

# Real-time Control Using Shell Script Based on The UNIX Philosophy

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# Correction

- ▶ P6. Bottom row in left column
- ▶ Wrong: " $\Delta = 0.01 \text{ ms}$ "
- ▶ Correct: " $\Delta = 10 \text{ ms}$ "

# Introduction

- ▶ As IoT devices become more complex, use embedded Linux
  - ▶ Connect to the network
  - ▶ Communication with peripherals
- ▶ Vulnerability of embedded devices that have been used for a long time becomes a problem
  - ▶ Software sustainability and portability are important
- ▶ Shell script-based development methods (especially those compatible with POSIX) are receiving attention and are not easily affected by operating system updates.

# Research purposes

- ▶ Proposed method
  - ▶ Established use shell script Real-time control method, the method emergency durability
- ▶ Authentication method
  - ▶ Stabilize the inverted pendulum using the proposed method

# Related Work

Improved the compatibility of real-time control

Real-time kernel  
( RTLinux / ART-Linux )

Sleep system call  
Regular processing  
[Kumagu et al., 2004]

Improve software sustainability

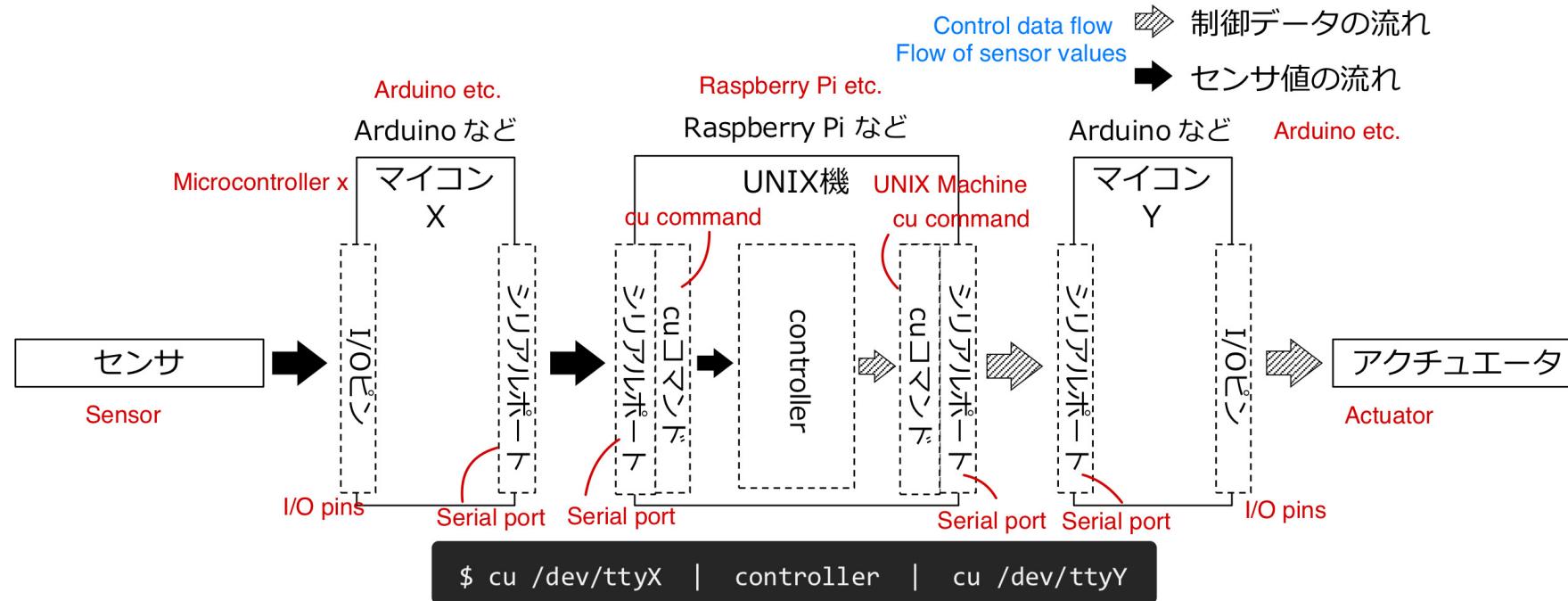
POSIX centralism  
programming  
POSIX-compliant  
development method  
using shell scripts  
[Matsuura et al. 2017]

Monogramming  
Apply the method of  
Matsuura et al. to  
manufacturing  
[Ohno et al., 2017]

Apply Ohno et al.  
method to (real-time)  
control  
  
(This research)

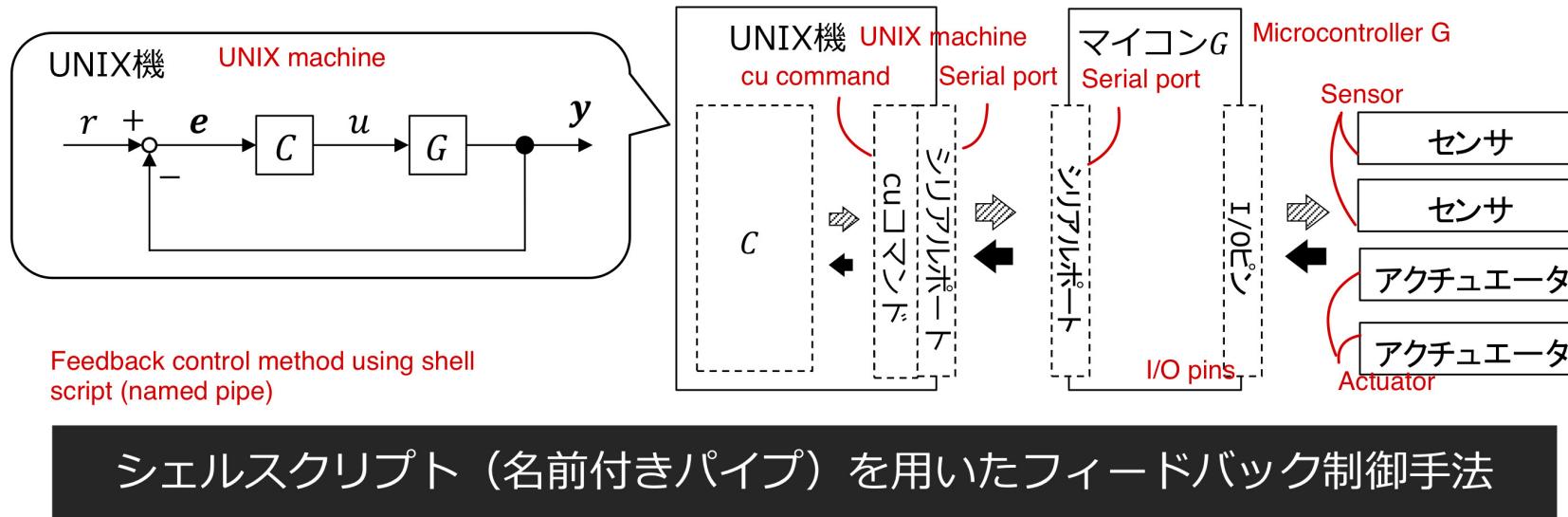
# Previous Research

- ▶ Monogramming2-Communication method between microcotrollers considering compatibility and sustainability
- ▶ Convert data using UNIX machine



