DIGITAL TWIN FOR BIOPRINTING PROCESS MONITORING AND CONTROL

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1. Research Background

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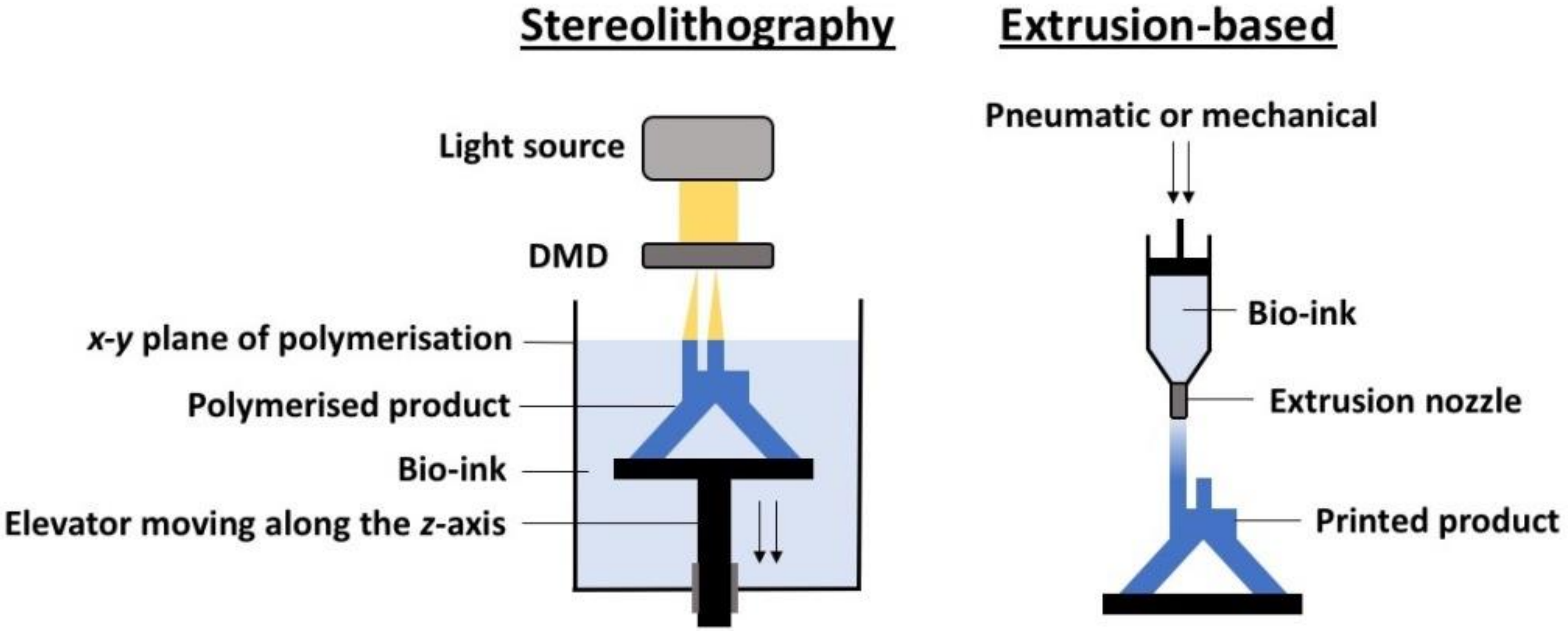
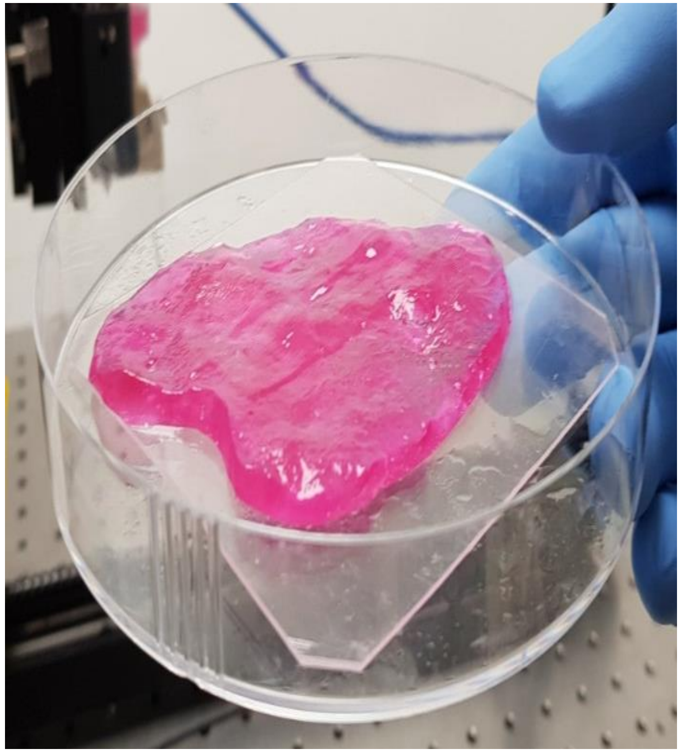
- Bioprinting is the printing of biological constructs.
- Two commonly used bioprinting technologies are stereolithography and extrusion-based printing.



