# VICTORIA UNIVERSITY OF WELLINGTON
*Te Whare Wānanga o te Ūpoko o te Ika a Māui*

## School of Engineering and Computer Science
*Te Kura Mātai Pūkaha, Pūrorohiko*

PO Box 600
Wellington
New Zealand

Tel: +64 4 463 5341
Fax: +64 4 463 5045
Internet: office@ecs.vuw.ac.nz

# Instrumentation System for Liquid Drop Impact and Evaporation

Daniel Eisen

Supervisor: Dr. Gideon Gouws

Submitted in partial fulfilment of the requirements for
Bachelor of Engineering with Honours.

### Abstract

//TODO rewriting
*Droplet impact and evaporation presents a complex physical process worth investigating not only from a fundamental research perspective but also in its potential for industrial application. However, in order to extract usable data from this small scale, fast phenomenon in the lab producing a droplet of repeatable volume and position as well as accucartly track and collect the data (temperature, impact, evaporation) is essential in order to extract reliable and study worthy results. This procedure form the basis of this project. This projects approach is to add motorised automation to droplet dispensing with aims to control for droplet volume, positional variation, contact angle and speed up the procedure and allow for greater flexibility in the experimental process.*

# Contents

# Chapter 1:  Introduction

//TODO re-write in progress

## 1.1  Motivation

The investigation of droplet impact and evaporation is an area of interest and application to various industries. Examples of these include milk powder spray drying, ink jet printing, and applications of evaporative cooling. This project will continue on from a previous instrumentation setup, evaluating its shortcomings, and designing the next generation. This will improve the reliability and usability of the collected data from the previous setup, and introduce methods of automating the process.
Applications of interest

- Spray cooling

- powder (Milk) manufacture

- ink-jet printing

- …

## 1.2  Goals

Goal: To characterise behaviour of a droplet impacting and evaporating from a given substrate.

- Increase Repeatability and Reliability of results

- Increase usability of process via automation

- Produce Extendible platform that can be built upon beyond this projects scope

# Chapter 2:  Background and Related Work

## 2.1  Instrumentation and the Experiment

Cover consideration with this kind of instrumentation/experimental measurement system and how it applied to this experimental application.

## 2.2  Background on Stepper motor control

//TODO more passes for clarity.
This section will cover the background of controlling bipolar stepper motors via a step/direction style driver setup, as its concepts will be mentioned later in the report.  This is a focused background on the key considerations and requirements when designing for and operating this specific subset, and by no means applicable to all driving and specific motor choices.
The stepper motors provide precise positioning and are capable of moving their rotor to a specified position and holding that position at a wide range of load torques. This capability makes the stepper motors popular in optics, medical instruments, factory automation, and industrial equipment.
The typical topology of a stepper driving system (based around the step/direction method) consists of a controller, driver, and stepper motor. The controller provides a direction signal and step pulses, while the driver converts these signals into actual electrical power and supplies them to the motor. The stepper motor moves in steps, each step covering one step angle, which can be described as the rotor displacement corresponding to one step pulse [1]. Stepper motors typically have a step size specification (e.g. 1.8° or 200 steps per revolution), which applies to full steps. Step/direction drivers usually provide a 'microstepping' mode which increases the resolution by allowing intermediate step locations, which are achieved by energising the coils with intermediate current levels [2].
The last major consideration in driving steppers is controlling the start-up and stopping speeds for the controller's provided pulse train to the driver.  As the motor is a mechanical device in the real world, expecting a perfect impulse response will lead to driving failure. Inertia ratio is critical to stepper motor acceleration [2].  Too great a difference in inertia ratio between system and motor risks missed steps or stalling the coils.  So when starting a stepper motor, acceleration and deceleration should happen through pulses to the motor that start slowly and gradually quicken in a process called ramping.

## 2.3  Other Approaches

//TODO: Go into greater detail to add context in the field of droplet instrumentation.
In literature, there exists a variety of rigs for similar experiments.  These were explored to gauge a range of what factors were controlled (and measured) and with what approaches. In summary:

- Controlled environmental factors with basic box [2] or measured factors only [3].

- Controlled for droplet position and volume with hard mounted pump plus needle, but lacks environmental control or automation, and there is no top view camera [4] [5].

- Incorporated stepper motor driven automation, but no environmental control or monitoring [6].

- Full environmental chamber and fixed droplet pump, but single camera, has separate uncontrolled rig for top view [7].

# Chapter 3:   Inital Evaluation

## 3.1   Current Experimental Setup

The instrumentation as exists is assembled with an optical breadboard and XYZ+R stages with micrometre controls. A central stage holds the substrate with internally mounted thermocouple. Two manual focus cameras are positioned in profile and top down views, and the droplet is dispensed manually via a syringe mounted horizontally to a XYZ+R stage. The current procedure is a manual process. The syringe tip is rotated above a marked point on the substrate, and hand emptied and refilled. This results in volume and positional variation between runs. This procedural variance is the focus of this project.