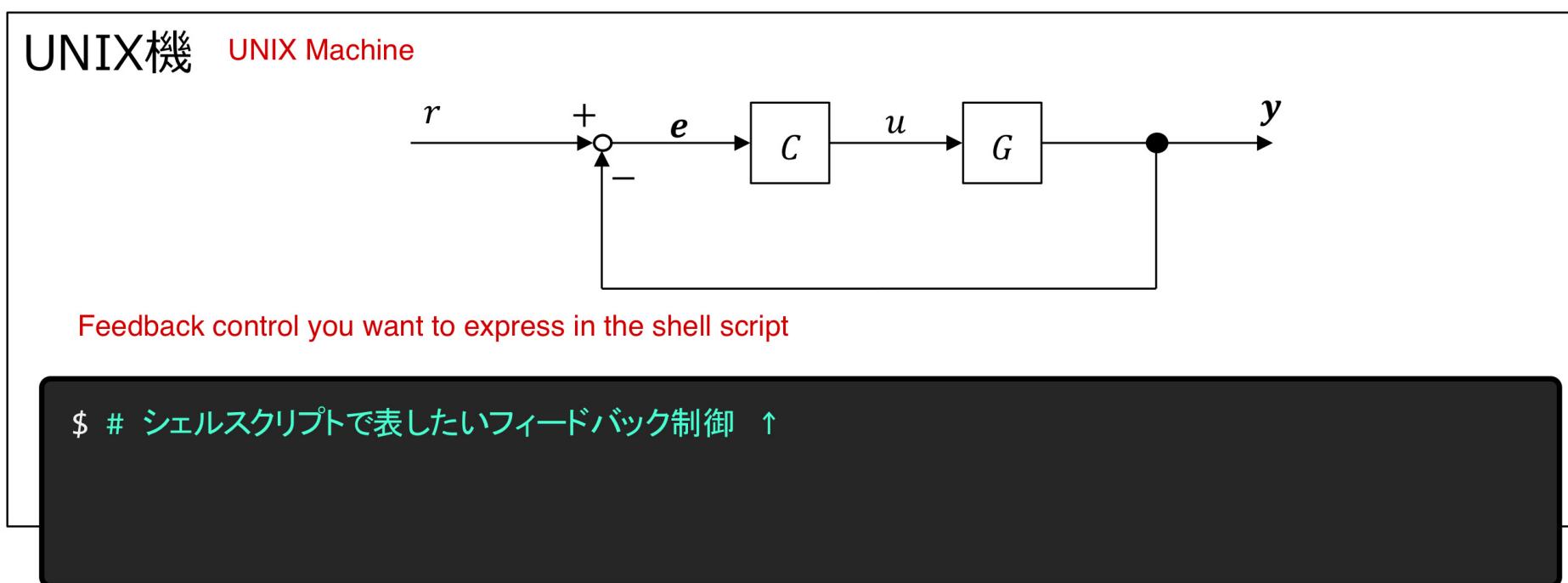
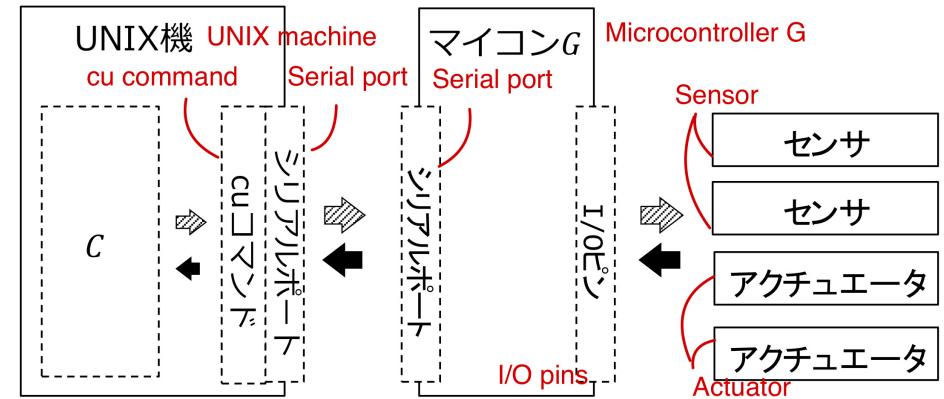
# Feedback system used in this study

- ▶ Role division according to "Monogramming 2"
  - ▶ Microcontroller: sensor/actuator management
  - ▶ UNIX machine: control amount calculation
- ▶ Linux is used on UNIX machines, the kernel is not tampered with (improves sustainability)



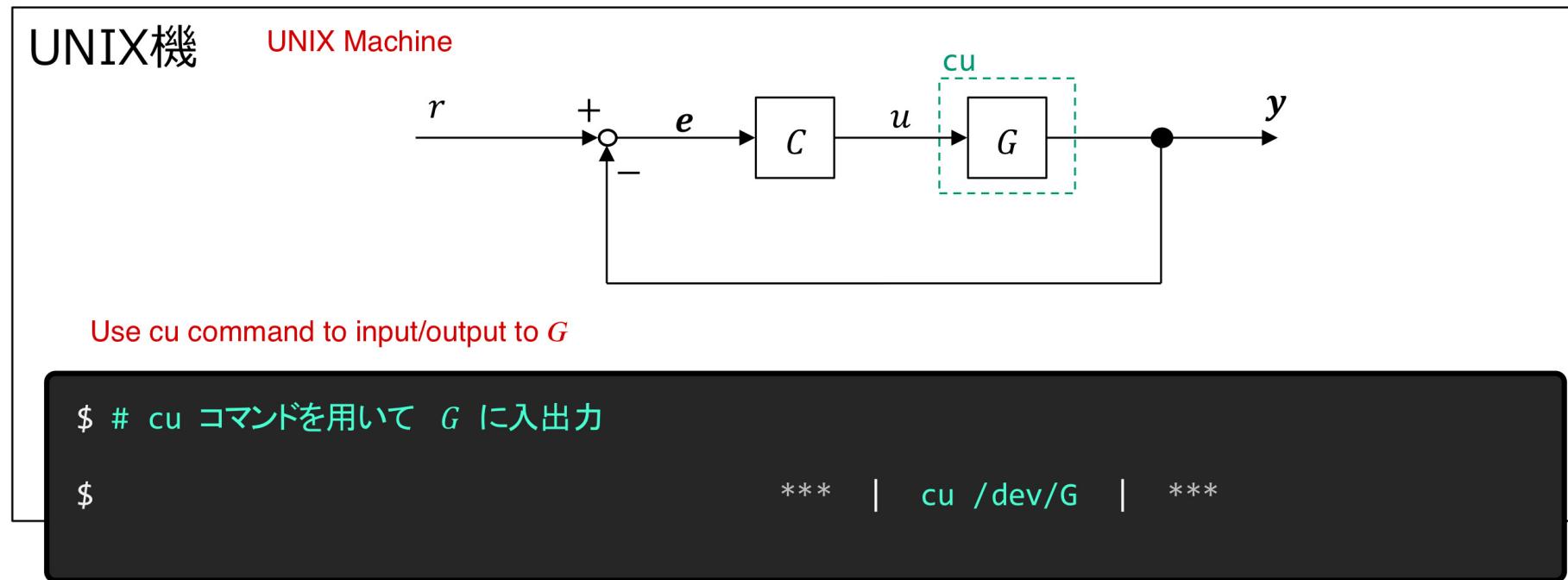
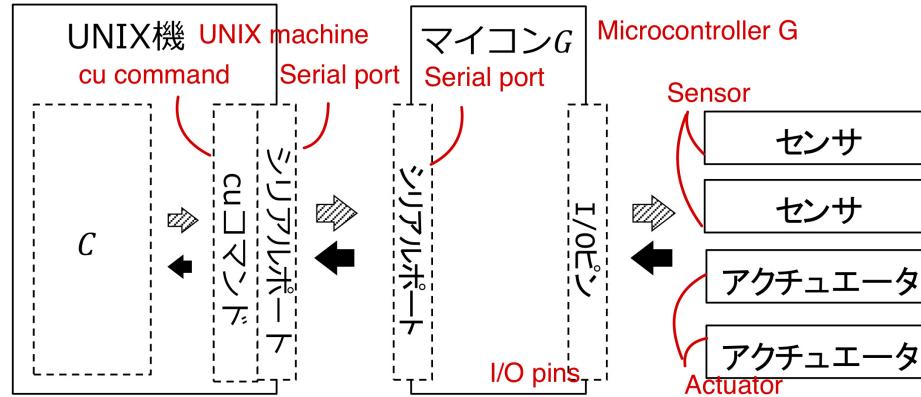
# Proposed method