1. Research Background

➢ Transform the healthcare landscape ranging from regenerative medicine to drug discover.

Regenerative medicine

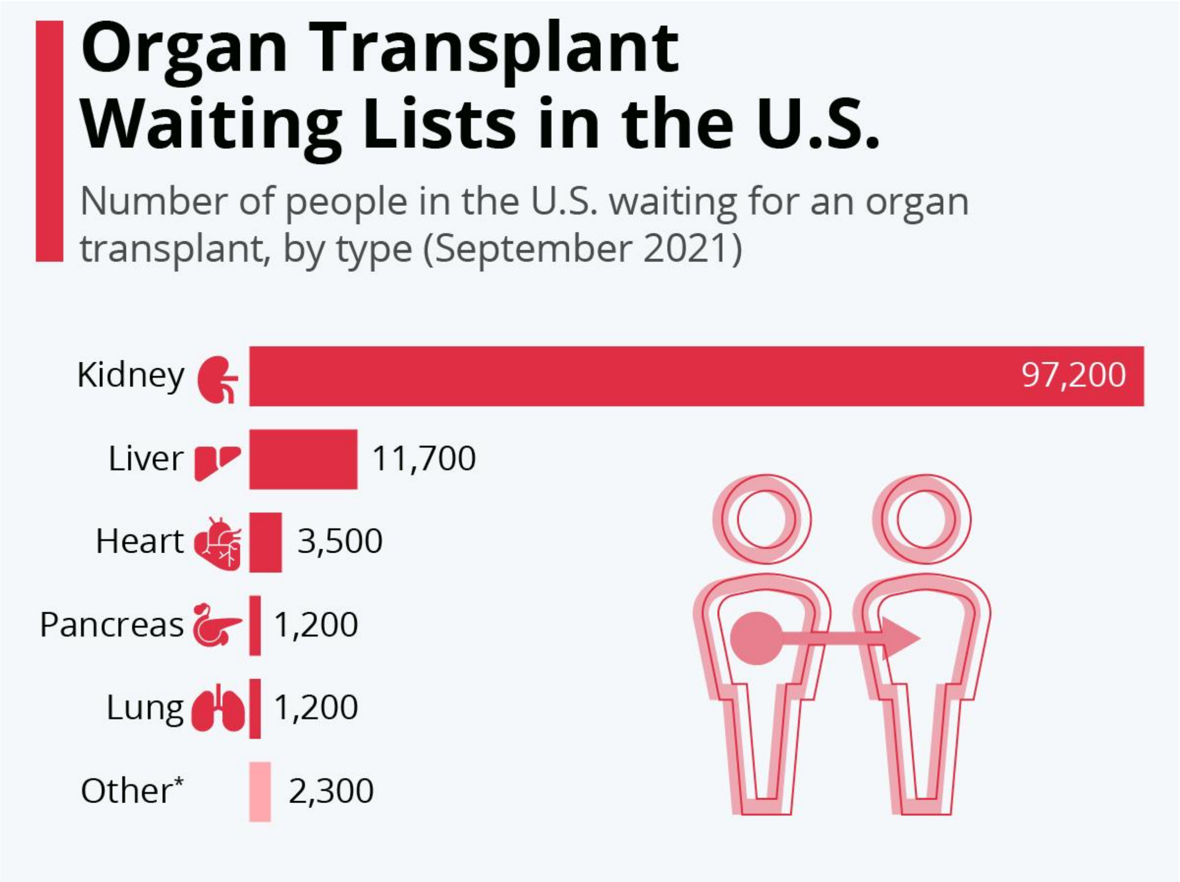


