Additive Manufacturing Guided with High-Speed Photography and Machine Learning

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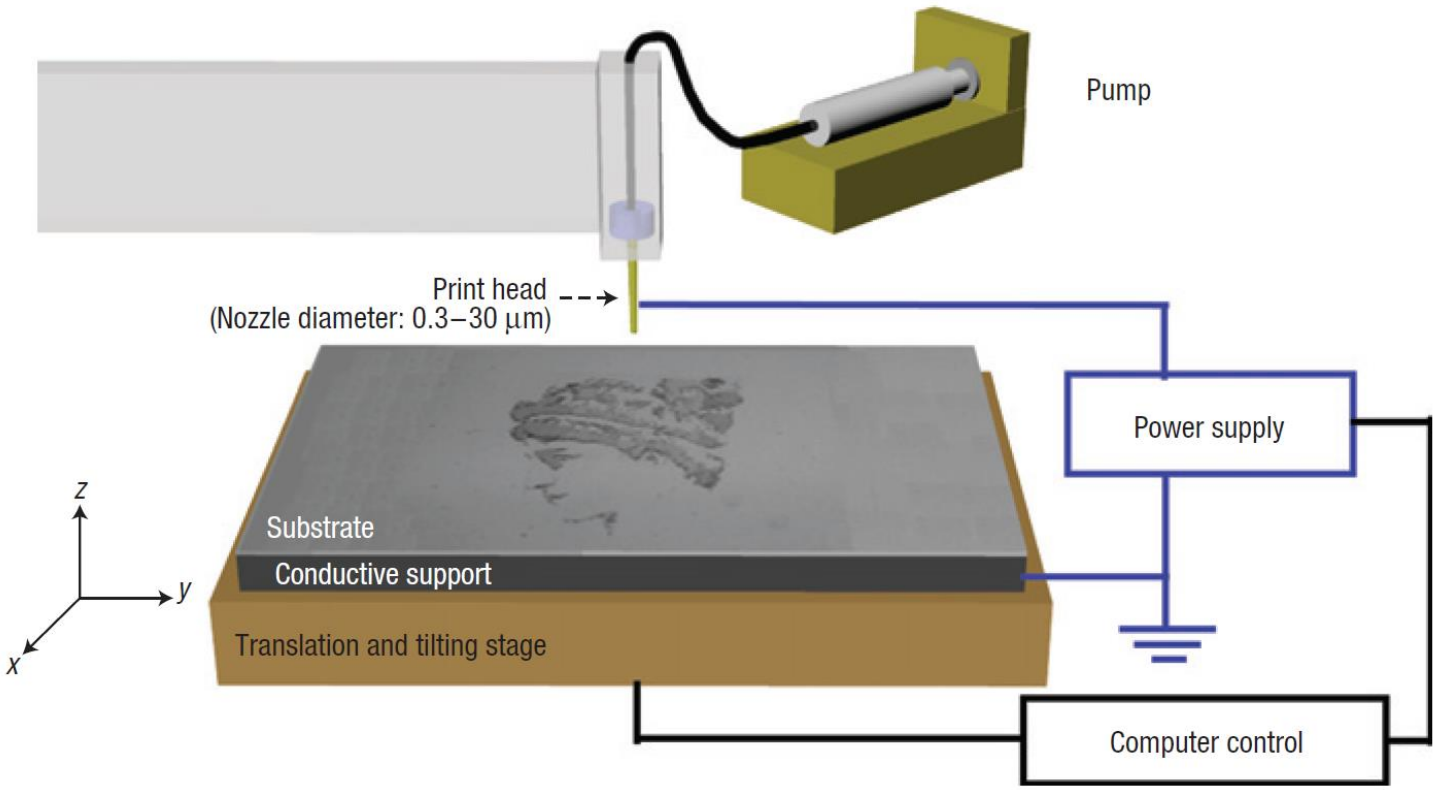
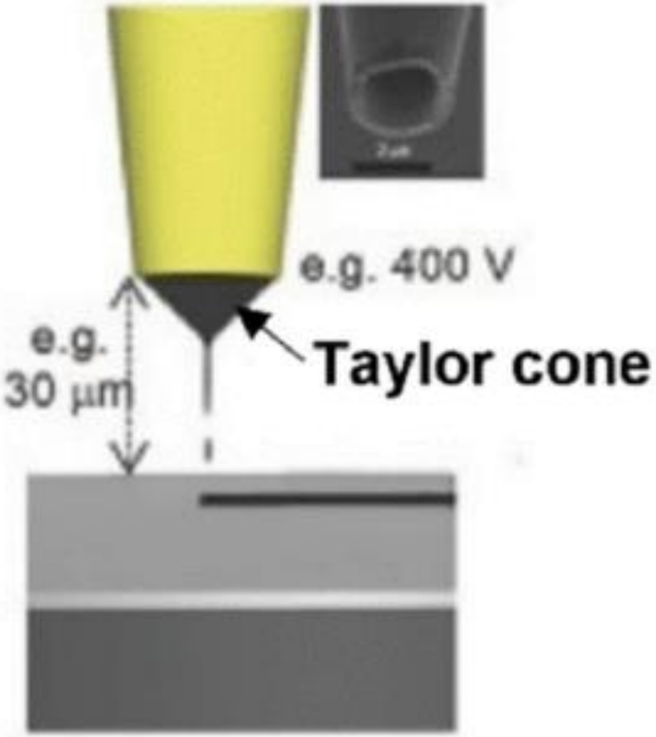
Background

