ILLINOIS TECH
Armour College of Engineering

Autonomous control using automated image analysis

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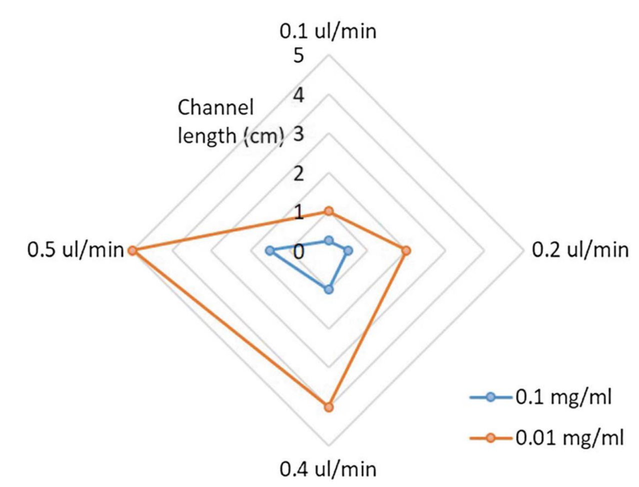
GitHub *https://github.com/Juhyunn0/Autonomous-control-using-automated-image-analysis*

Introduction

- Microfluidic cell culture platforms, including tissue-chip models, have emerged as pivotal tools in the development of therapies for obesity and cardiovascular diseases. [1], [2]
- These platforms provide a more physiological microenvironment for cells through features like perfusion, which enhances cell health and function.
- However, a significant challenge lies in the real-time measurement of cellular function within these microfluidic systems.
- While previous studies have demonstrated improved accuracy using inline methods, the current approach still relies on manually determining optimal flow rates for each experiment, leading to inefficiencies and susceptibility to errors. [1]



Plot representing the relationship between the channel dimensions, flow rate, and the concentration of the antibody [1]

Motivations

- The motivation behind this research is to address the inefficiencies and vulnerabilities in current methods of measuring cellular function in microfluidic systems.
- By developing a feedback control system that integrates automated microparticle tracking and analysis with imaging technology, this study aims to overcome the limitations posed by manual flow rate adjustments.
- This innovative approach promises to advance the capabilities of microfluidic platforms in biomedical research and therapeutic development.

Background

- **PID control**

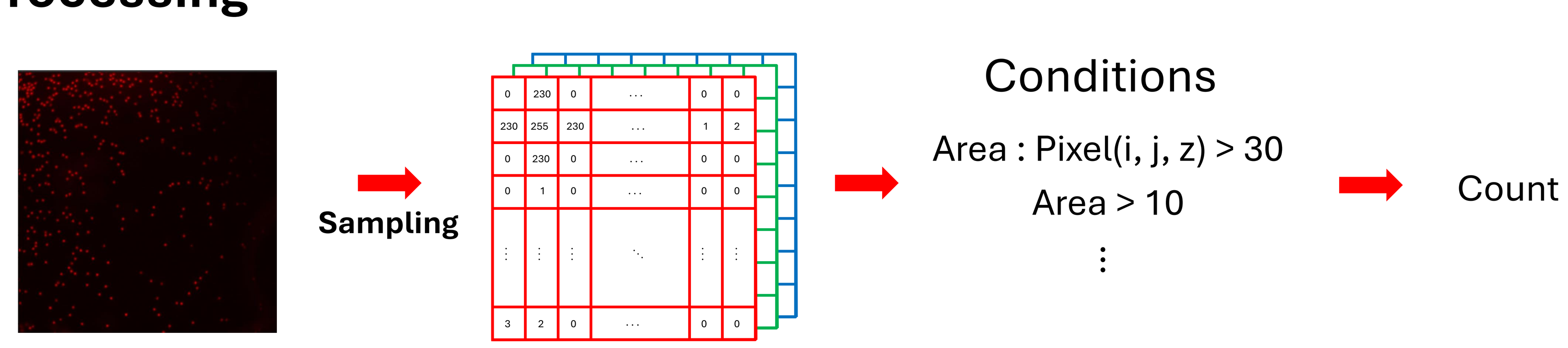
Proportional-Integral-Derivative (PID) control is a widely used control algorithm in industrial and engineering applications. It combines three control actions:

Proportional(P)	- Adjusts the control output proportionally to the error
Integral(I)	- Sums the error over time to eliminate steady-state errors
Derivative(D)	- Predicts future errors based on their rate of change

$$K_p \cdot e(t) + K_i \cdot \int e(t)\,dt + K_d \cdot \frac{de(t)}{dt}$$

K_p: *Proportional Gain*
K_i : *Integral*
K_d : *Derivative Gain*
$e(t)$: *error*

- **Image Processing**



Conditions

Area : Pixel(i, j, z) > 30
Area > 10
⋮

Count

Aim of the study

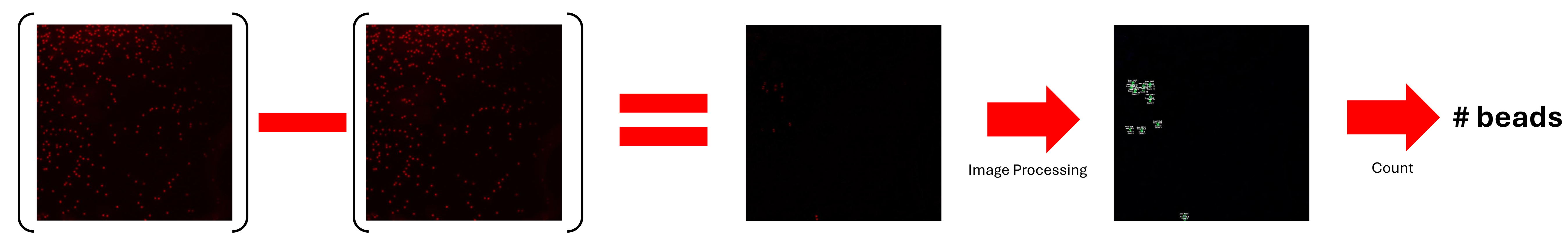
Develop and test **a feedback control system to capture and analyze images of moving particles,** using external hardware like pumps to adjust bead numbers based on user-defined goals.