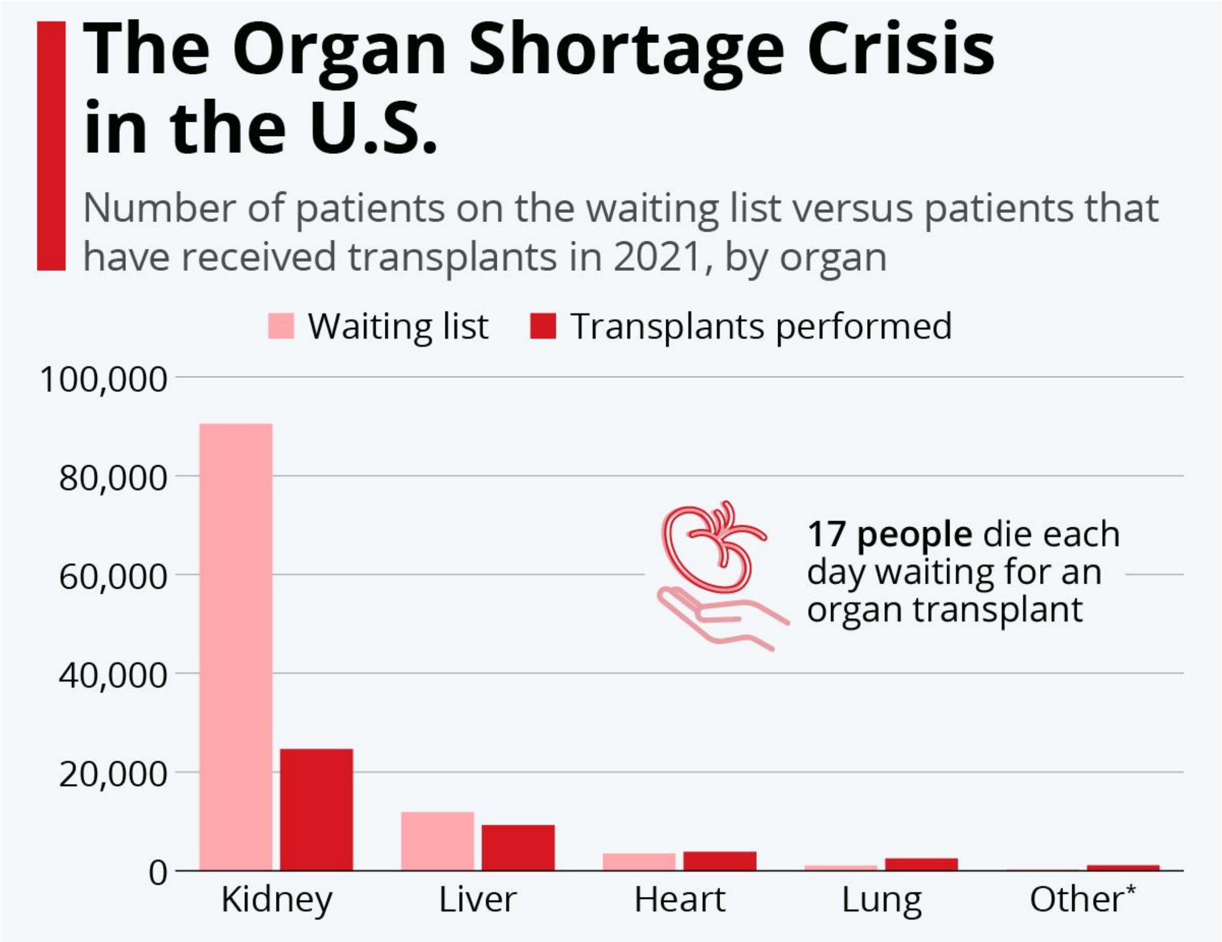
Animal-free meat

Drug discovery and development

1. Research Background

➢ Almost 120,000 people are on the national transplant waiting list in the U.S. alone.





