Bioprinting Security Framework for detecting Sabotage attacks using in-situ Process Monitoring

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Introduction

In this interdisciplinary project, we bring together bioprinting and cybersecurity expertise to investigate cyberattacks on extrusion-based bioprinters and their impacts on printed tissue.

Motivation:

- Security critical applications of bioprinting.
- No availability of security framework.
- No study of adversarial effects on print constructs.

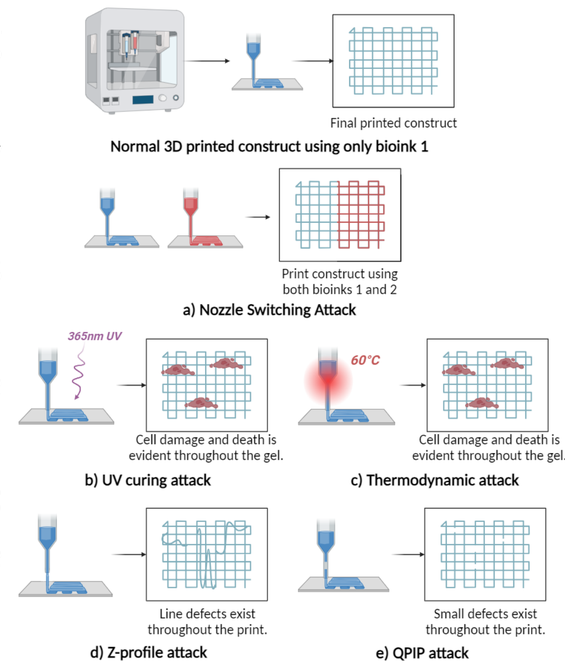
Contributions:

- Study of attacks and their adverse effects on cell viability and printability.
- A modular and scalable framework customizable to changing printing needs.
- Evaluation of Framework against the studied attacks.

Sabotage Attacks

Changing different printing parameters and measuring corresponding effects on cell viability and printability

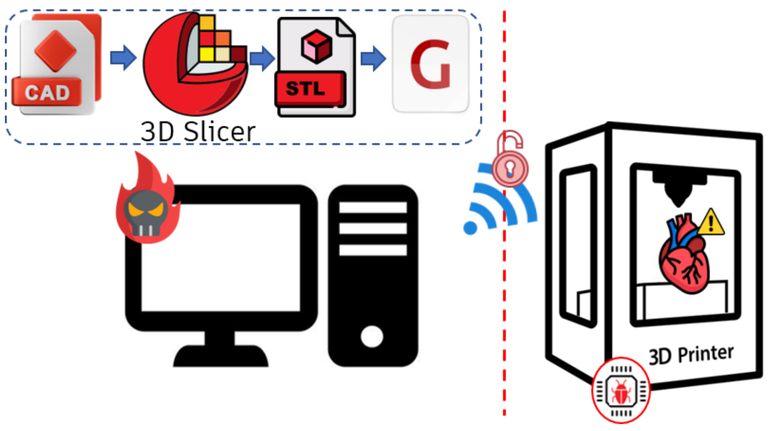
- **Nozzle Switching:** Switching between different cell type.
- **UV Curing:** Switching intensity or duration to change dosage.
- **Thermodynamic:** Effects gelling and cell-viability.
- **Z-profile:** Standoff distance impacts printability.
- **Quick pause in print (QPIP):** Adds voids/bubbles degrade structural integrity



Attack Vector

Adversaries can target following components to sabotage the process

- Firmware
- Slicer software
- Gcode file
- Slicer memory
- Communication protocols
- Control PC

