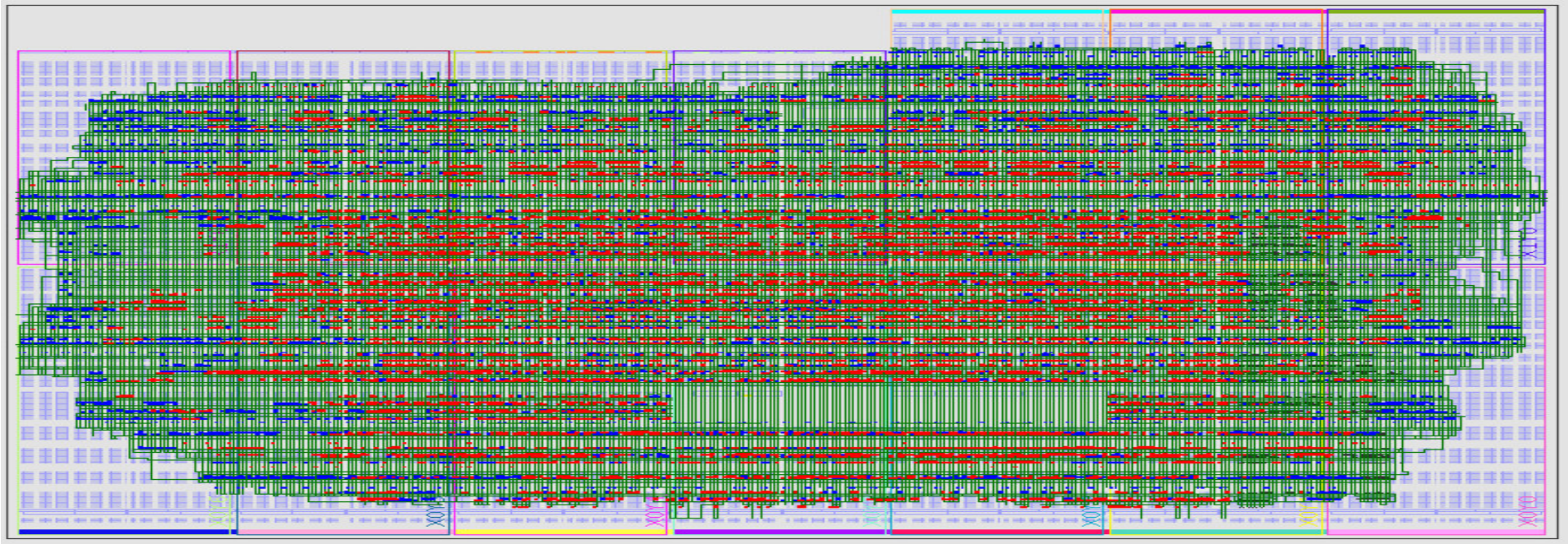

Implementation, Modeling, and Exploration of Precision Visual Servo Systems

Zhenyu Ye
Dynamics and Control
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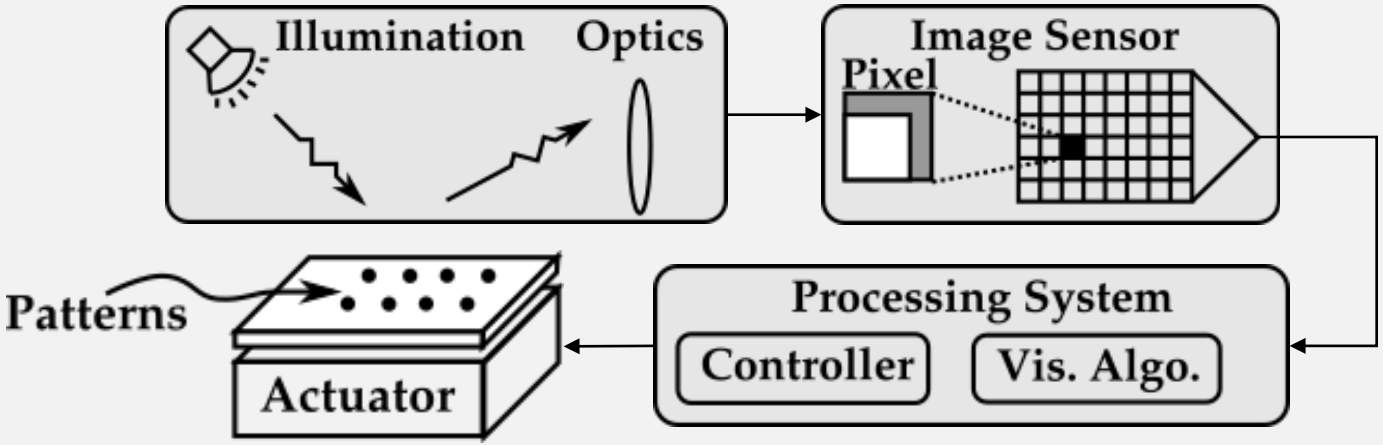
Introduction: Visual Servo Systems