## 3.2   Repeatability and Reliability

Data taken from a series of five droplet runs was analysed to extract the variety in droplets and its effect on the measure temperature profile.
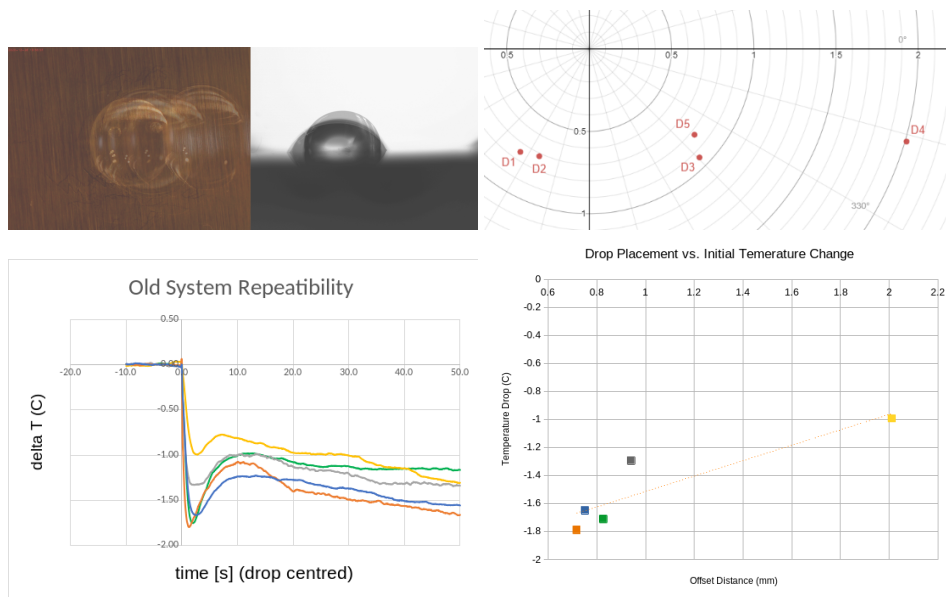


## 3.3   Revised Approach

The focus of the project is now twofold. Firstly on the automation of the process to allow for faster, pre-programmed runs to be carried out easier, and secondly to improve on the repeatability and reliability of the results by controlling the procedural factors of the experiment.

| *Droplet* | *Distance from Centre (mm)* | *Estimated Volume (mm^2)* |
|---|---|---|
| 1 | 0.7506 | 16.55 |
| 2 | 0.7164 | 17.91 |
| 3 | 0.9402 | 17.89 |
| 4 | 2.0104 | 17.57 |
| 5 | 0.8258 | 16.21 |

| | *Distance from Mark* | *Measured Temperature Drop* |
|---|---|---|
| Min Pos Offset | 0.71mm | -1.7901°C |
| Max Pos Offset | 2.01mm | -0.9944°C |
| | *Volume* | *Contact Angle* |
| Shape Variance | 0.629$mm^3$ | 25.894 degrees † |

Table 3.1: Variance in Setup

†This excluded an outlier of an almost spherical droplet with contact angles exceeding 95 degrees. This large variation is most likely due to inconsistency in surface chemisty from washing.

An electronic pipette will be used to dispense a precise volume, and motorised stages will be used to provide preprogrammed, repeatable motion. The environmental factors however are not to be ignored, though controlling them is outside of the scope of this project. They will, however, be monitored, and this project will implement data collection of temperature, atmospheric pressure and humidity so these factors can be correlated to any remaining variation in data. w

| Effector | Likelihood | Effect Strength |
|----------|------------|-----------------|
| Position | | |
| Volume | | |
| Contact angle* | | |
| Humidity | | |
| Temperature | | |
| Pressure | | |

# Chapter 4:   Design

## 4.1   Project Specifications and Justifications

The design process uses the goals of the experiment and the results of the initial evaluation to inform what and how various subsystems are designed.
From this there is a number of requirements to consider:

- **Mechanical Stability**:

- …

- **System Expandability**:

## 4.2   System Overview
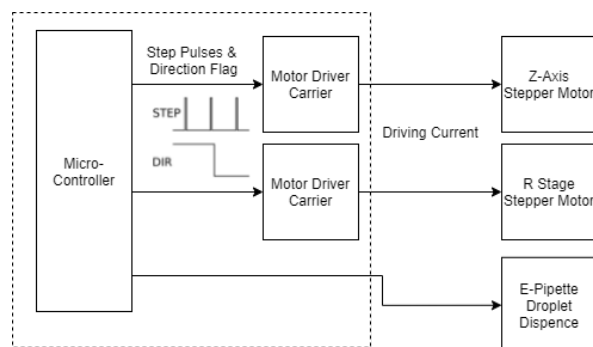


## 4.3   Mechanical Design

- Discuss requirements for minimising settling time, vibrations, oscillations.overshoot of the pipette motion

### 4.3.1   Rotating Pipette Mount

- 3D printed pipette clamp

- Laser cut Tower mounted

- motor interface and stage fastening

### 4.3.2 Z micrometer Control

- Requirements: micrometer motion/extension as its turn

- Sliding motor shaft to knob required (2 passed)

- How it imposed restrictions on the system (freedom of motion)

## 4.4 Electronic Design

### 4.4.1 Motor Driving

**The Requirements**

To drive the selected stepper motors, discrete step/direction style micro stepping drivers were chosen. This allows for the design to be flexible with its electronics placed to accommodate the experimental needs. Allows for a fairly agnostic choice for controller to supply the control signals, and standardised pinouts allow for requirement flexibility and replacements.

|  | A4988 | DRV8825 | STPIN820 | DRV8834 |
|---|---|---|---|---|
| Step Res | 1/16 | 1/32 | 1/256 | 1/32 |
| Logic Level | 3V3/5V | 3V3/5V | 3V3/5V | 3V3/5V |
| Current Limit | 1A | 1.5A | 0.9A | 1.5A |
| Drive Voltage | 8-35V | 8.2-45V | 7-48V | 2.5-10.8 |

Table 4.1: Comparison of considered drivers

Main consideration for device choice are: micro step resolution, driving current limit (passively cooled), and configuration pinout.

**The Choice**

The DRV8825 was ultimately chosen.

- High microstepping resolution, lower than the STPIN820 but cheap high resolution driver are prone to step skipping [2]

- Highest driving current as torque requirements are unknown for this design the headroom is nice even if it isn't use, especially as it will run cooler at lower power draw.

- It ranked above the DRV8834 due to it configuration pins (to set microstepping mode) as it provide all 3 pins without the requirement to leave pins floating as a setting thus allowing for full software control.

### 4.4.2 Pipette Triggering

//TODO maybe move to implementation

- Signal requirements that lead to a trigger environmental

- interfacing the controller with the board

### 4.4.3 Environmental Monitoring

- What will be measured?

- Power (battery?)

- Sleep the conserve

# Chapter 5: Implementation

//TODO rename sections to reflect work done

## 5.1   Mechanical Design

- Go into 3d printing/laser cutting refinement, testing and adjustment

- Tolerance and dimension adjustment

- Noted changed and drawback from design

### 5.1.1   Rotating Pipette Mount

### 5.1.2   Z micrometer Control

- Note initially large vibrations as z decreases, caused be loose tolerance, too small coupler. Caused droplet to prematurely detach at larger values.

## 5.2   Software

//Insert Serial Command Table (maybe only appendix)

### 5.2.1   Motorised Dispensing Controller

ESP32 based system controller with serial interface for issuing commands. Provides functionality to:

- Motorised stages, height and angular position

- e-Pipette droplet dispensing

### 5.2.2   Environmental Monitor

- Auto sleeping, button wake upon

- Circuit-Python implementation

### 5.2.3   LabView Temperature Logger

## 5.3   Electronic Design

- full circuit

- pcb

- any and all adjustment found and made during implementation

### 5.3.1 Motor Driving

### 5.3.2 Setup and Requirements

- characterised skipping issue at 100Hz, 180Hz-200hz in single step

- implemted micro stepping to solve

//TODO rewrite

Driving firmware was implemented on an ESP32 to validate its ability in producing the required pulse train step signal. The controller was required to produce N steps (pulses) at a set average speed, and ramp up and down that pulse speed at the head and tail of that signal.

Set values of 200 steps forward and back, at a speed of 200 steps per second, with max acceleration or 800 steps per second per second:

These pulses were captured on a second microcontroller listening for falling edges to trigger an interrupt routine to record and display that data.

### 5.3.3 Results

Figure 5.1:a shows a successfully produced signal of 200 pulses with an inferred acceleration at its head/tail. This speed ramping is better illustrated in figure 5.1:b showing the stepping change in pulses per second over the course of the pulse train.



