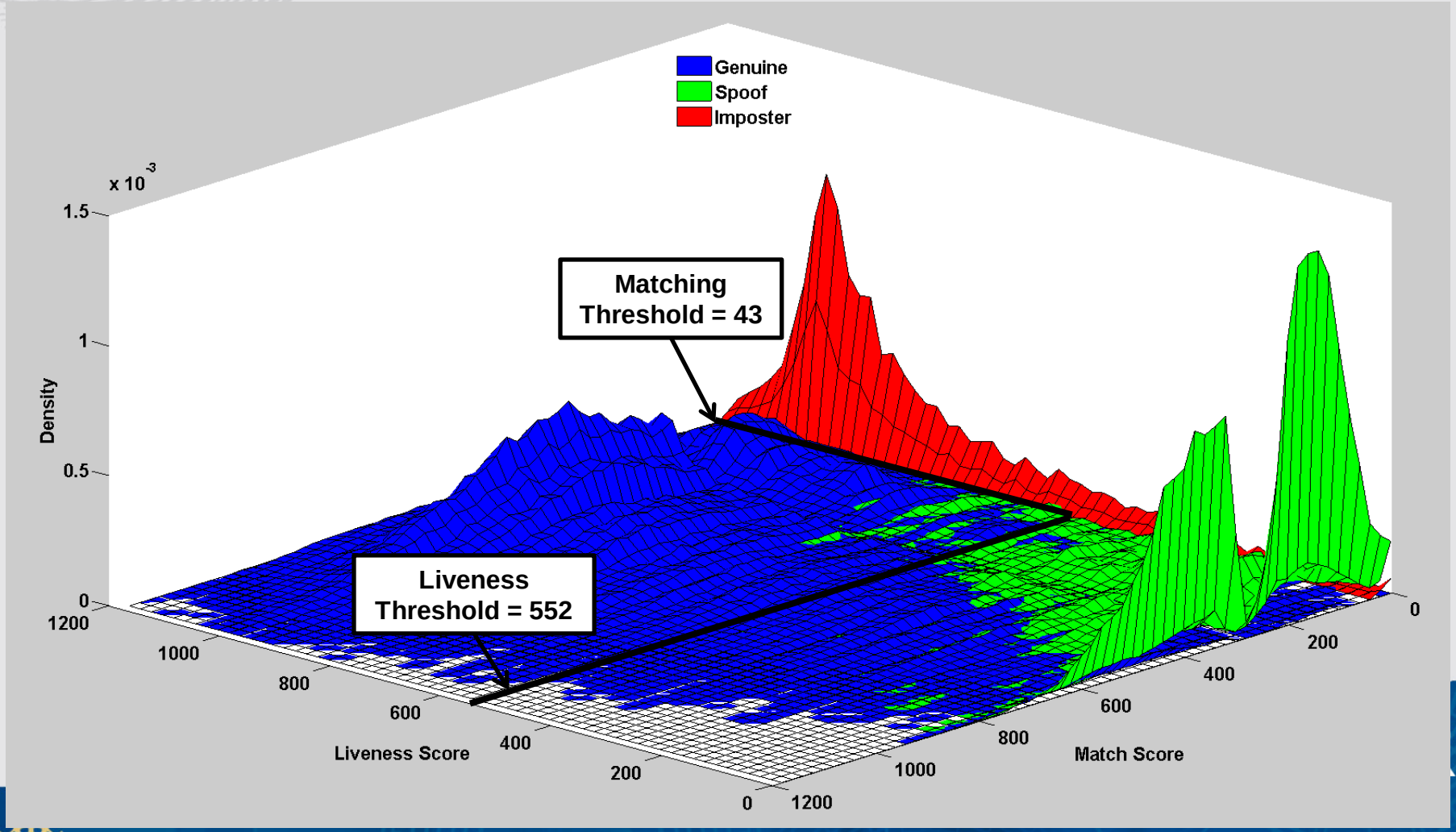


- Fingerprint is passed to signal processing subsystem regardless of PAD output
- Comparison subsystem makes decision based on both scores

Performance with PAD in Series (Liveness Algorithm 1)



Series System Decision Boundary



Parallel Fusion

- Parallel fusion:

  Comparison subsystem performs some fusion function $\boldsymbol{f}$ on the match score S_m and liveness score S_l

  Simplest example is the sum rule

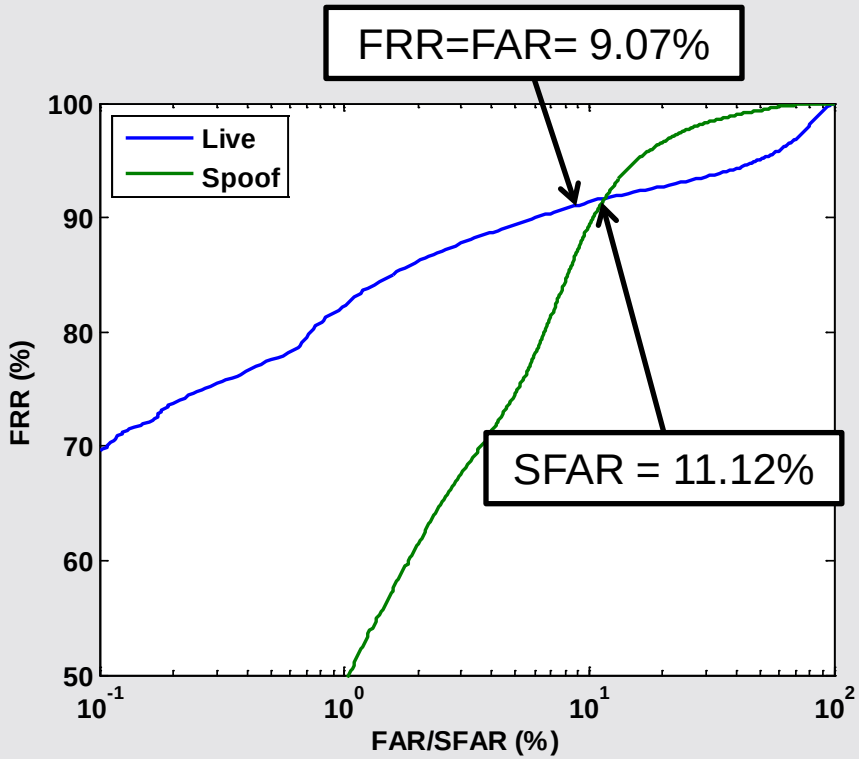
$$f = S_m W_m + S_l W_l$$

- Weights are calculated based on individual performance, such that $\sum_i \boldsymbol{W_i} = \mathbf{1}$