Electrohydrodynamic (EHD) printing: an emerging printing technique capable of producing micro- or nano-resolution products with various materials.

-- inexpensive, versatile, highly customizable with sub-micron resolution



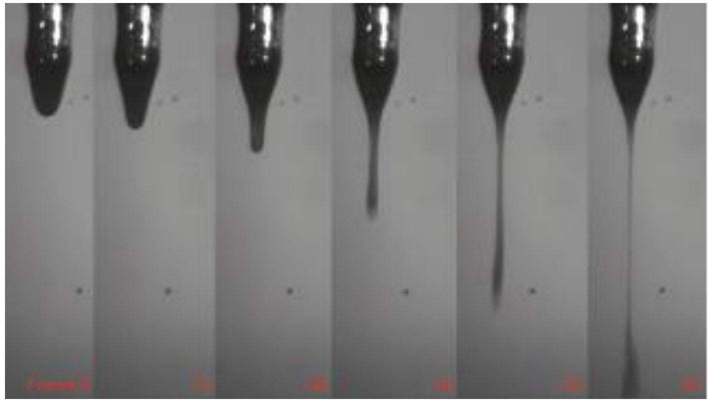
Schematic diagram of a high-resolution e-jet printer [1].



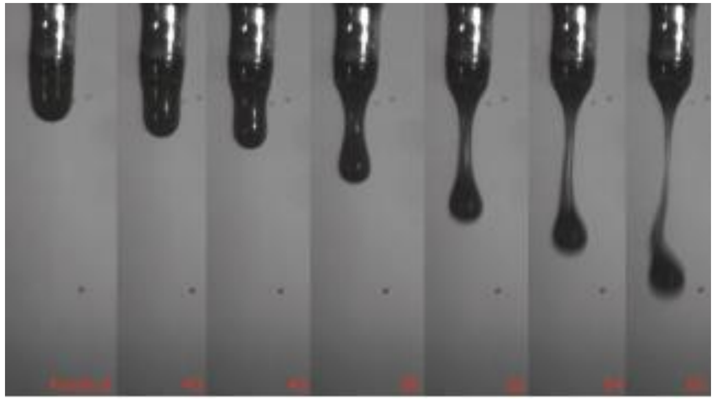
Jet is collected from the Taylor cone once the electrostatic force overcomes the surface tension and the viscous force of the printed material.

[1] Park et al. *Nature materials*, 6(10), pp.782-789.