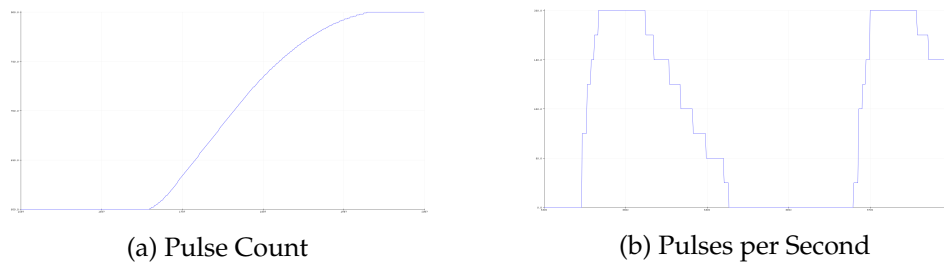(a) Pulse Count                    (b) Pulses per Second

Figure 5.1

### 5.3.4 Pipette Triggering

//TODO

### 5.3.5 Environmental Monitoring

//TODO

# Chapter 6:   Evaluation

## 6.1   Mechanical Stability

Perform Motor driving parameter sweep to optimise mechanical performance according to requirements; of minimising pipette tip overshoot and settling time.

### 6.1.1   Procedure

- Position tip at -1/4 revolution before zero point

- Set Speed/acceleration values

- Swing to zero position

- Repeat for value sleep=1rev/s, acc=1/rev/s/s $\rightarrow$ speed=2rev/s, acc=10/rev/s/s

- Note: acceleration is the ramp down at end/start of motion so is what we care most about

- Camera captured motion

## 6.2   Droplet Volume

Something the previous system could not achieve was dispensing a variety of volumes. Use e-pipettes programmable volume to investigate the limits of this project.

- How large a droplet can be held on to? (prelim: 8uL)

- How large (over above) can reliably self release (w/out touch down)

- How small a droplet can be dispensed (e-pipette has draw-back).

### 6.2.1   Results

//insert generated figures of tip position
//generated trend lines/aggregated data (settle, overshoot) from data.

## 6.3   Repeatability and Reliability

This section aims to produce the main set of comparable results for evaluating the projects produced system against the output of the previous setup. Thus justifying the success of one of main goals.

### 6.3.1  Procedure

- **Initial Setup:** Roughly Position substrate stage, reservoir platform and note angular positions as well as vertical clearance requirements.

- **Zero System:** Using overhead camera precisely position pipette tip above substrate centre

- **Data Acquisition:** Initialise cameras, collect pixel:mm calibration data for analysis, initial LabView temperature logger, and environmental monitor noted. Info: temperature data rate, camera frame rate

- **Automated Sequence:** Via the serial link, enter the procedures command sequence to represent → lower, draw up fluid, raise, position over substrate, dispense, lower, raise, clear camera view. With appropriate delays.

- **Capture:** Begin data collection and automated dispense.

- **Repeat:** Minimum of 5 times. Each time carefully cleaning substrate surface to minimised up measured factors.

### 6.3.2  Analysis

To show the system successfully increases the consistency of droplet position,

# Chapter 7:  Conclusions and Future Work

Future work should not just be a list of things that you would have done if you had a little more time. Talk about new things that are possible now that you have finished your project. What projects could an ENGR489 student tackle next year if they started from your end point?

## 7.1  Conclusion

## 7.2  Future Work

# Bibliography

[1] "Implementing a step-direction interface-based stepper motor controller," *Application Note AC413*, pp. 1–9, 2014.

[2] "Stepping motors and their microprocessor controls, second edition takashi kenjo & akira sugawara, 1994 oxford, oxford university press isbn 0 19 859385 6," *European Journal of Engineering Education*, vol. 20, no. 3, pp. 386–386, 1995.

[3] E. Gatapova, A. Semenov, D. Zaitsev, and O. Kabov, "Evaporation of a sessile water drop on a heated surface with controlled wettability," *Colloids and Surfaces A Physicochemical and Engineering Aspects*, vol. 441, pp. 776–785, 01 2014.

[4] J. H. Moon, D. Kim, and S. Lee, "Spreading and receding characteristics of a non-newtonian droplet impinging on a heated surface," *Experimental Thermal and Fluid Science*, vol. 57, 09 2014.

[5] P. Hänichen, A. Bender, B. Voß, T. Gambaryan-Roisman, and P. Stephan, "Drop evaporation of hydrocarbon fluids with deposit formation," *International Journal of Heat and Mass Transfer*, vol. 128, pp. 115–124, 01 2019.

[6] M. Frasão, A. Oliveira, and R. Gonçalves dos Santos, "Determination of nukiyama and leidenfrost temperatures for hydrocarbons using the droplet evaporation method," 03 2018.

[7] S. David, K. Sefiane, and L. Tadrist, "Experimental investigation of the effect of thermal properties of the substrate in the wetting and evaporation of sessile drops," *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 298, pp. 108–114, 04 2007.