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# Evaluation of Presentation Attack Detection: An Example

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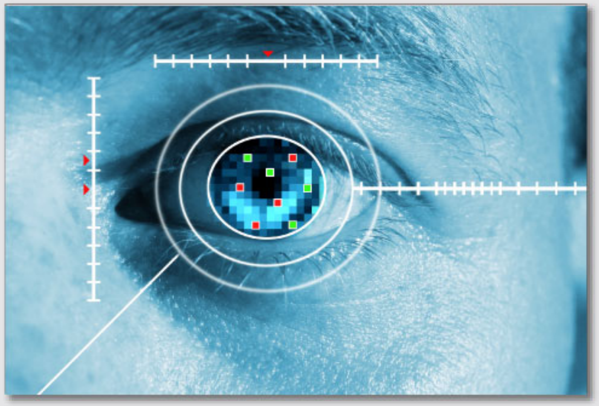
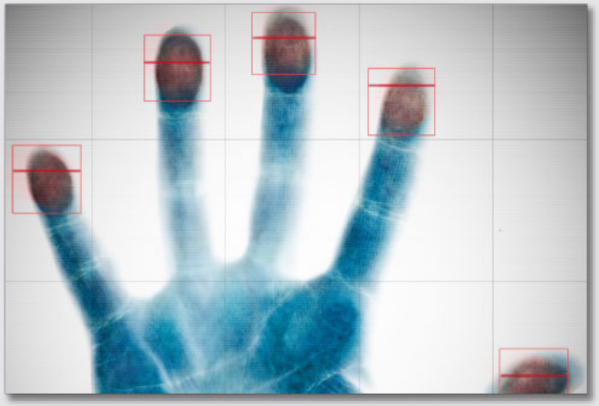
Clarkson University





Clarkson University defy convention

The University of Arizona

West Virginia University

# 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*

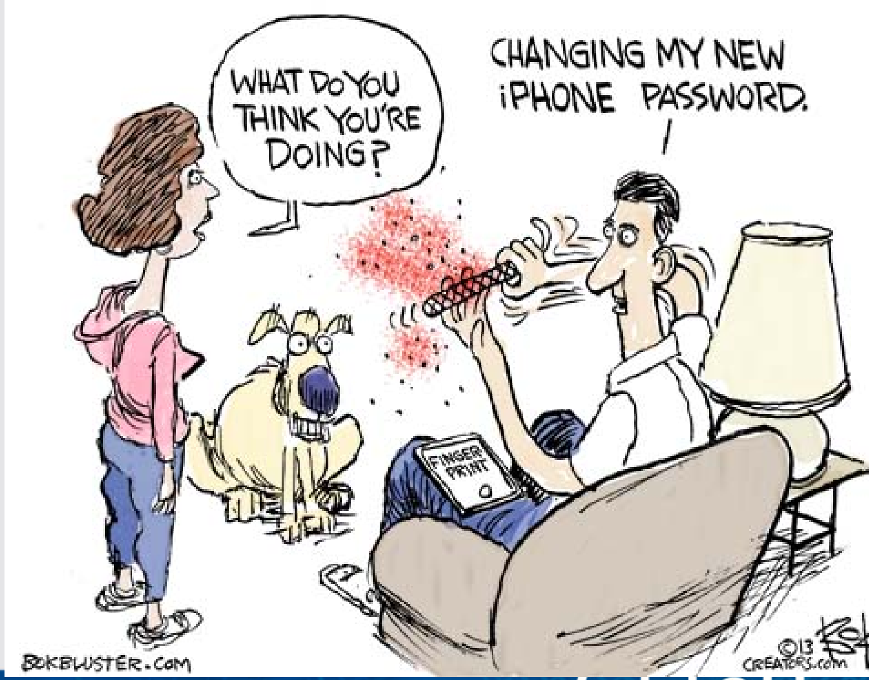
- Why?

  Posing as another individual

  - Positive ID applications

  Hiding your identity

  - Negative ID applications
  - May form ‘new’ identity for positive ID


WHAT DO YOU THINK YOU'RE DOING?
CHANGING MY NEW iPHONE PASSWORD.
FINGER PRINT
BOKBLUSTER.COM
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*from: ISO/IEC CD 30107-1, Information Technology — Biometrics -- Presentation Attack Detection

# Fingerprint Presentation Attacks

- Cooperative

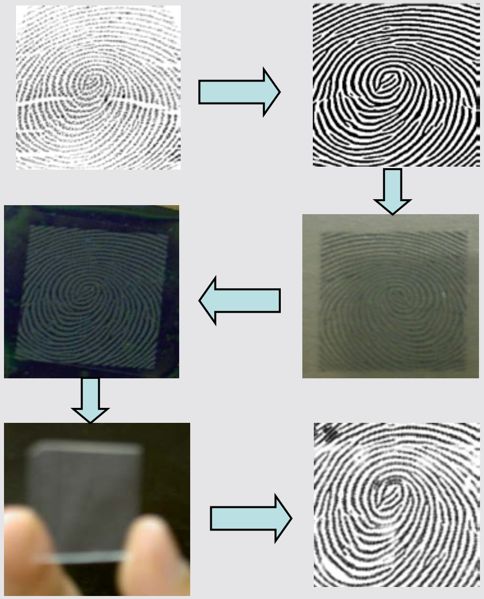
  Characteristic captured directly from individual with assistance (e.g. finger mold)

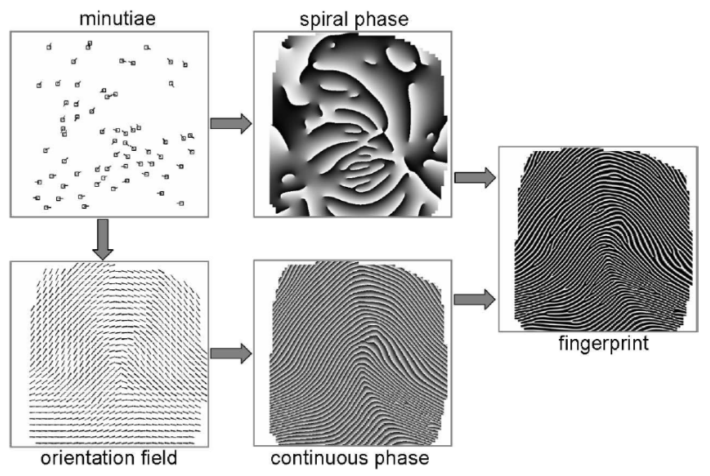
- Latent

  Characteristic captured indirectly through lifting a latent sample

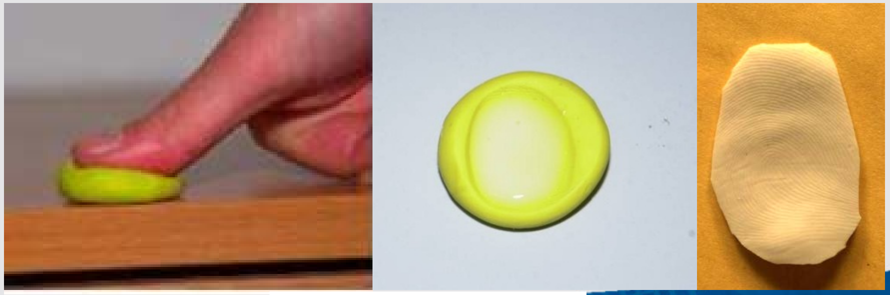
- Synthetic

  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]

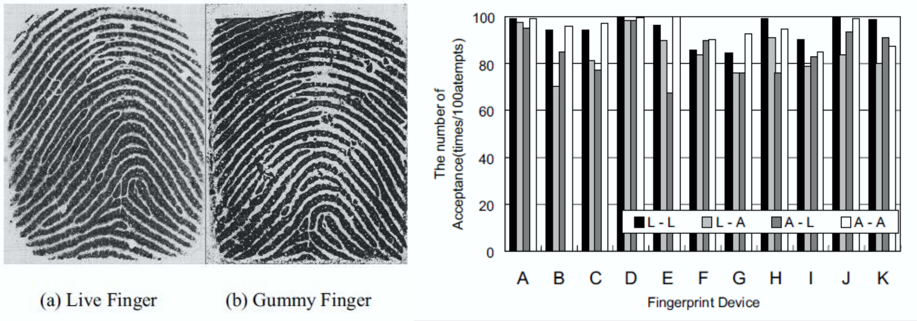
  Tested various techniques for spoofing biometric systems