- ▶ Use shell scripts for feedback control



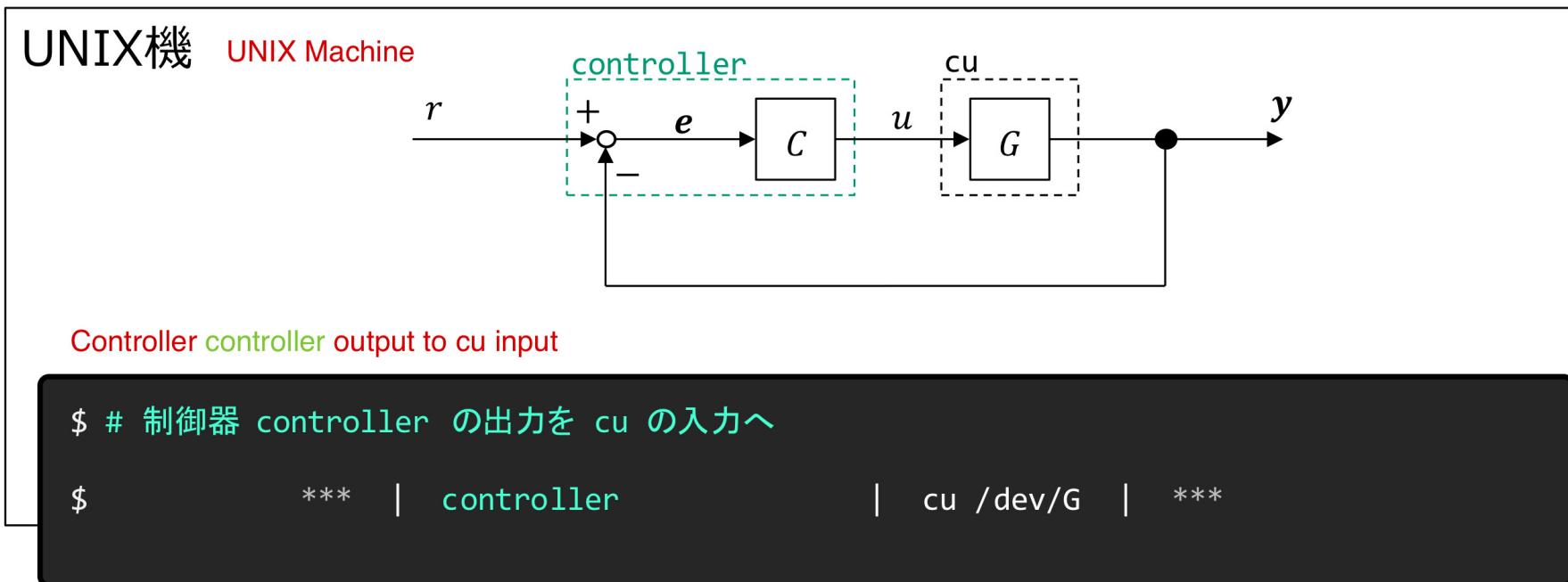
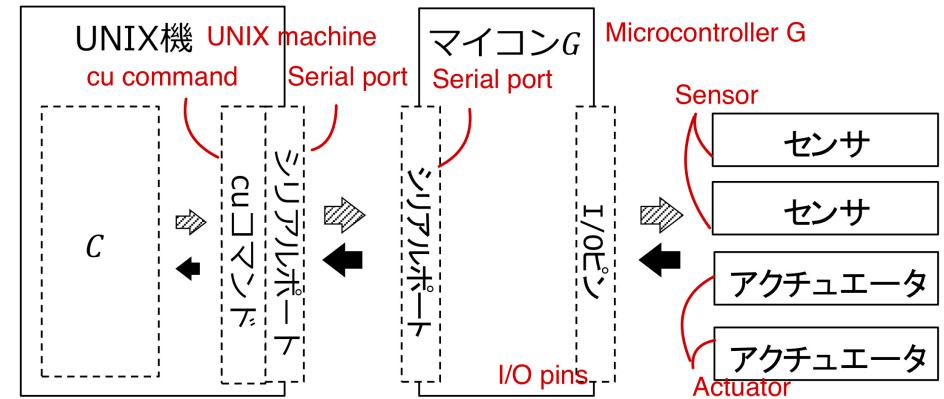
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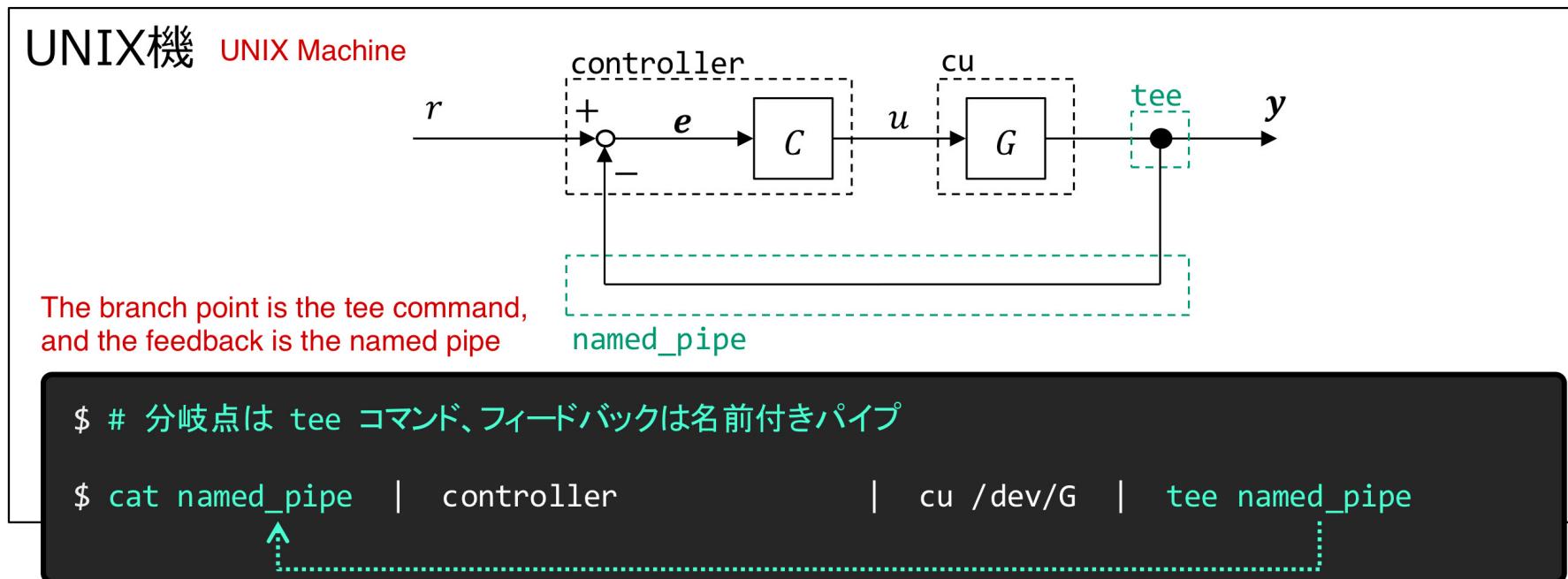
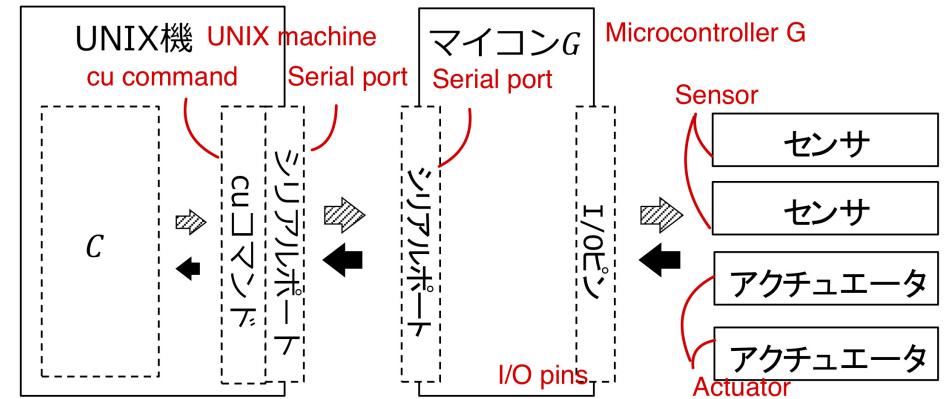