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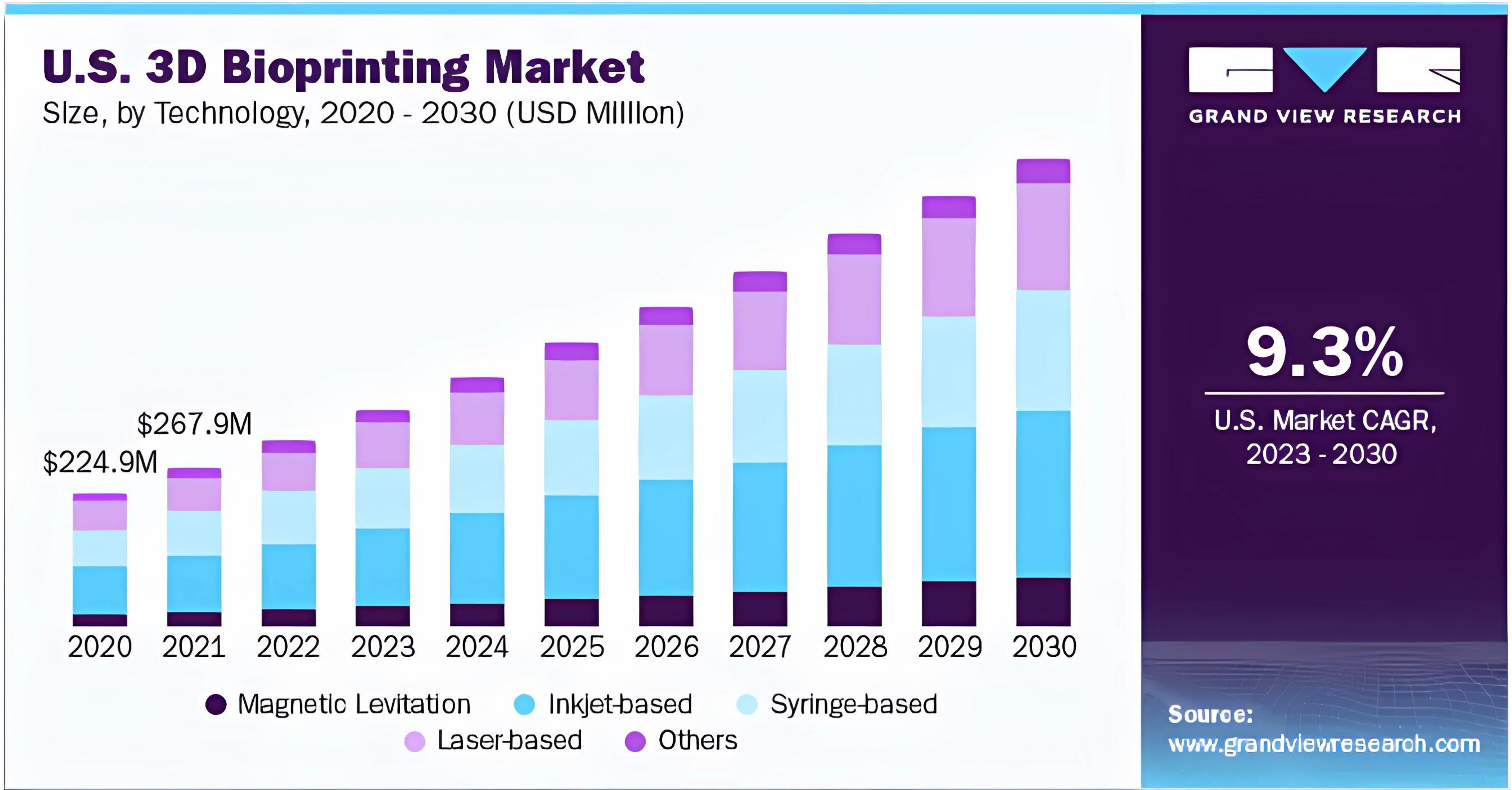
- U.S. market size



2. Research Status

- Digital twin technology has been increasingly applied in healthcare and patient well-being in recent years.
  - Create personalized medicine and treatment plans for the individual based on unique genomic makeup, lifestyle habits, and behavior.
  - Integrate with wearable sensors to diagnose functions of human body based on blood pressure, oxygen levels, etc..

3. Challenges

➢ Requirements of material selection

Mechanical properties

Blood compatibility

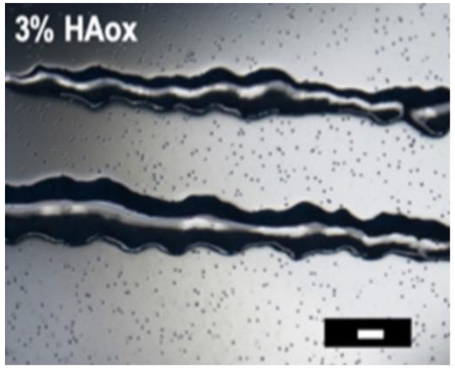
Endothelium friendliness

Biodegrad-ability

	Natural biomaterial	Synthetic biomaterial
Examples	Agarose, alginate, collagen, fibrin, gelatin and hyaluronic acid	Pluronic® [13] and Poly(ethylene glycol) (PEG)
Pros	Compatible with the natural cell environment	1) Widely available; 2) Better mechanical properties
Cons	Poor mechanical property	Poor biocompatibility

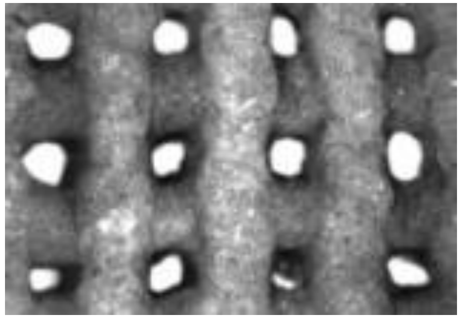
3. Challenges

- Visible anomalies in bioprinting process
  - Non-homogeneous strands, strand fusion, strand collapse, etc.