  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]



(a) Live Finger

(b) Gummy Finger

# 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

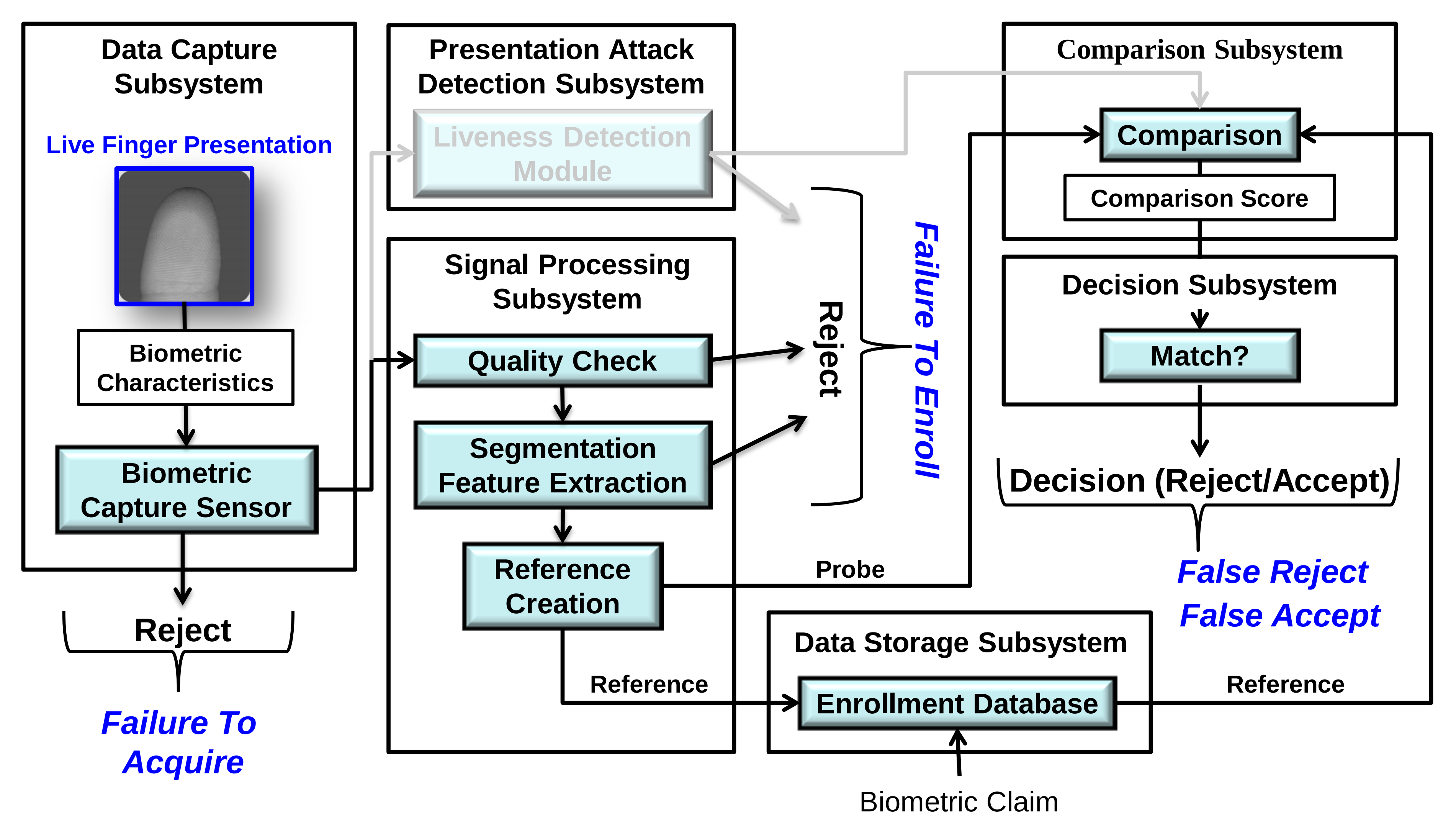
# Challenge

- 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

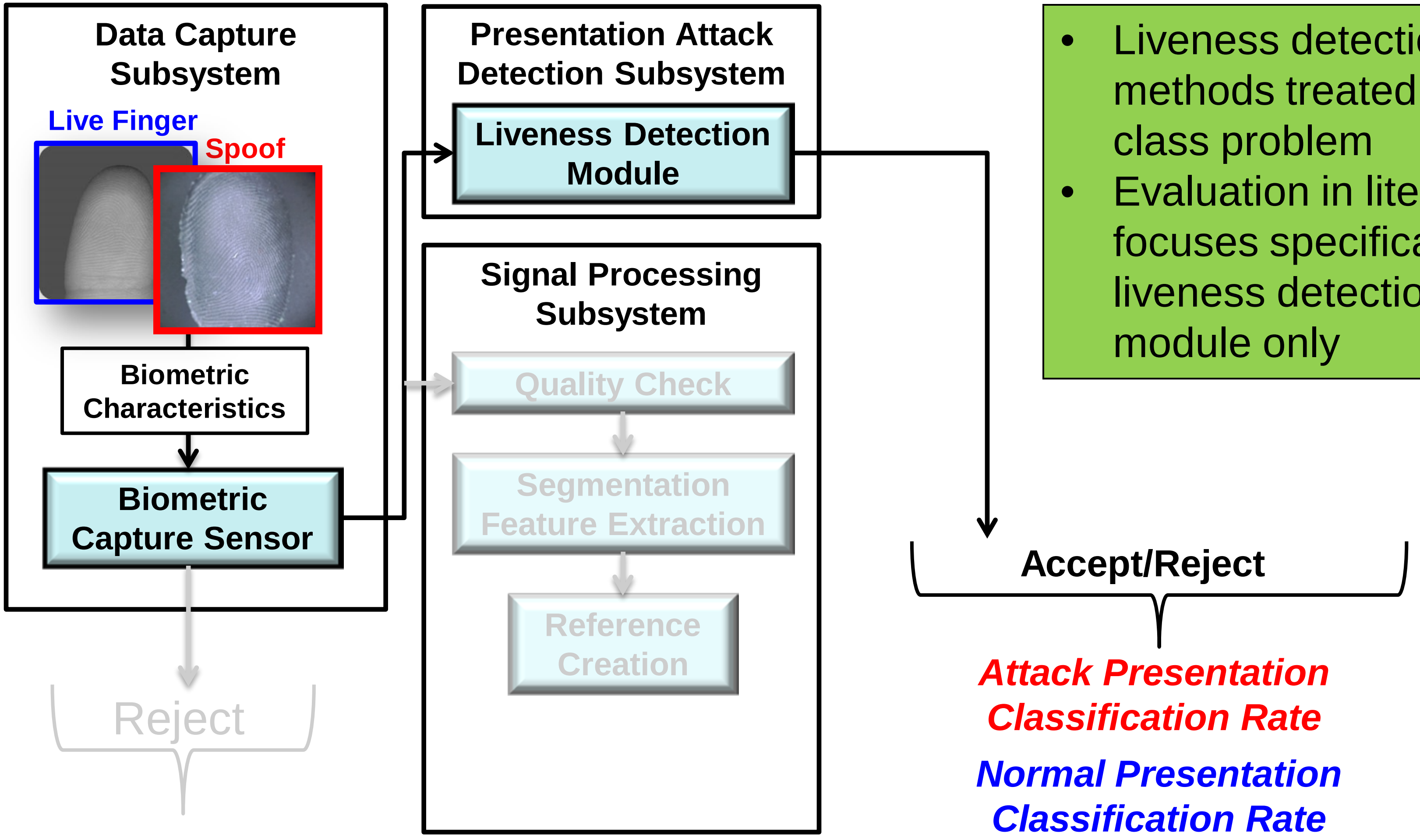
# Objective

- 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)

