Universidade Federal de Minas Gerais
Escola de Engenharia
Curso de Graduação em Engenharia de Controle e Automação

# EHDA closed loop control system based on real time non-visual spray mode classification

Relatório de Atividades 4
Projeto Final de Curso

Orientador: Vitor Angelo
Supervisor: Luewton L F Agostinho
Aluno: João Pedro Miranda Marques
Matricula: 2017050495

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# 1 Summary

Electrohydrodynamic Atomization (EHDA), also known as Electrospray (ES), is a way to disintegrate a liquid into droplets by exposing it to a strong electric field. EHDA surveys have contributed as an important tool for the development of water technology (thermal desalination and metal recovery), material sciences (nanofibers and nano spheres fabrication, metal recovery, selective membranes, and batteries), and biomedical application (droplet encapsulation). Besides that, the project is merged with the Energy Transition strategy and Innovation Agenda Agriculture, Water, and Food, Key Enabling Technologies (KETs). Although, there are EHDA applications in industry, stabilizing the cone-jet spray mode is done empirically and based on mean current measurements.

The electric current flowing transported by the spray reveals characteristic shapes for different spray modes. Those shapes cannot simply be summarized by its mean value. In figure one we can see an example of cone-jet mode electrospray.

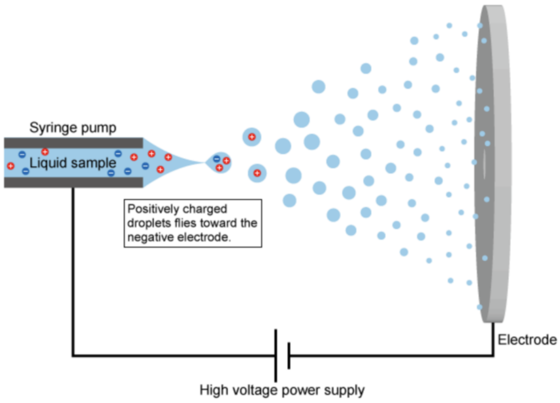



Figure 1: EHDA

Signal processing techniques can allow a non-visual classification of the spray mode based on the electric current shape. The spray process imposes noise and random sequences on the measured signal making its classification not a trivial task.

Industrial applications demand automated stabilization of a spray mode. This can be achieved by a closed-loop control system. Figure 2 shows the control model implemented in this project.

The setup used for this project can be seen in the Figure 3 and 4. To run the experiment automatically it is used a computational processing machine to integrate the peripherals and run their routines, system sensors such as the oscilloscope and the high speed camera and also the system actuators which is represented by the high voltage power supply and the syringe pump.