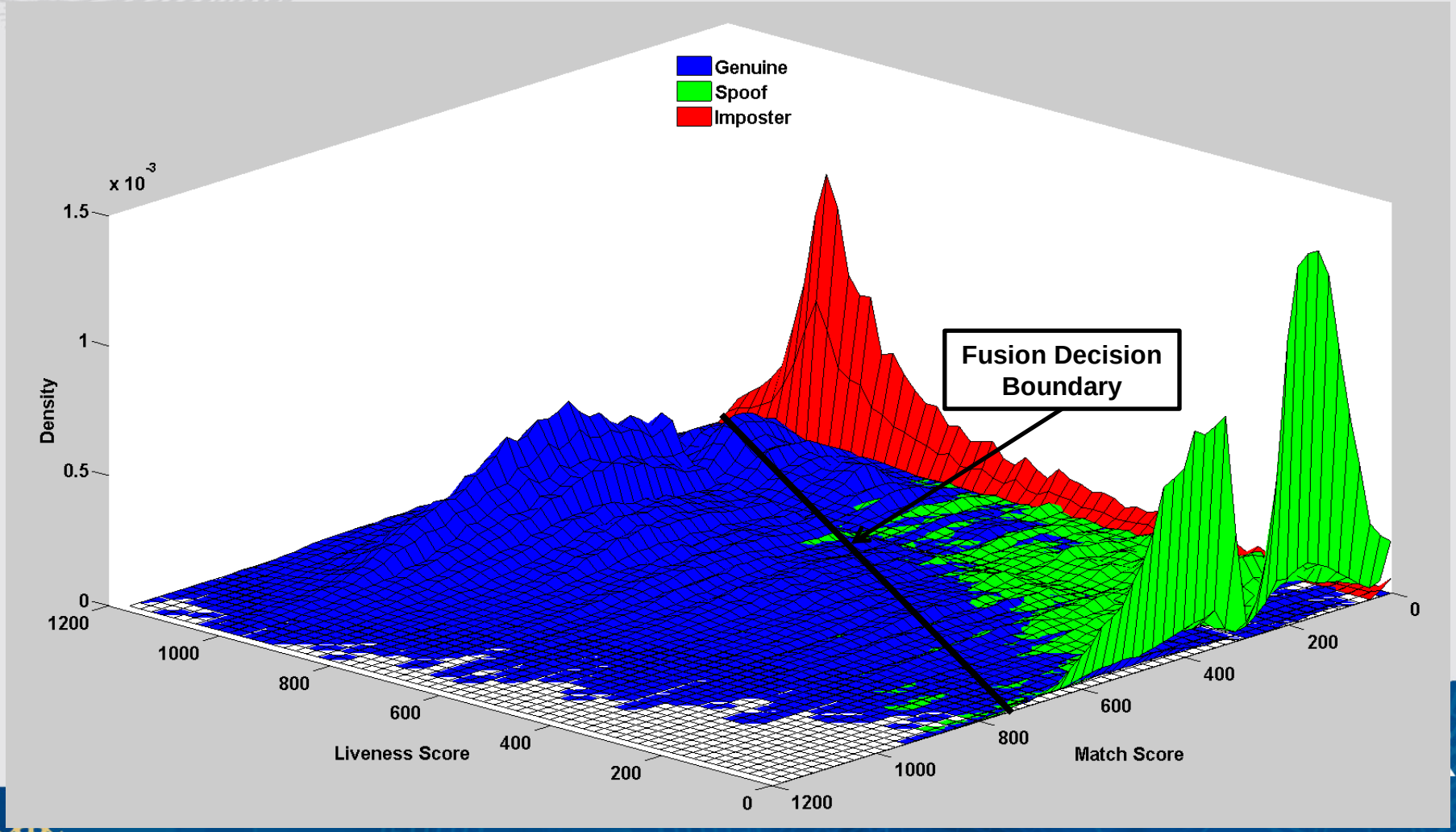
$$W_i = \frac{1 - 2EER_i}{2 - \left(2EER_i + 2EER_j\right)}, i \neq j$$

- Score $\boldsymbol{S}$ is first transformed to normalized score $\boldsymbol{S_N}$ using min-max normalization