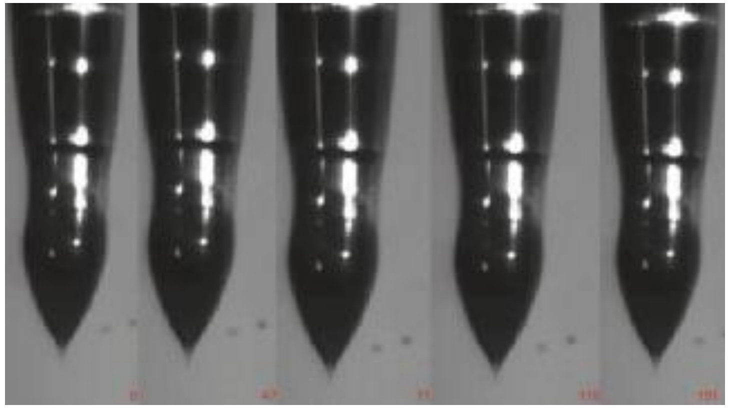
Modes of Jetting:



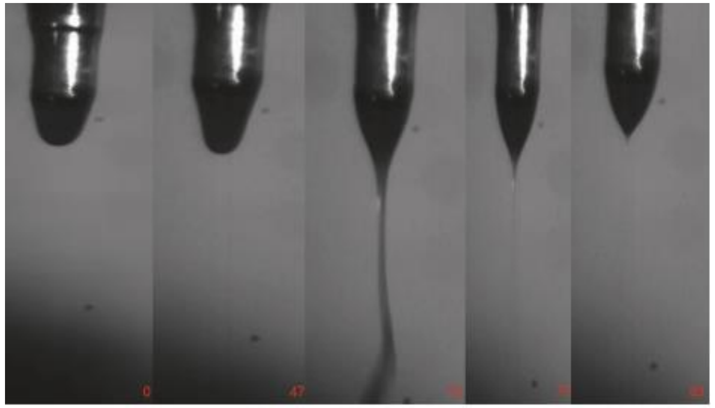
Microdripping



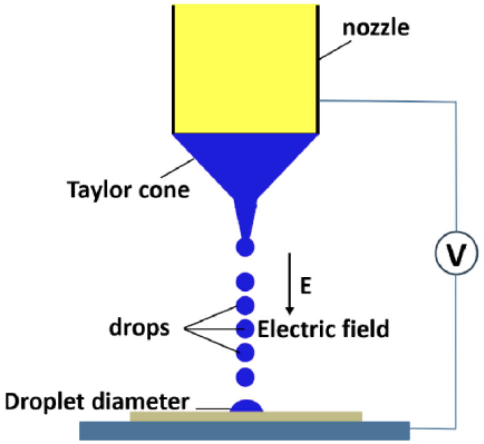
Dripping



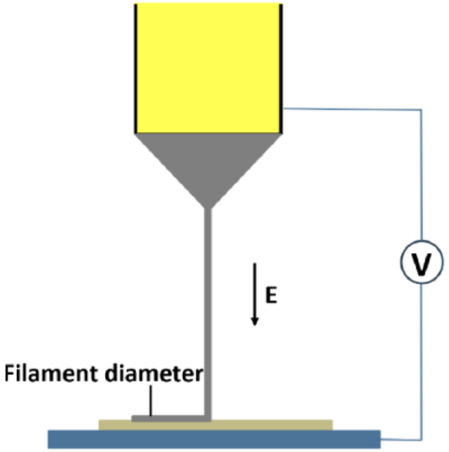
Cone-jetting



Unstable Cone-jetting



Microdripping



Cone-jetting

Objectives:

Predict jetting behavior for wide combination processing conditions and materials (from a wide range of sources).

Current Gaps:

Expensive *trial-and-error* experiments explored limited materials and process conditions.

