PUFshield: A Hardware-Assisted Approach for Deepfake Mitigation Through PUF-Based Facial Feature Attestation

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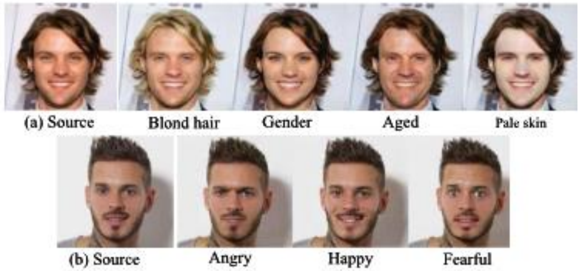
Outline

- Introduction to Deepfake
- Deepfake Techniques and Classification
- Deepfake Mitigation
- Introduction to PUF
- Proposed PUF-based Facial Feature Attestation Scheme
- Experimental Validation
- Conclusion & Future Research Directions

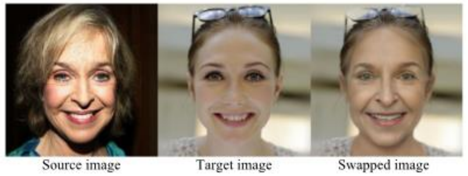
Deepfake

AI can be fooled by fake data

Attribute Manipulation



Identity Swapping

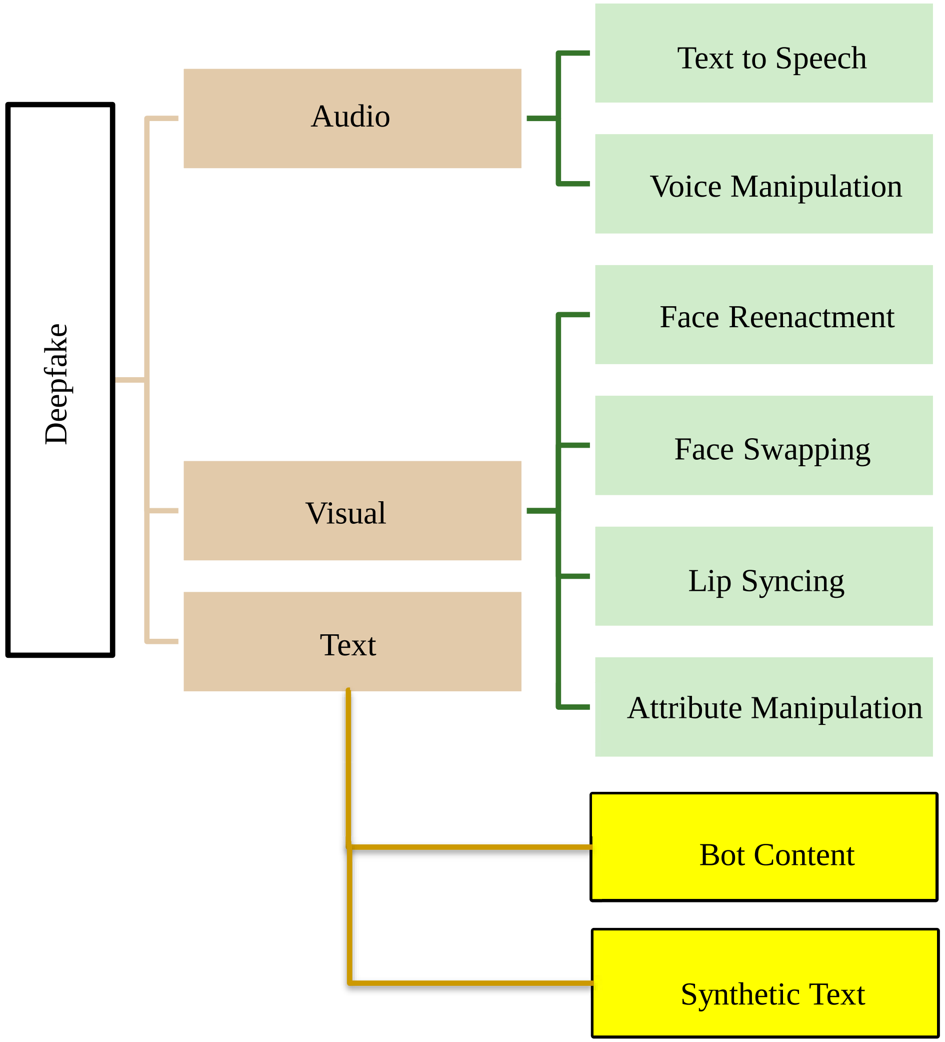


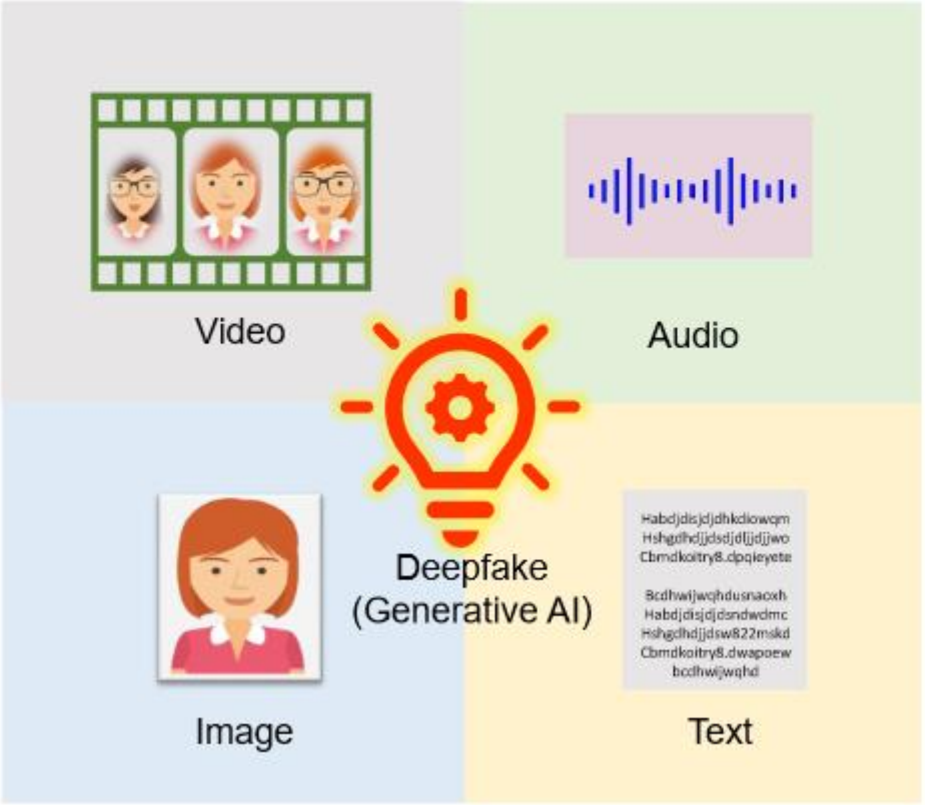
1. Deepfake refers to super realistic, but fake images, sounds, and videos generated by machine learning methods.
2. Deepfake leverages a Generative adversarial network (GAN) which enables the modification of human faces in a video or image.
3. Deepfakes can be classified as Audio, Visual and Text