$$S_N = \frac{S - \min(S)}{\max(S) - \min(S)}$$

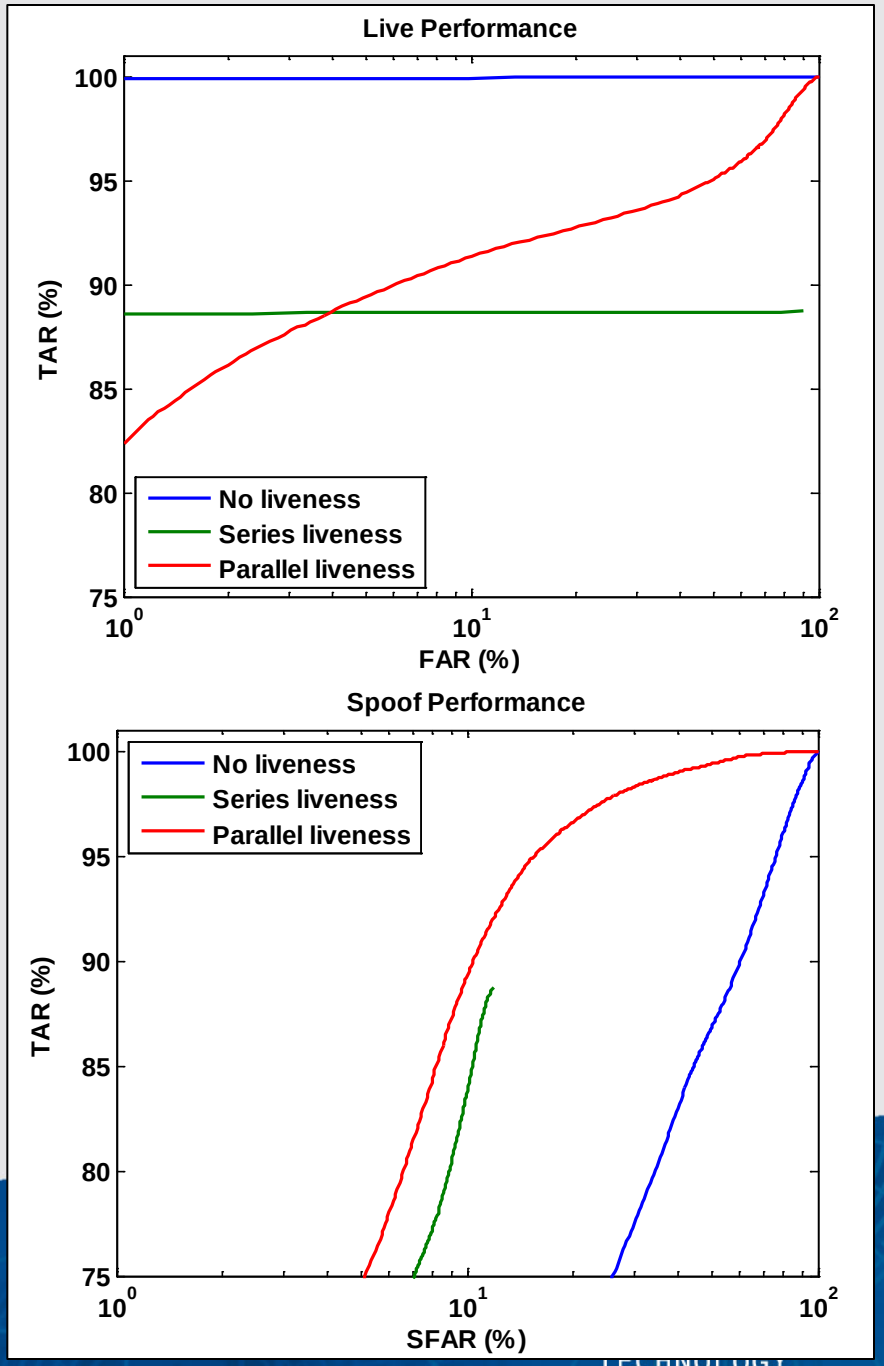


Sum Rule Fusion Decision Boundary



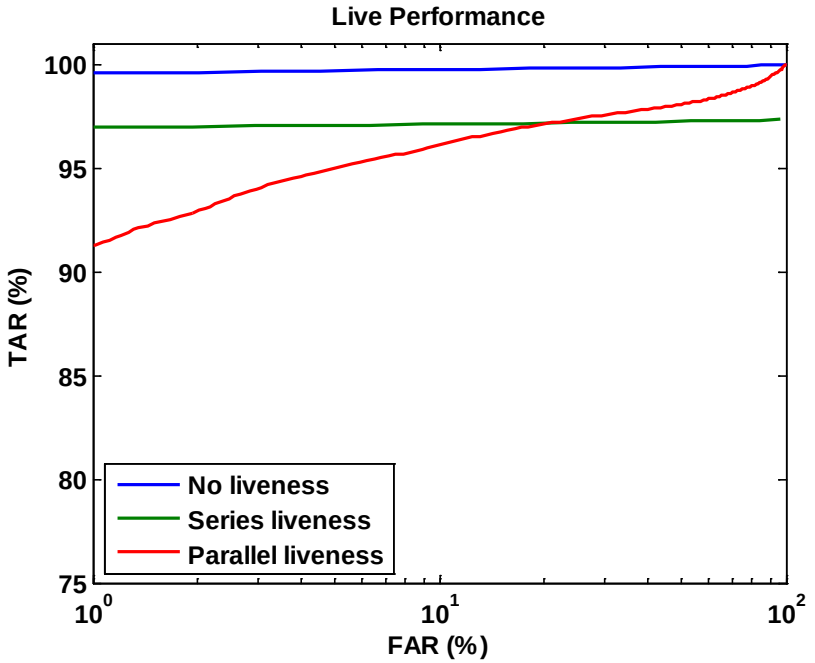
Performance Comparison Training

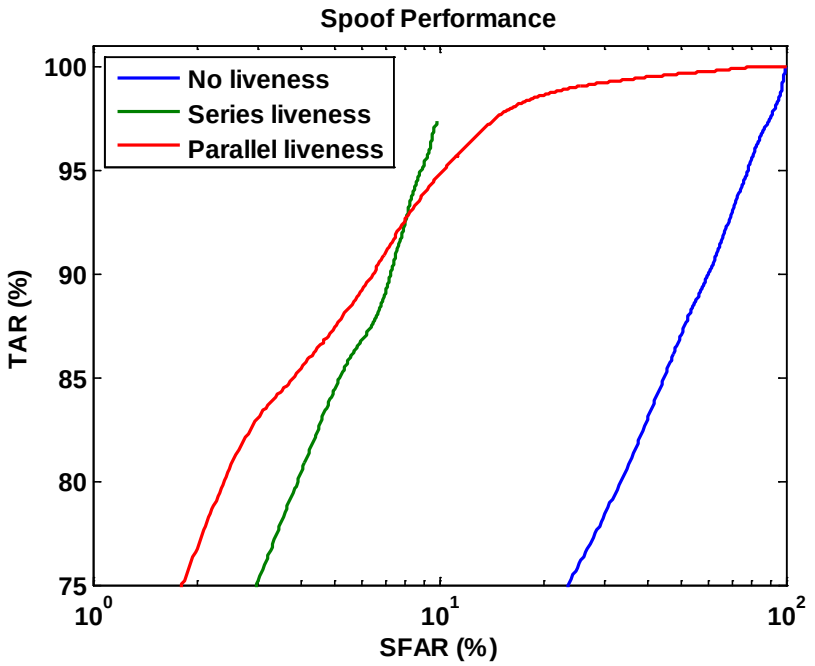
- Thresholds are chosen based on the training set
- System 1: No liveness
  - Matching Threshold = 30
  - FRR = 0.1%
  - FAR = 0.1%
  - SFAR = 98.02%
- System 2: Liveness in series
  - Matching threshold = 43
  - Liveness threshold = 552
  - FRR = 11.58%
  - FAR = 11.58%
  - SFAR = 11.58%
- System 3: Liveness in parallel
  - Fusion threshold = 0.3083
  - FRR = 9.07%
  - FAR = 9.07%
  - SFAR = 11.12%



Performance Comparison Testing

- Performance of three systems is evaluated on the testing set
- System 1: No liveness
  - Matching Threshold = 30
  - FRR = 0.59%
  - FAR = 0.003%
  - SFAR = 98.35%
- System 2: Liveness in series
  - Matching threshold = 43
  - Liveness threshold = 552
  - FRR = 3.55%
  - FAR = 0%
  - SFAR = 9.49%
- System 3: Liveness in parallel
  - Fusion threshold = 0.3083
  - FRR = 5.75%
  - FAR = 3.33%
  - SFAR = 9.41%





Summary

- Performance metrics for PAD system

  Normal Presentation Classification Rate (NPCR): percentage normal presentations that are accepted as normal presentations

  Attack Presentation Classification Rate (APCR): percentage of attack presentations correctly classified as attack presentations

- Performance metrics for combination of PAD subsystem and Comparison subsystem

  False accept rate (FAR): Percentage of imposters accepted by the system

  False reject rate (FRR): Percentage of genuine users rejected by the system

  Spoof False Accept Rate (SFAR)--Percentage of spoof samples that are accepted by the system (i.e. by matching and PAD)

- The training and testing datasets are available by request for download for further experimentation

  http://www.clarkson.edu/citer/research/collections/index.html

Summary -con-

- Two distinct implementations of presentation attack detection in a fingerprint recognition system have been examined
  - Series: Detecting fingerprint liveness prior to matching and filtering out spoof samples
  - Parallel: Detecting fingerprint liveness alongside matching and implementing a fusion function in the comparison subsystem
- The series implementation resulted in a significant reduction in performance regarding live fingers
  - FRR dropped from 0.59% to 3.55% on testing set
- The simple sum rule fusion did not improve upon the series result
  - Sum rule still provides a linear decision boundary
  - A more complex (nonlinear) decision boundary fitted to the score densities is likely to improve performance

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