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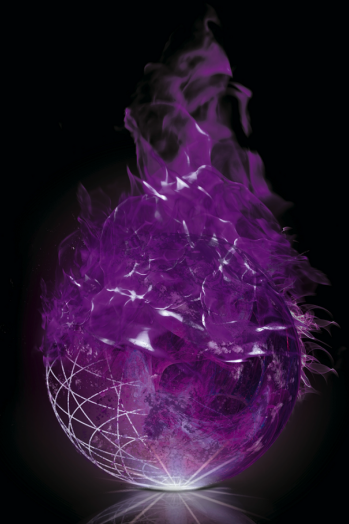
A Digital Twin for Controlling Thermo-Fluidic Processes

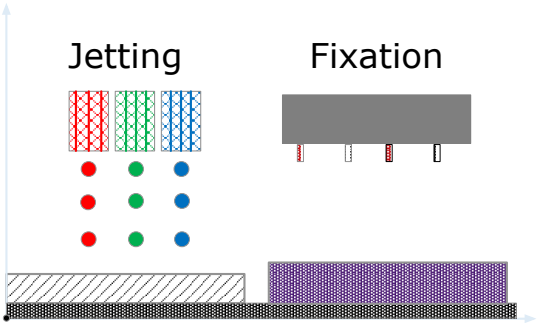
Amritam Das



Inkjet Printer

Inkjet Printer

Interaction of solids and fluids



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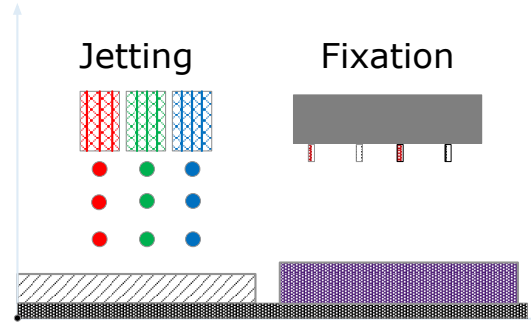


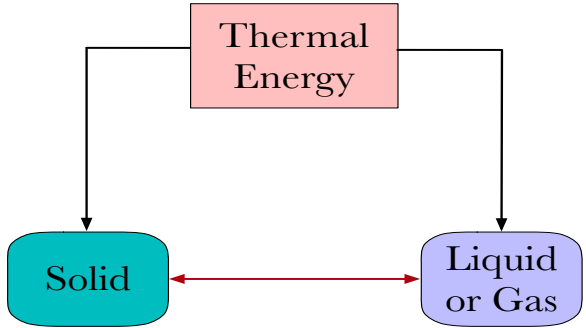
For good print-quality

1. Liquid temperature
2. Moisture and temperature of paper

What we want?

Achieve good print-quality without adding new sensors or actuators

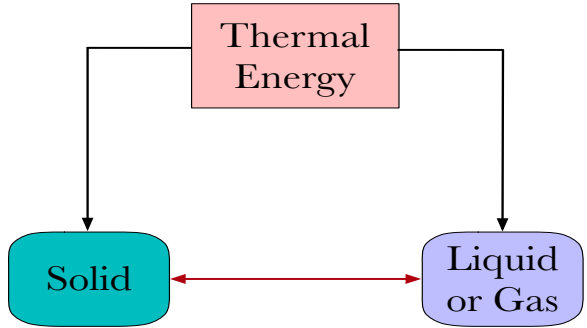
Interaction of Solids and Fluids: Thermo-Fluidic Processes



Features

1. Interacting components
2. Quantities vary over space and time

Interaction of Solids and Fluids: Thermo-Fluidic Processes



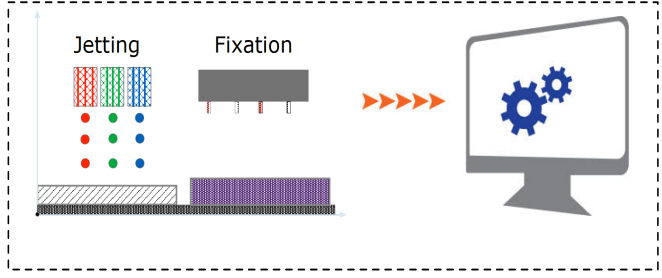
Features

1. Interacting components
2. Quantities vary over space and time

Question: How to control thermo-fluidic processes to achieve best print-quality?

