32nd International Conference
ENGINEERING MECHANICS 2026
Medlov, Czech Republic, May 11 – 13, 2026

DESIGN OF A SENSOR-INTEGRATED ROBOTIC HEAD FOR AUTONOMOUS INDOOR NAVIGATION OF A BIPEDAL ROBOT

Pohludka J.[1], **Vechet S.**[2], **Krejsa J.**[2], **Chen K. S.**[3]

Abstract: *This article describes the design of a robotic head desingned for the autonomous indoor navigation of a bipedal walker. The head features modular mechanical interface allowing the use of various panels equipped with different sensors, displays and other devices, depending on the use-case. The system is powered by a Raspberry Pi 5 running a Python script handling the operation of the LiDAR sensor, cameras and other modules. System also runs a lightweight local YOLO model for object detection. A TCP communication is implemented to send raw sensor data, camera frames and optionally YOLO results to an external device for processing or monitoring. System provides data necessary for localization using a Particle Filter. The fusion of these sensors creates a foundation for robust SLAM algorithms.*

Keywords: Particle Filter, Walking Robot, Biped Robot

1. Introduction

Autonomous and humanoid bipedal robots operating indoors require stable and adaptive motion, but another very important factor is the reliable perception of their surroundings. Although significant progress has been made in the field of controlling bipedal walking using model-based and reinforcement methods (Grandia et al., 2024; Schulman et al., 2017), effective autonomous navigation highly depends on the robot's perception abilities for reliable obstacle recognition, localization, and planning safe trajectories.

The primary focus of previous research was to design robust locomotion and gait optimization to compensate for the inherent instability of bipedal systems (Krejsa and Vechet, 2018). However, even well-optimized locomotion controllers are insufficient for fully autonomous operation without reliable sensory feedback and environmental awareness (Vechet et al., 2020). Additionally, for humanoid robots designed to interact with humans and operate in shared spaces safely, perception and visual object recognition must be integrated with the motion control itself.

Vision sensors play a key role in perception capabilities. Cameras provide rich visual information about the environment, while LiDAR sensors offer more accurate geometric measurements and are much less dependent on ambient lighting conditions. Their combination provides a suitable solution for autonomous indoor navigation, where both factors are required. Therefore, integrating these sensors into a compact, mechanically stable, and customizable form factor is crucial for such systems.

In this paper, the design and implementation of a robotic head equipped with a LiDAR sensor, cameras, and other devices specifically developed to support the autonomous indoor movement of a bipedal humanoid robot is presented. The proposed head architecture serves as a unified sensory platform, providing the necessary data for the tasks mentioned above. The design emphasizes modularity, mechanical robustness and focuses on ease of use, implementation, and production.

This contribution builds on previous work in learning-based locomotion control Vechet et al. (2024), forming another step toward a fully autonomous bipedal walker.

[1] Ing. Jan Pohludka: Brno University of Technology, v.v.i., Technicka 2, 616 69, Brno; CZ, 216846@vutbr.cz
[2] Assoc. Prof. Stanislav Vechet, Ph.D., Assoc. Prof. Jiri Krejsa, Ph.D.: Institute of Thermomechanics AS CR, v.v.i., Technicka 2, 616 69, Brno; CZ, vechet@it.cas.cz, krejsa@it.cas.cz
[3] Prof. Kuo-Shen Chen, PhD.: National Cheng Kung University, Department of Mechanical Engineering, No.1, Ta-Hsueh Road, Tainan 701; Taiwan, kschen@ncku.edu.tw

ISSN: 1805-8256, doi: 10.21495/em2026-105

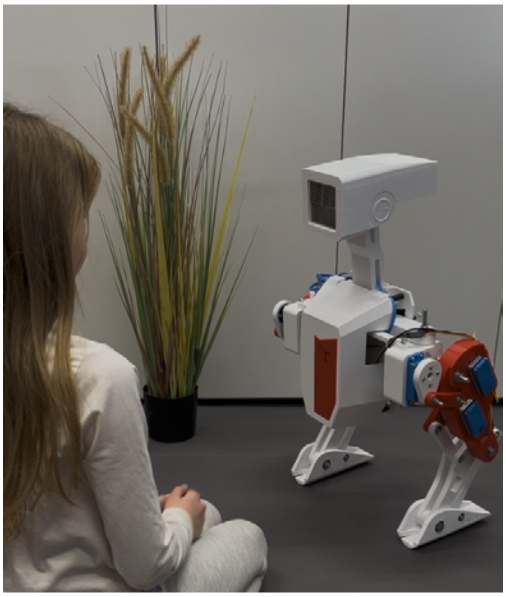

Fig. 1: Personal Autonomous Walking Optimizer (PAWO) robot in it's latest design configuration during social interaction with human operator.