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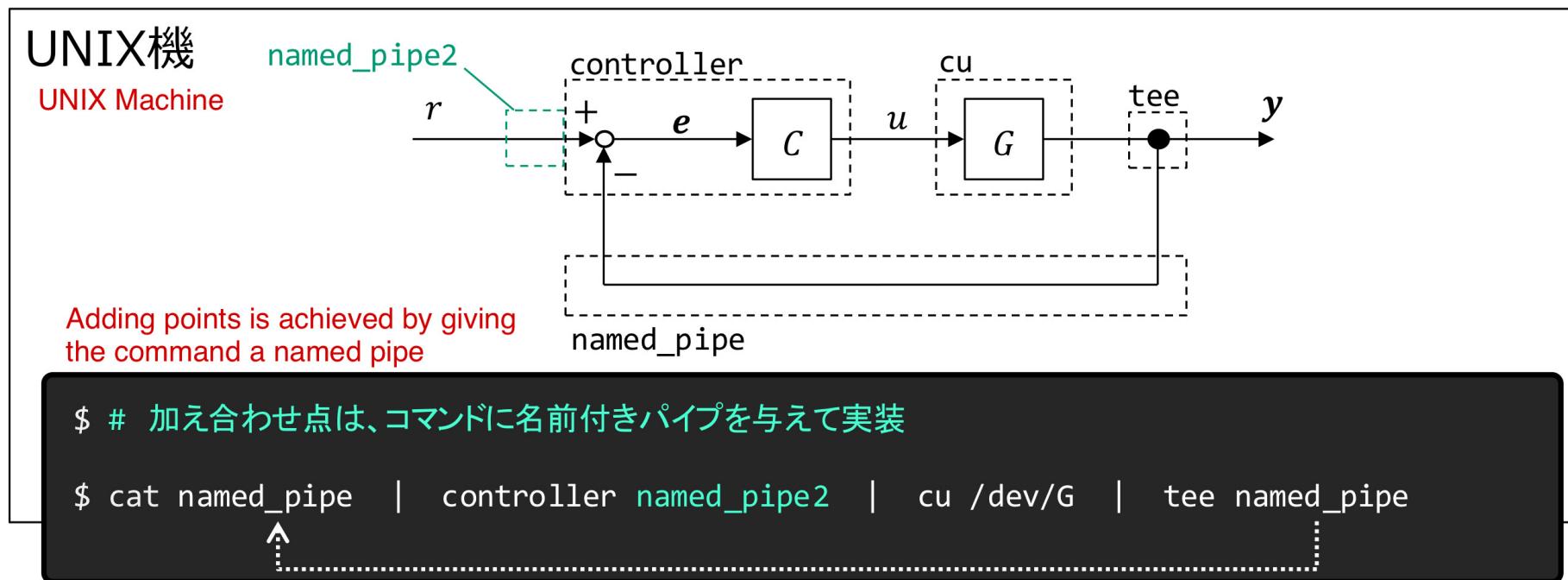
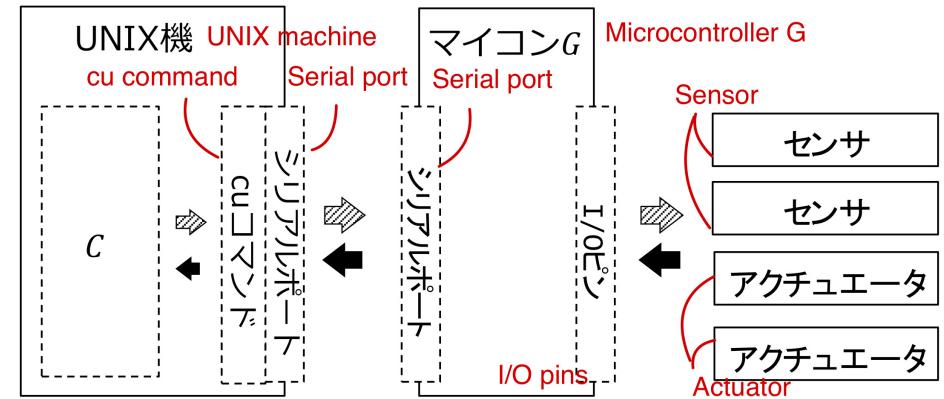
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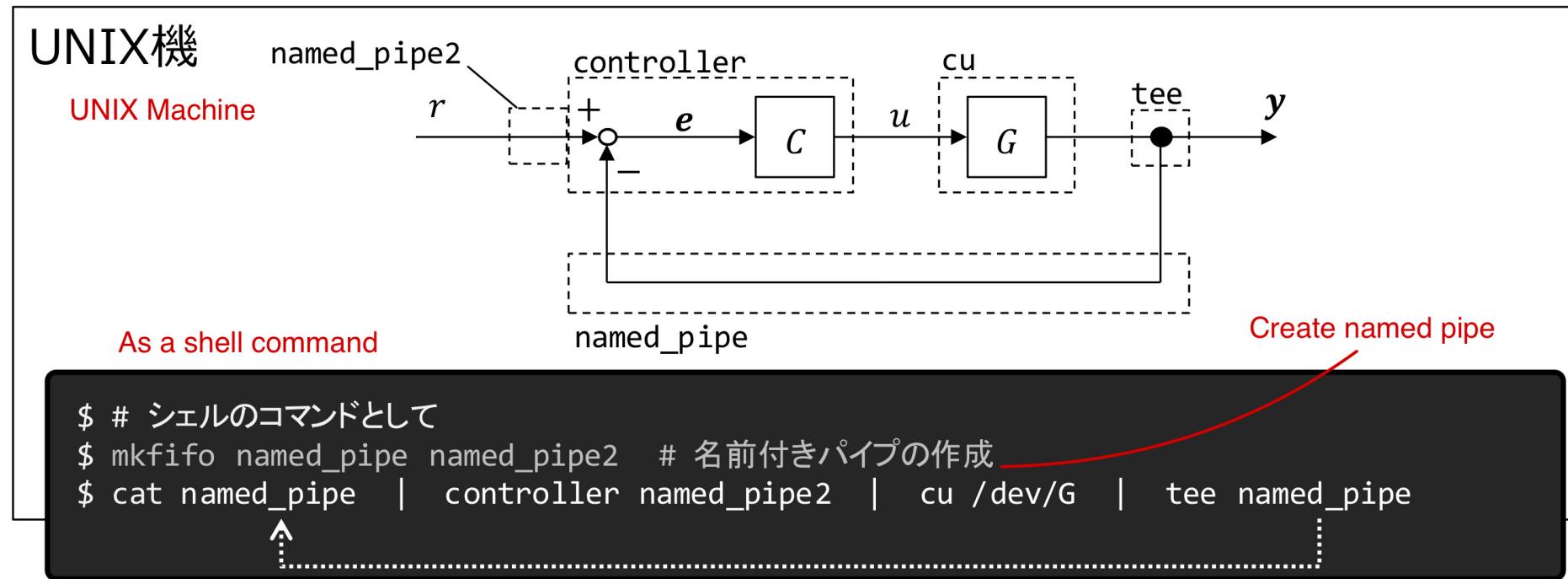
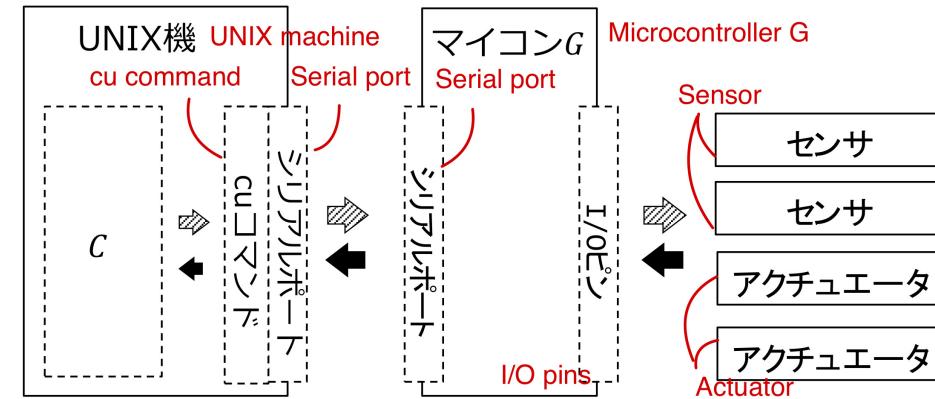
# Proposed method