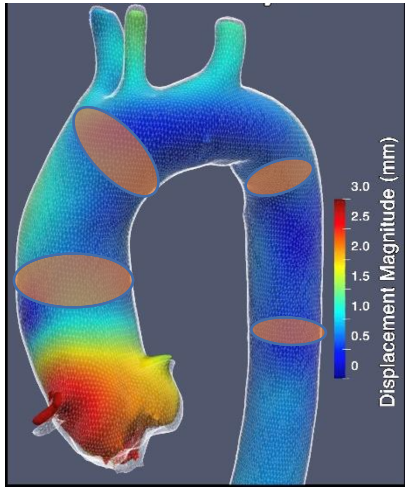
Non-homogeneous strand

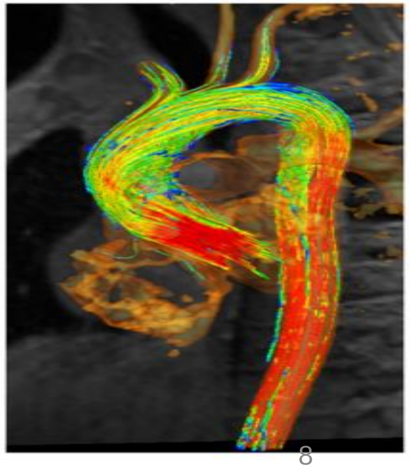
Strand fusion



Non-homogeneous holes

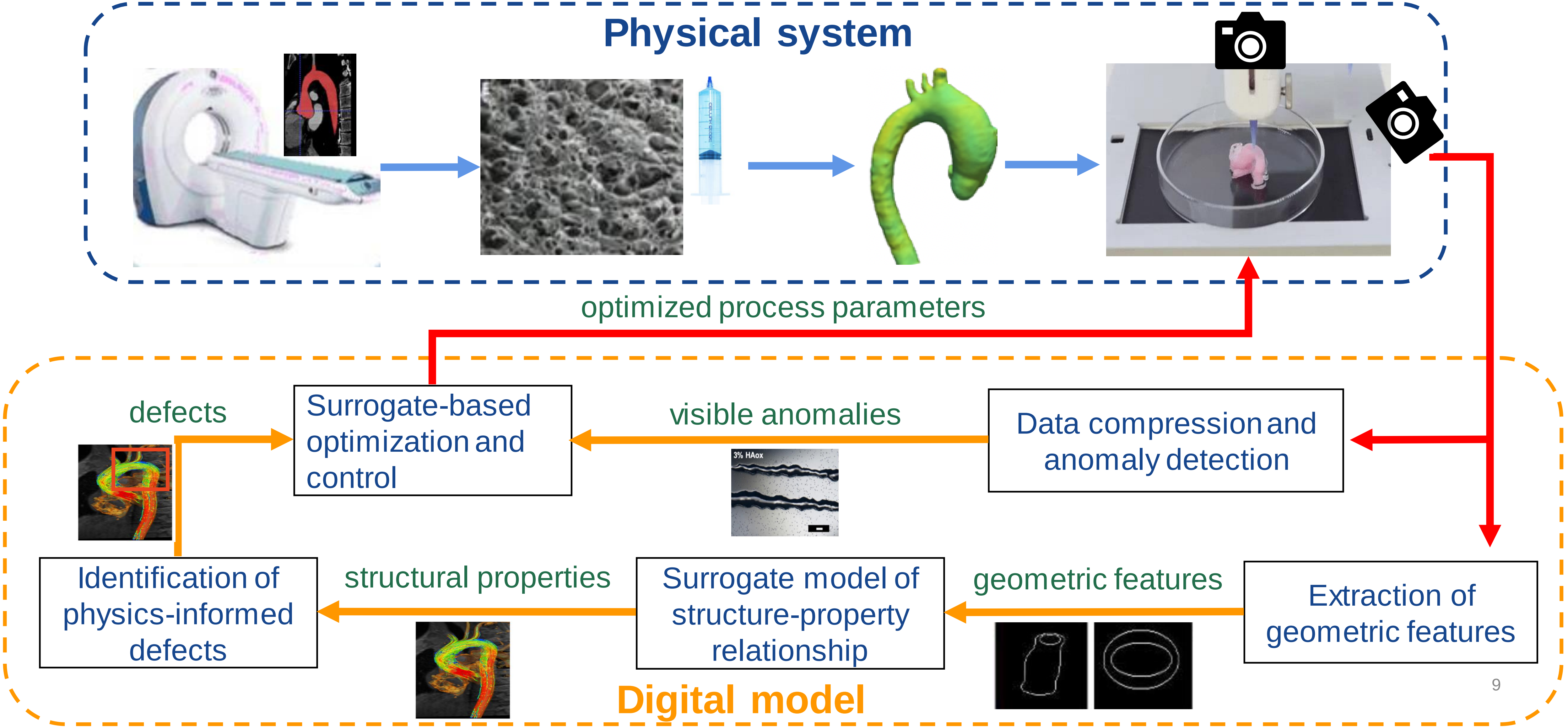
- Physics-informed anomalies in bioprinting process
  - Need a virtual model to establish the correlation between material, structure, mechanical property, and physical quantity (displacement, pressure, blood flow, etc.)