My Approach: Building a Digital Twin for Inkjet Printer

Virtual representation of the asset on a computer



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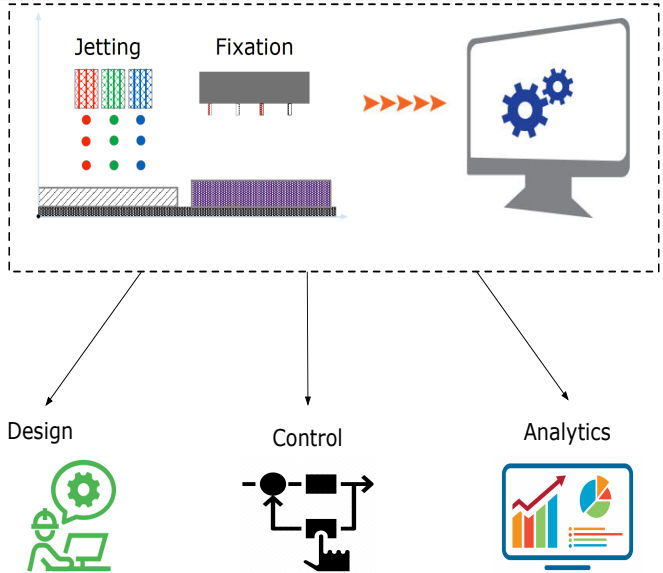

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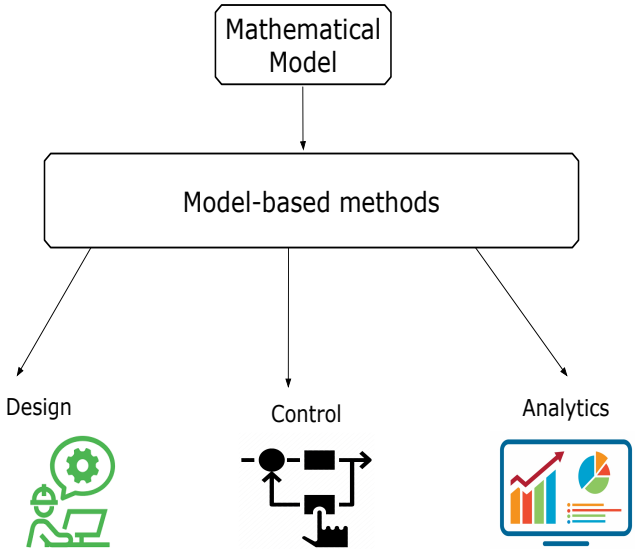
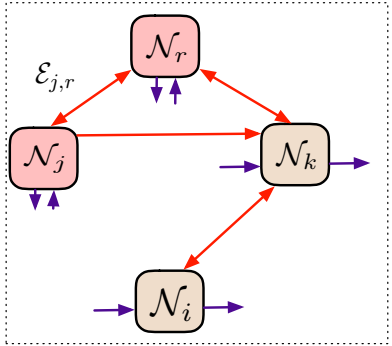


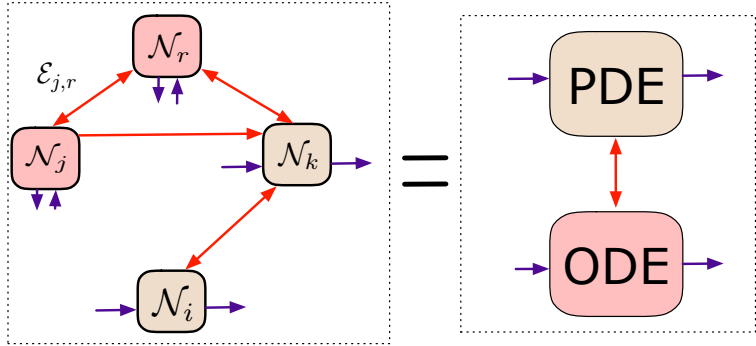
Modeling Thermo-Fluidic Processes



Contribution

- A systematic way to modularize and upscale the model
- A set of alternative representations are available at user's disposal

