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Design of Flow Control Algorithm Based on Estimation Models for Hydraulic Mobile Manipulators

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1. Introduction

The Korea Atomic Energy Research Institute (KAERI) has developed the ARMstrong robot, a hydraulic manipulator designed to perform response tasks in radiation disaster scenarios, replacing human operators in hazardous environments. The ARMstrong robot is developed with a human-like scale, allowing it to pass through standard doorways while maintaining a compact form factor. Despite its small size, the robot integrates a high-energy-density hydraulic system, enabling powerful actuation.

Conventional hydraulic systems are primarily utilized in large-scale machinery such as excavators and mobile cranes. However, the ARMstrong robot required a downsized and simplified hydraulic system due to its compact design. To address this challenge, a Micro Hydraulic Power Unit (MicroHPU) was developed, effectively overcoming these limitations by providing a downsized hydraulic supply system.

Nevertheless, during rapid movements of the ARMstrong robot, the MicroHPU exhibited limitations in supplying the required flow rate. In such cases, hydraulic flow imbalances or backflow occurred in specific joints, leading to control instability. As a result of these issues, unintended motion occurred in certain joints, along with significant variations in joint velocities, which degraded the robot's control stability.

To address these challenges, this study proposes a Flow Estimation Model, which estimates the hydraulic supply flow of the hydraulic power unit and the robot's demanded flow. Furthermore, based on this model, a Flow Distributor control algorithm is introduced to prevent the robot's required flow rate from exceeding the available hydraulic supply, thereby improving control stability.

2. Flow Estimation Model

To estimate the hydraulic supply flow of the mHPU and the required flow of the robot, it is essential to model the hydraulic system. However, due to the inherent nonlinear characteristics of fluid dynamics, as well as factors such as friction and leakage, mathematical modeling of hydraulic systems is highly complex and requires significant time and effort.

To overcome these challenges, this study proposes a simplified approach by constructing a Lock-up Table based on experimental data. In this model, the hydraulic supply capacity of the mHPU is represented as the "supply flow rate," while the robot's required output is expressed as the "demand flow rate."

2.1 Supply flow Estimation model

The HPU of a hydraulic dual-arm robot consists of a fixed displacement pump and an electric motor." o enhance energy efficiency, the supplied flow rate is adjusted in proportion to the position error. This supplied flow rate Q_{supply} is estimated using the pump's displacement per revolution (V_{pump}) and the motor's rotational speed (N_p).

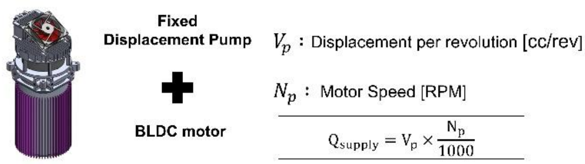

Fig. 1. Supply flow estimation model

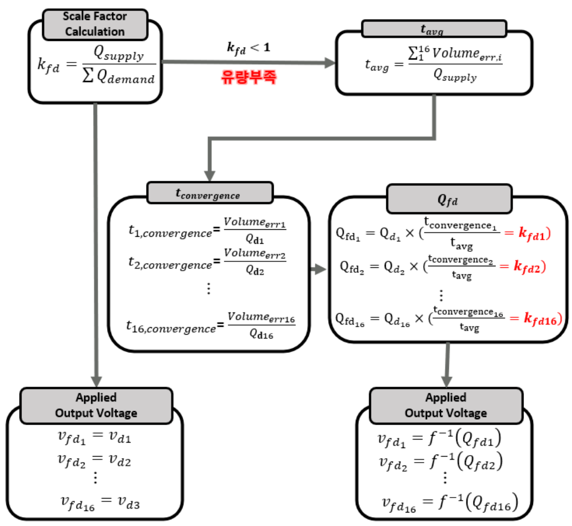

Fig. 2. Flow Control Algorithm.

2.2 Demand flow Estimation model

The voltage was applied as an input under various conditions. The flow rate along each axis was then measured as an output. Based on the experimental results, a Lock-up Table was constructed and utilized to develop a demand flow model.

3. Flow Control Algorithm

We developed a Flow Distributor to optimize flow distribution across each axis. This system ensures that the demand flow rate does not exceed the supply flow rate, following the constraints set by the previously calculated Estimation Model.

3.1 Flow Distributor

To effectively distribute the flow, an appropriate criterion is required. Therefore, we devised a method that allocates flow based on convergence time, which considers position error, cylinder volume, and supply flow.

In this approach, the cylinder volume is first calculated using the position error. Then, this volume is divided by the supply flow to determine the average convergence time. Finally, the flow is distributed in a way that ensures all axes converge within this average convergence time.

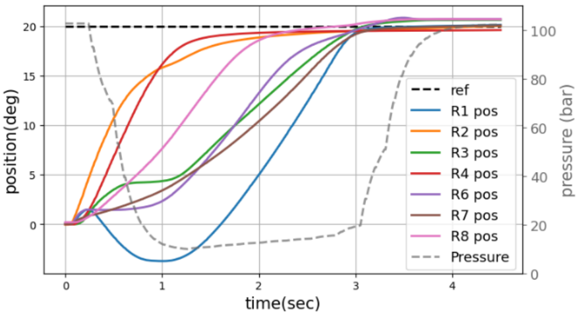

Fig. 3. Step Input Test(Distributor_Off)

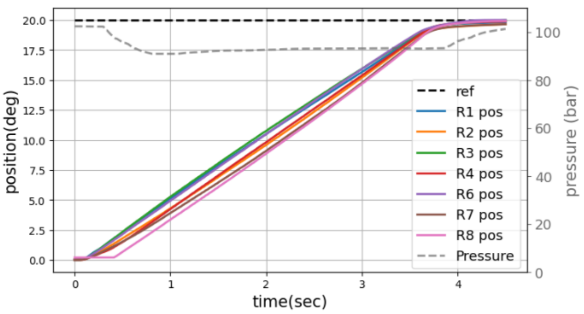

Fig. 4. Step Input Test(Distributor_On).

4. Experience & Result

The experimental results showed that when the Distributor was off, certain axes experienced flow imbalance or backflow, causing unintended movement opposite to the control intent or significant speed deviations between axes.

Additionally, the system pressure dropped rapidly from 110 bar to below 20 bar. This confirmed that insufficient supply flow led to control instability.

5. Conclusion

This study simplifies the hydraulic system into two key factors: supply flow and demand flow, to address control issues caused by insufficient supply flow in hydraulic manipulators.

Using this approach, we developed the Estimation Model and Flow Distributor Algorithm to mitigate control issues such as flow imbalance and backflow under limited supply flow conditions.

ACKNOWLEDGEMENT

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