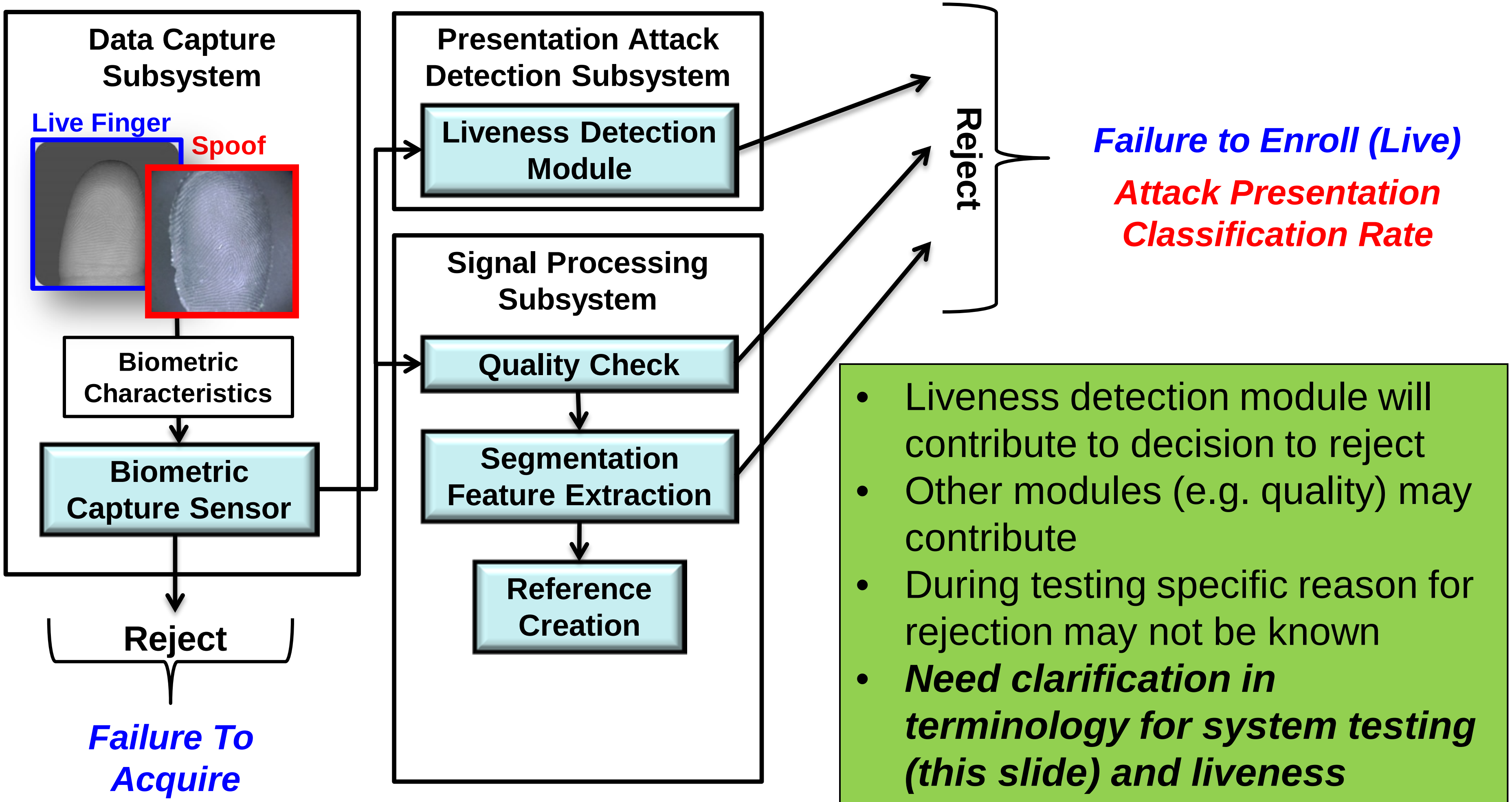


# Additional Metrics (Spoof Input)


Data Capture Subsystem
Live Finger
Spoof
Biometric Characteristics
Biometric Capture Sensor
Reject
Presentation Attack Detection Subsystem
Liveness Detection Module
Signal Processing Subsystem
Quality Check
Segmentation Feature Extraction
Reference Creation
Accept/Reject
Attack Presentation Classification Rate
Normal Presentation Classification Rate

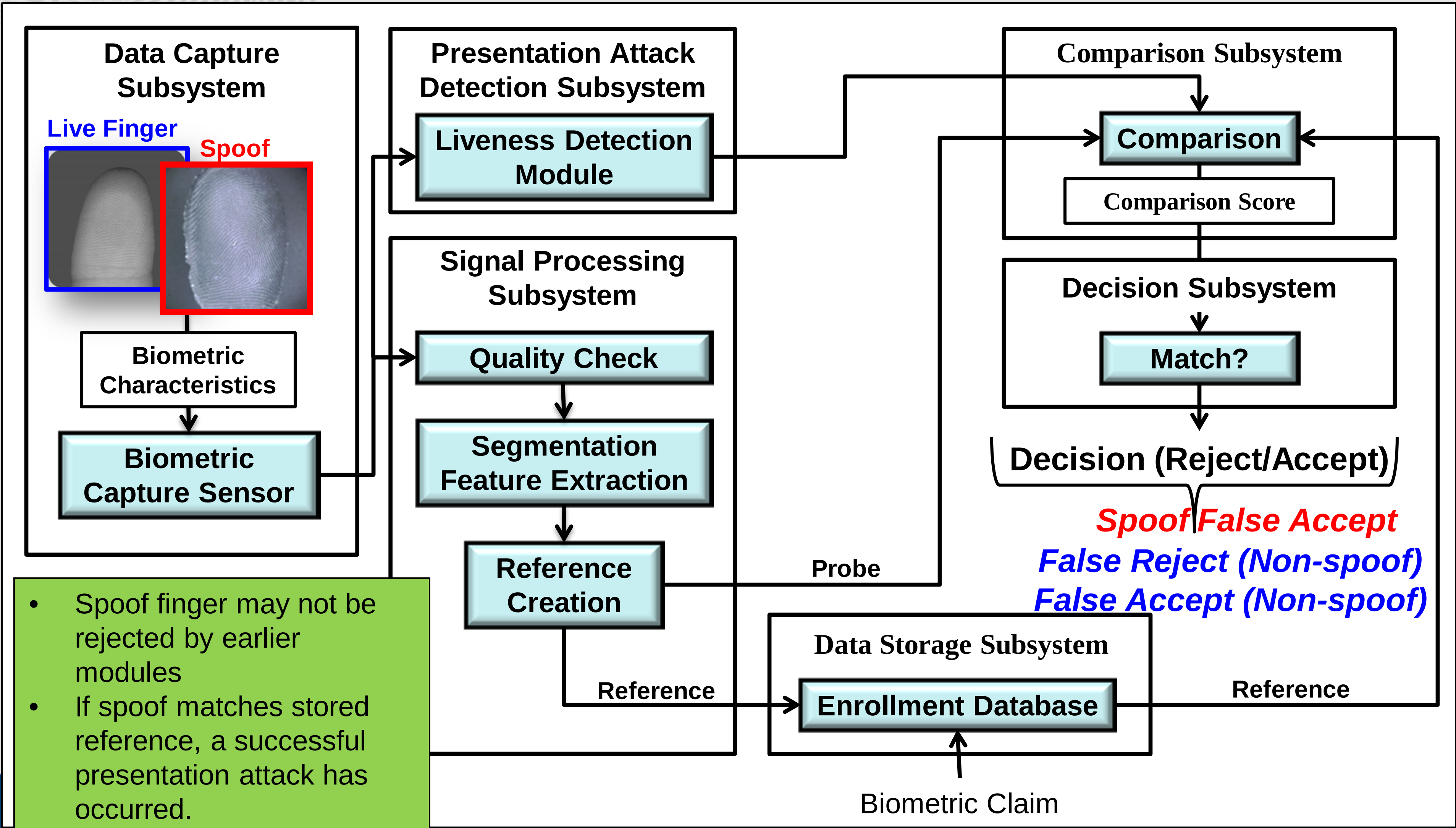
- Liveness detection methods treated as two class problem
- Evaluation in literature focuses specifically on liveness detection module only