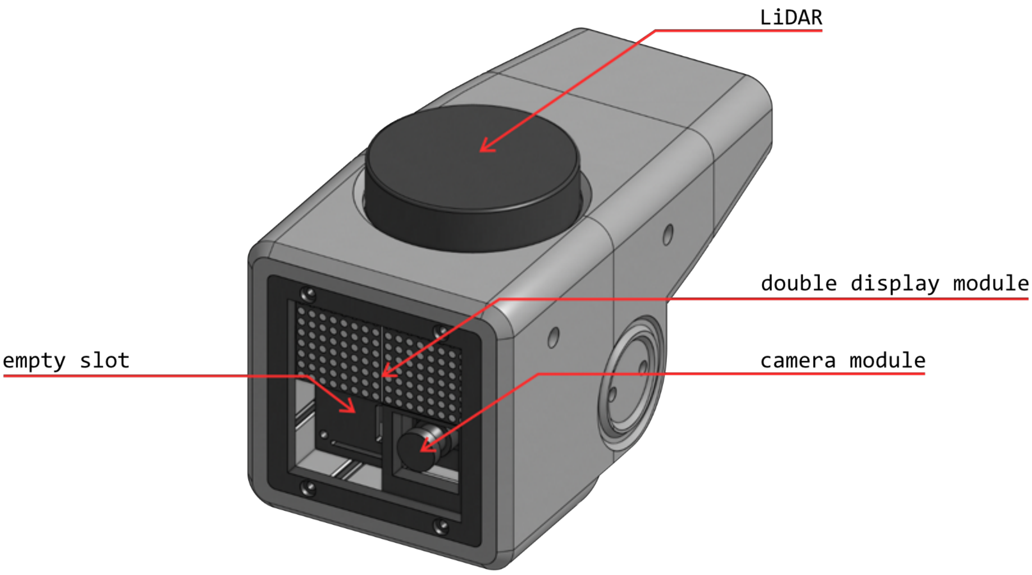

Fig. 2: CAD model of the modular robotic sensor head assembly, showing the 2x2 reconfigurable panel (currently featuring dot-matrix displays, camera and empty slot) and the top-mounted 360° LiDAR sensor.

2. Materials and Methods

The robotic head was designed as a universal sensory platform adaptable for image processing, human-robot interaction, and navigation. Serving as an extension of the original PAWO bipedal walker's head, this article describes its mechanical design, electronic/software architecture, and future localization methods.

2.1. Modular Mechanical Design

The mechanical architecture features a front modular panel that allows versatility through interchangeable components. The panel consists of four fields arranged in a 2x2 matrix, secured by a locking frame. This layout accommodates larger components or single-field modules, such as a PiCamera or matrix display (Fig. 2). By swapping panels, the head is easily reconfigured from the human-interaction mode (Fig. 1) to a spatial navigation mode.

Prioritizing accessibility, all structural parts are designed for Fused Deposition Modeling (FDM) 3D printing, ensuring easy reproduction in typical lab settings. A dedicated top mount provides the Light Detection and Ranging (LiDAR) sensor with an unobstructed 360-degree field of view. The LiDAR holder is structurally separate, allowing simple integration of different models.

2.2. Electronics and Software Architecture

The Raspberry Pi 5 was selected as the central computing unit due to its balance of computing power, low weight, cost-effectiveness, and extensive Python/OpenCV community support. This ensures compatibility with standard libraries while maintaining the low power consumption essential for independent bipedal operation.

The main Python script manages the sensor operations, storing measured data temporarily. The system supports local object detection using a lightweight You Only Look Once (YOLO) model (Redmon et al., 2016), enabling the robot to recognize humans or obstacles.

For advanced data analysis, the program can send data to external devices using the TCP protocol. The transmitted data includes full image matrices for complex vision models as well as 2D point clouds from the LiDAR sensor. The communication is bidirectional; based on the received data, an external device can send instructions back to control components, such as LED modules. This data transfer can also be used for monitoring purposes, as illustrated in Figure 3, which displays the camera output with YOLO object detection alongside the LiDAR data visualization.