4. Digital Twin of Bioprinting

4.1 Framework of DT in bioprinting



4. Physics-Informed Machine Learning

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4.1 Physics-constrained dictionary learning

- ➢ Improve sensing efficiency and detect anomalies simultaneously

$$\min_{\Phi,\Psi,C}\left(\alpha\|S-\Psi\gamma\|_F^2+\|\Phi S-\Phi\Psi\gamma\|_F^2+\beta\|L-C\gamma\|_F^2\right)$$

$s.t.\ \ \Phi = f(\Psi)$ ←--------→ Optimize Φ based on Ψ

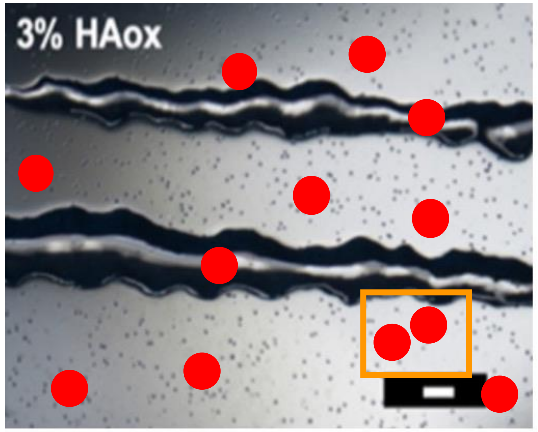
$\|\gamma_i\|_0 \le s_l,\ \forall i$ ←--------→ Restrict sparsity level

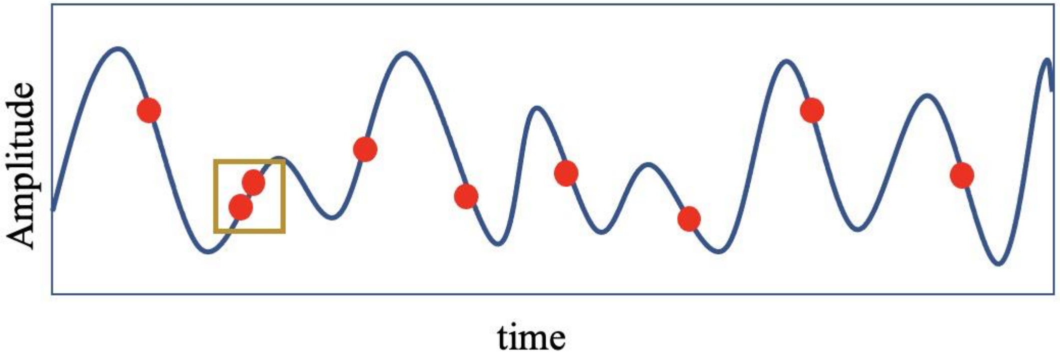
$I_{ij}(\Phi)\ge r,\ \forall i, j$ ←--------→ Reduce redundant infromation