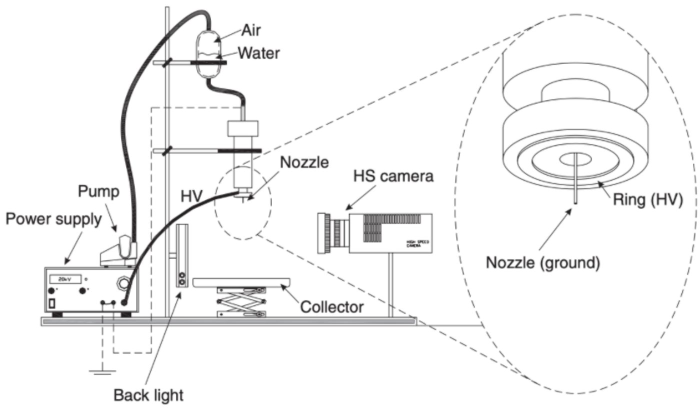



Figure 2: System Diagram

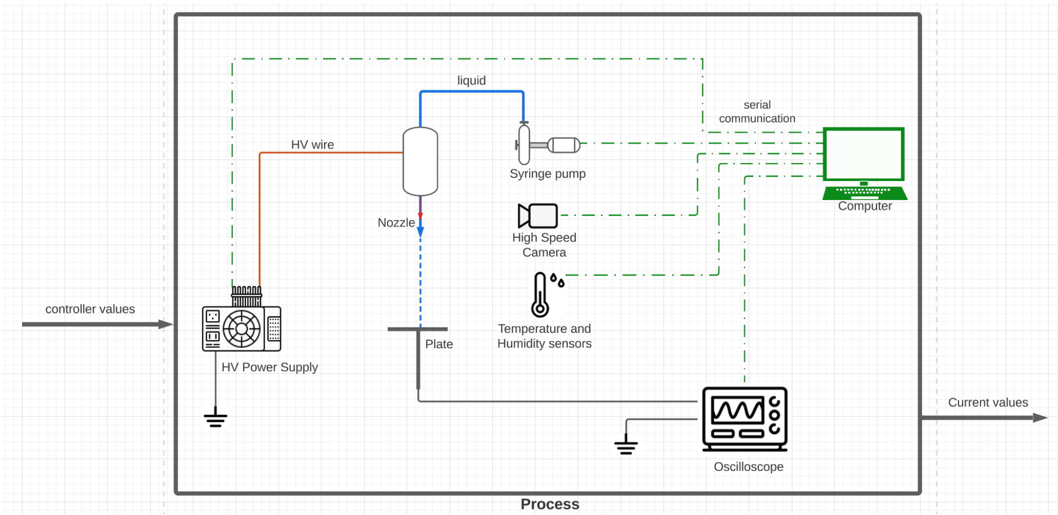



Figure 3: System Automation Diagram

Automated classification of the spray mode is a crucial part of a control system same as the development of an appropriate control algorithm. Signal processing implementations of previous projects of the NHL Stenden Water Technology group are showing good classification results. Further research is necessary to improve the classification accuracy and research and implementation of a suitable classification algorithm. Because of that, this work is being done by the Water Technology Group at NHL Stenden University of Applied Sciences and in combination with Dutch companies to match analysis possibilities with knowledge and infrastructure availability.

# 2 Metodology and Results

The following subsections are about the work done in this 4rd part of the project.

## 2.1 Save experiment in real time

With the mapping routine the experiments time and data size started to make difference. One experiment generates in average 6GB of data and takes arround 1,5 hours to complete. The saving section was working with the python json library and with the function json_dump(). One thing about using json objects is that the structure should be closed. The function json_dump() need the complete json file in order to save it. For that the routine was saving all the data in python dictionaries. And after that creating and saving the json file. Two new problems were happening. If the experiment crashes in the middle all the experiment data get lost. And it is not clear if the operational system or python kernel will support all the experiment data in program memory.

To solve that a new thread was created *save_data_thread()* in order to save each sample in a selected file in the non-volatile memory. Also was needed to use another python json library developed for streamming data in json structure in a file. It is called *jsonstreams*.

With those new improvements we are abble to:

- Save data for big experiments. Depending just on the non-volatile memory storage.
- Use a raspberry pi for processing and saving big experiments.
- Interrupt and exit an experiment in real time and get the data saved.
- Less waiting time after the experiment to save all the data.

The new software design can ben represented in the model showed in Figure 2.

