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Research on Humanoid Robot Control Based on Environmental Feedback

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Abstract. This paper investigates systematically key technologies in order to make humanoid robots real time adaptive in dynamic unstructured environment. It builds up a closed loop architecture for development of control paradigms, hardware configurations physical limitations, and state reconstruction of sensing systems. At the control level, this research focuses on the combination of model-based optimal control and data-driven learning approaches, where a hybrid architecture is proposed where model-based safety boundaries are used for learning. With regard to the hardware and sensing, the significance of morphological computation in sharing of control task is revealed from this research and the transition of sensor configuration towards multi-source heterogeneous fusion of vision, inertia and touch to resolve state loss in complex conditions is discussed. In addition, this research stress on the point that future developments will be limited to 'biological fusion' and bringing together algorithmic 'transparency' and generalization to enable robots to advance from simple locomotion to high level cognitive interaction. This is the conclusion proposed by this research, which suggests that future technological advances will come from the efficient synergy of perception, control and hardware, and hardware and software co-design, which will enable robots to truly move on to the open world.

Keywords: Humanoid robots, environmental feedback, real-time control

1. Introduction

In the current era of Industry 4.0, robot development is experiencing repetitive fixed instructions to the current autonomous movement in the dynamic environment. As a type of robot that is important to the core, humanoid robot appears to be one. The form and trajectory of movements of humanoid robots have special advantages in our modern human-centered world. Research has shown that humanoid robots are complex dynamic systems. Any application starts with determining the best trajectory, but also has to have the characteristics of robustness in the presence of the kinds of disturbances generated by unpredictable environments [1]. The fixed trajectory planning or, strictly speaking, the strict adherence of fixed kinematic models have proved to be inadequate to solve real-world problems. In highly complex and structured environments, blind execution of fixed operations is easy to fail in the face of ground displacement or obstacles that move around it. Consequently, the most important challenge for humanoid robots is performed real-time control based on environment

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feedback. To handle this, robot must use integrated embedded sensor networks such as position encoders, vision system and LIDAR. By taking advantage of these sophisticated sensors robots are then equipped with the necessary parts to help bridge the gap between the physical interaction, and intelligent response [2].

Currently, the research world applying to these issues consists mainly of two dominant paradigms: model-based control and learning-based control. The model-based paradigm is focused on the control of humanoid robots using simplified models of the physical reality and intensive optimizations. To make real time computation practical, researchers have tried to use reduced-order models to capture essential characteristics of walking. Among these, Linear Inverted Pendulum Model (LIPM), Spring-Loaded Inverted Pendulum (SLIP) model have been applied widely [3]. These models usually use stability criteria such as Zero Moment Point (ZMP) and Foot Rotation Indicator (FRI) to keep the balance. However, using the templates alone can be limiting. To do so, a standard framework for this purpose, Model Predictive Control or MPC, has emerged. It enables the online solution of constrained trajectory optimization problems, which are able to carry the alternating contact sequences and force constraints of legged locomotion [4]. Learning-based control methods try to address these limitations and get control policies directly from data. These approaches use the sensor feedback as the main input for the neural networks in order to directly map the states of the environments to the actuation commands. This data-driven approach is very good for autonomous learning that is customized to a variety of task requirements.

These different ways in which they control and the way these foot structures are built-up requires special demands in feedback processing. Research has shown that on flowable substrates like sand, the established assumptions of rigid contact between the ground and the building are no longer valid [5]. In such environments, robots need to actively modify the environment in terms of the terrain and use extremely particular gait strategies that take into account the traction forces generated by the deformable region. This demand for environmental adaptability does not only cause problems of testing the hardware structure but more importantly, poses new challenges to the design of low-level feedback control algorithms.

This work aims at a systematic evaluation of the sensing, processing and combination of environment feedback in humanoid real-time control loops. It all starts with the exploration of the unique functions of sensors which is followed by a comparison of feedback processing in model-based and learning-based paradigms. The paper ends with a discussion of the implications of robot hardware and software co-design for control requirements. Ultimately, we would like to create a theoretical reasoning and practical roadmap to be followed by future studies in this area.