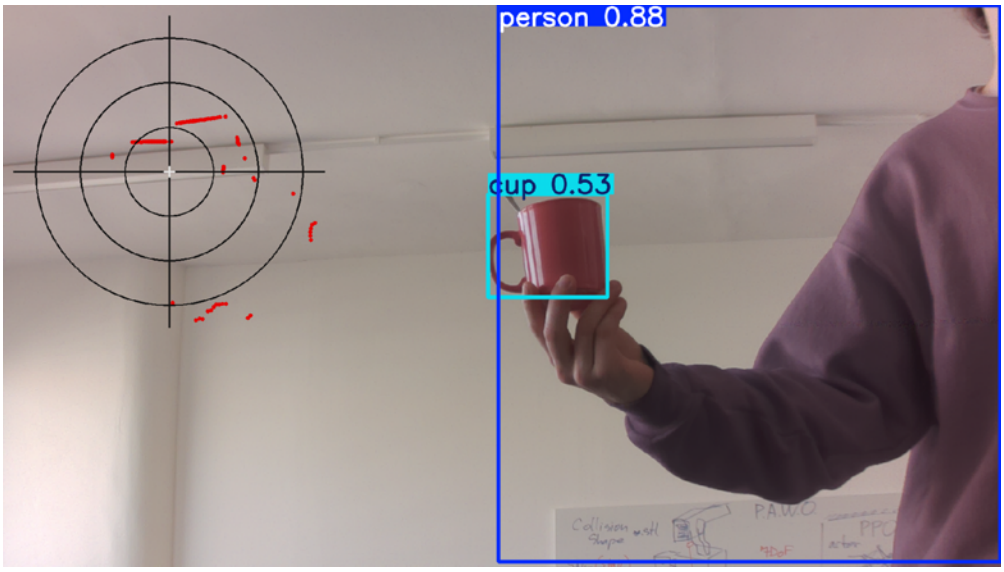

Fig. 3: Visualization of the data available for remote monitoring: 2D LiDAR point cloud (top-left) and the camera's RGB stream with object detection (YOLO) performed locally on Raspberry Pi 5.

2.3. Mathematical Framework for Localization

Spatial localization relies on LiDAR data to implement the Particle Filter algorithm. Frequently used for walking robots, it is significantly more reliable than simple odometry by reducing cumulative error. It can be extended to full mapping using Fast Simultaneous Localization and Mapping (FastSLAM) (Thrun et al., 2004).

The Particle Filter represents the position of the robot using particles defined by a state vector $x_t = [x, y, \theta]^T$. Their probability distribution is calculated iteratively:

$$p(x_t|z_{1:t}, u_{1:t}) \propto p(z_t|x_t) \int p(x_t|u_t, x_{t-1})p(x_{t-1}|z_{1:t-1}, u_{1:t-1})dx_{t-1} \quad (1)$$

Here, u_t describes the movement command (represented as step lengths and velocity vectors for the biped), and z_t represents the LiDAR data (formatted as a 2D array of angles and distances). By comparing real-time scans with a virtual map (Thrun et al., 2005), the particles converge on the most probable location. The autonomous control system then uses the estimated state vector x_t to plan safe trajectories and avoid obstacles in real time. SLAM allows mapping (Krejsa and Vechet, 2018) in unmapped environments.

3. Conclusions

This integrated robotic head marks a significant step toward fully autonomous operation for the PAWO bipedal walker. Its modular design supports diverse tasks, from complex human-robot interaction to obstacle avoidance.

The Raspberry Pi 5 provides sufficient performance for local YOLO object detection, sensor management, and wireless data transmission. Future work will deploy Particle Filter localization in known environments, utilizing real-time state vectors for trajectory planning, followed by SLAM for unknown areas. Fusing LiDAR geometry with camera-based recognition will yield a robust autonomous navigation system.

Acknowledgments

This study was realized with the institutional support RVO: 61388998.

References

Grandia, R., Knoop, E., Hopkins, M., Wiedebach, G., Bishop, J., Pickles, S., Müller, D., and Bächer, M. (2024) Design and control of a bipedal robotic character. In *Robotics: Science and Systems XX*.

Krejsa, J. and Vechet, S. (2018) Fusion of local and global sensory information in mobile robot outdoor localization task. In *Proceedings of the 2018 18th International Conference on Mechatronics - Mechatronika (ME)*.

Redmon, J., Divvala, S., Girshick, R., and Farhadi, A. (2016) You only look once: Unified, real-time object detection. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*.

Schulman, J., Wolski, F., Dhariwal, P., Radford, A., and Klimov, O. (2017) Proximal policy optimization algorithms. *arXiv preprint arXiv:1707.06347*.

Thrun, S., Burgard, W., and Fox, D. (2005) *Probabilistic robotics*. MIT Press.

Thrun, S., Montemerlo, M., Koller, D., Wegbreit, B., Nieto, J., and Nebot, E. (2004) FastSLAM: An efficient solution to the simultaneous localization and mapping problem with unknown data association. *Journal of Machine Learning Research*, 4, 3.

Vechet, S., J., K., and Chen, K. (2024) Vertical stabilization of bipedal walking drone PAVO with proximal policy optimization. In *2024 21st International Conference on Mechatronics - Mechatronika (ME)*.

Vechet, S., Krejsa, J., and Chen, K.-S. (2020) Agvs mission control support in smart factories by decision networks. In *2020 19th International Conference on Mechatronics - Mechatronika (ME)*.