AI can create fake data (Deepfake)

Source: A. Malik, M. Kuribayashi, S. M. Abdullahi and A. N. Khan, "DeepFake Detection for Human Face Images and Videos: A Survey," in *IEEE Access*, vol. 10, pp. 18757-18775, 2022, doi: 10.1109/ACCESS.2022.3151186.

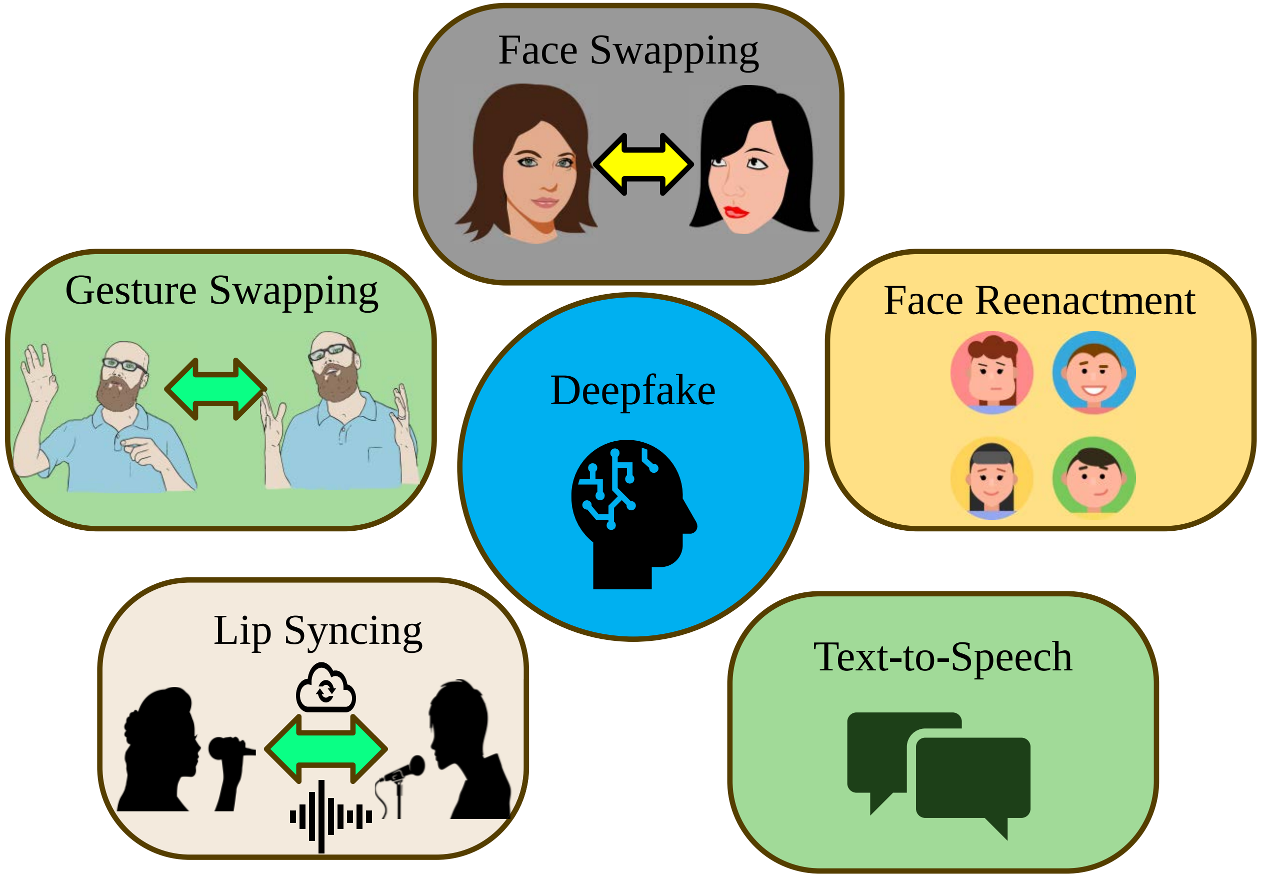
Deepfake Classification



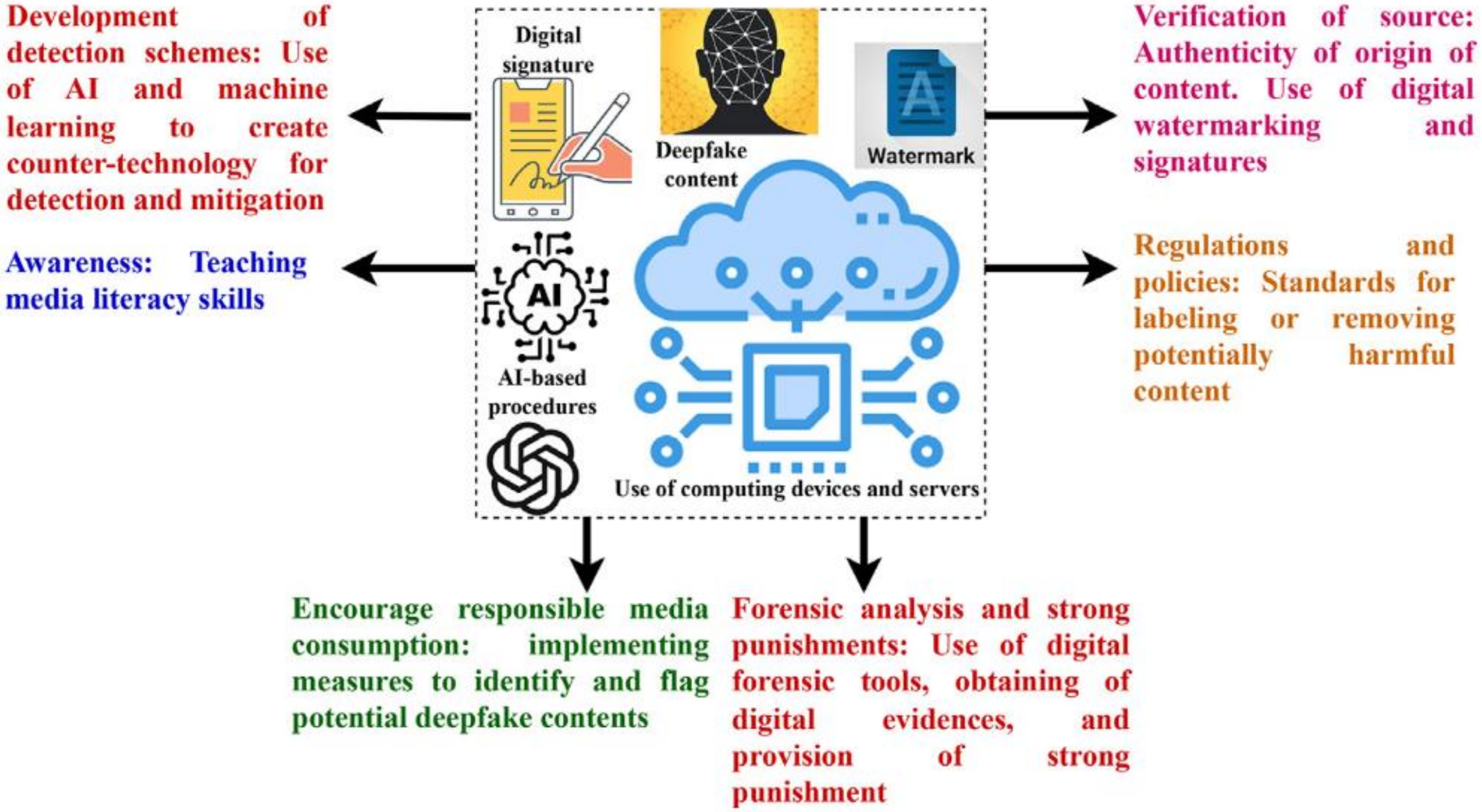


Source: A. Mitra, **S. P. Mohanty**, and E. Kougianos, "The World of Generative AI: Deepfakes and Large Language Models", *arXiv Computer Science*, arXiv:2402.04373, Feb 2024, 9-pages.

Deepfake Techniques



Deepfake Mitigation



Development of detection schemes: Use of AI and machine learning to create counter-technology for detection and mitigation

Awareness: Teaching media literacy skills

Verification of source: Authenticity of origin of content. Use of digital watermarking and signatures