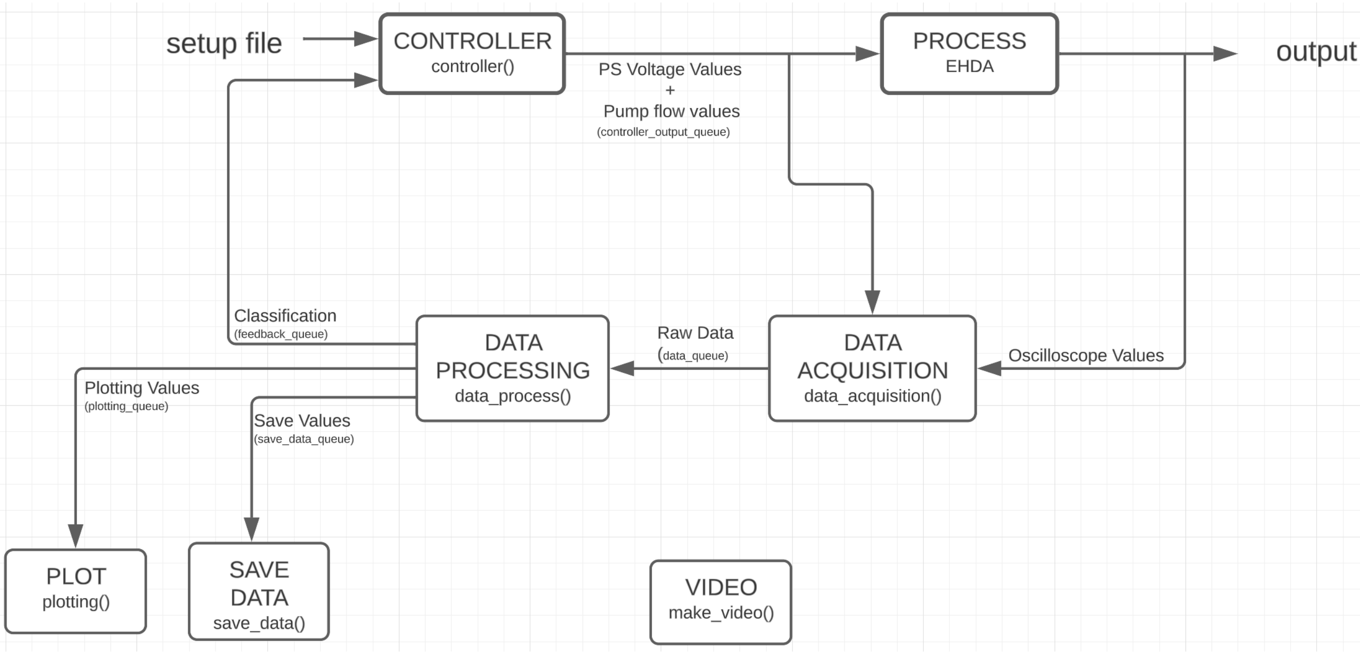
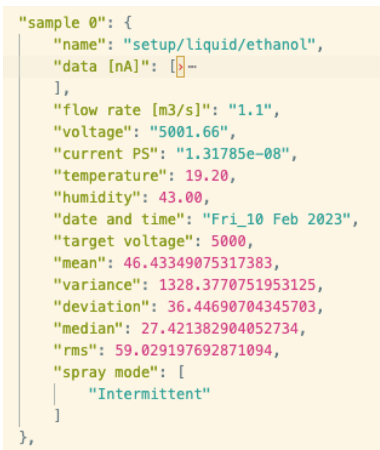



Figure 4: Control model implemented in software

## 2.2 Saved Data Structure

With the new streamming model of saving a new structure of the collected data were created. Instead of having all data measurements values and after all data processing values we now are saving for each sample the measurements and processing values. The structure of the



```
"sample 0": {
    "name": "setup/liquid/ethanol",
    "data [nA]": [...
    ],
    "flow rate [m3/s]": "1.1",
    "voltage": "5001.66",
    "current PS": "1.31785e-08",
    "temperature": 19.20,
    "humidity": 43.00,
    "date and time": "Fri_10 Feb 2023",
    "target voltage": 5000,
    "mean": 46.43349075317383,
    "variance": 1328.3770751953125,
    "deviation": 36.44690704345703,
    "median": 27.421382904052734,
    "rms": 59.029197692871094,
    "spray mode": [
        "Intermittent"
    ]
},
```

Figure 5: Output data json structure

To work with this data I'm using pandas Dataframe. With the command:
pandas.read_json("PATH", orient='index').

The json file is good to store the data and to read the file. But as it is getting a lot of data working with pandas Dataframe is being way faster. Also saving the dataframe in a compressed type of file called feather is much faster to work with the data.

