

# MEVIUS2: Practical Open-Source Quadruped Robot with Sheet Metal Welding and Multimodal Perception

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**Abstract**—Various quadruped robots have been developed to date, and thanks to reinforcement learning, they are now capable of traversing diverse types of rough terrain. In parallel, there is a growing trend of releasing these robot designs as open-source, enabling researchers to freely build and modify robots themselves. However, most existing open-source quadruped robots have been designed with 3D printing in mind, resulting in structurally fragile systems that do not scale well in size, leading to the construction of relatively small robots. Although a few open-source quadruped robots constructed with metal components exist, they still tend to be small in size and lack multimodal sensors for perception, making them less practical. In this study, we developed MEVIUS2, an open-source quadruped robot with a size comparable to Boston Dynamics’ Spot, whose structural components can all be ordered through e-commerce services. By leveraging sheet metal welding and metal machining, we achieved a large, highly durable body structure while reducing the number of individual parts. Furthermore, by integrating sensors such as LiDARs and a high dynamic range camera, the robot is capable of detailed perception of its surroundings, making it more practical than previous open-source quadruped robots. We experimentally validated that MEVIUS2 can traverse various types of rough terrain and demonstrated its environmental perception capabilities. All hardware, software, and training environments can be obtained from Supplementary Materials or [github.com/haraduka/mevius2](https://github.com/haraduka/mevius2).

## I. INTRODUCTION

A wide variety of quadruped robots have been developed to date [1]–[3], and their advancement has been remarkable. This progress has been greatly driven by the emergence of compact, low-reduction, high-torque motors developed in the MIT Cheetah series [2], [4], [5]. Combined with advances in reinforcement learning, these developments have significantly enhanced the locomotion capabilities of quadruped robots [6]–[8]. Today, various quadruped robots such as ANYMAL [3], Unitree Go1 [9], and DEEPRobotics Lite3 [10] are commercially available. However, these commercial robots have several limitations: low-level control is often inaccessible, the design cannot be modified to suit specific research purposes, and users cannot easily repair the hardware themselves. If research institutions and individual researchers could engage with all aspects of development – from mechanical design to low-level control – it would greatly expand the possibilities for research.

Building on this trend, several open-source quadruped robots have recently been developed, with both hardware



Fig. 1. MEVIUS2 – Practical open-source quadruped robot with sheet metal welding and multimodal perception, developed in this study.

and software fully released to the public. Notable examples include Solo [11], [12] and PAWDQ [13]. These robots can be built entirely from scratch by anyone using commercially available motors, circuits, and 3D printing. Thanks to the flexibility of 3D printing and the ease with which individual researchers can produce structural parts, many open-source quadruped robots have been developed using plastic components fabricated by 3D printers [11]–[21]. However, 3D-printed structures tend to be mechanically fragile and do not scale well in size. As a result, most open-source quadruped robots to date have been relatively small, and few examples exist of such robots traversing diverse outdoor terrains. While a few open-source quadruped robots made with metal components have been developed [22], their size has remained comparable to that of the Unitree Go1 [9]. With such configurations, tasks like walking on stairs that are commonly used by humans remain challenging. Moreover, existing open-source quadruped platforms generally lack multimodal perception systems with LiDARs and cameras.

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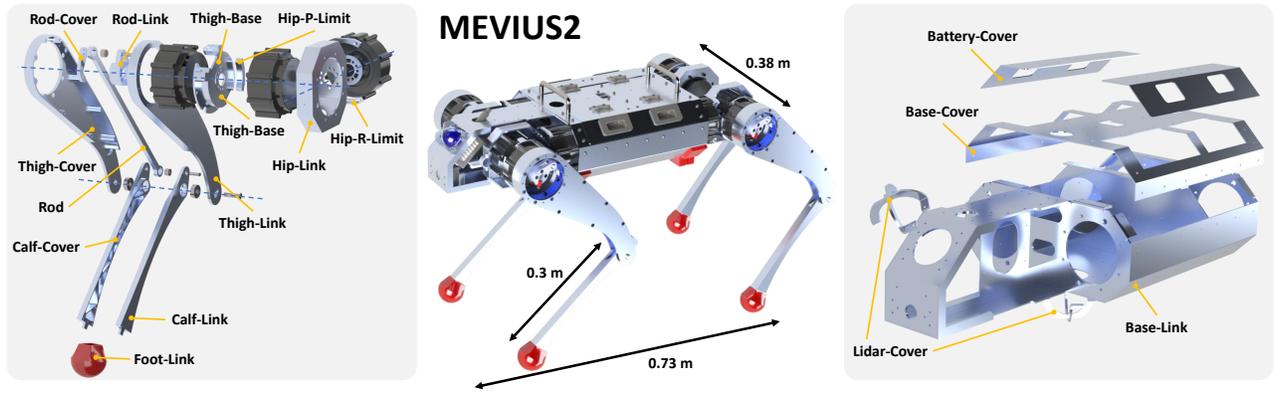