Using visual feedback for control purposes.



Advantage: measurement at the point of interest.

Research Challenges

Challenge 1:

Visual feedback: low **sample rate,** large **delay,** coarse **quantization**.

Challenge 2:

Control law design for **characteristics** of visual feedback.

Challenge 3:

An **early estimation** of delay in **customized** vision systems.

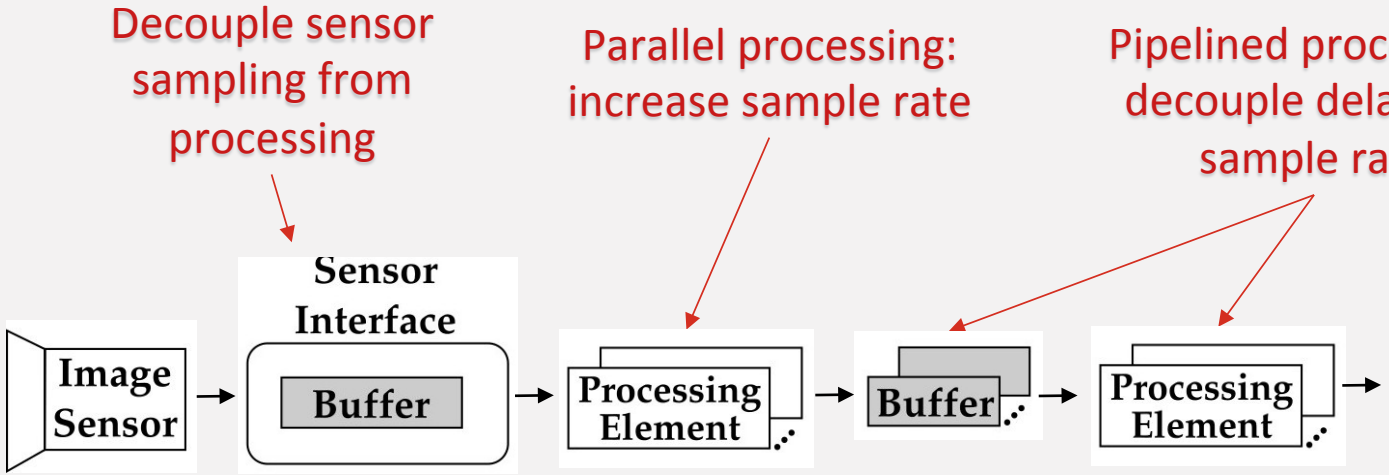
Challenge 4:

Cross-domain **modeling** and **exploration** of design trade-offs.

Challenge 1 and Contribution

Visual feedback: low **sample rate,** large **delay,** coarse **quantization**.

Contribution: design method for high-speed, high-precision vision systems.



