SUSTAINA-OP™: Kid-sized Open Hardware Platform Humanoid Robot with Emphasis on Sustainability

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1. Introduction

- There is a problem of **high hardware development cost** in the Humanoid League.
  - ➢ **Open platform robots** are sometimes utilized for participating.
- Open platform robots must exhibit sufficient flexibility.
  - ➢ E.g., rapidly adapt to evolving competition rules and research challenges
- Developed the novel **SUSTAINA-OP™** open hardware platform humanoid.
- **The data of the developed robot is available on GitHub [1].**
  - ➢ To overcome high development costs and continuity issues,
  - ➢ To accelerate the progress of research

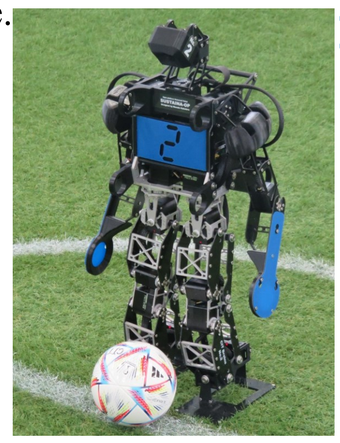

Fig. The SUSTAINA-OP™ open hardware platform humanoid robot

Table Specification of SUSTAINA-OP™

Type	Specification	Value	
General	Height · Weight	647 mm · 5.18 kg (Battery included)	
	Battery	LiHv 11.4V 3S1P 2,800mAh	
	Battery life	Max. 30 min. walking possible	
	Materials	A2017, GFRP, POM, TPU, PLA, etc.	
Actuators	Total	10 × B3M-SC-1170-A	9 × B3M-SC-1040-A
	Stall torque · current	7.6 Nm · 5.4 A	4.6 Nm · 3.6 A
	No load speed	46 rpm	54 rpm
Sensors	IMU	TDK MPU-9250 (Magnetometer not used in software)	
	Camera	e-con Systems™ e-CAM50_CUNX	
	Camera lens	TOWIN S02512512524F 160°(D) · 125°(H) · 90°(V)	
	Encoders	Contactless magnetic 12bit/1round	
Control boards	System on module	NVIDIA® Jetson Xavier™ NX	
	Carrier board	AVerMedia EN715	
	Electronics boards	Main Board Ver. 2.2	
		EN715 Expansion Board Ver. 1.1	
		Start Stop Switch Ver. 3.0	

2. Related Work

- DARwIn-OP [2]
  - ➢ Platform is widely used by researchers
- Sigmaban+ [3]
  - ➢ 4th consecutive win in the RoboCup 2016-2019
- Wolfgang-OP [4]
  - ➢ Address fall-related damage prevention

3. Design Concept

- Designed the SUSTAINA-OP™ based on the concept of **"sustainability."**
  - ➢ User-friendly for new participants, software developers, facilitating long-term development
  - ➢ Increase flexibility in adapting to new competition rules
  - ➢ Enhance robustness, minimize resources required for repairs and maintenance
    - Versatile, identical platform that can play all roles, including attacker and goalkeeper

4. Mechanical Design

- Designed to enable even first-time robot developers to build, maintain, and operate
- Design of mechanism for stable walking without falls
  - Utilize the actuator's torque with margin
  - Use of parallel link structures for the legs
  - Add deceleration device to the crotch roll joint
  - ➢ Confirmation of **continuous walking without falls for up to 30 minutes** when using battery
- **Adopts cross roller bearings** for crotch yaw joints
  - ➢ Easy assembly by eliminating gap adjustment as when thrust bearings are used
- **Adopts plain bearings** for all bearings except for the crotch yaw joint
  - ➢ Almost undamaged by impact when walking
- **Installs with TPU material bumpers** to reduce impact in case of falls
  - ➢ **Reduces impact up to 80%** with a total of 8 bumpers in front, back, left and right

