Inkjet-Printed Droplet Classification & Printing Parameter Optimization Using AI

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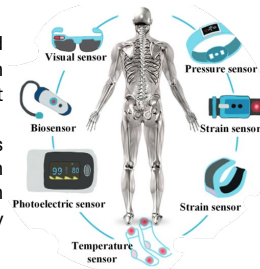
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FLEXSEML Flexible Sensors, Electronics, and Machine Learning

Flexible Electronics

- ❑ Flexible electronics are embed circuits and sensors which can bend or wrap around an object such as skin or clothing
- ❑ The flexible/printed electronics market is worth 30–40 billion now and is projected to reach roughly **70–80 billion** dollars by the early 2030s
- ❑ Common flexible electronics manufacturing processes include:
  - ➢ Laser patterning
  - ➢ Inkjet printing
  - ➢ Carbon-based printed inks
  - ➢ Screen printing
  - ➢ Aerosol-jet printing
  - ➢ Gravure printing

Visual sensor, Pressure sensor, Biosensor, Strain sensor, Photoelectric sensor, Strain sensor, Temperature sensor
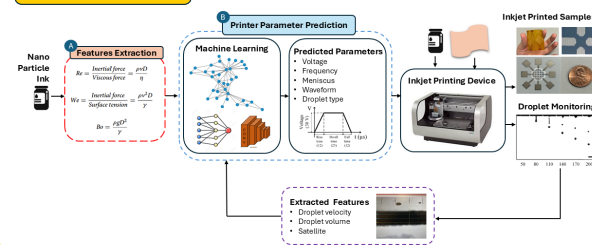
Inkjet Printing

- ❑ In **Inkjet printing (IJP)** process functional materials deposit as droplet to create different pattern for electronics devices, sensors and e-textiles:
  - ➢ Line resolution and feature quality
  - ➢ Device performance and reliability
  - ➢ Print yield and efficiency
- ❑ **Inkjet printing (IJP)** is a key technology benefitting these flexible devices because it:
  - ➢ Allows rapid prototyping of any electronics devices
  - ➢ Works with diverse inks (metals, polymers, biologics)
  - ➢ Enables printing on many solid and flexible surfaces, including plastics, glass, photo paper, and textiles

- ❑ **Challenge**: Operators must manually adjust printing parameter such as voltage, jetting frequency, and meniscus pressure for every new ink— slow, wasteful, and not scalable
- ❑ **Goal**: This work develops machine learning methods to classify droplet behavior and automate parameter optimization across diverse inks and substrates
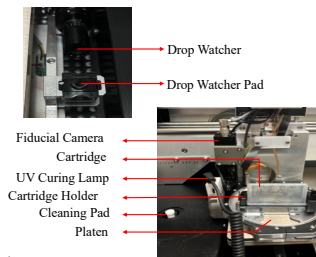
Methodology

Drop Watcher Setup and Data Collection

- ❑ Inkjet Printer Setup:
  - ➢ Fujifilm Dimatix DMP-2850 Materials Printer
  - ➢ Drop Watcher imaging system with UV lamp and fiducial camera
  - ➢ Enables real-time droplet observation and classification

Drop Watcher, Drop Watcher Pad

Fiducial Camera, Cartridge, UV Curing Lamp, Cartridge Holder, Cleaning Pad, Platen

- ❑ Systematic Parameter Variation:
  - ➢ Voltage: 18–40V (controls droplet ejection pressure)
  - ➢ Jetting Frequency: 5–30 Hz (controls droplet spacing)
  - ➢ Meniscus Pressure: 0.5-10 in H_2O (affects ink refill)
  - ➢ Temperature: 30℃, 40℃, 50℃ (impacts ink viscosity)
- ❑ Dataset Characteristics:
  - ➢ Total samples: 4000+ droplet experiments
  - ➢ Training: 2000+ samples
  - ➢ Multiple ink types tested for generalization


No Drop, Satellite, Drop, Regular Ink Flow
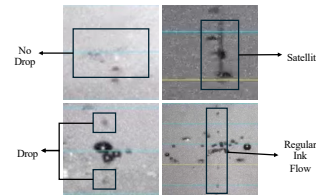
- ❑ Voltage–temperature–meniscus sweeps were converted into categorical outcome maps revealing the "safe jetting window" for each conditions

Outcome Maps & Operating Windows

- ❑ Results:
  - ➢ Processed 50+ high-speed droplet videos to extract geometric features (aspect ratio, solidity, circularity, "top thinness") and a combined "score" for each condition
  - ➢ Outside this window, the score drops sharply and features indicate satellites (high aspect ratio, low solidity) or weak/no jetting
  - ➢ The top 10 highest-score conditions in a small region of operating space, giving a clear target zone for reliable printing with the Ethaline Water ink
- ❑ Ethaline Water 75-25 Meniscus 0.5
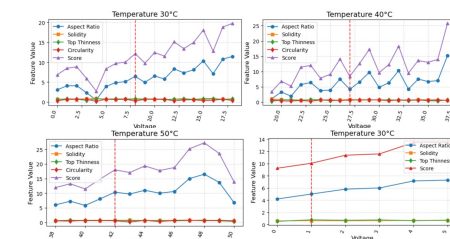
Conclusion

- ❑ Impact
  - ➢ Replace traditional trial-amd-error tuning with AI for optimal printer setup
  - ➢ Speed up inkjet-printing fabrication while providing a general framework to test new ink materials for devices
- ❑ Conclusion
  - ➢ Develop a future closed-loop control system for inkjet printing fabrication process
  - ➢ Outcome maps highlight safe operating windows and defect-prone regions, supporting future closed-loop control of inkjet printing
- ❑ Future work
  - ➢ Develop a real-time, video-based system to monitor and label droplet behavior during printing and to train AI models to predict optimal printing parameter and droplet outcomes