2. Environment feedback based control methods

2.1. Model based optimal control methods

In dynamic environments, humanoid robots are vulnerable to external accelerations and obstacles and force them to need robust modeling factor to cope with environmental perturbations to keep the stability. Within this paradigm, the robot dynamics and environmental physical properties act as actual time constraints with which the controller can continuously integrate the feedback from the sensors and solve for the best joint torques or gait parameters to the robot. To solve these challenges the latest research has led to different optimization frameworks that incorporate environmental feedback at different model abstraction levels. In the area of simplified dynamics, a 'Direct Centroidal Control' technique based on a 5-mass system model was put forward. Compared to the standard Linear Inverted Pendulum Model (LIPM) this approach takes a better account of the non-

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uniform distribution of inertia. By controlling the Center of Mass (CoM) in real-time and using real-time IMU feedback it is able to achieve natural whole-body compliance [6]. Simultaneously, researchers have made some major improvements to the robustness of the classical LIPM by adding angular momentum and moment of inertia to the prediction of the foot placement. This confirms that the demonstrative modeling of rotational dynamics enhances the stability of telescopic-legged robots against ground-impact disturbances [7]. Moving closer to the higher fidelity research, the researchers have used the Horizon framework to integrate Whole-Body Nonlinear Model Predictive Control (NMPC). This work shows that with the solution of whole body dynamics, it is feasible to create feasible open-loop walking trajectories that satisfy complicated kinematic and contact constraints [8]. In the sphere of biomimetics, scientists have transferred the 'Tegotae' feedback mechanism, a quantitative measure that expresses double relation between the perception and action. By directly coupling this tactile information, obtained from environmental reaction forces, into the phase dynamics equations of Central Pattern Generators (CPG), robotic systems are able to spontaneously control the phase and the frequency of the oscillator. This allows the system to 'resonate' with the intrinsic dynamics of the environment in an energy efficient and adaptive gait [9]. Furthermore, an improved trajectory generation method has been proposed by using Pose Matrix. This approach means the addition of strict Inverse Kinematics (IK) constraints to the rhythmic output layer of the CPG and the execution layer. In this way, it converts the abstract oscillatory signals into a foot end-effector pose commands that concur with the robot's structure. This mechanism can not only ensure the kinematic feasibility of the generated joint trajectories but also helps to improve the intrinsic self-stability of the bipedal robot during the dynamic locomotion through real-time correction of poses [10].

A comparative analysis of such methods reveals a unique tradeoff between model fidelity and computational efficiency. Whole-body NMPC offers the best possible theoretical framework to deal with multi-contact constraints. However, its high computational cost often deflects towards open-loop execution, or relatively low-frequency updates, reducing its irritation in data damages and in immediate reactive capability to the action of non-modeled perturbations [9]. In contrast, refined models with angular momentum as well as multiple mass distributions provide enough physical insight to allow high frequency feedback control and would thus be more useful. Ultimately, in terms of reaching a rhythmic locomotion, the bio-inspired feedback mechanisms can prove more effective to finally reach a sense of intrinsic stability in comparison to only using computationally expensive numerical solvers (optimization).

2.2. Data based approaches to learning control

In comparison with model-based control, data-based models, paradigms are stood to be the ultimate solution to managing the complicated nature of humanoid robotics in unstructured environments. This transition is intended to deal with the shortcomings of the traditional rule-based systems in the context of dynamic changes in the environment which are analytically intractable. There is a substantial change from handcrafted feature extraction to machine learning based multi sensor fusion from the research, thus increasing robot robustness and adaptability in the real world scenarios [11]. However, this transition is facing a critical hurdle which can be termed as 'Reality Gap'. Despite simulators being essential training tools, the initial departure of simulators from physically real life often implies that policies learnt would fail in a real-life axis.

To solve the aforementioned problems, learning-based approaches use large amounts of data on human-environment interaction to train controllers (usually neural networks) to draw a direct relationship between environmental feedback and actuation commands without explicit physical

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equations. Through Reinforcement Learning (RL) algorithms like Deep Q-Networks or DQN and Proximal Policy Optimization or PPO, robots learn by optimizing their decision making processes with help of maximizing real-time reward signals generated from constant interaction with their environment [12]. Specifically, in the field of locomotion control large-scale model-free reinforcement learning approaches such as Causal Transformer-based reinforcement learning architectures have been introduced. By improving some of the techniques to predict actions based on a history of proprioceptive observations, these methods enable zero-shot transfer on diverse real-world terrains without the requirement of weight updates [13]. Furthermore, ways of learning have moved onto the rectification of the perception loop itself. A neuro fuzzy learning mechanism was introduced to calibrate inherent errors present in robot visual perception by the researchers. By taking advantage of the nonlinear mapping capability of neural networks and the advantage of reasoning, this method defines an adaptive error compensation model by learning the mapping relationship between input image coordinates and real physical coordinates. Consequently, this data driven correction mechanism leads to a significant improvement of the quality of input information needed by following control algorithms [14].