Implementation:
Sample rate: >1khz
Delay: <2ms
Quantization: <1um

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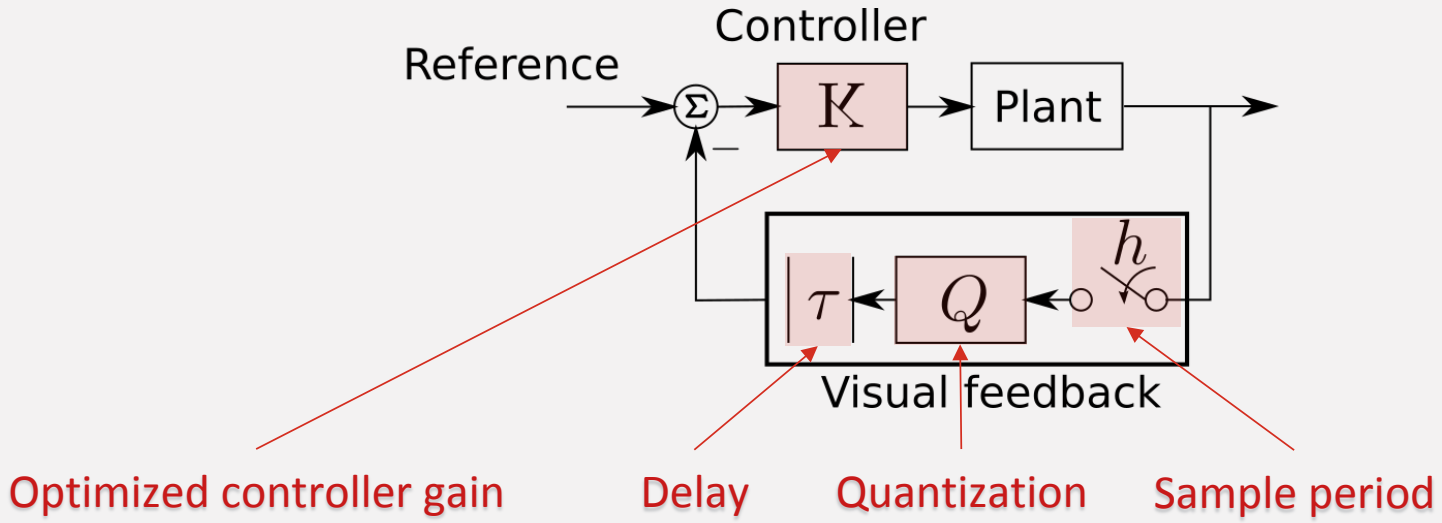
Challenge 2 and Contribution

Control law design for **characteristics** of visual feedback.

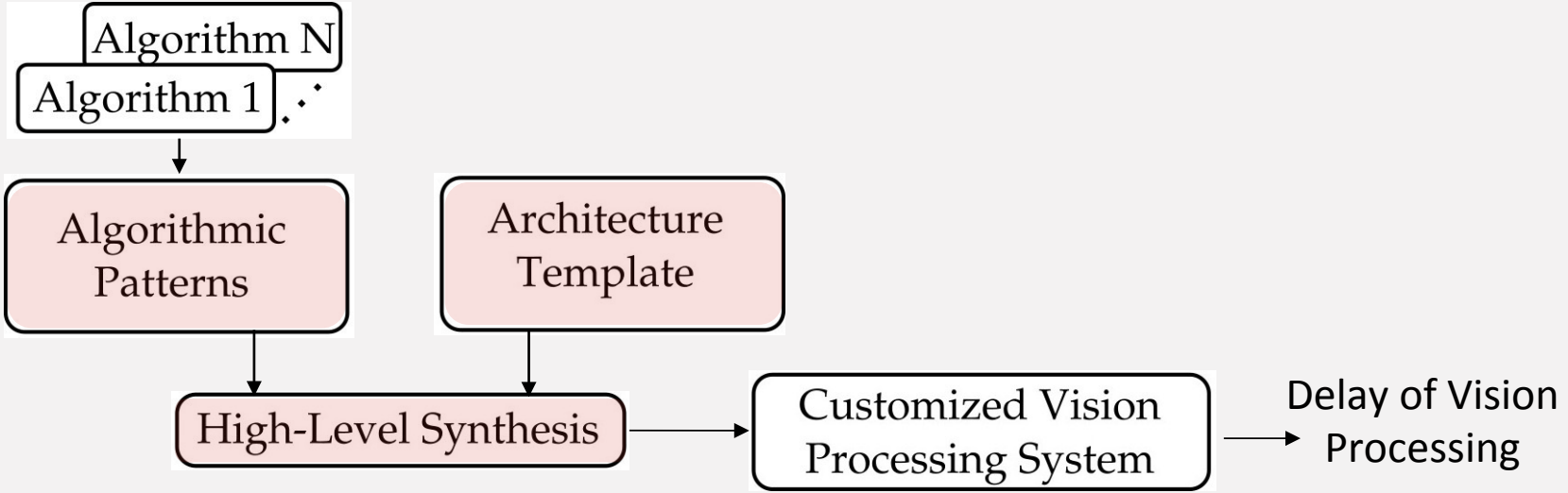
Contribution: controller synthesis and optimization for visual feedback.