# Additional Metrics (Spoof Input)


Data Capture Subsystem
Live Finger
Spoof
Biometric Characteristics
Biometric Capture Sensor
Reject
Failure To Acquire
Presentation Attack Detection Subsystem
Liveness Detection Module
Signal Processing Subsystem
Quality Check
Segmentation Feature Extraction
Reference Creation
Reject
Failure to Enroll (Live)
Attack Presentation Classification Rate

- 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<br>R2: 1,896 | R1: 724<br>R2: 491 | 519,198 | 911,476 | 106,943 |
| Testing | 24 | R1: 2,153<br>R2: 1,783 | R1: 749<br>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

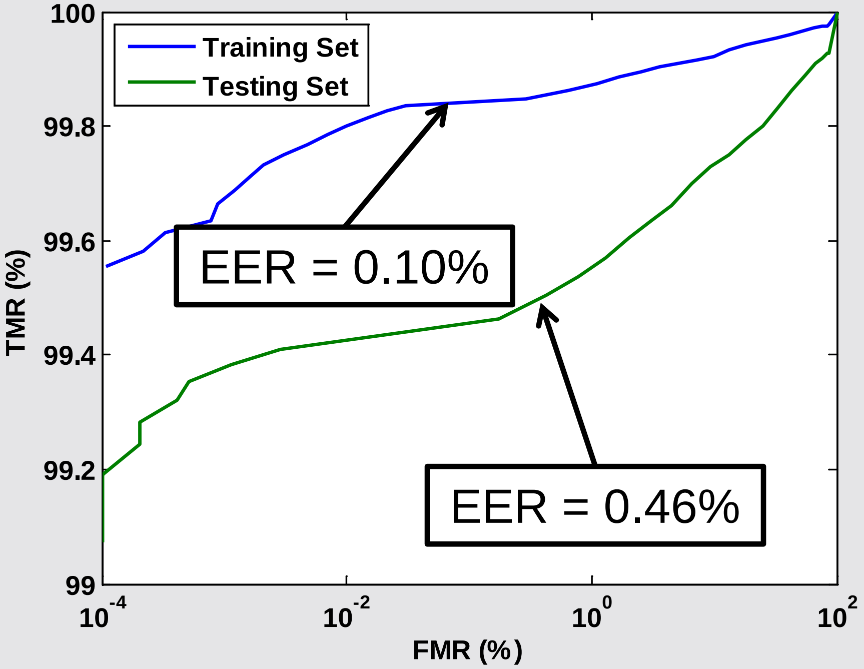
  **True match rate (TMR):** TMR = 100 – FNMR

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

  Matching threshold = 30

  FRR = 0.59%

  FAR = 0.003%



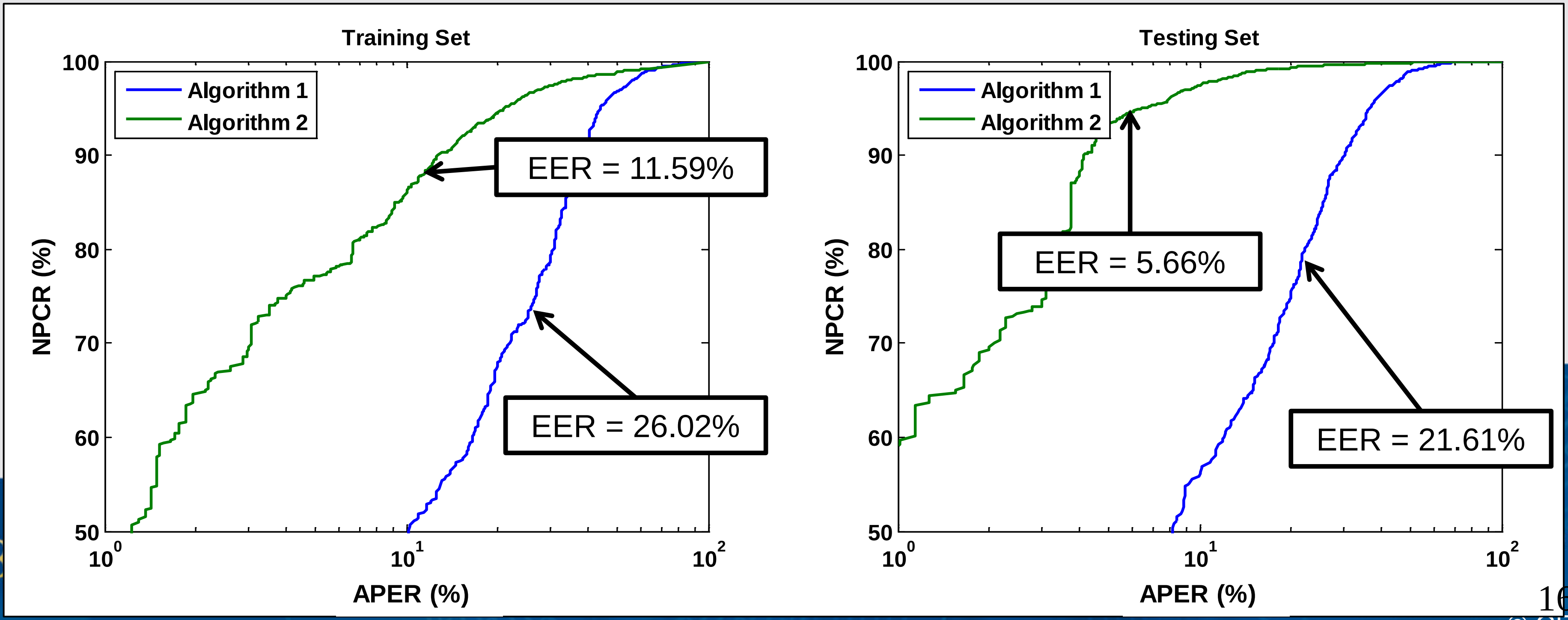
# Performance Metrics – PAD

- 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)