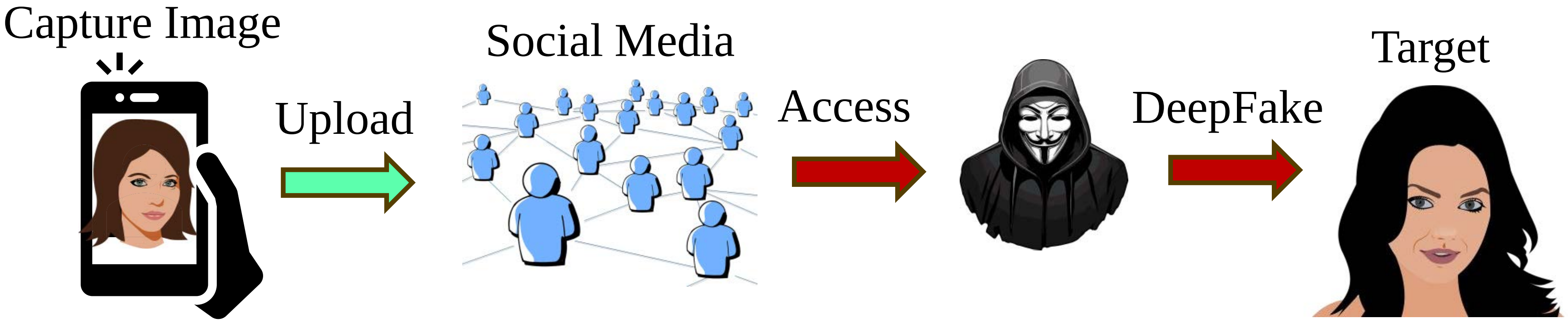
Regulations and policies: Standards for labeling or removing potentially harmful content

Encourage responsible media consumption: implementing measures to identify and flag potential deepfake contents

Forensic analysis and strong punishments: Use of digital forensic tools, obtaining of digital evidences, and provision of strong punishment

Source: Wazid, M., Mishra, A. K., Mohd, N., & Das, A. K. (2024). A Secure Deepfake Mitigation Framework: Architecture, Issues, Challenges, and Societal Impact. *Cyber Security and Applications*, 100040.

Threat Model



Addressing visual Deepfake of individual content captured as a video/image is important and necessary to counter facial attribute manipulation which includes modifying facial attributes like eyes, nose, lips and replacing them with target's attributes.

