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Performance Evaluation and Enhancement of a Miniature Hydraulic-Power-Unit for Mobile Hydraulic Robots

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1. Introduction

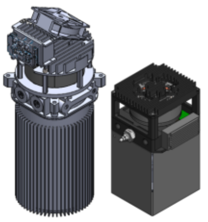
Hydraulic systems are suited for high-risk, high-load nuclear scenarios, such as decommissioning and accident response, due to their exceptional power density and robustness compared to electric motors. However, conventional hydraulic power units (HPUs) are typically too bulky and heavy for integration into human-scale mobile platforms. Prior work proposed the design concept and control structure of a m-HPU utilizing a low-cost sensorless speed controller to address these spatial and economic barriers. Building upon this previous development, this paper provides an analysis of the platform's performance and economic feasibility. Furthermore, through high-load and high-speed experiments, we identify technical limitations and propose specific enhancements to improve the system's operational reliability in nuclear fields.

2. Performance of m-HPU

The developed Gen.2 m-HPU integrates the manifold, motor mount, and heat exchanger into a single frame to minimize its physical footprint. Compared to the previous generation, the unit achieved a 59% reduction in volume and a 119% increase in power density. Economically, manufacturing costs were reduced to 1/20 of conventional high-precision units by replacing expensive servo drivers with a low-cost sensorless ESC and RPM counter. Practical capability was verified through performance tests on a human-scale robot:

(1) High-load Task: Pull-up tests confirmed the unit's ability to deliver sufficient power for heavy-duty lifting.

(2) High-speed Task: Bottle-throwing experiments validated the system's capacity to provide the rapid flow rates required for dynamic motion.



Spec.		Gen.1	Gen.2
Power	[kW]	1.64	1.47
Volume	[L]	8.3	3.4
Power density	[kW/m³]	197	432
Cost	-	1	1/20

Fig. 1. Specifications of m-HPUs

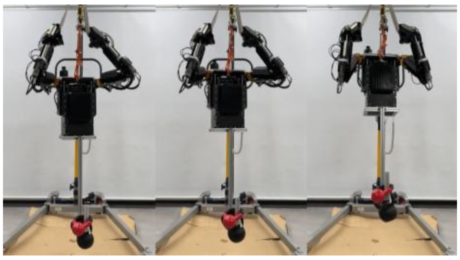


Fig. 2. High-load task: pull-up

Fig. 3. High-speed task: bottle-throwing

3. Problem Identification and Enhancements

3.1. Problem Identification

Despite the verified feasibility, two critical control issues were identified during the experiments:

(1) Low Resolution and Response Delay: The system exhibited a significant deadband in motor response and time delays between command input and actual mechanical reaction.

(2) Insufficient Tracking Accuracy: The motor speed failed to accurately follow the target RPM under varying hydraulic loads, resulting in steady-state errors.

3.2. Cause Analysis and Proposed Directions

The primary cause of low resolution is the 8-bit PWM bottleneck (0–255 steps), which limits the granularity of speed commands. Response delays are attributed to the internal filtering and phase lag of the industrial ESC. Furthermore, the current feedforward model is limited by its single-variable linear structure that does not account for load-induced resistance torque. To address these, we propose the following directions:

(1) Transition to Microsecond Control: Shifting to a 1000–2000 μs signal range will enhance input resolution eight-fold, minimizing the deadband.

(2) Pressure-Aware Multi-variable Control: Incorporating real-time pressure P feedback into the feedforward logic ($Duty = f(\omega_{ref}, P)$) will allow the system to preemptively compensate for hydraulic resistance, thereby improving tracking accuracy and operational reliability.

4. Conclusion

The m-HPU developed in this study demonstrated exceptional power density and economic feasibility, confirming its strong potential for high-risk, high-load nuclear environments such as decommissioning and accident response. While the system achieved significant reductions in volume and manufacturing costs compared to conventional units, experimental evaluations revealed certain control limitations, including low control resolution and degraded tracking accuracy under varying loads.

To address these issues, this research proposed a multi-variable control framework utilizing pressure variables and a microsecond-level signaling system, which offers higher resolution than standard PWM methods. Future work will focus on the physical implementation and verification of the proposed algorithms, alongside long-term durability testing under continuous duty cycles to ensure operational reliability in extreme environments.

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REFERENCES

[1] Cho, B., Kim, M. S., Kim, S. W., Shin, S., Jeong, Y., Oh, J. H., & Park, H. W. (2021). Design of a compact embedded hydraulic power unit for bipedal robots. IEEE Robotics and Automation Letters, 6(2), 3631-3638.
[2] Cui, Z., Rong, X., Li, Y. (2022). Design and control method of a hydraulic power unit for a wheel-legged robot. Journal of Mechanical Science and Technology 36 (4) (2022) 2043~2052.