Fig. 2. Design overview of MEVIUS2: excluding mirrored parts, the robot consists of 16 unique metal components, three of which are fabricated using sheet metal welding to achieve complex and large geometries as single integrated parts.

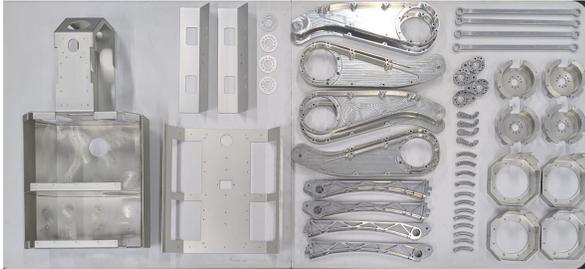


Fig. 3. All metal components used in MEVIUS2.

Solving these issues would allow anyone to build a more practical quadruped robot from the ground up.

To address this, we developed MEVIUS2, a metal-based open-source quadruped robot that matches the size of Boston Dynamics’ Spot [23] and can be assembled entirely from components ordered via e-commerce. By leveraging sheet metal welding, we achieved a large and robust structure while significantly reducing the number of parts. All machined and welded metal components can be automatically quoted and ordered from STEP files or part numbers using meviy [24], a machining and fabrication service by MISUMI. MEVIUS2 is also equipped with multimodal perception using LiDARs and a high dynamic range camera, enabling detailed sensing of its environment. We applied reinforcement learning to the developed MEVIUS2 and confirmed through experiments that it can successfully traverse various rough terrains. By releasing all hardware, software, and training environments, we aim to empower research institutions and individual researchers to modify and extend the platform – facilitating the creation of even more innovative research outcomes.

## II. DESIGN AND CONFIGURATION OF MEVIUS2

### A. Design Overview of MEVIUS2

The design of MEVIUS2 developed in this study is shown in Fig. 2. MEVIUS2 is composed of 16 metal components, as illustrated in Fig. 3. Among these, 11 parts are machined from A7075 aluminum alloy, while the remaining 5 parts are sheet metal components made from A5052. Three of the sheet metal components – Base-Link, Hip-Link, and Lidar-Cover – are fabricated through sheet metal welding, as detailed in Fig. 4. Although most of the structural components

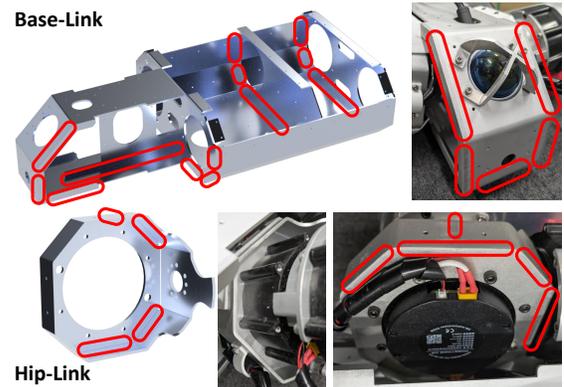


Fig. 4. Details of sheet metal welding for the Base-Link and Hip-Link. The welded sections are highlighted in red.