Related Research

Work	Approach	Technique	Methodology	Tools	Features
Kato et.al [5]	Mitigation	Visual	Scapegoat Image Generation	StyleGAN2	Privacy and Anonymity
Zheng et.al [23]	Mitigation	Visual	PUF-based device and data hash	CMOS Image sensor	Image content authenticity
Krause et. al [8]	Detection	Audio	Language and phoneme focused	Logistic regression	Detection using mouth movements
Pishori et.al [15]	Detection	Visual	Eye Blink rate	CNN+RNN, OpenCV	Efficient through eye blink rate detection
Wang et.al [17]	Mitigation	Visual	GAN based secret message embedding in an image	GAN	Personal photo protection
Zhao et.al [22]	Detection	Visual	Image watermarking	Neural network with encoder and decoder	Effective image quality preservation
Ashok et.al [16]	Detection	Visual	Training XceptionNet using faceforenscis++ dataset	XceptionNet Model	Identifying Deepfake from Original content
Doan et.al [2]	Detection	Audio	Identifying silence, breathing, talking in an Audio	RawNet2	Biological sound-based detection
PUFshield (Current Work)	Mitigation	Visual	PUF-based Facial Feature Attestation	PUF, Dlib Facial detection and landmark prediction	Image and device integrity

Novel contributions

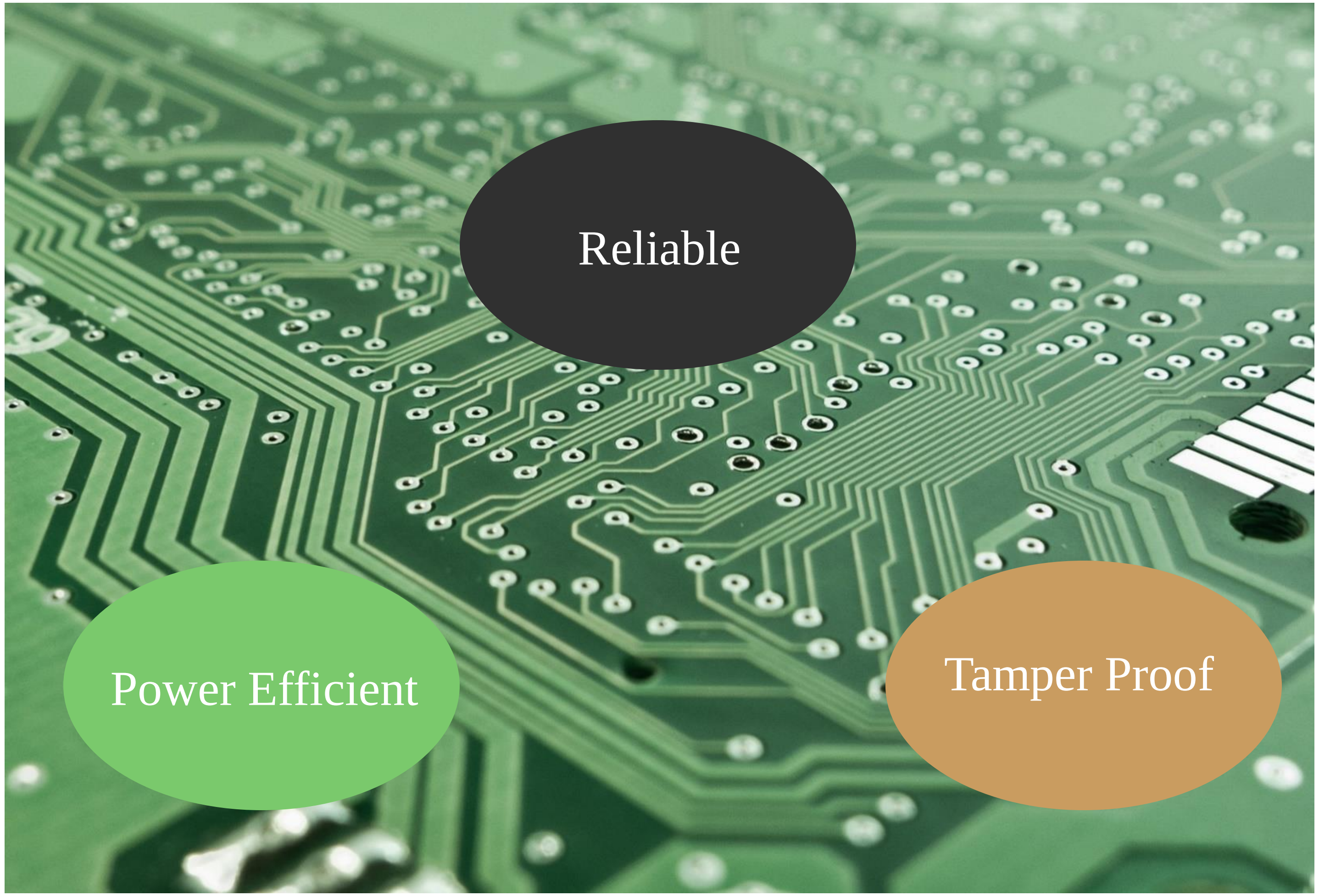
- A secure digital content integrity verification scheme through hardware enabled attestation.
- Presenting a state-of-art PUF-based approach for digital content attestation.
- A state-of-art solution for countering facial attribute manipulation to prevent visual Deepfakes.
- A device security framework providing PUF-based digital fingerprint for the camera capturing image/video.
- An approach to counter Deepfakes countering facial attribute manipulation.

Physical Unclonable Function (PUF)-Introduction

Why PUFs?