Previously developed models not applicable to new material

Outline of the presentation

Jetting behavior (y)
$$= f(ink\ parameters, instrument\ paramaters, processing\ paramters\ \ ....)$$

- **Machine learning prediction of *y* for a given set of parameters**
  - Role of high-speed videography in the learning process
  - Incorporation of physics during the learning process
- **Inverse problem: For a target *y* predict the set of parameters**

Methodology

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Machine learning

Train-test split: 80:20

Feature importance analysis:

Random forest

Models

- **Regression:**
  Kernel ridge regression (KRR)

- **Classification:**
  Support vector machine (SVM)

A detailed breakdown for materials in the dataset

Materials	Materials properties (X)	Printing parameters (X)	Jetting mode (Y)	Diameter of the printed materials (Y)
Paraffin wax ■ PCL ■ AgNW ■ AgNP ■ Mixtures of glycerine, water and NaCl ● PEDOT:PSS ● PS ● PMMA ● Field's metal ■ Glycerin ■	Surface tension (x_1) Viscosity (x_2) Density (x_3)	Electric field (x_4) Pressure (x_5) Nozzle size (x_6) Printing temp (x_7) Printing speed (x_8; only for filament)	Filament Droplet (Y_1)	Diameter of filament (Y_2) Diameter of droplet (Y_3)

● **Data from literatures** ■ **Our Experiments**

The input features and output target in each dataset

Dataset No.	Input Features (X)	Output target (Y)
1	$x_1, x_2, x_3, x_4, x_5, x_6, x_7$	Y_1 (109 samples)
2	$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8$	Y_2 (72 samples)
3	$x_1, x_2, x_3, x_4, x_5, x_6, x_7$	Y_3 (53 samples)