Training Set

EER = 11.59%

EER = 26.02%

Testing Set

EER = 5.66%

EER = 21.61%

# 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

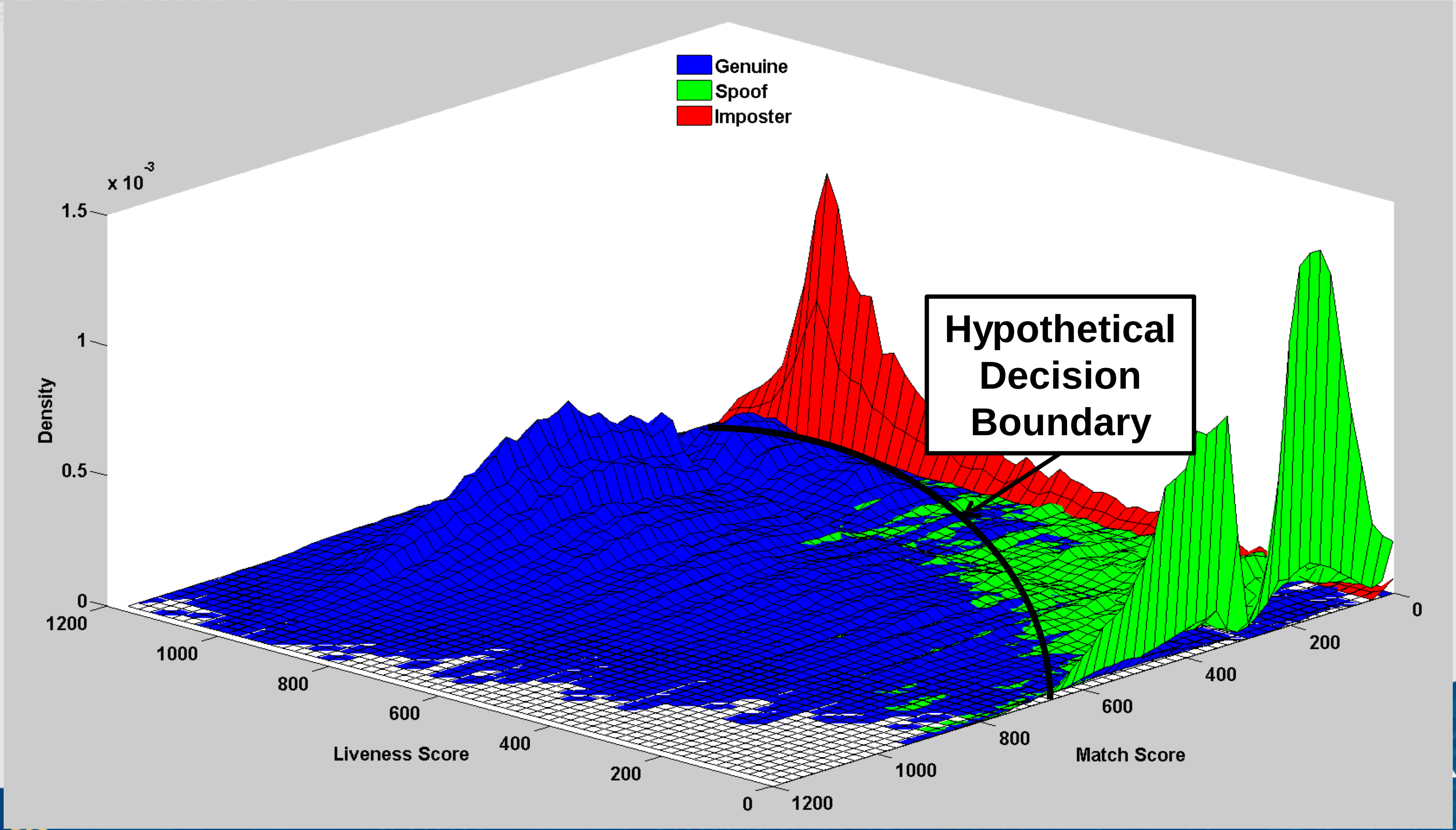
TYPE OF TEST

DECISION

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

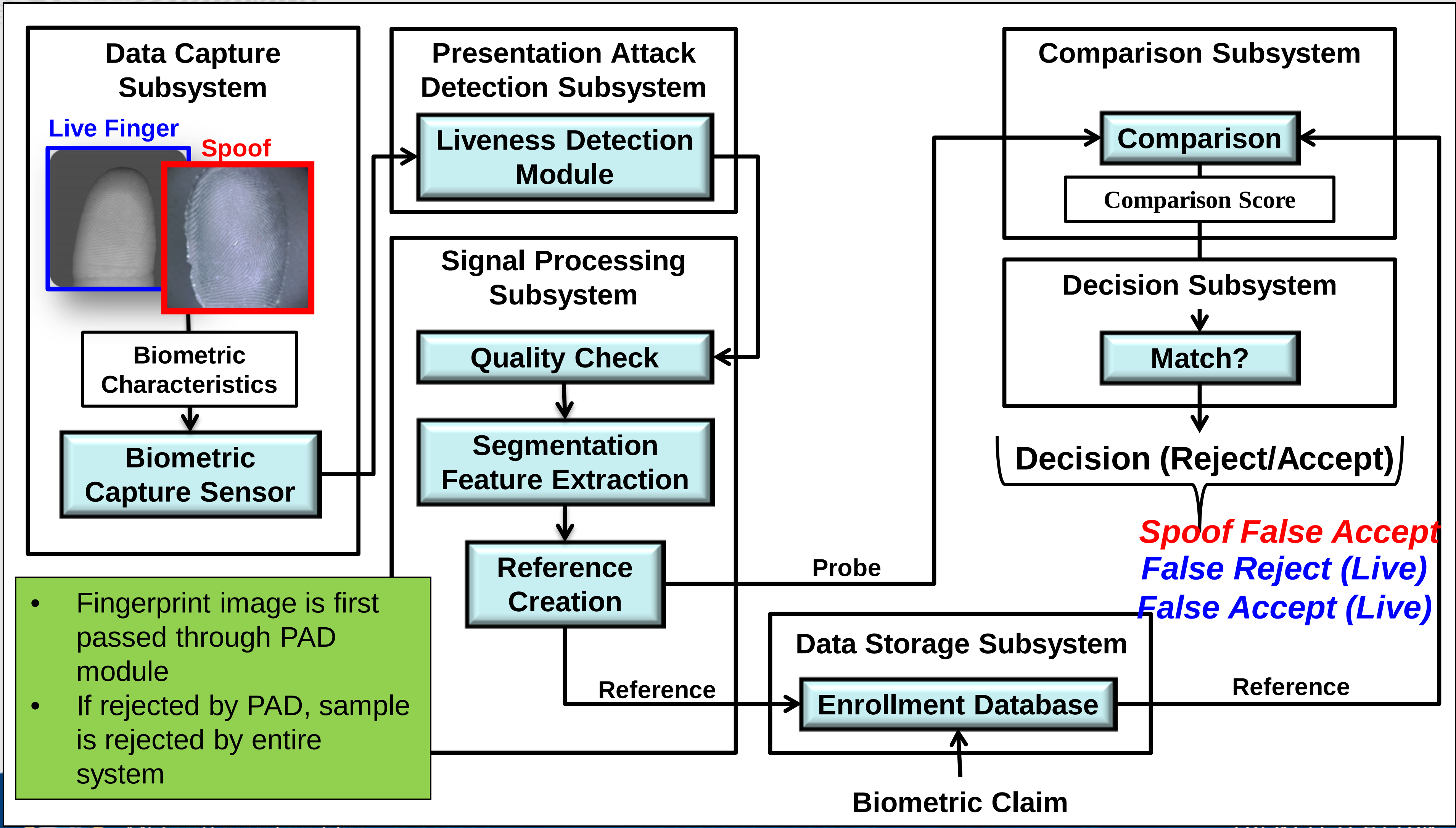
*Incorrectly rejected by PAD OR Matcher
**Correctly rejected but for the wrong reason (PAD)

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



Hypothetical Decision Boundary

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



Data Capture Subsystem

Live Finger

Spoof

Biometric Characteristics

Biometric Capture Sensor

Presentation Attack Detection Subsystem

Liveness Detection Module

Signal Processing Subsystem

Quality Check

Segmentation Feature Extraction

Reference Creation

Probe

Reference

Comparison Subsystem

Comparison

Comparison Score

Decision Subsystem

Match?

Decision (Reject/Accept)

Spoof False Accept

False Reject (Live)

False Accept (Live)