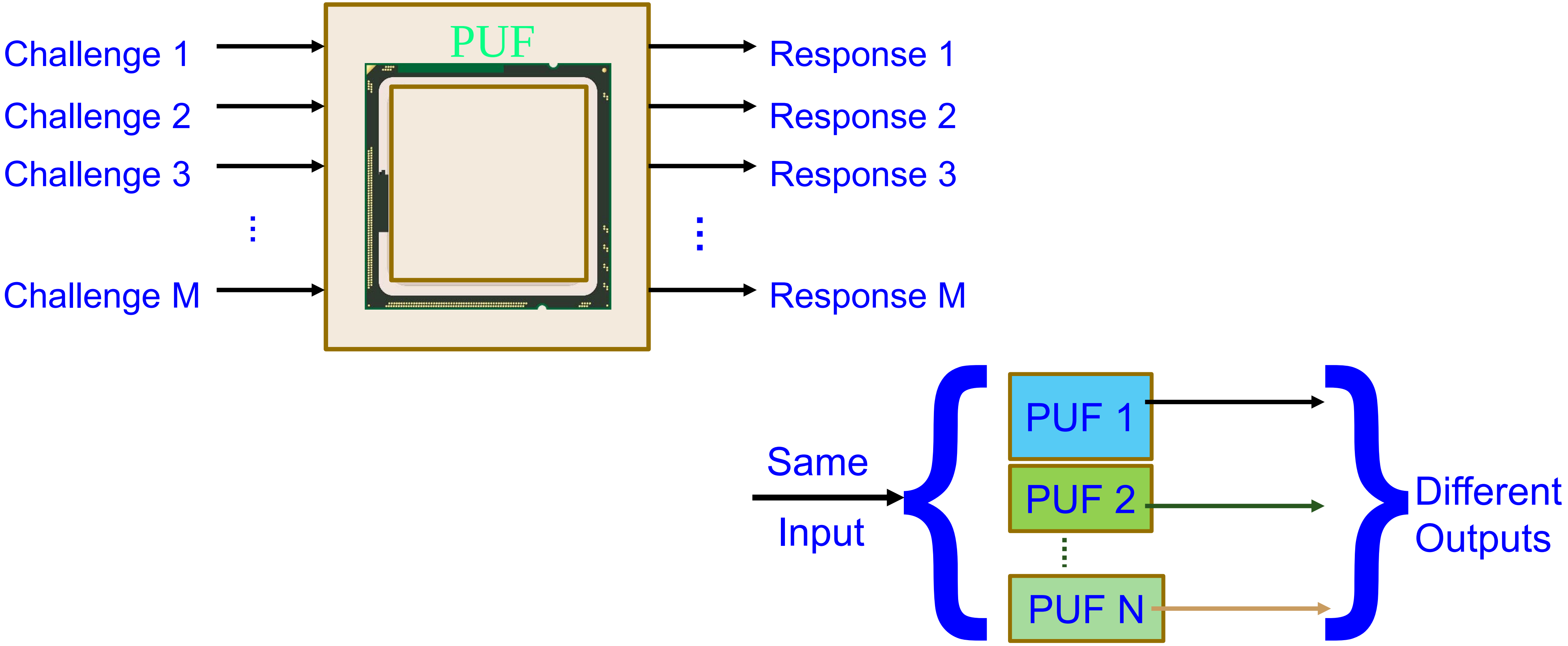
- Hardware-assisted security.
- Key not stored in memory.
- Not possible to generate the same key on another module.
- Robust and low power consuming.
- Can use different architectures with different designs

PUF: A Hardware-Assisted Security Primitive



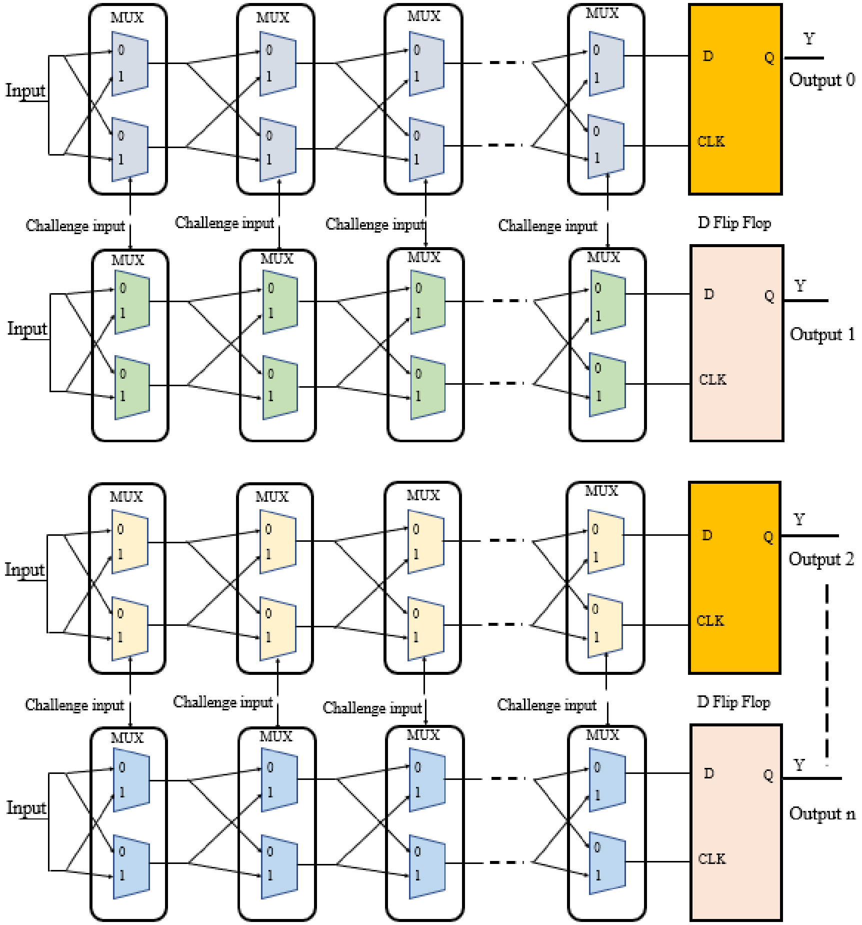
- A secure fingerprint generation scheme based on process variations in an Integrated Circuit
- PUFs don’t store keys in digital memory, rather derive a key based on the physical characteristics of the hardware; thus secure.
- A simple design that generates cryptographically secure keys for the device authentication