## 2.3 Mapping experiments

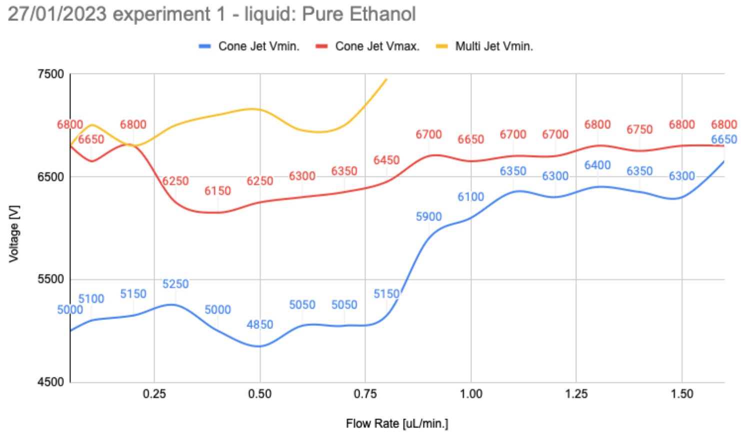



Figure 6: Control model implemented in software

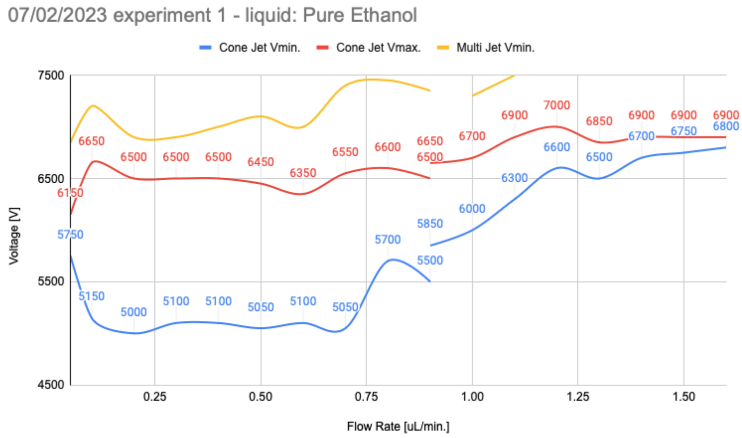



Figure 7: Control model implemented in software

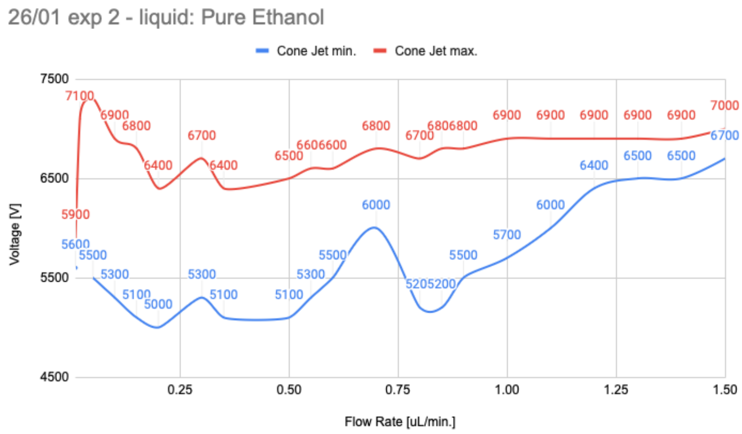



Figure 8: Control model implemented in software

## 2.4 Manual x Automatic Mapping

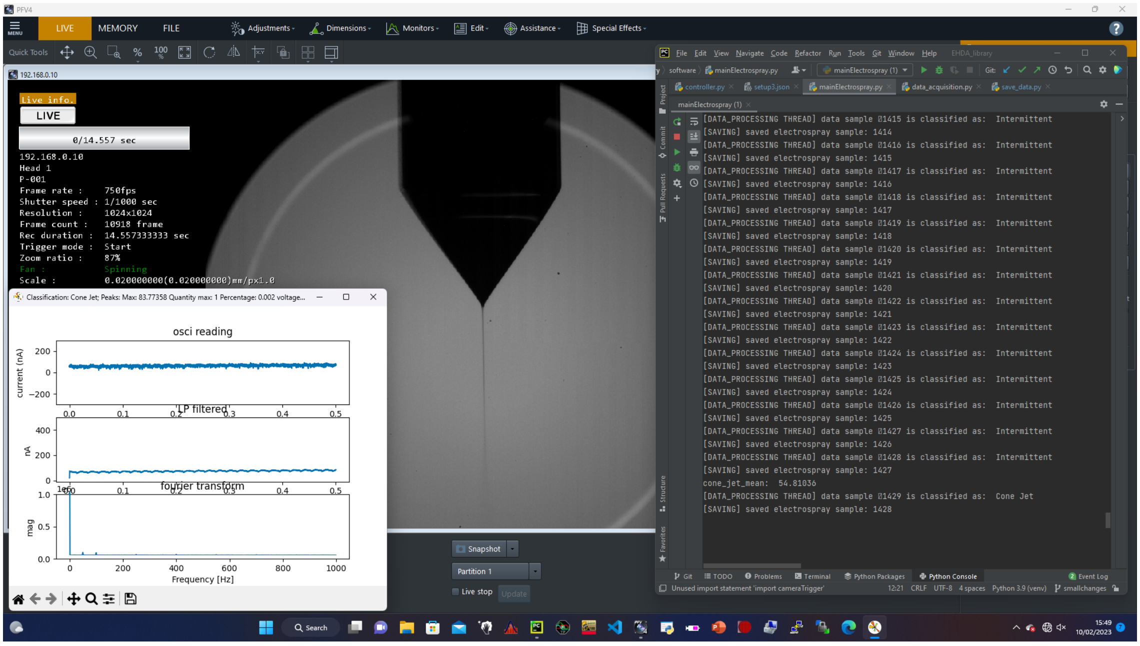



Figure 9: Control model implemented in software

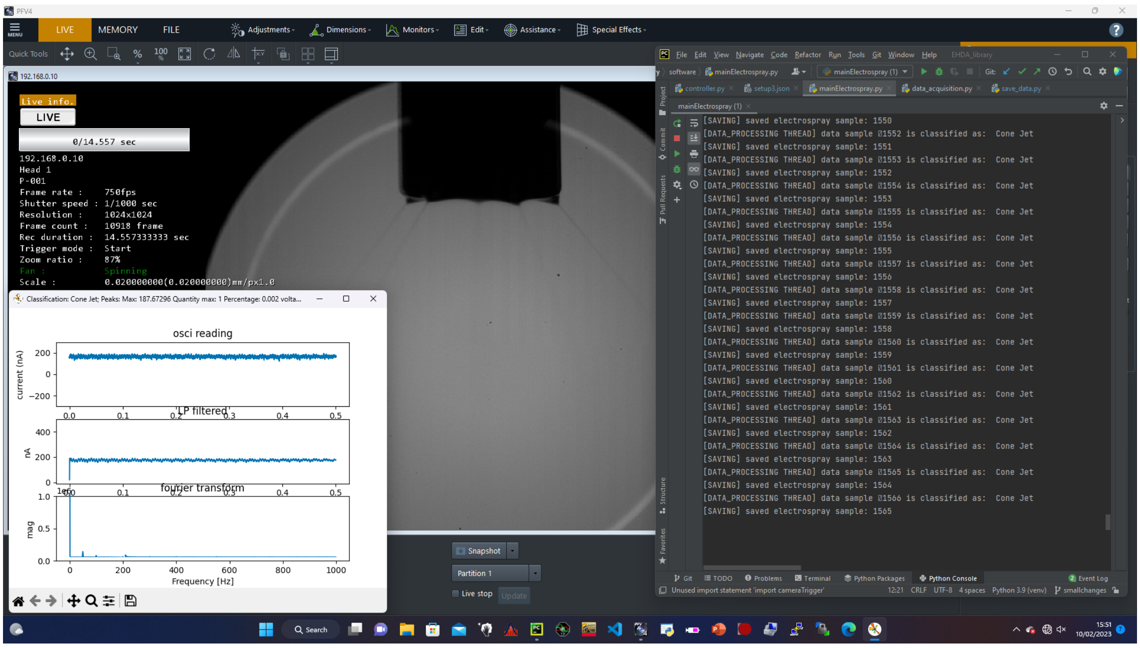



Figure 10: Control model implemented in software

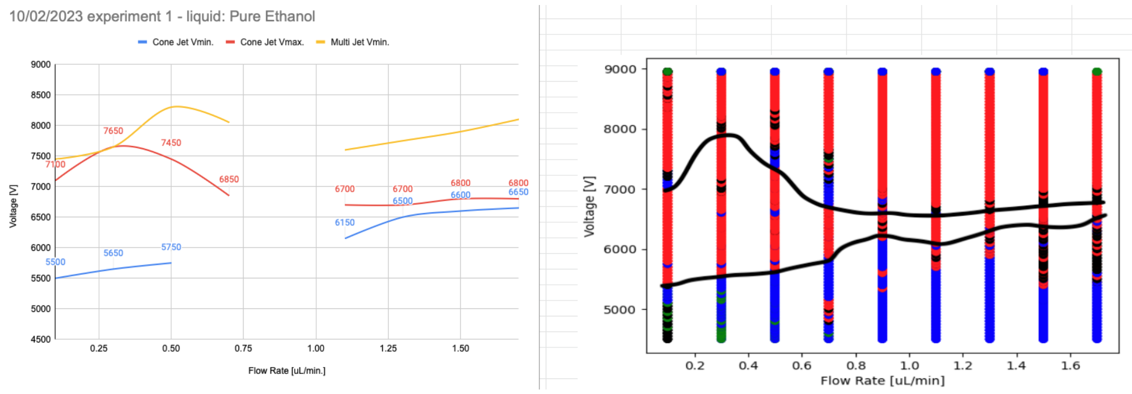