- ▶ Use shell scripts for feedback control



# Proposed method

- ▶ Use shell scripts for feedback control



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# Relationship with UNIX philosophy [Gancarz 1995] (9 theorems)

Among the nine theorems, the one that satisfies

- ▶ Connect and execute programs (commands) dedicated to each function (Theorem 1, Theorem 2)
- ▶ Efficiency < Portability (Theorem 4)
- ▶ Numerical data is output in ASCII (Theorem 5)
- ▶ The use of shell scripts (Theorem 7)
- ▶ Design the program as a filter (Theorem 9)

# Advantages of the proposed method

As a shell command

```
$ # シェルのコマンドとして  
$ mkfifo named_pipe named_pipe2 # 名前付きパイプの作成  
$ cat named_pipe | controller named_pipe2 | cu /dev/G | tee named_pipe
```

named\_pipe

Create named pipe

Shell script

- ▶ Improve sustainability and compatibility (the main purpose of this research)

Pipeline

- ▶ Natural realization of block diagram

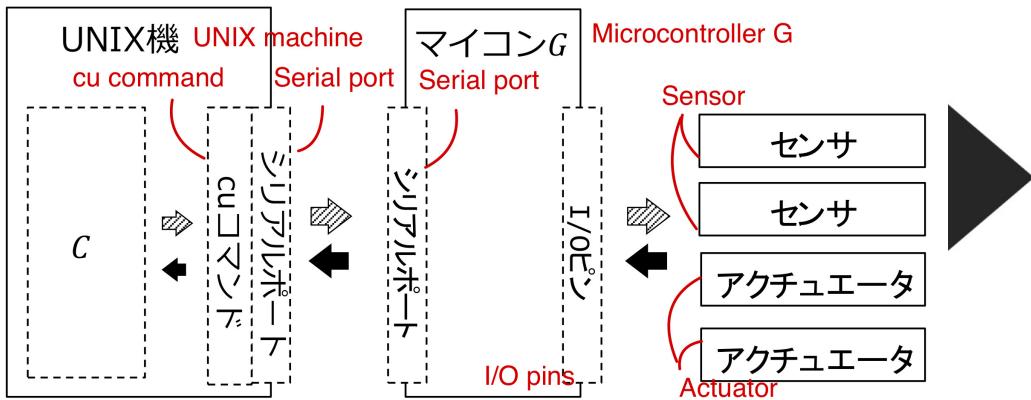
Command

- ▶ The control algorithm can be easily changed by replacing

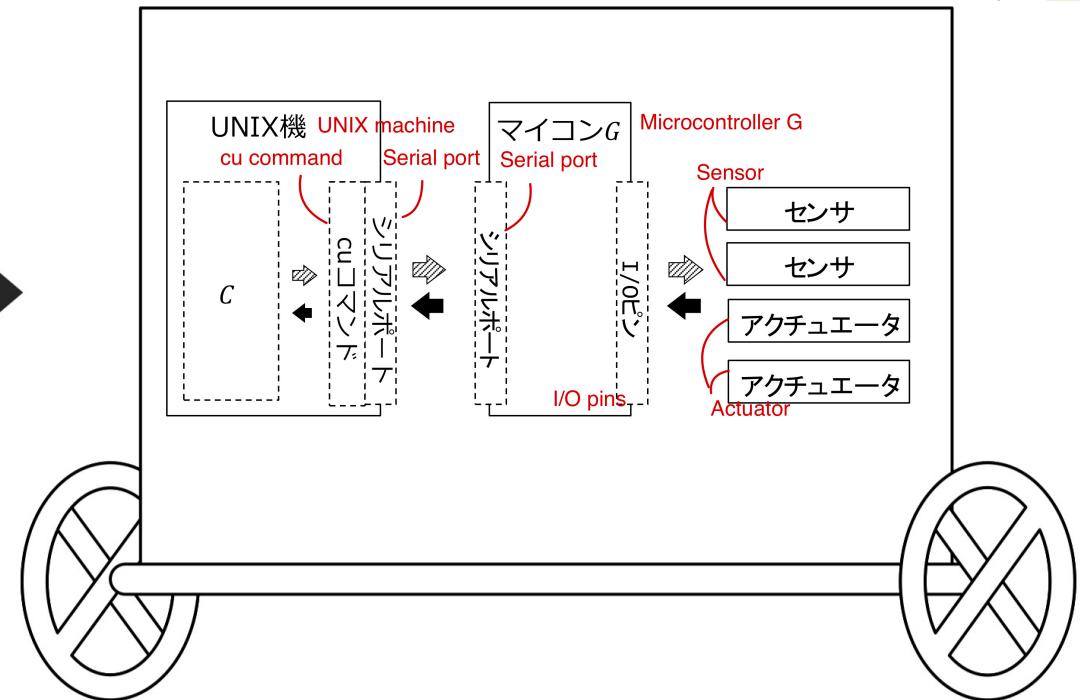
# Stability of the inverted pendulum used for verification

Especially the so-called coaxial two-wheeled models

Proposed method



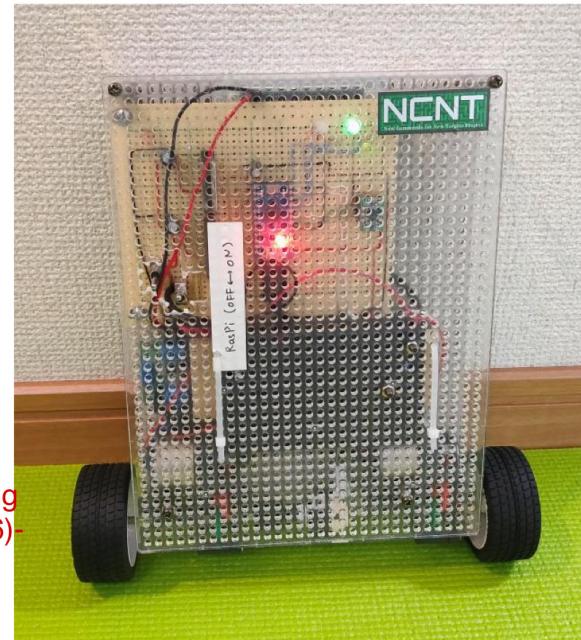
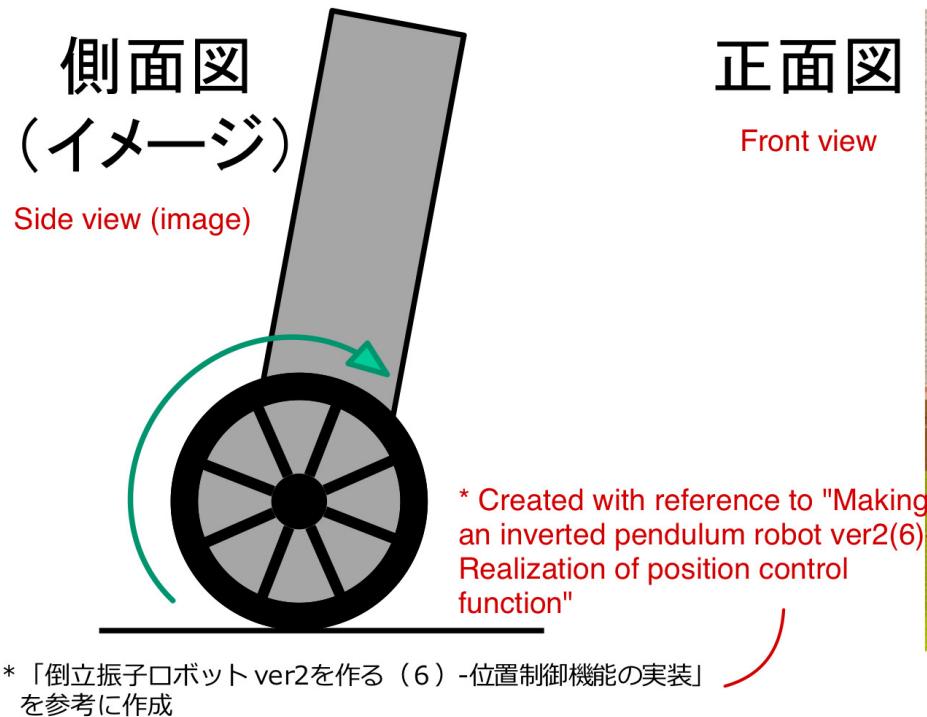
Method to verify validity



# Inverted Pendulum

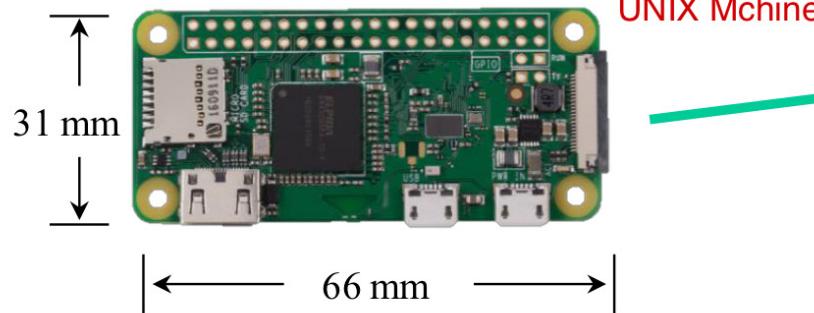
Independent motorcycle

- ▶ If you cannot control it, it will fall, but if you can control it, it can reverse it.



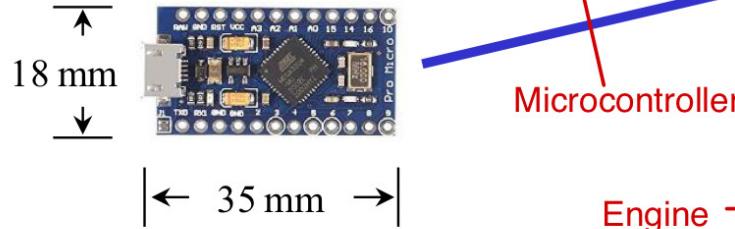
# Assemble

Raspberry Pi Zero (UNIX機)