Data Storage Subsystem

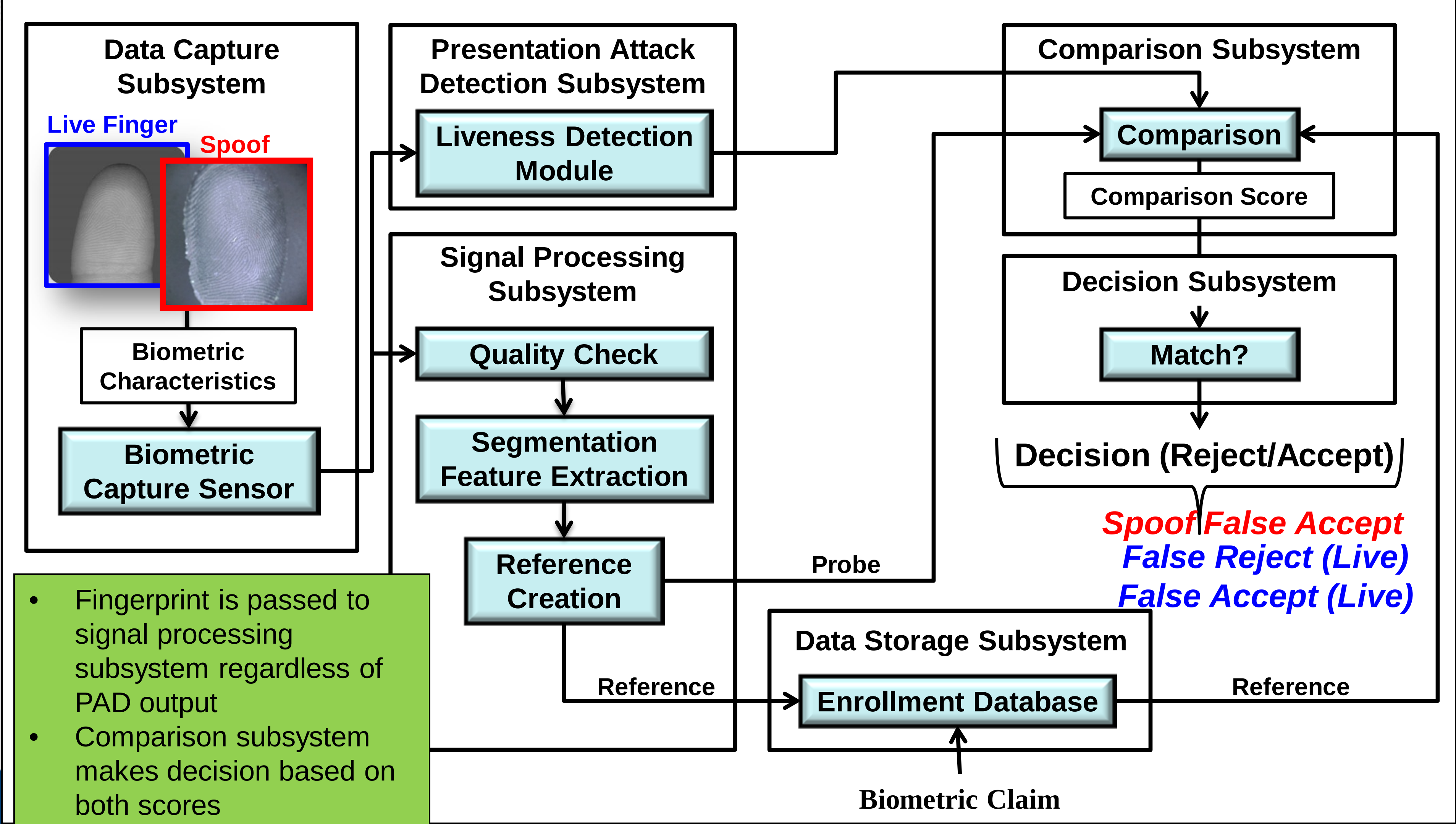
Enrollment Database

Reference

Biometric Claim

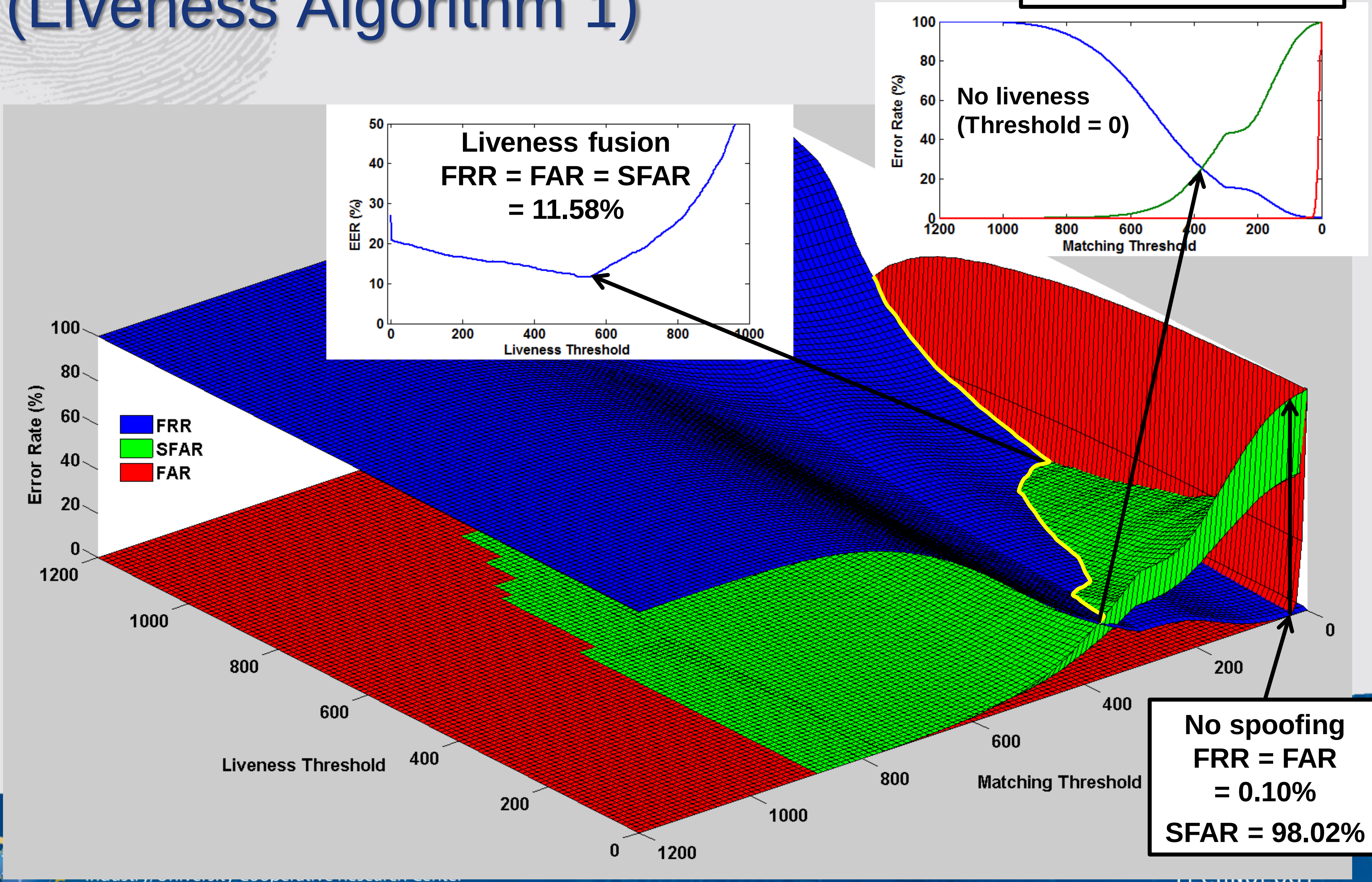
- Fingerprint image is first passed through PAD module
- If rejected by PAD, sample is rejected by entire system

# 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)



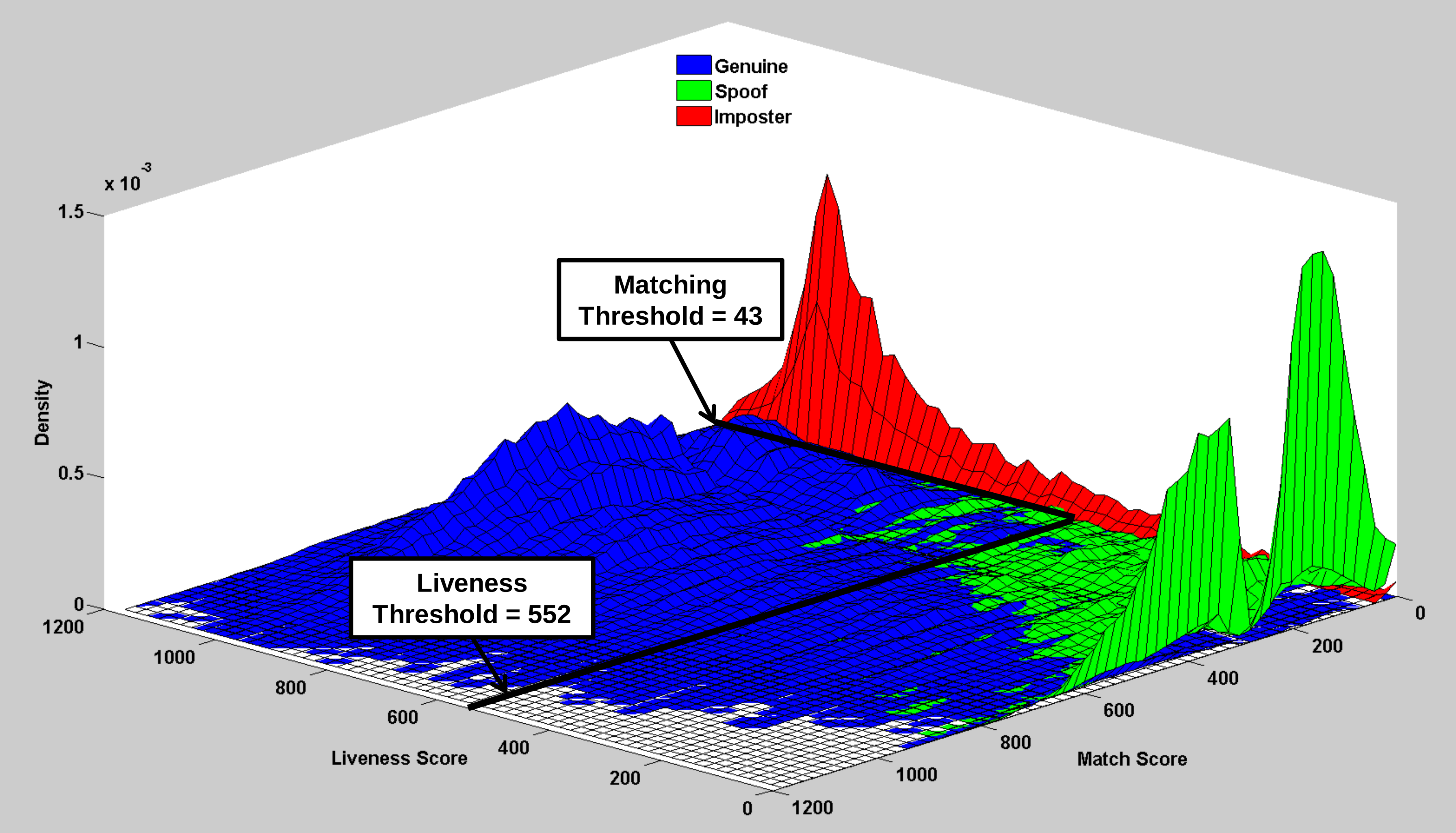
Liveness fusion
FRR = FAR = SFAR
= 11.58%