Figure 11: Control model implemented in software

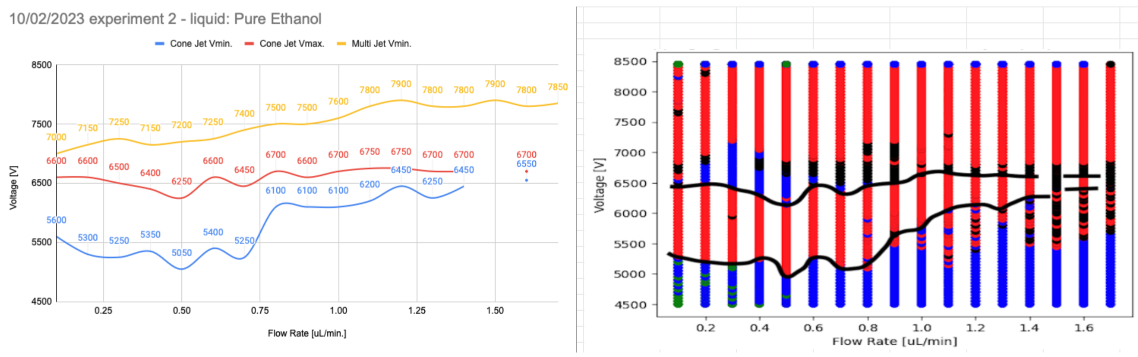



Figure 12: Control model implemented in software

## 2.5 Multi Jet classification by mean value

There is not many articles about the multi jet dynamics and classification. This makes sometimes hard to define when is in multi jet mode, if its defined by the meniscus, quantity of jets or stability.

We therefore know that the multijet current mean value is above of the cone jet mean value.[1]. This current mean value increases for each new jet created. This could also be noticed experimentally in our setup.

For that, in our automatic classification algorithm, as the current acquired in cone jet and multi jet has the shape (constant) but different DC values. We decided to save the cone jet mean value and multi jet mean values and analyse what is this step.

Making a statistical analysis in all data collected using the same liquid (ethanol) and setup we found that the Multi jet can be classified when the current is 1.14 the value of the Cone Jet mean. I implemented this logic in the automatic classification and got the following results.