Results: Feature Selection Analysis

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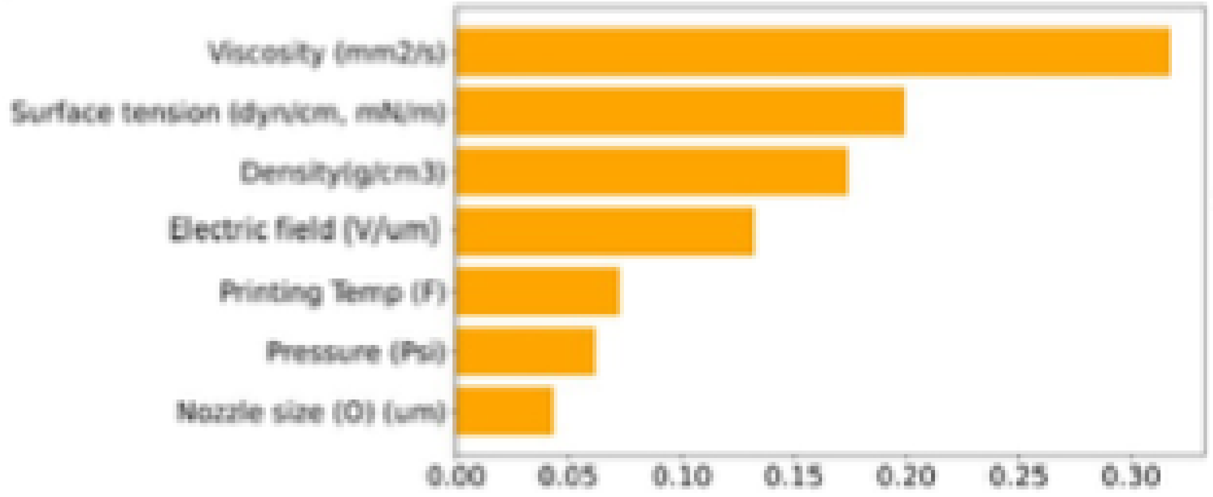
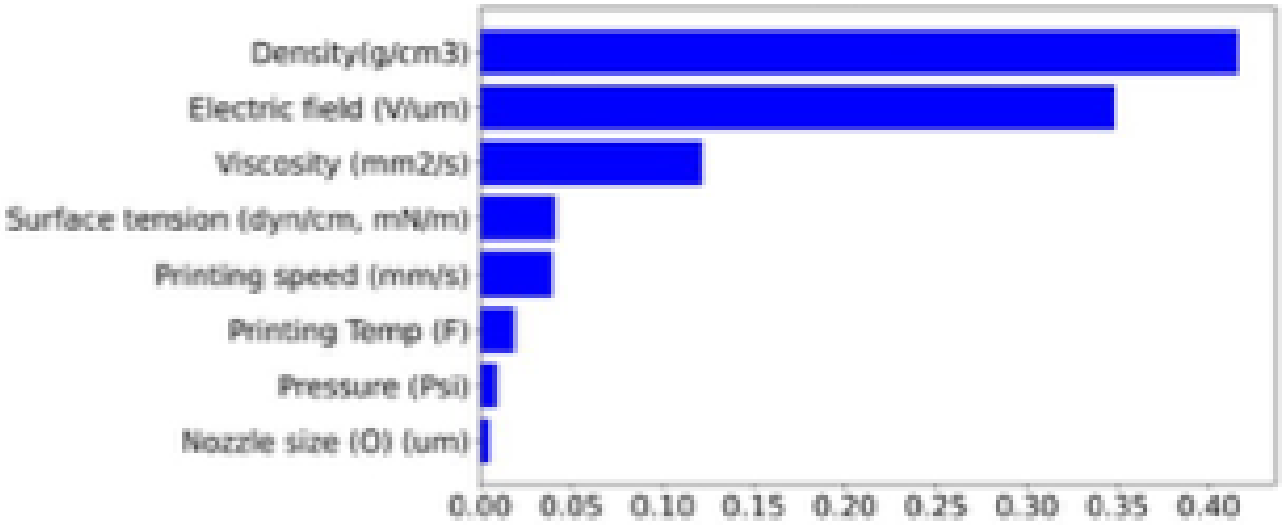
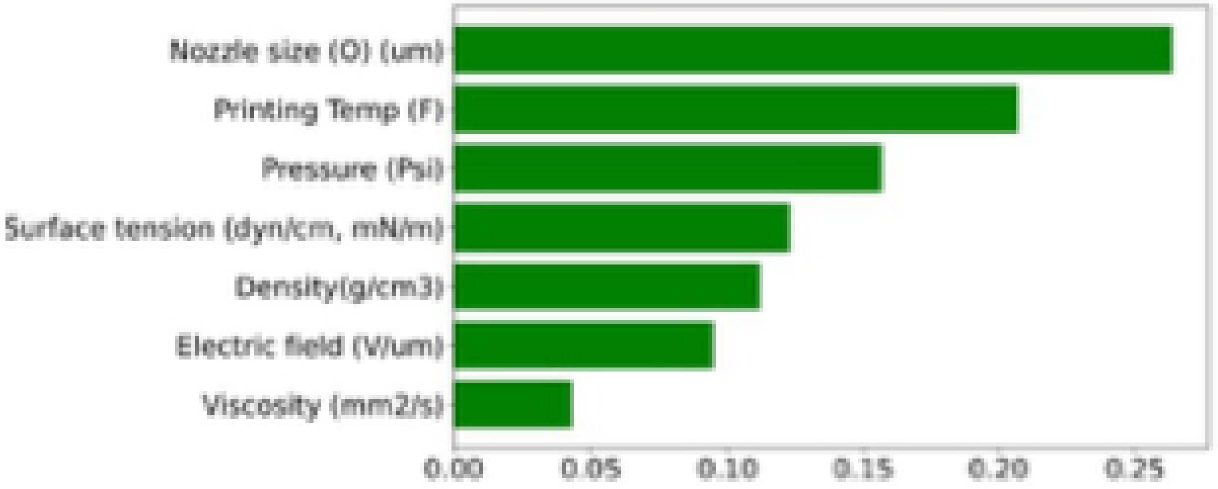


(a) Classification (droplet or filament);