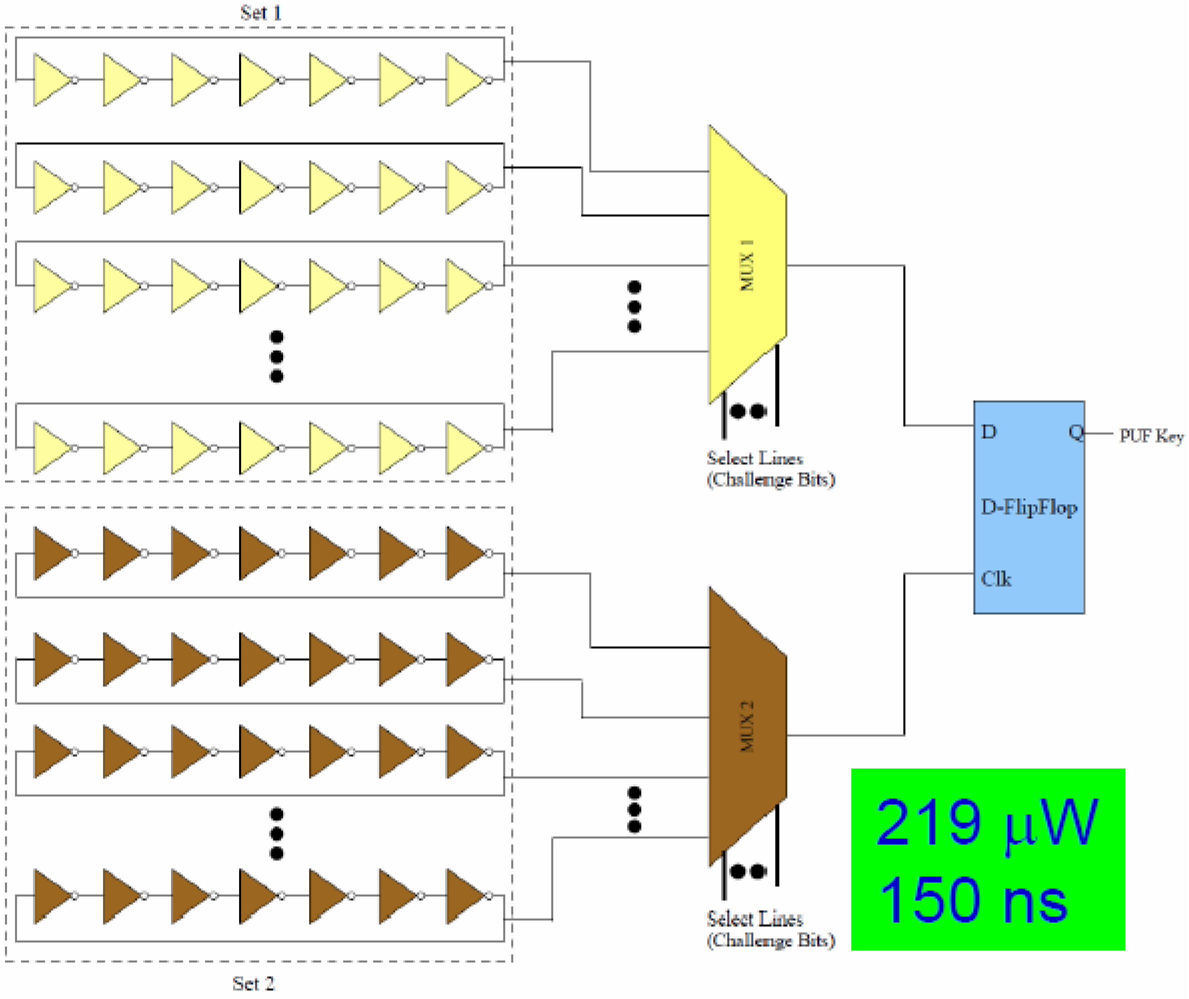
PUF Key Generation and Working



Source: International Symposium on Smart Electronics Systems (iSES) 2019 Demo (PUFchain: Hardware-Integrated Scalable Blockchain)

PUF Designs

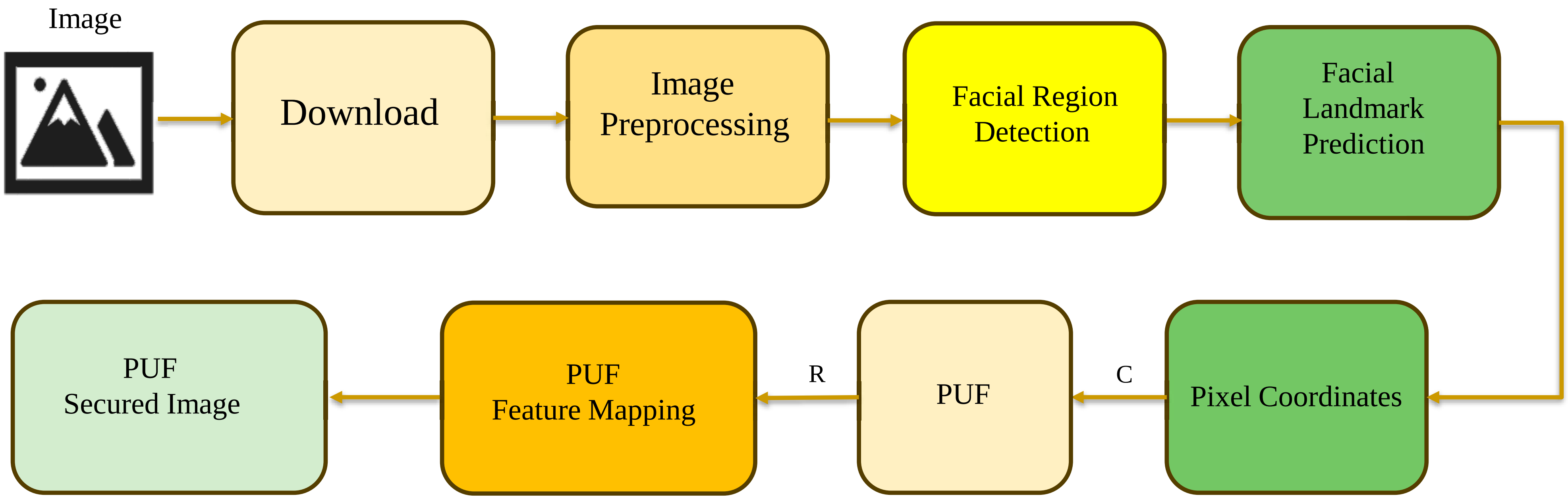




219 µW
150 ns

Source: iSES 2019 Demo (PMsec: PUF-Based Energy-Efficient Authentication of Devices in the Internet of Medical Things (IoMT))

PUFshield: Proposed Deepfake Mitigation Technique



Facial Landmarks Coordinates in Dlib

Facial Landmarks	Pixel Coordinates
Left Eye	36-41
Right Eye	42-47
Left Eyebrow	17-21
Right Eyebrow	22-26
Jaw	0-16
Nose Bridge	27-30
Lower Nose	31-35
Outer Lip	48-59
Inner Lip	60-67