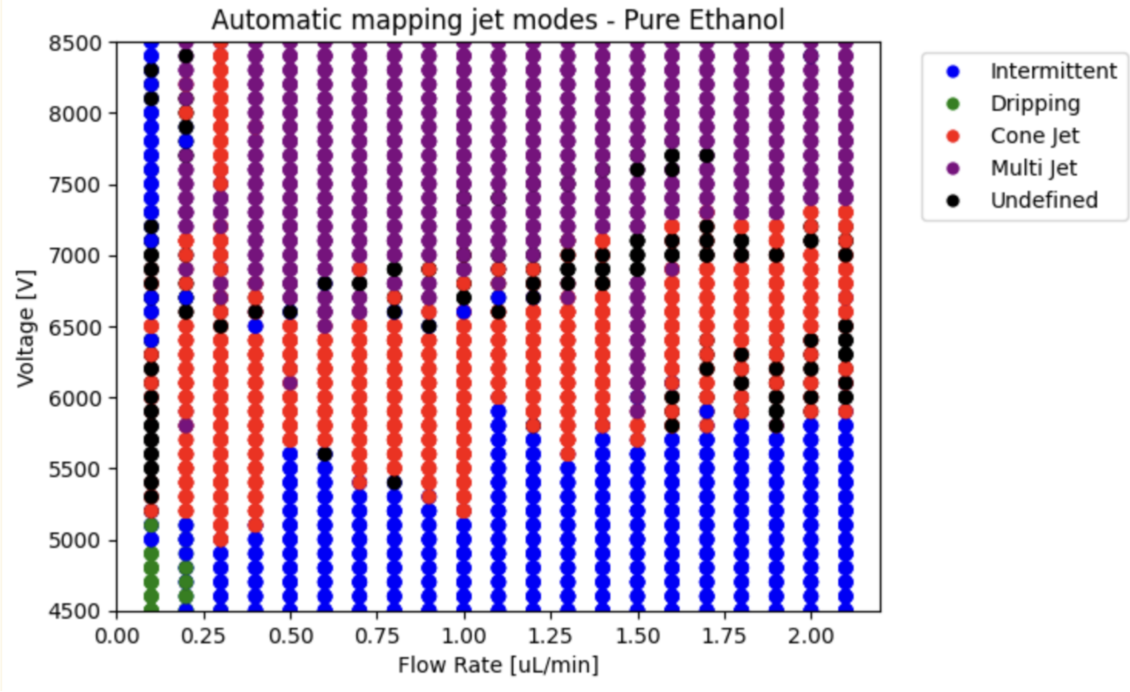



Figure 13: Control model implemented in software

Comparing this results with the manual results of the same experiment we can see that the algorithm could classify the Multi Jet with a good accuracy.

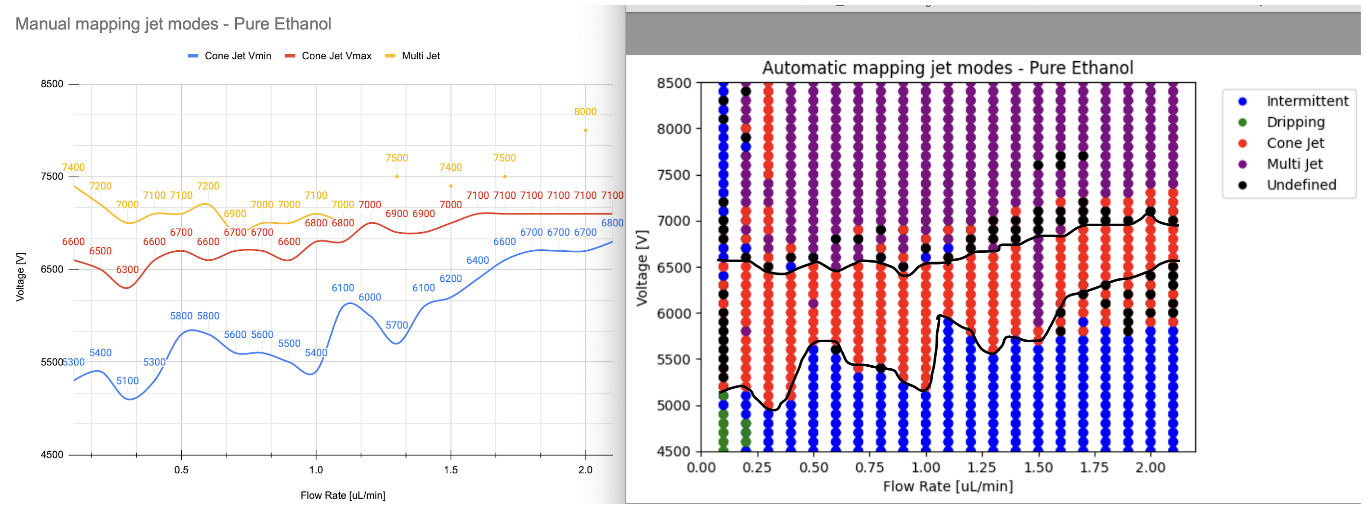



Figure 14: Control model implemented in software

## 2.1 Raspberry pi

# 3 Conclusion

# References

[1] C.N. Ryan, K.L. Smith, and J.P.W. Stark. "Characterization of multi-jet electrospray systems". In: *Journal of Aerosol Science* 51 (2012), pp. 35–48.