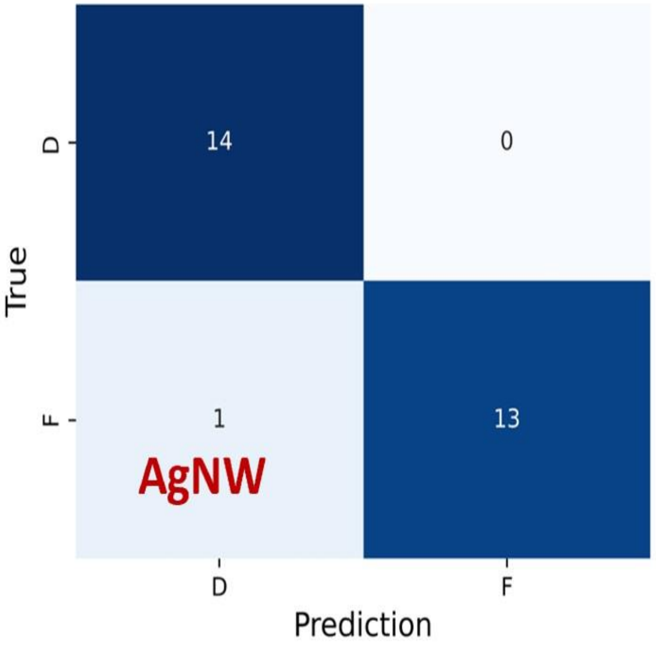
(c) Regression (diameter of filament).



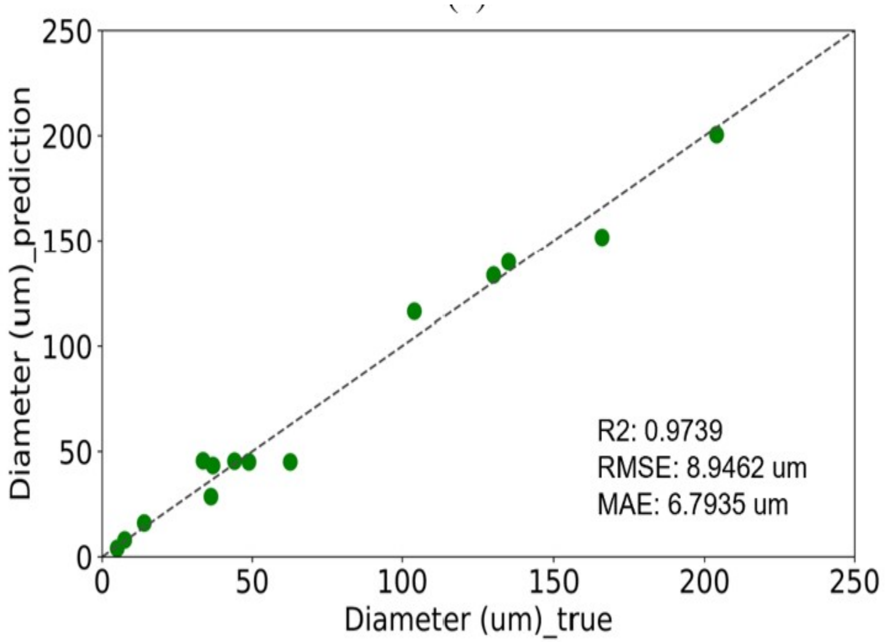
(b) Regression (diameter of droplet);

- Ink parameters (viscosity, density and surface tension) is ranked the highest among the features in determining the jetting mode.
- Both nozzle size and pressure are very important in controlling the droplet diameter.
- Density and electric field affect the filament diameter