Challenge 3 and Contribution

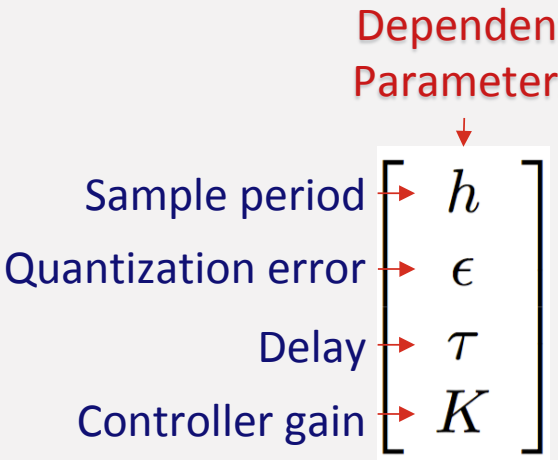
An **early estimation** of delay in **customized** vision systems.

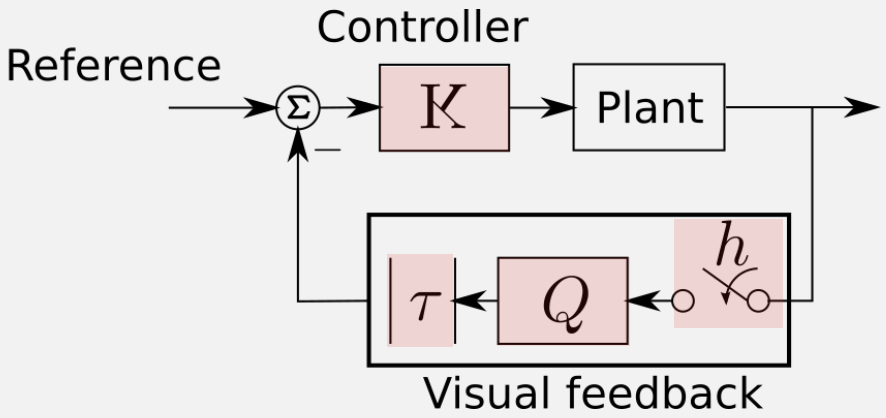
Contribution: algorithmic patterns, architecture template, high-level synthesis.



Challenge 4 and Contribution

Cross-domain **modeling** and **exploration** of design trade-offs.





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Challenge 4 and Contribution

Cross-domain **modeling** and **exploration** of design trade-offs
Contribution: cross-domain modeling using **axiomatic design** method.