Modeling Thermo-Fluidic Processes



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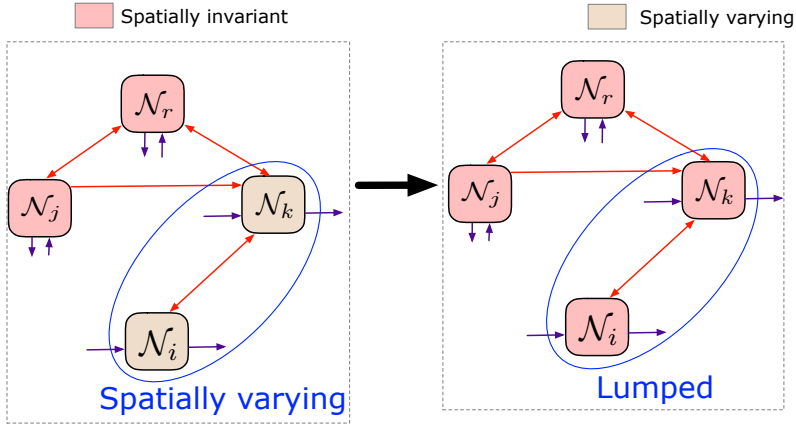
- A set of alternative representations are available at user's disposal

Method 1: Using Lumping

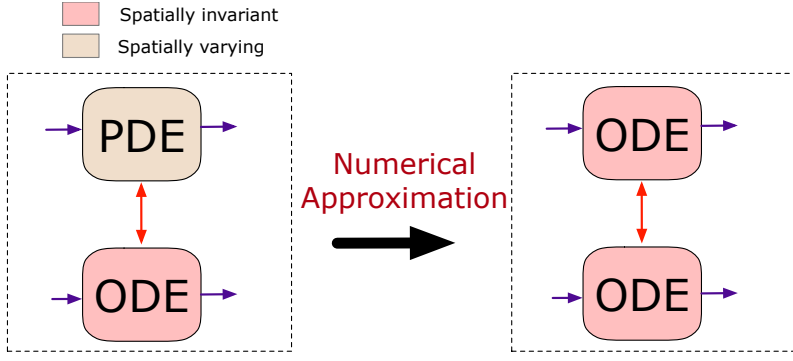


Neglecting spatial variation

Contribution

1. Not compromising on model-accuracy

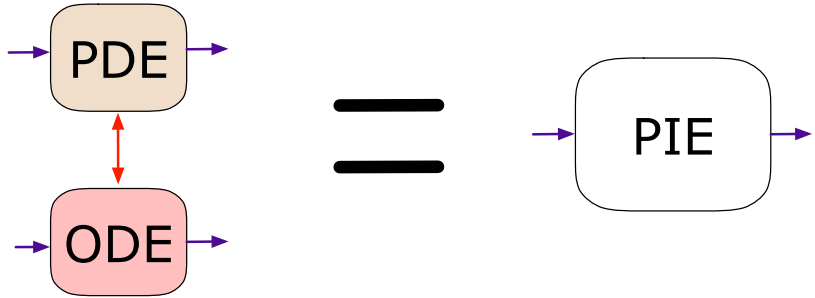
Method 2: Using Approximation



Contribution

- The interaction among adjacent components is preserved

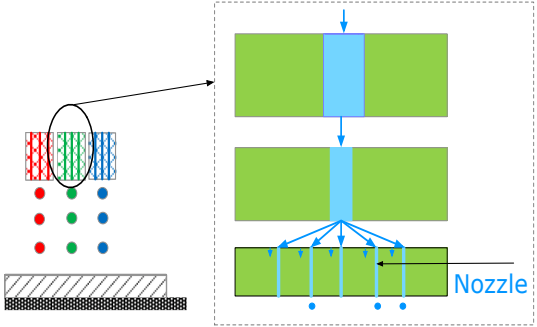
Method 3: Using Partial Integral Equation (PIE)