Φ: optimize pixel locations

Ψ: maximize signal sparsity

C: classifier to identify anomaly



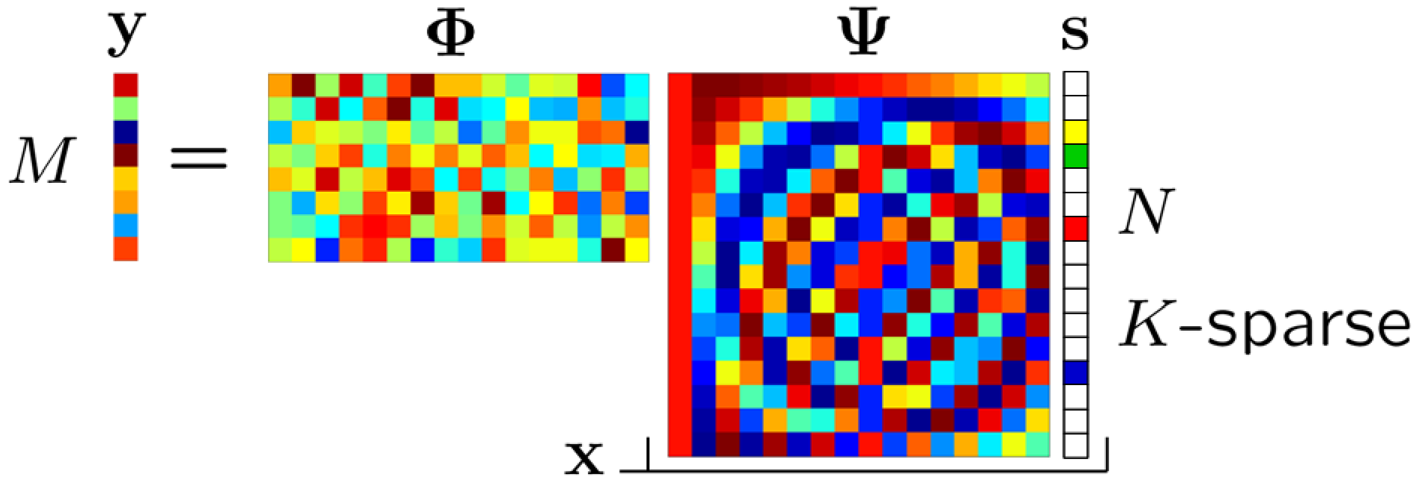


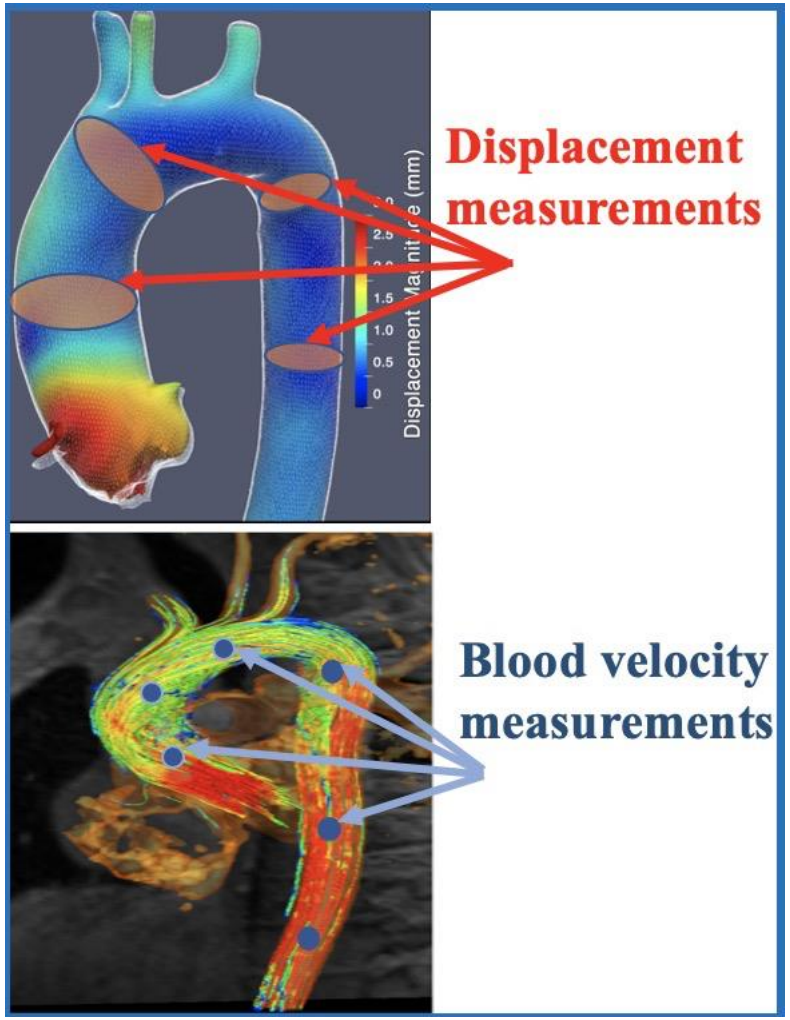
Lu, Y., & Wang, Y. (2021). A physics-constrained dictionary learning approach for compression of vibration signals. *Mechanical Systems and Signal Processing*, *153*, 107434.