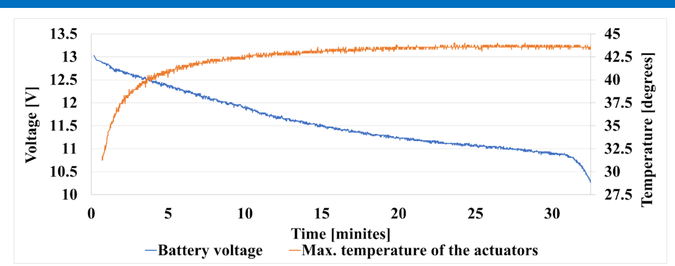

Fig. Battery voltage and maximum actuator temperature when the robot is walking

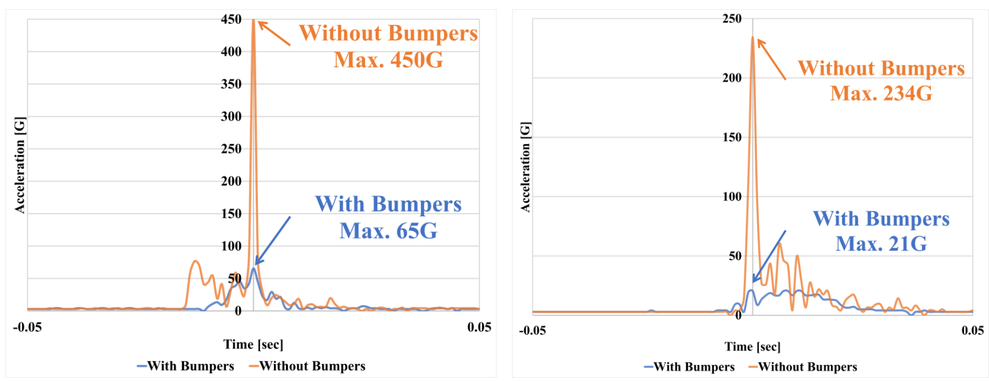

Fig. Impact of falling with(blue) and without(orange) TPU bumpers in fall forward(left) and backward(right)

5. Electrical Design

- Adopts NVIDIA® Jetson Xavier NX™, a **System on Module with GPU**
  - ➢ Enables real-time walking control and object recognition
- Seamless switching between the two power supplies
  - ➢ Allows battery changing at halftime of competition without powering down the computer
- High-speed communication board developed based on QUADDXL [5] with 4-parallel
  - ➢ Solves the problem of difficulty in acquiring sensor values within a 10ms control cycle
  - ➢ **Enables high-speed control** of full-body command servo motors and state logging

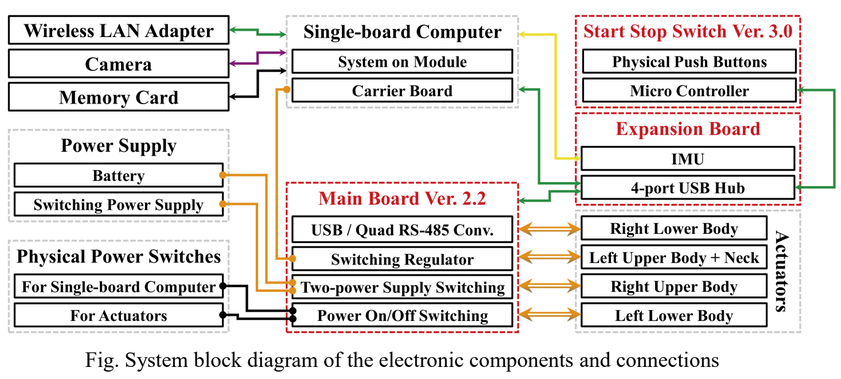

Fig. System block diagram of the electronic components and connections

6. Development Result

- Material cost of this platform (excluding machining costs) is about **7,000€**
  - ➢ Low cost compared to other platform robots
- During RoboCup2022, SUSTAINA-OP™ experienced a total of **47 falls** in 9 matches
  - ➢ **Not one robot left the competition arena** due to hardware failure
  - ➢ Goals achieved: "enhancing robustness and minimizing the resources required for repair and maintenance."
- **Awarded first place** in the RoboCup2022 Humanoid League KidSize Soccer Competition
  - ➢ Showed potential as a hardware platform for humanoid robots

7. Future Work

- To accelerate software development and humanoid research
  - ➢ Add various sensors
  - ➢ Support annually updated competition rules
- As an open hardware platform
  - ➢ Improve publicly available materials

References

[1] SUSTAINA-OP™ Open Hardware Platform website. https://github.com/SUSTAINA-OP. Accessed 16 April 2023
[2] Ha, I., et al.: Development of open humanoid platform DARwIn-OP. SICE Annual Conference 2011, pp.2178-2181 (2011)
[3] Bestmann, M., et al.: Wolfgang-OP: A Robust Humanoid Robot Platform for Research and Competitions. 2020 IEEE-RAS 20th International Conference on Humanoid Robots (Humanoids), pp.90-97 (2021)
[4] Rhoban Football Club – Robot Specification Humanoid Kid-Size League, Robocup 2023 Bordeaux. Accessed 16 April 2023
[5] Bestmann, M., et al.: High-Frequency Multi Bus Servo and Sensor Communication Using the Dynamixel Protocol. RoboCup 2019: Robot World Cup XXIII, pp.16–29 (2019)