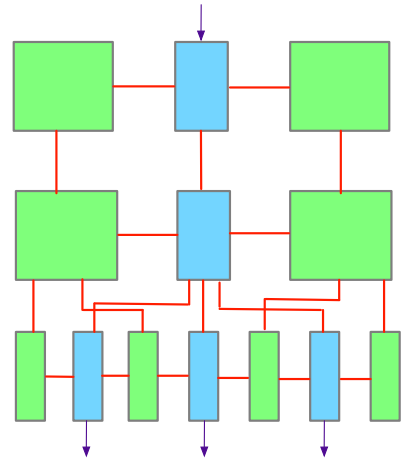
Contribution

1. A new mathematical representation of thermo-fluidic processes
2. Tools for analysis and synthesis on PIE
3. A software package **PIETOOLS** is co-developed to perform functionalities of PIE

Digital Twin Shows How to Control Temperature of Jetting Liquid



Lumping based model



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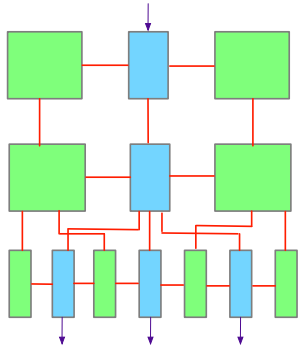

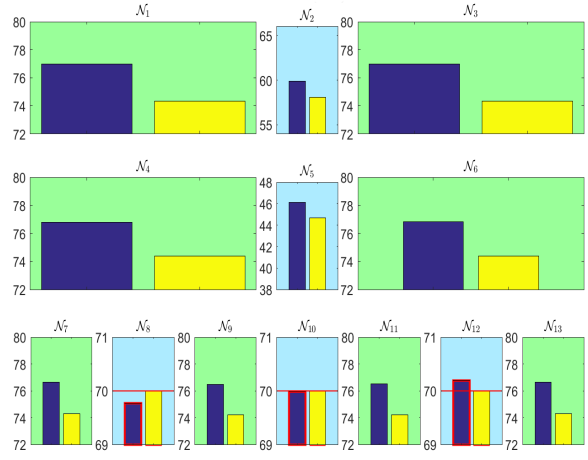

Result

Without adding new sensors or actuators, fluctuation in liquid temperature among nozzles is kept below $\pm 0.3^{\circ}C$

Conclusions

How to control thermo-fluidic processes to achieve best print-quality?

1. Digital twin is a generic tool for controlling thermo-fluidic processes
2. Digital twin is flexible and modular for printers of industrial scale
3. Digital twin's three approaches provide computational tools and ways to control print-quality

Implication: What I show

- Easy to upscale the design for any number of nozzles
- Jetting process achieves desired performance without adding new sensors or actuators
- Moisture content of a paper can be optimally estimated during fixation
- Digital twin's framework is generic for other applications

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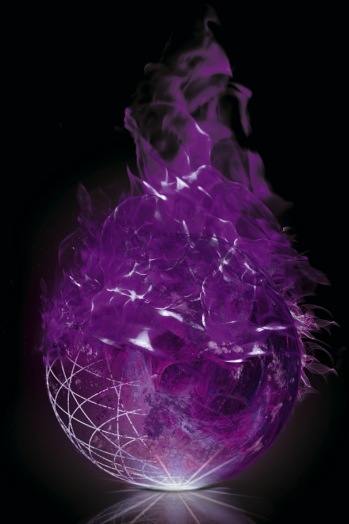
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