While purely data-driven approaches have shown an astounding ability to adapt to new situations, the training efficiency of these approaches has become a key issue, and this has spurred more discussion about exploring hybrid approaches. A case in point is the hierarchical framework, which exploits optimal action sequences generated by a value function-based Model Predictive Control (MPC) to speed up the policy search in the case of free model reinforcement learning (in this case, Soft Actor-Critic). Experiments show that this approach comes with faster convergence and better robustness as compared to pure RL [15]. This paradigm that combines physical priors with data-driven adaptability is emerging as a key strategy to help cross the reality gap, for setting up a feedback control in complex environments.

3. Hardware configuration and hardware configuration effects on the control

3.1. Classification on the basis of configuration

Hardware configuration is the physical basis for humanoid motion control configuration, the hardware configuration directly affects the upper limit of the control system's complexity and the lower limit of the system's control performance. The main difficulty in this field is currently to achieve an optimal compromise to make them light-weight, with high power output, and adaptable to the environment. Researchers note that with the shift of humanoid robots from the laboratory to the real world, traditional rigid high gain control has revealed major limitations. Specifically, poor compliance level and low energy efficiency levels in the unstructured environment. This has lunged a switch from exact track on trajectories to morphology computation in the design philosophy. The novelty of this transition is due to the fact that the modern design of hardware is already not just an executor of control algorithms. Instead, by means of underactuated structures, biomimetic materials or special foot configurations, it deliberately offloads partial computational tasks as well as stability tasks. For example, although introducing new actuation systems (e.g., artificial muscles or hydraulics) and combining them with bio-inspired structures creates non-linearity in modeling, it has great potential to produce more robust robots in the face of unknown disturbances [16].

To solve the above issues, different configuration schemes have been proposed by researchers. Based on the difference in structural complexity and interaction mode with the environment, the existing hardware configurations can be classified into three classes: namely of 'Minimalist Underactuated Configurations', 'Interaction-Enhanced Configurations' and 'Biomimetic Compliant

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Configurations'. As summarized in Table 1, the characteristics of these categories and their particular effect on control strategies are described in detail below. In particular, 'Mugatu' is the ultimate expression of extreme innovation in minimalist design. Achieving stable bipedality using a single hip actuator connecting two rigid links, it is an example of the superiority of mechanics for being able to create useful walking systems that, with the appropriate structure (i.e. CoM distribution and leg proportions) do not even require closed-loop control to maintain a gait cycle exploitably offloading a lot of computational costs [17]. On the other hand, researchers have been choosing the physical interaction between foot configurations and environmental media, suggesting a 'Robophysics' point of view. By engineering specific lugged feet, robots can use their native physical morphology to generate 'solidification' or 'fluidization' effects in a soft granular media. This hardware level innovation allows slope climbing without the control algorithm having to accurately sense the state of each and every single grain of sand [5]. Regarding upper limb and whole-body actuation, researchers have gone over the development from rigid motors to Pneumatic Artificial Muscles (PAMs) and smart materials. They note that design innovation with focus on lightweight construction and high power density such as the cable-driven systems and parallel mechanism converse to allow robots to maintain force output while reducing distal inertia. As a result this leads to an increased safety of the dynamical manipulation [18].

Table 1. Comparison of robot hardware configurations and their implications for control systems

Taxonomy of Hardware Configurations	Representative Designs and Characteristics	Impact on Control Strategies and Requirements
Minimalist Underactuated Configurations	Single actuator, two rigid bodies, leveraging passive dynamics (e.g., Mugatu)	Reduced control dimensionality: Achieves open-loop stable walking by exploiting natural frequencies, obviating the need for complex feedback loops; however, it remains sensitive to initial conditions.
Interaction-Enhanced Configurations	Lugged feet, hybrid wheel-leg structures, variable morphology feet	Physical-level control: Actively remodels terrain (e.g., sand fluidization) via foot structure to enable blind locomotion, reducing reliance on high-frequency slip detection algorithms.
Biomimetic Compliant Configurations	Series Elastic Actuators (SEAs), pneumatic/hydraulic artificial muscles, parallel kinematic legs	Physical-level control: Actively remodels terrain (e.g., sand fluidization) via foot structure to enable blind locomotion, reducing reliance on high-frequency slip detection algorithms.