No liveness
(Threshold = 0)

FRR = SFAR = 25.40%

No spoofing
FRR = FAR
= 0.10%
SFAR = 98.02%

# Series System Decision Boundary



Matching Threshold = 43

Liveness Threshold = 552

# 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

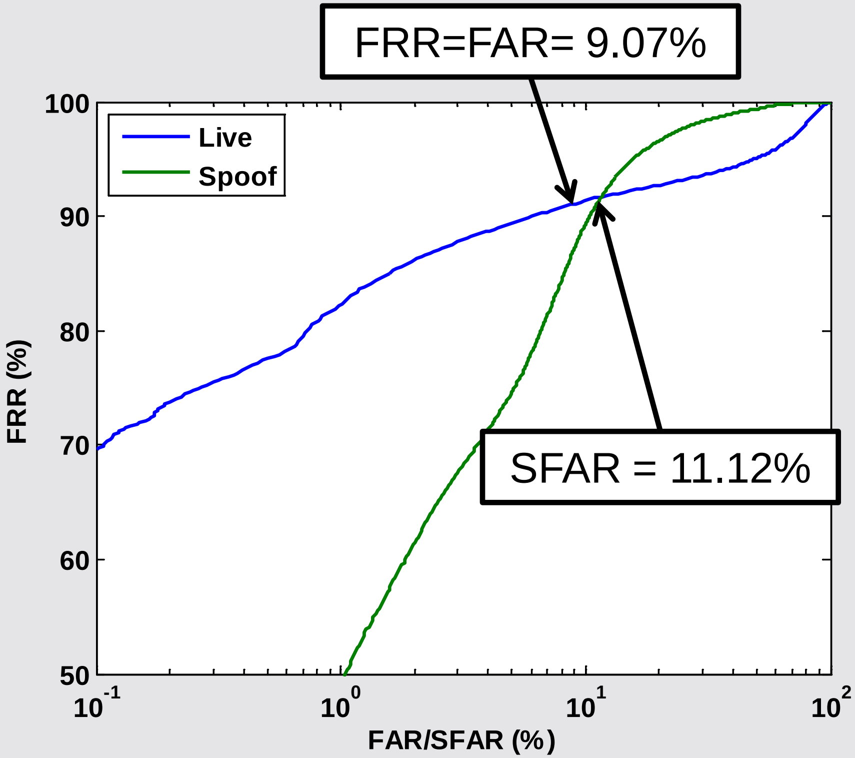
$$f = S_m W_m + S_l W_l$$

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

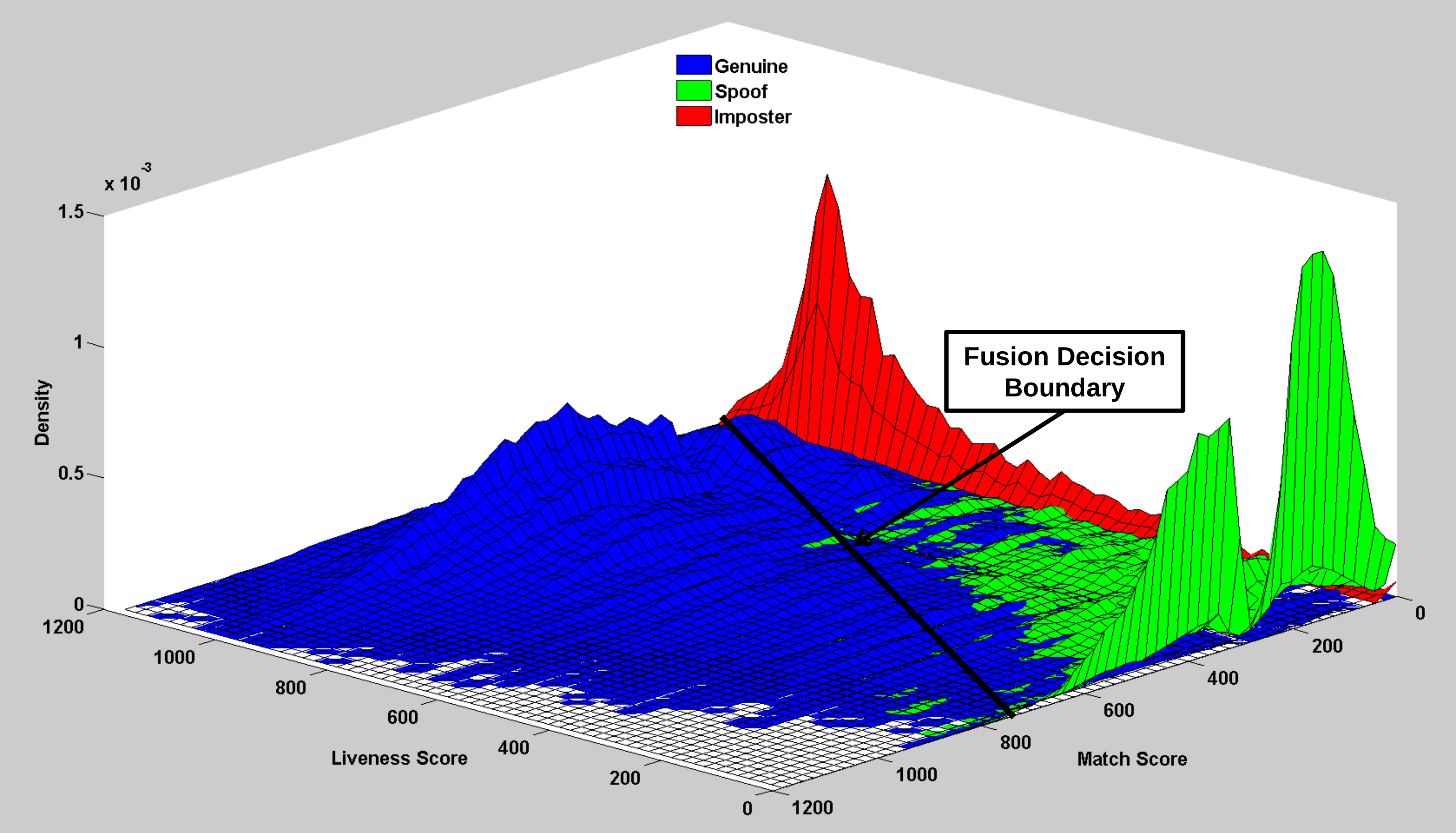
$$W_i = \frac{1 - 2EER_i}{2 - (2EER_i + 2EER_j)}, i \neq j$$