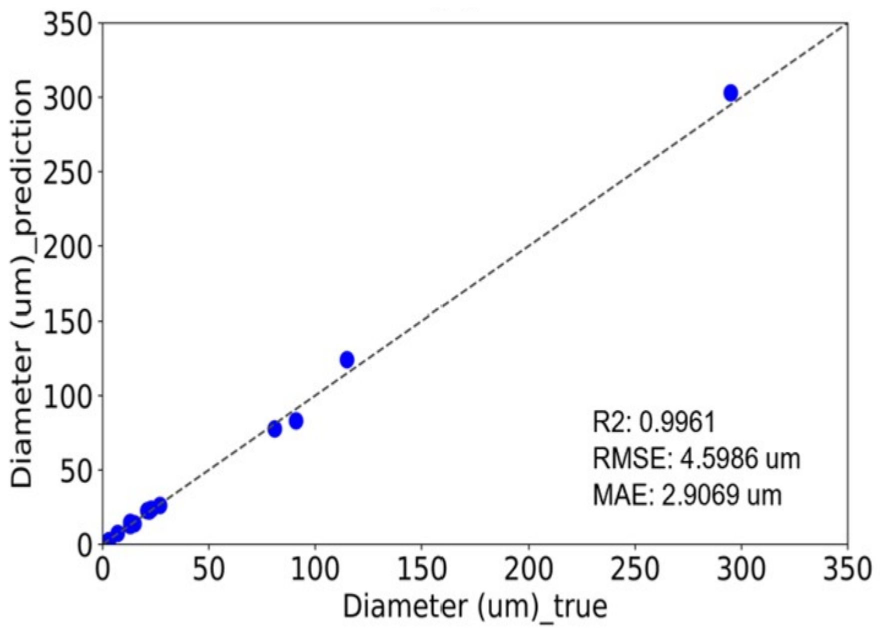
Results



(a)



(b)



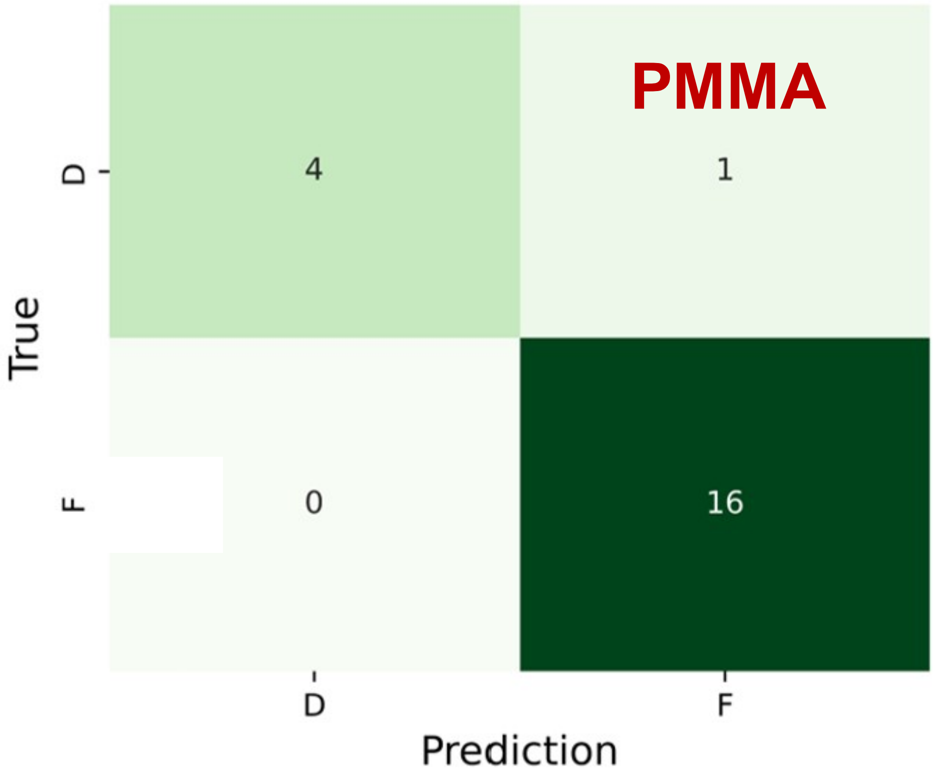
(c)

Classification (SVM) (droplet or filament)

Regression (KRR) (diameter of droplet)