Dependent Parameters

Design Matrix

Design Parameters

$\star$: Dependence
0 : Independence

$$\begin{bmatrix} h \\ \epsilon \\ \tau \\ K \end{bmatrix} = \begin{bmatrix} \star & 0 & 0 & 0 \\ \star & \star & 0 & 0 \\ \star & \star & \star & 0 \\ \star & \star & \star & \star \end{bmatrix} \begin{bmatrix} I_s \\ alg. \\ arch. \\ P \end{bmatrix}$$

Sample period → h
Quantization error → ϵ
Delay → τ
Controller gain → K

I_s ← Image sensor
$alg.$ ← Vision algorithm
$arch.$ ← Processing architecture
P ← Plant

Performance criteria →

Precision → $RMSE = f_1(\epsilon, h, \tau, K)$
Bandwidth → $BW = f_2(\epsilon, h, \tau, K)$

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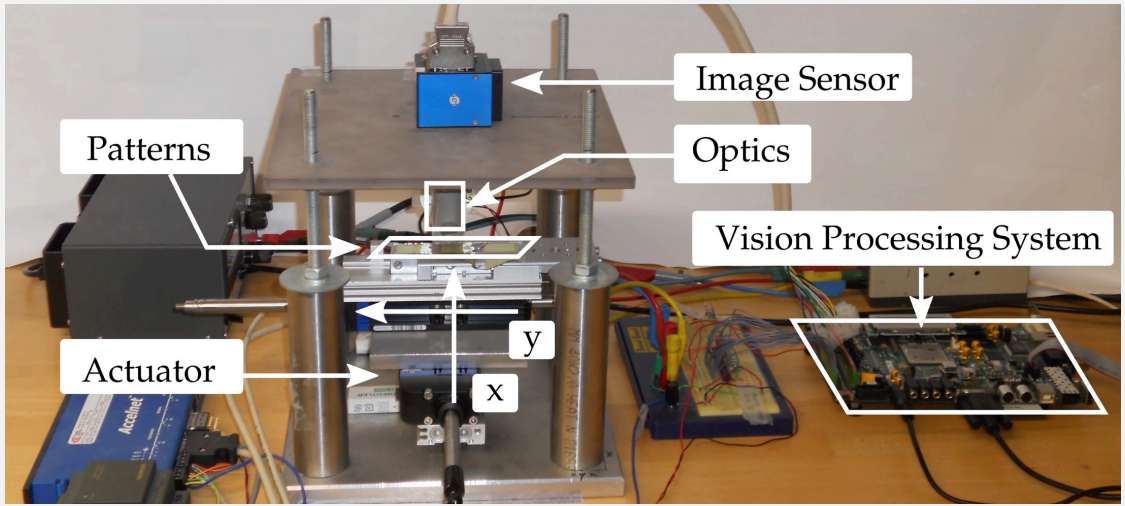
Implementation and Exploration

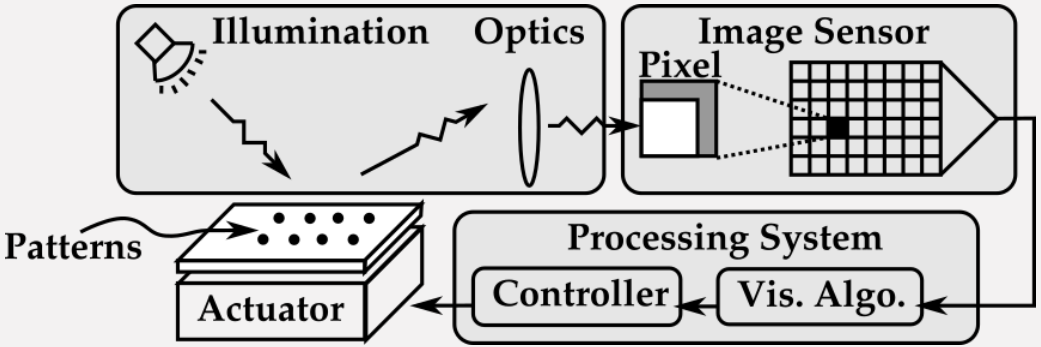
Implementation: validation of design methods.



Exploration: optimization of performance with cost constraint.

Result: performance improvement
- 20% for **high-precision** application
- 43% for **high-bandwidth** application

Conclusions



Contributions of this thesis:

1. Methods to **design** high-speed, high-precision visual servo systems.
2. Methods to perform cross-domain **modeling** and **exploration**.
3. By **implementation** and **case study**, these methods are demonstrated to be effective.