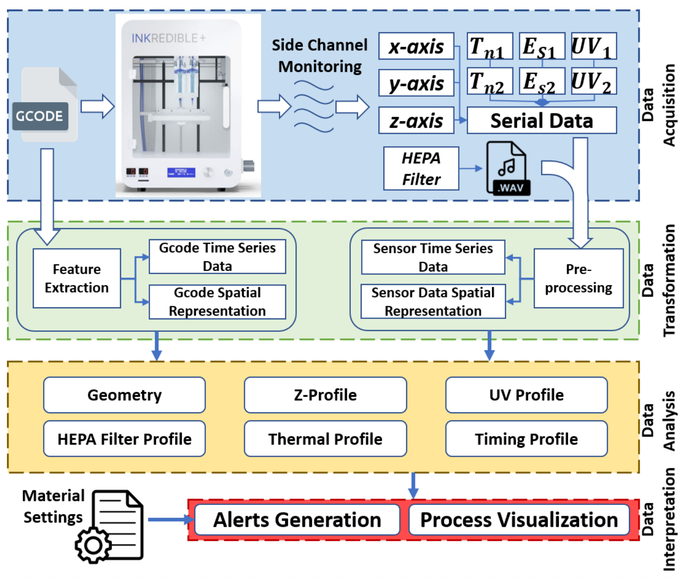


Security Framework

Scalable, Modular design adaptable to bioprinting material properties

4 Modules

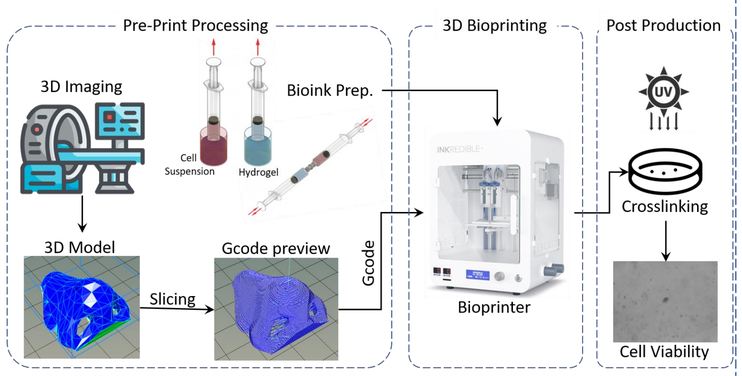
- Data Acquisition
- Data Transformation
- Data Analysis
- Data Interpretation



Bioprinting Process Chain

Bioprinting stages

- Imaging: MRI, CT scan
- Modelling: CAD
- Slicing: STL to Gcode
- Bioink preparation
- Printing
- Post-processing: Curing, Cross-linking, Cell incubation
- Quality Control: Imaging, Biochemical assays



Evaluation and Results

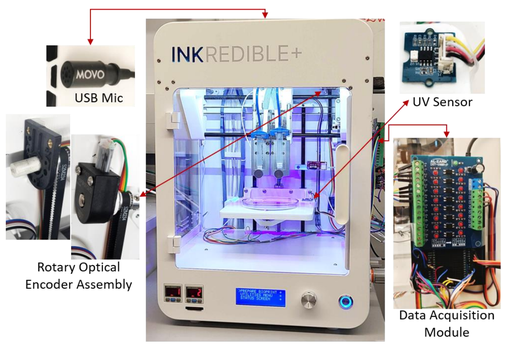
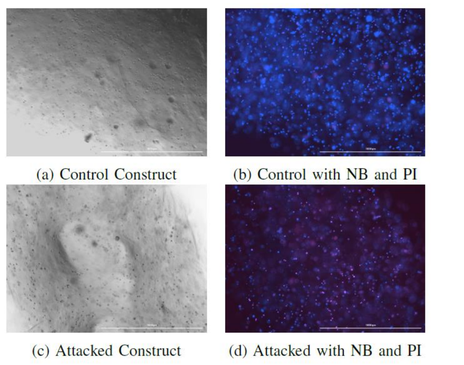


Figure: Experimental Setup

Sr. No.	Attacks	Verifying Profile	Attack Magnitude	Detection Performance	Detection type
1	Nozzle Switching	Geometry	$1mm$	Next layer	Visual
2	UV	UV Profile	UV type, $\Delta t > 1sec$ $\Delta z > 1mm$	Current layer	Alert
3	Nozzle Temp.	Thermal Profile	$3°C$	$\Delta T > 2°C$	Alert
4	Layer Thickness	Z-Profile	$0.1mm$	Next layer	Alert
5	QPIP (Outer)	Geometry	$1mm$	Next layer	Visual
6	QPIP (Infill)	Geometry	$1mm$	Next layer	Visual
7	HEPA filter	Fan Speed	$\pm 2\%$	$5sec$	Alert
8	Print Speed	Timing	$\Delta S = 100mm/sec$	$\Delta t > 2sec$	Alert

TABLE 5: BioSaFe attack detection performance



(a) Control Construct (b) Control with NB and PI (c) Attacked Construct (d) Attacked with NB and PI

Figure 8: Cell viability after 24 hrs for normal and attacked construct

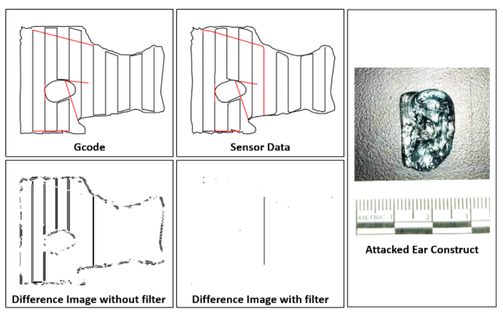
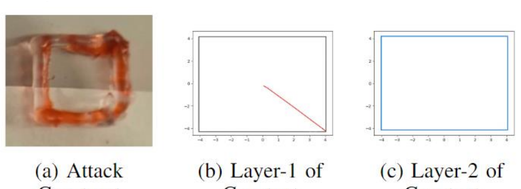


Figure 12: Infill attack on human ear construct Layer 1



(a) Attack Construct (b) Layer-1 of Constuct (c) Layer-2 of Constuct

Figure 11: Nozzle Switching attack spatiotemporal view

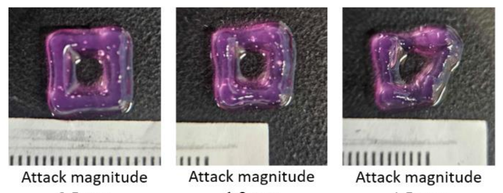


Figure 9: Z-profile attack on square construct

Quality Matrices

Printability Ratio

- Defines bioink printability.
- Pr = L^2/16A
- Pr = 1 indicates a perfect square shape formed by the gel.

Cell Viability

- Percentage of cells that remain alive after printing.
- Considered optimal at a threshold above 90% average.