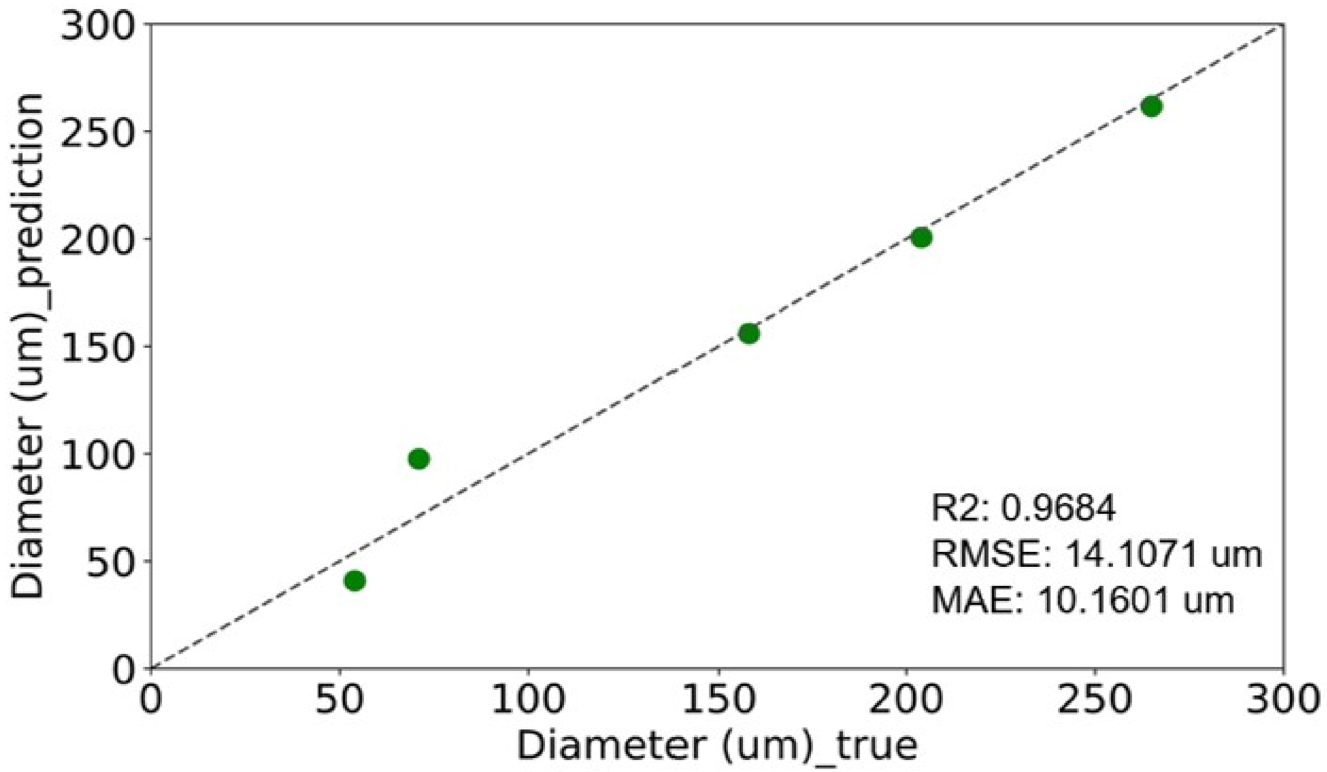
Regression (KRR) (diameter of filament)

Results: Prediction for New Material



(a)

Classification prediction for PMMA and AgNP (droplet or filament);



(b)

Regression prediction for PMMA (diameter of droplet).

Summary

In this research on ML guided EHD printing study:

- ML models are developed to predict jetting model and diameter of printed materials with high accuracy in both random train/test split and new material prediction cases.
- Importance information behind the competition among the materials properties and processing conditions on determining jetting mode and diameter of printed materials.
- Machine learning can lead the research to a more comprehensive, more efficient direction with less cost and consumed time, which help us relieve the issues caused by the experiments.

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