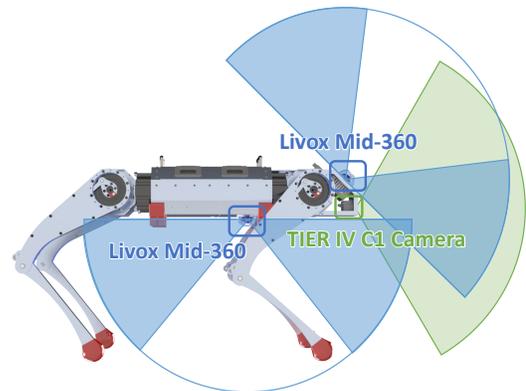


Fig. 5. The sensor configuration of MEVIUS2.

are made of metal, the foot tips and body-supporting contact points are 3D printed in TPU to enable soft contact with the environment. MEVIUS2 uses 12 Robtstride03 motors, each with a continuous torque of 20 Nm and a peak torque of 60 Nm. A parallel-link mechanism is employed to transmit the knee joint motion from a proximally located motor, resulting in lighter distal leg segments.

A key feature of this design is the structure of the Base-Link and the sensor layout. The Base-Link consists of five welded sheet metal plates and integrates all mounting points for the legs, circuit components, LiDARs, and RGB camera into a single part. This allows for a significant reduction in the number of components while enabling the

TABLE I  
COMPARISON BETWEEN EXISTING QUADRUPED ROBOTS AND MEVIUS2

Name	Weight	Leg Length* <sup>1</sup>	Materials	Open/Closed (CAD)	Off-the-shelf (Circuit)	Maximum Torque	Cost (USD)	Perception
Mini Cheetah [2]	9.0 kg	0.20 m	<b>Metal</b>	Closed	No	17 Nm	-	-
ANYMAL [3]	30.0 kg	0.25 m	<b>Metal</b>	Closed	No	40 Nm	150k	<b>LiDAR/Camera</b>
Spot [23]	33.8 kg	0.34 m	<b>Metal</b>	Closed	No	85 Nm* <sup>2</sup>	75k	<b>LiDAR/Camera</b>
Solo-12 [12]	2.5 kg	0.16 m	Plastic	<b>Open</b>	No	2.5 Nm	12k	-
PAWDQ [13]	12.7 kg	0.22 m	Plastic	<b>Open</b>	<b>Yes</b>	21 Nm	8k	Camera
MEVIUS [22]	15.5 kg	0.25 m	<b>Metal / POTICON</b>	<b>Open</b>	<b>Yes</b>	25 Nm	12k	-
MEVIUS2 (this study)	22.9 kg	0.30 m	<b>Metal</b>	<b>Open</b>	<b>Yes</b>	60 Nm	13k	<b>LiDAR/Camera</b>

\*<sup>1</sup> The average of the link lengths of the thigh and calf links.

\*<sup>2</sup> Because the maximum torque varies depending on the joint angle, we use the average within the joint range of motion.

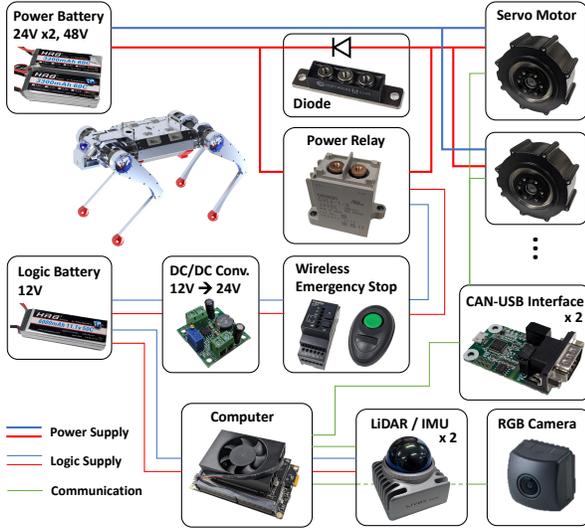


Fig. 6. Circuit configuration of MEVIUS2: servo motors are connected to the PC via two CAN-USB interfaces, and the system is equipped with a wireless emergency stop, power relay, diode, LiDAR/IMU, and RGB camera.

construction of a large, high-strength body structure. All of these metal parts can be automatically quoted and ordered from STEP files using meviy [24], MISUMI’s machining and fabrication service, making it possible to complete the entire procurement process through e-commerce. Notably, this leg configuration uses the fewest number of components among quadrupeds with parallel-link mechanisms [22], enabling a highly simplified assembly process.