Methods

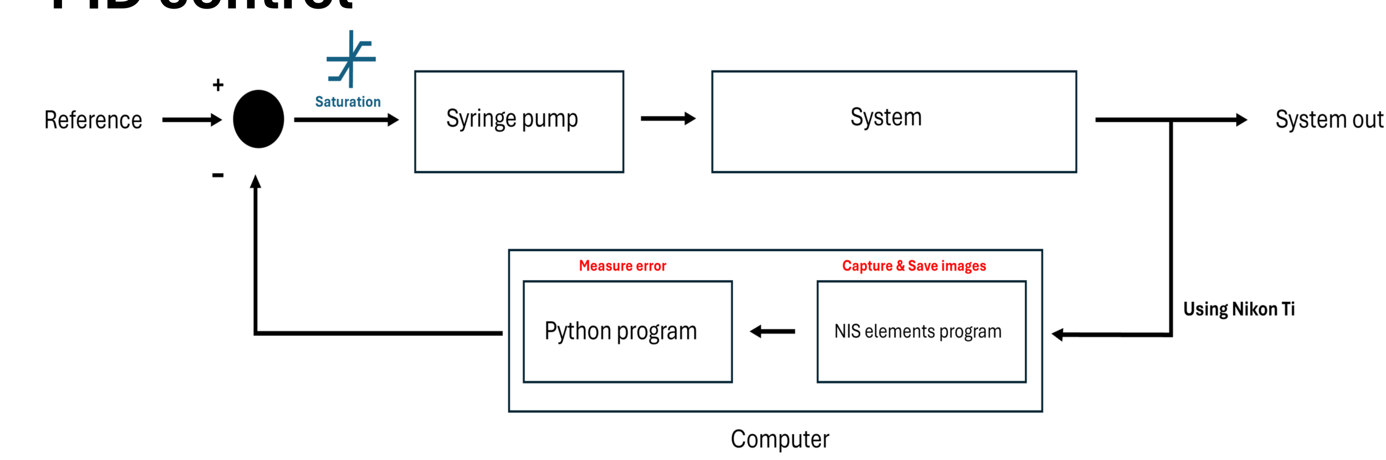
- **Image Processing**

Noise Reduction and Static Object Exclusion in Image Processing

Implementing Background Subtraction and Noise Reduction for Dynamic Object Detection



- **PID control**

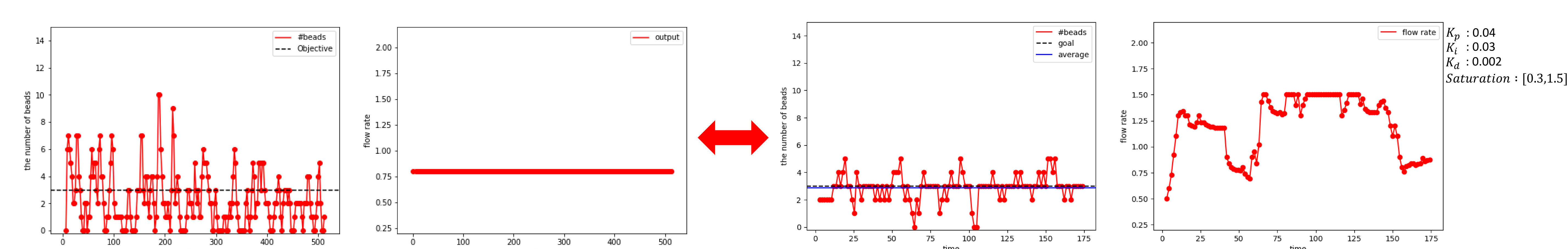


<Block Diagram schematics of closed-loop control systems>

Empirical PID Parameter Tuning

Given the unknown mathematical relationship between flow rate and bead quantity, a manual testing approach was employed to optimize PID parameters

Results



<Without PID control> <With PID control>

Using PID control significantly reduces the error in bead quantity adjustment compared to maintaining a constant flow rate without PID control

Conclusions

The integration of PID control and advanced image processing techniques has enabled accurate and automated adjustment of bead quantities according to user-specified targets

References

[1] Q. Luan, S. Cahoon, A. Wu, Shyam Sundhar Bale, M. Yarmush, and A. Bhushan, "A microfluidic in-line ELISA for measuring secreted protein under perfusion," Biomedical microdevices, vol. 19, no. 4, Nov. 2017, doi: https://doi.org/10.1007/s10544-017-0244-6.

[2] S. Karnik, C. Lee, A. Cancino, and A. Bhushan, "Real-time measurement of cholesterol secreted by human hepatocytes using a novel microfluidic assay," Deleted Journal, vol. 06, no. 03n04, pp. 135–141, Sep. 2018, doi: https://doi.org/10.1142/s2339547818500097.

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