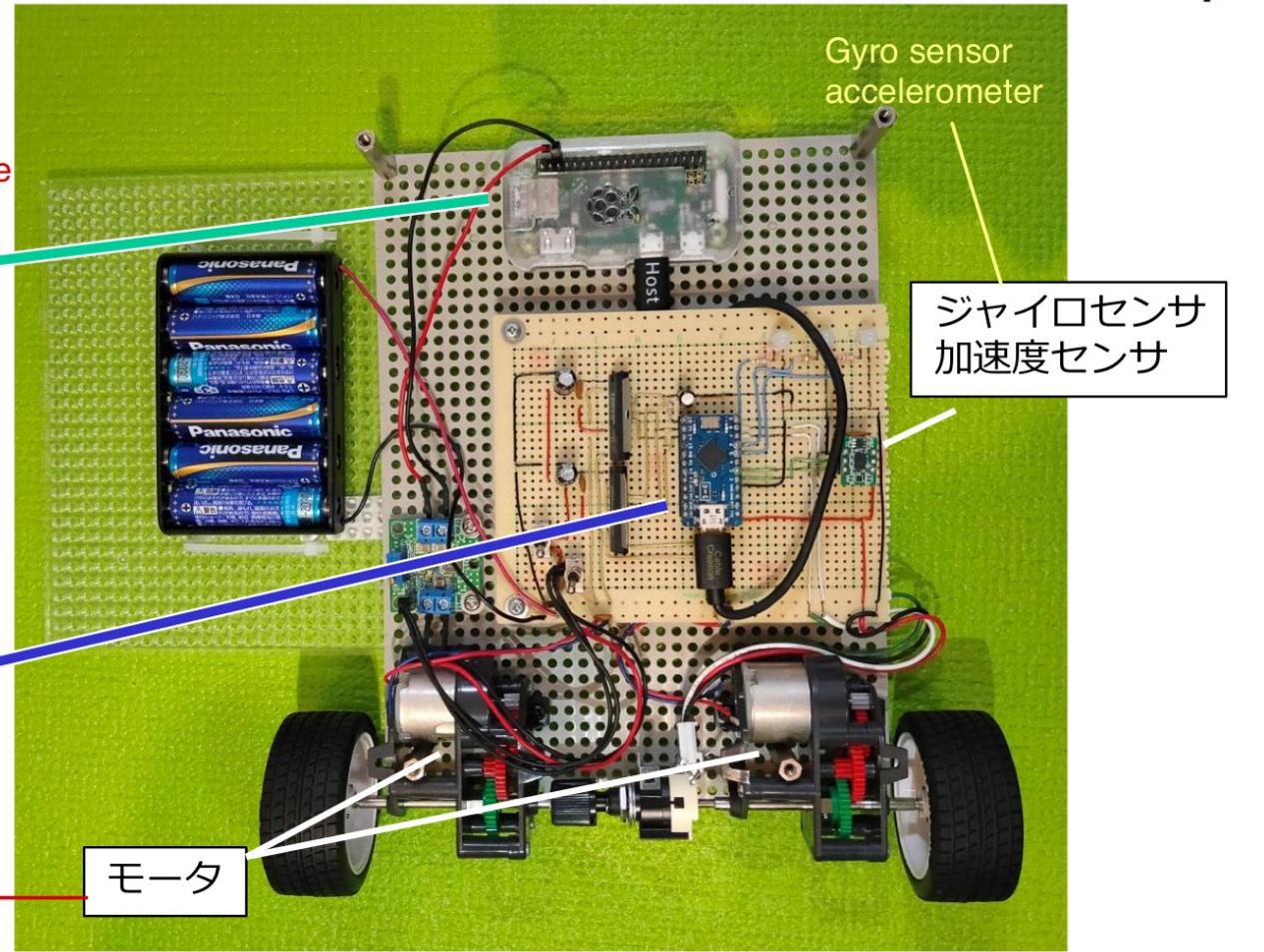
UNIX Mchine

Arduino Pro Micro (マイコン)



Microcontroller

Engine モータ



# Stability of inverted pendulum

デモ動画 Video



<https://www.youtube.com/watch?v=Ixh-YFtMypY>

# Stability control command

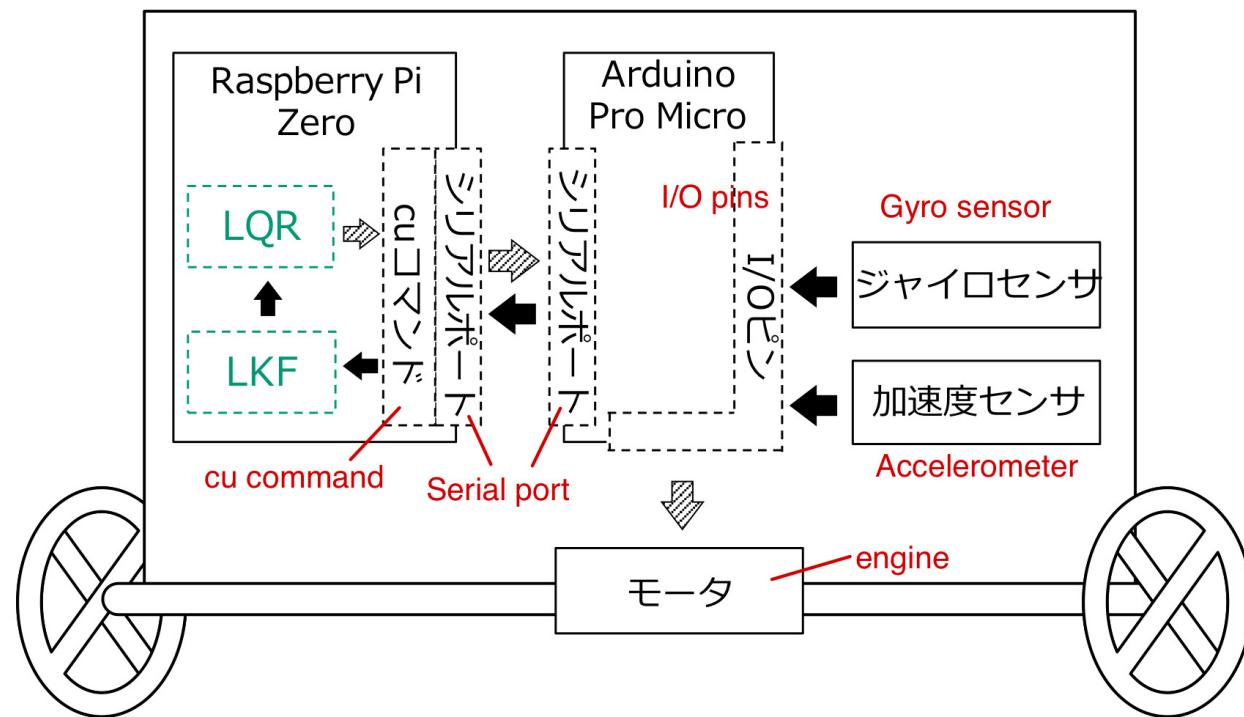
Create and use two commands instead of the controller

LQR (Linear Quadratic Regulator)

- ▶ Control amount calculation

LKF (Linear Kalman Filter)