The robot’s body is equipped with two LiDAR sensors (Livox Mid-360) and a high dynamic range RGB camera (Tier IV C1 Camera), which together provide detailed environmental perception. The perception coverage area of these sensors is illustrated in Fig. 5.

### B. Comparison with Existing Quadruped Robots

A comparison between MEVIUS2 and previously developed quadruped robots is shown in Table I. Representative commercial quadruped robots include the MIT Mini Cheetah [2], ANYMAL [3], and Boston Dynamics Spot [23]. These robots differ in size, weight, and maximum torque, but all are constructed from metal and do not have their design or circuit details released as open-source. In contrast, Solo-12 [12], PAWDQ [13], and MEVIUS [22] are open-source robots, allowing anyone to build them from scratch.

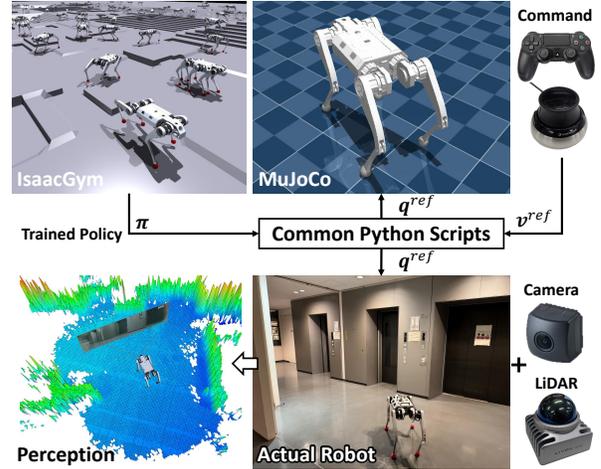


Fig. 7. Control system of MEVIUS2: policies trained in IsaacGym are verified in MuJoCo and deployed to the actual hardware using common Python scripts.

Among them, only MEVIUS is constructed from metal – despite the use of a specialized plastic (POTICON) for some parts – while the others are primarily made of 3D-printed plastic components. MEVIUS2, on the other hand, is a fully open-source quadruped robot made of metal, with size, weight, and maximum torque comparable to ANYMAL and Spot. Furthermore, it is equipped with more sensors than other open-source quadruped robots, enabling more practical and detailed environmental perception. Its cost is also significantly lower than that of commercial robots of comparable size, making it more accessible to a wider range of researchers.

### C. Circuit Configuration of MEVIUS2

The circuit configuration of MEVIUS2 is shown in Fig. 6. The system adopts a very simple architecture, where 12 servo motors are controlled via two CAN-USB interfaces. For motor power, two 24V, 3300mAh LiPo batteries are connected in series, while a separate 12V, 6000mAh LiPo battery is used as a logic battery for powering the control circuits. With this configuration, approximately one hour of continuous operation is possible; however, since there is sufficient space in the payload area, a higher-capacity battery can also be installed. The onboard PC is a NVIDIA Jetson, to which two LiDAR sensors and an RGB camera are connected; image and point cloud processing is performed



Fig. 8. Walking experiments in various environments: (A) concrete, grass, and soil; (B) stairs; (C) steep slopes; (D) slippery stairs after rainfall; and (E) indoor settings.

using the GPU on the Jetson. Other components include a wireless emergency stop system, power relays, and diodes – all of which, like the metal structural parts, can be procured entirely via e-commerce platforms.

#### D. Control Architecture of MEVIUS2

The control architecture of MEVIUS2 is shown in Fig. 7. MEVIUS2’s locomotion is primarily trained through reinforcement learning conducted in IsaacGym [25]. The resulting policy is first validated on MuJoCo using a common Python script and then deployed to the actual hardware. Details on the reward function and parameters used in the reinforcement learning policy can be found in [github.com/haraduka/mevius2](https://github.com/haraduka/mevius2). For perception, elevation mapping [26] is employed, allowing MEVIUS2 to precisely perceive its surroundings using data from both the LiDAR sensors and the RGB camera.