- 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



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%

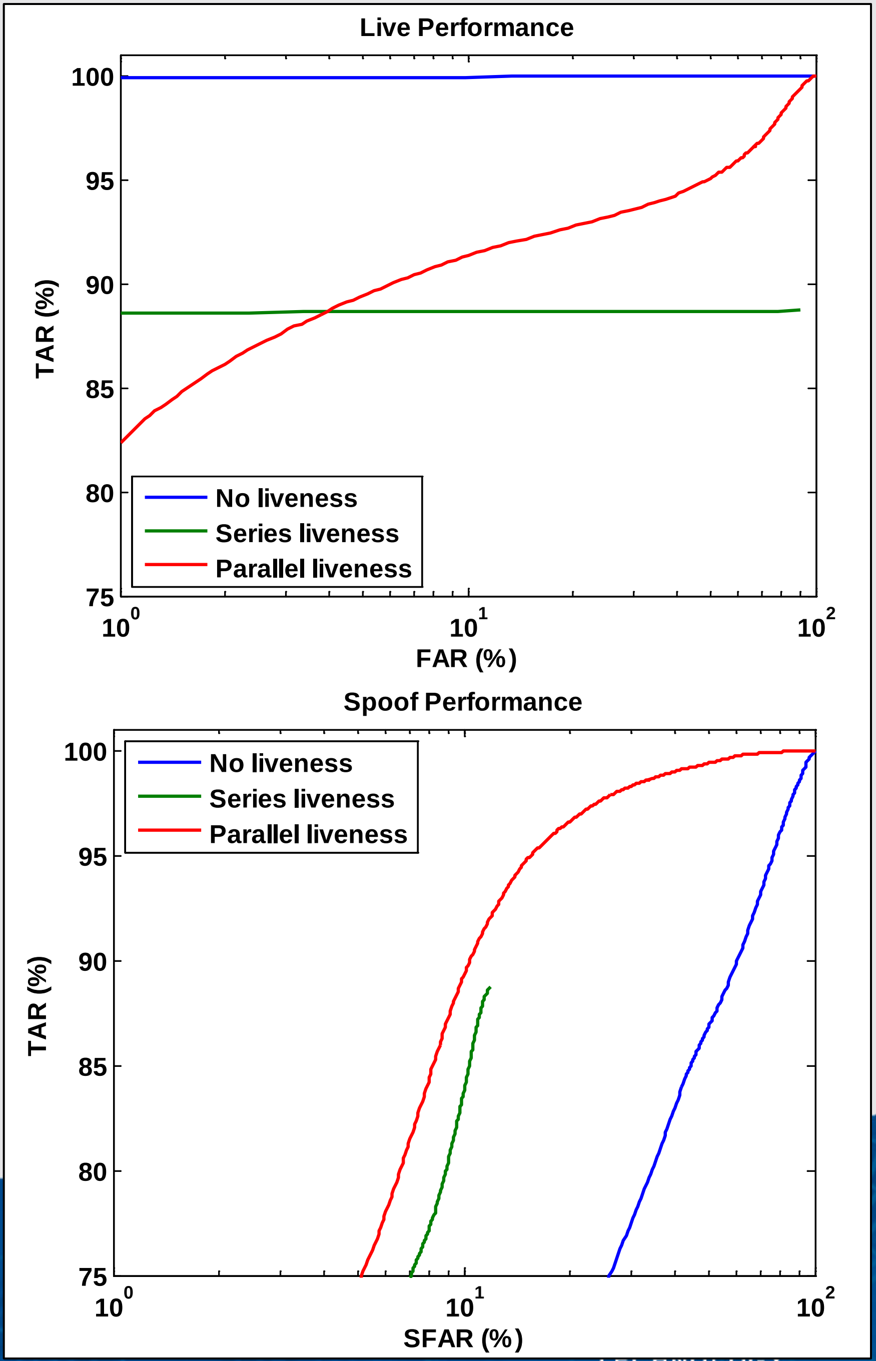
  SFAR = 11.58%
- System 3: Liveness in parallel

  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%

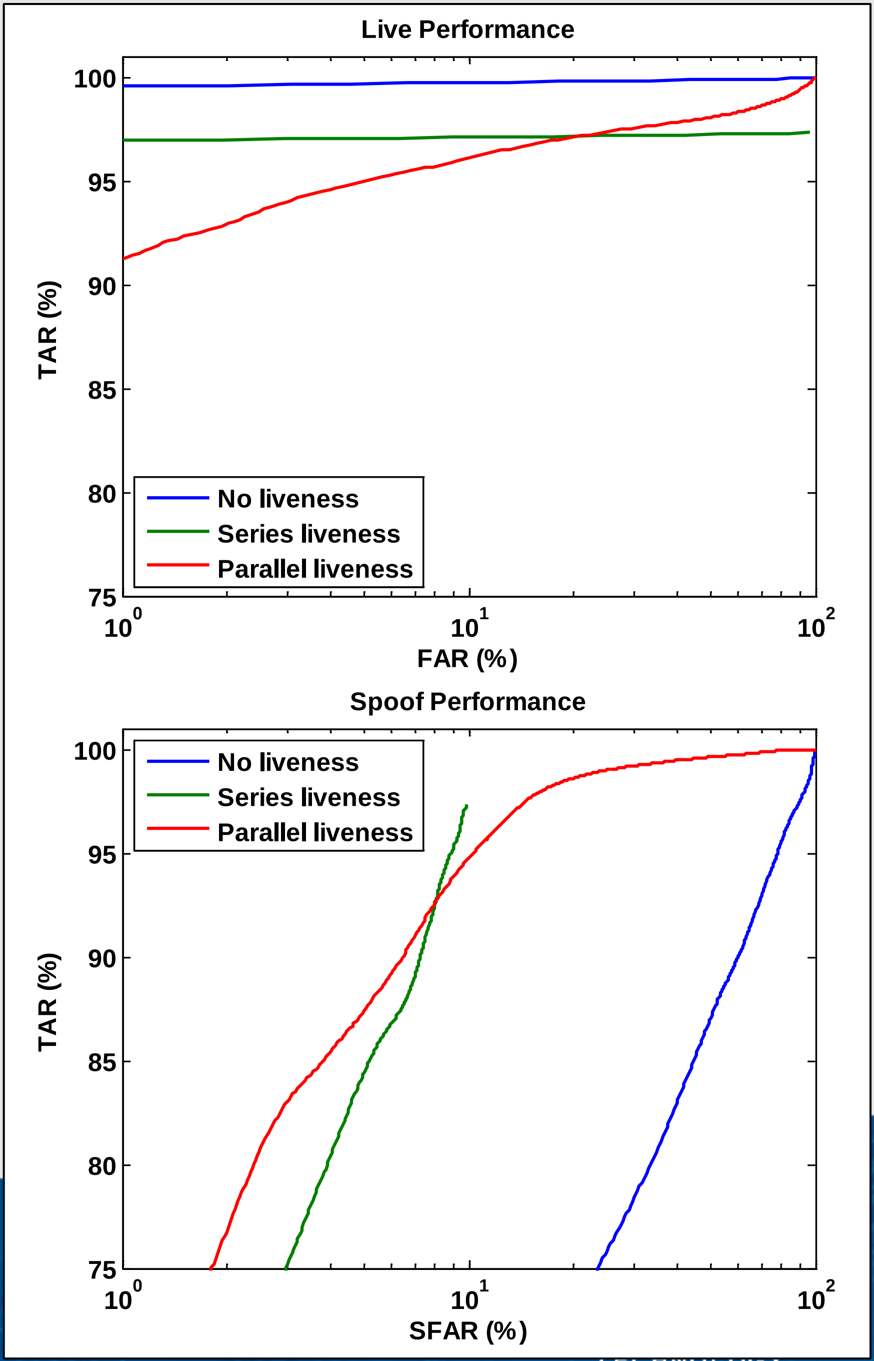
  SFAR = 9.49%
- System 3: Liveness in parallel

  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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