- ▶ Noise reduction

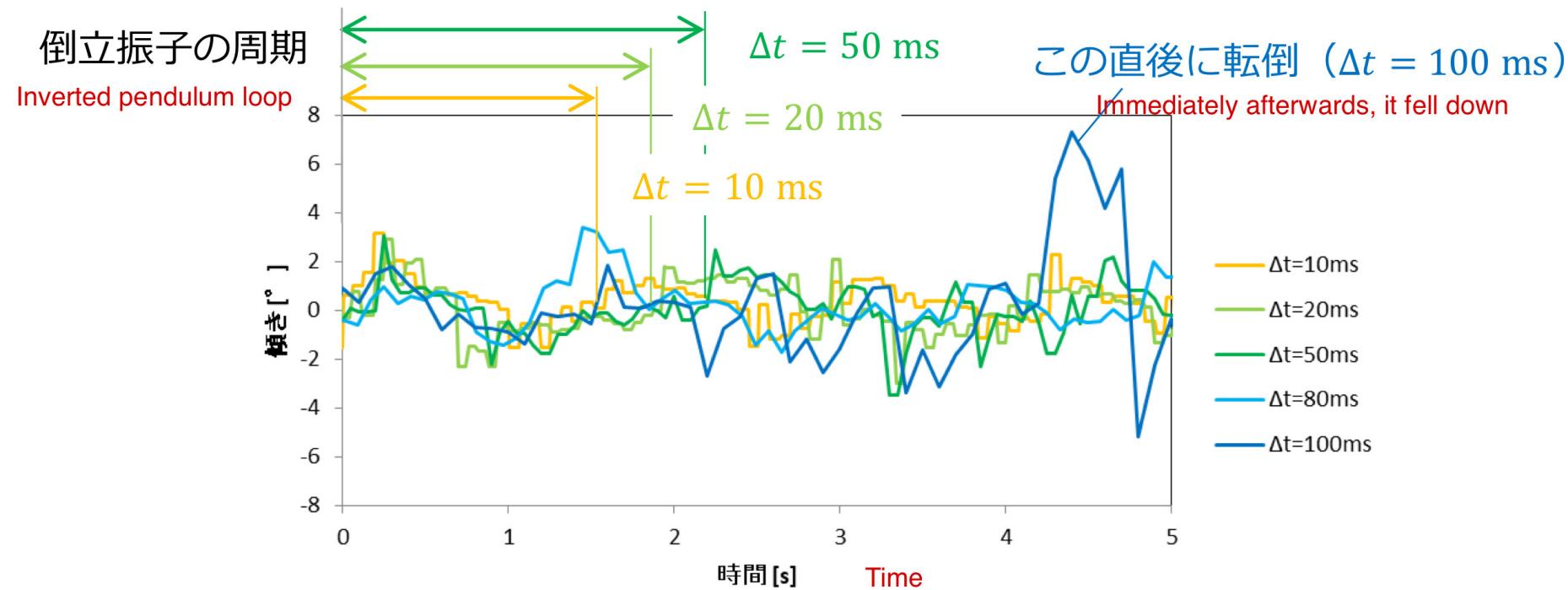


LKF needs sampling interval  $\Delta t$  for calculation

- ▶ Operation verification at  $\Delta t = 10 \text{ ms} \sim 100 \text{ ms}$

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# Sampling interval $\Delta t$ behavior when the inverted pendulum changes



- ▶ Shorter  $\Delta t$  makes repetitive exercises faster

# Conclusion

- ▶ A real-time control method using shell script is proposed
  - ▶ Implement block diagram data flow in shell script flow
- ▶ The proposed method stabilizes the coaxial two-wheeled vehicle type inverted pendulum
- ▶ Shows the potential to bring a high degree of sustainability and compatibility to control software

# Future Work

- ▶ Move the inverted pendulum back and forth according to external instructions
- ▶ Conditions under which this method can be applied
  - ▶ Inverted pendulum behavior when the sampling interval  $\Delta t$  is small
  - ▶ The relationship between the physical properties of the inverted pendulum and the proposed method
- ▶ Operate the inverted pendulum from the outside/move on a plane

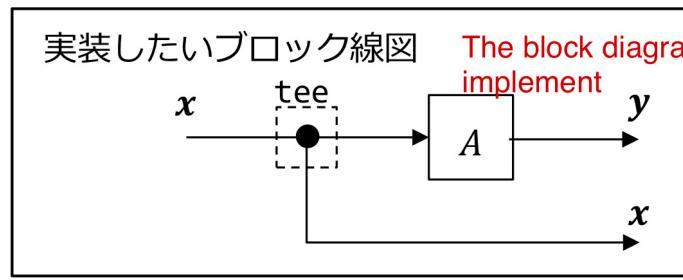
# FAQ

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# FAQ Q1

How to apply the proposed method as a mechanical algorithm to complex block diagrams

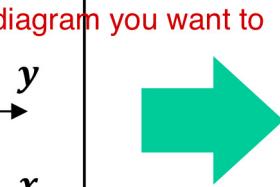
- ▶ Correct parallel processing after connecting the branch points in series.



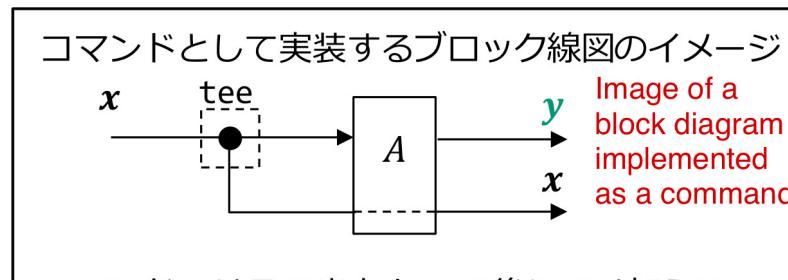
$x$  のデータ

$xData$

```
$ cat x  
x1  
x2  
x3  
...
```



Command A is designed to add its output after  $x$



コマンド A はその出力を  $x$  の後につけて加えるという設計

```
$ cat x | A  
x1 y1  
x2 y2  
x3 y3  
...
```

# FAQ Q2

Even if it can be configured as a simple pipeline in normal processing, what if something goes wrong?

- ▶ There are several error handling methods.
  1. Incorporate the error handling module into the block diagram
  2. Output so that it can be treated as an error and then discard all output at some point

```
$ cat np | cmd1 | drop-if-error | cmd2 | ... | tee np
```

- 3. Process the result output as standard error outside the pipeline

```
$ (cat np | cmd1 2>&3 | cmd2 2>&4 | ... | tee np) 3>cmd1.log 4>cmd2.log ...
```

# FAQ Q3

How much does it cost to make a similar inverted pendulum?

- ▶ About 20,000 yen

Total	About 20000 yen
<b>合計</b>	<b>約20000円</b>
Raspberry Pi Zero	1320
Arduino Pro Micro	1980
電源、モータ、センサ他	約16000
Power supply, motor, sensor, etc.	About 16000

# FAQ Q4

**When creating a set of tools to make the proposed method easy to use, what kind of control commands can be considered as a basis?**

- ▶ Since PID control is most commonly used in the field, PID control commands should be the basis.

# FAQ Q5

**The proposed method may make the data flow more difficult to understand than the block diagram.**

- ▶ Since it was created from a block diagram, the data flow is a bit confusing. Even if you write the control code, it is good to keep the block diagram based on it.

# FAQ Q6

**The proposed method is real-time control, but can it be guaranteed from input to output?**

- ▶ Currently, there is a trade-off between improving sustainability and portability, which I think is difficult to guarantee. In this study, it is assumed that the standard Linux kernel (the default scheduling algorithm of kernel version 4.19.66 is CFS) is used to improve portability and sustainability. In addition, this command does not change the priority.