Working Flow of PUFshield:

Step 1 : Capture Image
Step 2 : Perform Image Preprocessing
  Image → 600 X500
  Image → Gray Scale
Step 3 : Perform Facial Region (RoI) Detection
  Histogram of Gradients → RoI
Step 4 : Access PUF at the Camera
Step 5 : Obtain Facial Landmarks Pixel Coordinates
Step 6 : Facial Landmarks→ PUF→R1
  Extract for a set of 8 coordinates at a time
  Extract for all 68 facial landmarks R1-----R17
  Perform XOR Operation of all facial coordinates
Step 7 : Final image fingerprint is final XORed output

Experimental Validation of PUFshield

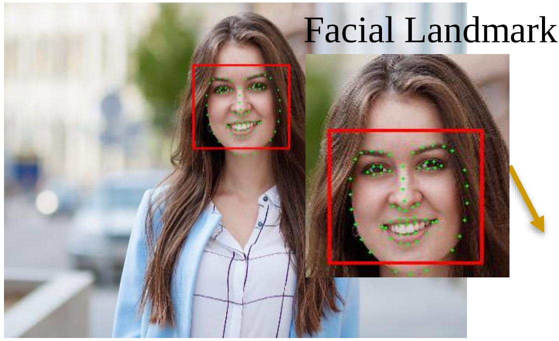
Images

Facial Landmarks

Facial Landmark Coordinates

PUF Attestation

Final PUF Keys



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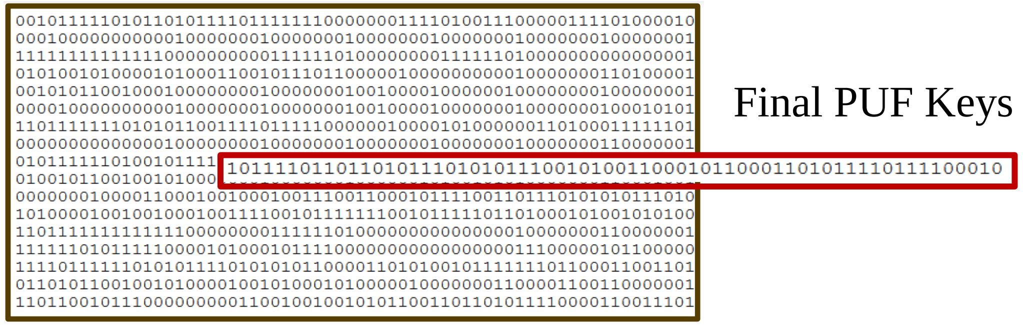

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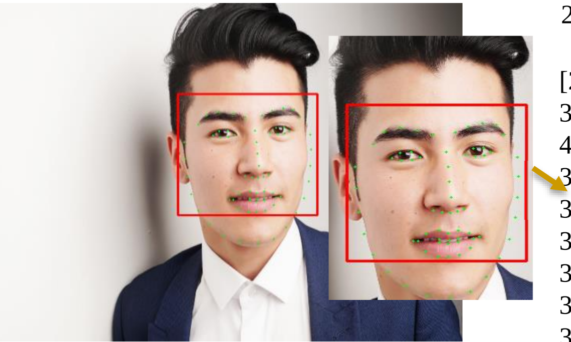

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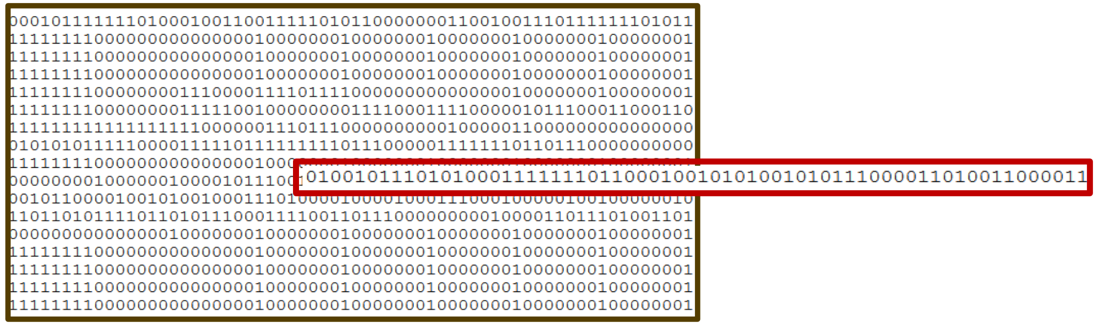

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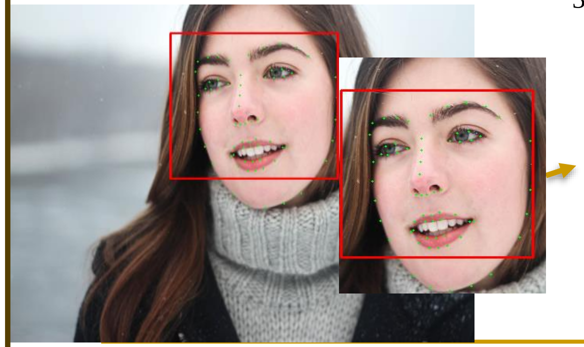

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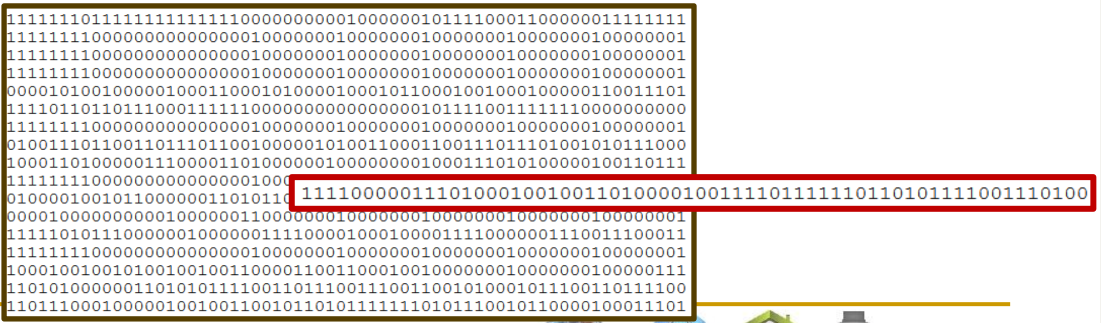