4. Physics-Informed Machine Learning

4.2 Physics-based compressive sensing (PBCS)

- ➢ Integrate physical modeling and compressed sensing





Φ: measurement matrix

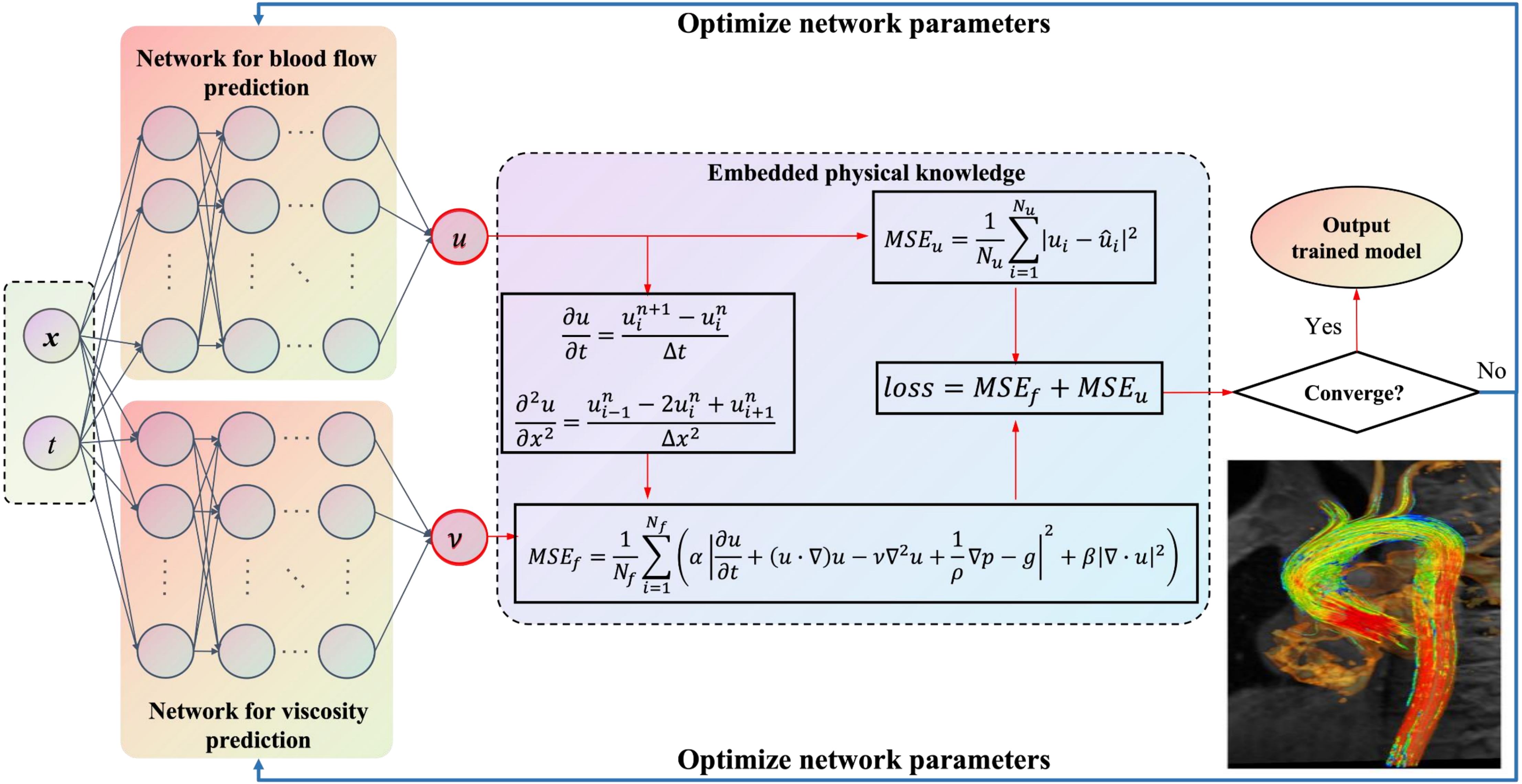
ψ: basis matrix (transformation matrix in CS or stiffness matrix in PBCS)

S: coefficient vector in CS or load vector in PBCS

Lu, Y., & Wang, Y. (2021). Physics based compressive sensing to monitor temperature and melt flow in laser powder bed fusion. *Additive Manufacturing*, *47*, 102304.

4. Physics-Informed Machine Learning

4.3 Physics-informed neural networks



5. Vision

- Creation of complex and functional tissues and organs that closely mimic the structure and function of natural tissues
  - Optimize printing process
  - Predict the behavior of the printed tissue in vivo
  - Personalize the printing process for individual patients

- Enable early detection of potential problems after transplantation

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Thanks for your attention!

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