### III. EXPERIMENTS

To verify the robot’s ability to traverse various types of uneven terrain, walking experiments were conducted in the following environments: (A) concrete, grass, and soil; (B) stairs; (C) steep slopes; (D) slippery stairs after rainfall; and (E) indoor settings. These experiments are shown in Fig. 8. MEVIUS2 successfully walked not only on diverse terrains including stairs and steep slopes but also managed to maintain walking without falling, even in slippery conditions

where it occasionally lost balance. In particular, stairs like those in (B), which are commonly used by humans, could not be traversed by the smaller MEVIUS [22]; however, MEVIUS2 was able to climb them without any issues, which is a significant improvement. Furthermore, during the indoor walking experiments, elevation mapping using LiDAR and a camera was performed, demonstrating that detailed shapes of the surrounding environment could be captured.

### IV. CONCLUSION

In this study, we developed MEVIUS2, a practical, metal-based open-source quadruped robot that incorporates sheet metal welding and multimodal perception. Compared to 3D-printed parts, metal components are more challenging to fabricate in arbitrary shapes; however, by leveraging sheet metal welding, we were able to construct a large and robust body structure as a single integrated component, significantly reducing the number of individual parts. Equipped with LiDARs and a high dynamic range camera, MEVIUS2 can acquire detailed environmental information, achieving a more practical configuration in terms of both scale and sensing compared to existing open-source quadruped robots. With the ability to traverse various types of rough terrain through reinforcement learning and a high degree of customizability due to the full release of all hardware and software, we anticipate that MEVIUS2 will serve as a foundation for a wide range of future research.

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## DESCRIPTION OF SUPPLEMENTARY MATERIALS

### A. Overview

The Supplementary Materials for this study include the following files:

- **PartsList.xlsx**: A list of all components used in MEVIUS2.
- **MEVIUS2-STEP.tar.gz**: STEP files for each individual MEVIUS2 component.
- **MEVIUS2-Assembly.STEP**: The full assembly file of MEVIUS2.
- **LeggedGym.tar.gz**: The reinforcement learning environment for MEVIUS2.
- **Software.tar.gz**: The software package for MEVIUS2.
- **Video.mp4**: The video of experiments.

### B. Hardware

This section provides information related to the hardware, with a focus on key points regarding the parts list. Currently, the total cost of MEVIUS2’s metal components is approximately 6,150 USD, and the full system – including motors, sensors, and other components – amounts to 12,905 USD. The parts list includes details such as part names, materials, quantities, and prices, but the most critical information is the part numbers used for ordering via meviy. All metal components used in this study can be ordered simply by specifying their part numbers. Of course, it is also possible to place orders by uploading the corresponding STEP files. The quoted price is based on a 20-day delivery time; however, a shorter lead time of approximately three days is also possible at the earliest. All mechanical parts can be ordered through MISUMI and meviy, and for electronic components, individual URLs are provided in the list.

### C. Software

This section provides information related to the software. The reinforcement learning environment is based on LeggedGym and includes the URDF model of MEVIUS2. The reward functions and parameters used are consistent with those commonly applied to quadruped robots. The control software includes the Python scripts necessary for operating MEVIUS2, covering both MuJoCo-based Sim-to-Sim simulation and real-world Sim-to-Real deployment. It also includes launch programs for the LiDARs and camera, which can be visualized using ROS and Rviz. Accordingly, the package also contains the MuJoCo XML model files and URDF files for Rviz visualization.

### D. Limitations

Several limitations of MEVIUS2 are discussed below. First, the current MEVIUS2 does not feature a waterproof or dustproof design, and therefore special care is required when operating it outdoors. While this is a critically important issue for future development, realizing a waterproof and dustproof structure in a form that can be released as open source is extremely challenging and remains an open problem. Second, although the welded metal structure can be fabricated relatively easily by using manufacturing services

such as meviy or conventional machining vendors, building it from scratch as an individual is more difficult compared to standard metal machining processes. As a means to achieve a large metal-based quadruped robot at low cost with a small number of parts, it is necessary to explore alternatives to sheet metal welding in future work. Third, while this study implements environmental perception using LiDARs and cameras, achieving truly practical environmental perception will likely require the integration of a wider variety of sensors, such as RTK-GNSS, thermal cameras, and foot contact sensors. Future work should therefore focus on incorporating additional sensors and developing more advanced perception methods that leverage them. Finally, safety remains an important issue. MEVIUS2 has not undergone formal risk assessment, and thus must be operated with sufficient caution. Safety-related challenges, such as pinch hazards and behavior during emergency stops, need to be addressed in future work.