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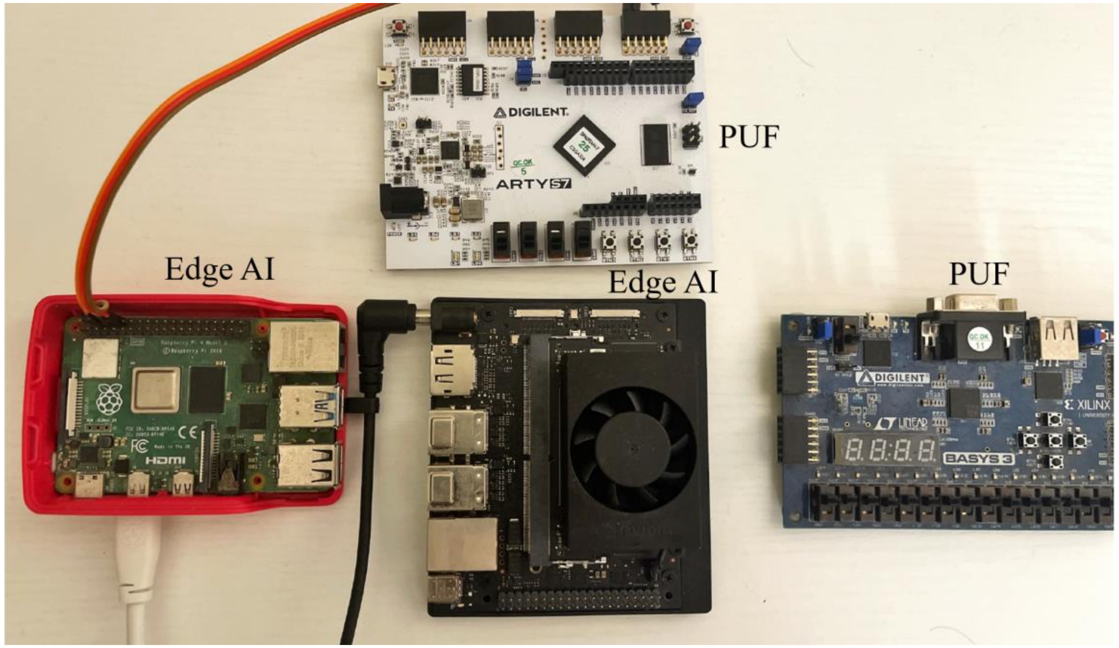
Performance Analysis

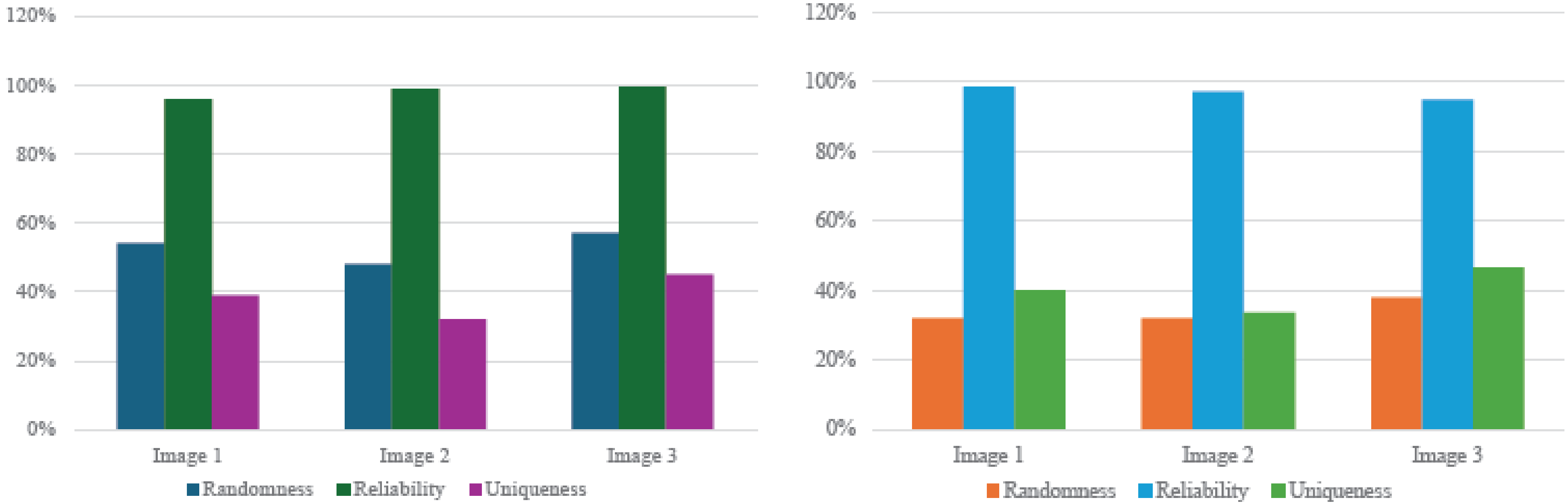
Prototype



Computational Time Analysis

Content	Parameter	Results
Image 1	Facial detection Facial Landmark Prediction	60 ms 3 ms
Image 2	Facial detection Facial Landmark Prediction	57 ms 2 ms
Image 3	Facial detection Facial Landmark Prediction	56 ms 3 ms
All images	Attestation Time	300 ms

Image Attestation Metrics



(a) Artix-7 FPGA

(b) Spartan-7 FPGA

Conclusion and Future Research

- This research work presented and validated a state-of-art Deepfake mitigation technique that utilizes the potential of PUF for secure facial feature mapping and attestation.
- The proposed work experimentally validated the PUF-based facial feature attestation process for an image. This work can effectively counter Deepfake particularly facial attribute manipulation technique.
- The metrics evaluation results and computational time and power analysis on various hardware clearly demonstrates the potential of the proposed PUFshield.
- As a direction for future research, countering other techniques of visual Deepfakes such as face swapping, lip syncing in video and audio Deepfakes using PUF can be potential areas for PUF-based Deepfake mitigation.

Thank You!