Synthesizing these architectural innovations, it becomes clear that the three configuration categories are in a triangular trade off between control simplicity, versatility and robustness. Although single actuator robots have low versatility (it is difficult to manipulate the object in a complex way), the presence of this technique strongly highlights the immense potential of passive dynamics in obtaining energy efficiency and simplification of control. However, when dealing with complexities in the real world, mere underactuation is not adequate. It is essential to introduce a compliant actuation process to mitigate safety hazards as a result of rigid collision. While this inclusion means adding non-linear elasticity, making it extremely difficult to accurately control the position, it requires a paradigm shift from the conventional PID control algorithms to the more complicated model based impedance control. In this context, superior hardware design of the foot represents 'mechanical intelligence'. This 'hardware as control' paradigm is better than the methods of obstacle avoidance which only exploits visual feedback because visual data tend to be latent and inaccurate under terrain deformation. Therefore, ideal design of a system should not consist of unidirectional commands from algorithms to hardware. Instead it requires a profound mixture of physical morphology and digital control. By simply by filtering high frequency physical disturbance

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(by using the passive adaptability of the hardware), upper level computational resources are liberated to emphasize on lower frequency decision making and planning processes.

3.2. Configuration of sensor and state estimation

Precise state estimation is the basic prerequisite in reaching high dynamic balance and interaction control in humanoid robots. However, the characteristics of these systems are that they are characterized by high-dimensional non-linear dynamics and have to operate in unstructured environments with numerous uncertainties. Consequently, single modal sensors are often unable to meet the strict requirements of high precision and real time capability at the same time. Through the use of comparative experiments, the researchers have noted that, while external Motion Capture (MoCap) systems can provide near-perfect state ground truth in lab environments, robots are completely dependent on on-board sensing systems in practical applications, outside of the lab. Consequently, the inherent onboard IMU integration-drift that is inex sponsorship is a major barrier that prevents humanoid robots from achieving 'real-world autonomy'. Furthermore, although visual perception provides rich semantic information on the environment, it requires a large volume of information processing. It is also very prone to changes in lighting, motion blur and calculation delay. This makes applying vision directly to low level feedback control loops at high frequencies difficult. Therefore, preventing technology innovation in the current research has moved from improvement of single sensor to 'Multimodal Sensor Fusion' [19].

In order to overcome such challenges researchers have proposed several different sensor configuration schemes which significantly boost the accuracy and robustness of estimation of the state. For the core problems of localization and attitude, The fusion of vision with inertial or lidar sensors has been mainstreamed. Studies show that by combining the visual features with the IMU data by using a conventional Kalman Filter, the pose parameter distribution model can be effectively built. By adopting the visual information to correct the long-term drift of the IMU, this method greatly improves the autonomous pose correction ability of the bipedal robots. It finally attains high-precision attitude estimation at low price [20]. Building on this basis, a combination of monocular vision and laser ranging was added to deal with more complex physical disturbances. Through the use of the Robot Control Generation method, or RCG, the system was able to achieve high levels of precision control with a maximum deviation in localization of only 0.01 meters. Experiments show that the high frequency ranging characteristics of the laser sensors make it feasible for the robot to recover their attitude much faster in cases of lateral and forward impacts [21]. In order to further innovate on the algorithmic side, researchers have suggested the use of a PID Neural Network to fuse laser and vision data together. In comparison to the traditional particle filtering algorithms, this technique improved both real time performance and accuracy of trajectory tracking to a large extent. This result shows the great potential of data driven methods in the point of sensor fusion [22]. Regarding interaction perception at higher level the importance of 'Visual Tactile' fusion is also emphasized by the researchers. They note that if robots are to imitate the cognitive ability of people, they need a combination of global guidance from vision and local perception from touch. This fusion not only helps to increase stability in grasping, but gifts the robot a 'pseudo cognitive' ability to classify materials and textures of objects they grasp. This is an efficient way to compensate the blind spots that are inherent in vision at the moment of contact [23].

A thorough comparison of different sensor configurations and fusion strategies shows that 'multi-source heterogeneous fusion' is the best solution for state estimation of complex environments. However, the choice of any particular scheme is a compromise between the performance and the cost. The fusion of laser and vision has the best performance in terms of localization accuracy and

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the robustness to disturbance. In turn, it is especially suitable to complex navigation tasks that require a high precision environmental modeling. Nevertheless, the high cost as well as the large quantity of lidar sensors have some limits on their application in lightweight robots. In contrast, although the fusion of vision and IMU is inferior in terms of absolute precision, it has been adopted as the mainstream configuration in commercial humanoid robot since it is inexpensive, low-power and low size. From the point view of the evolution of the algorithm, we can see that neural network fusion methods have better nonlinear fitting ability than traditional Kalman filtering. This means that the future of state estimation technology will shift slowly from the 'model-driven' technology which relies on precise physical equations, towards 'data-driven' technology. Furthermore, visual tactile fusion is a leaping from perception technology in the field of 'passive localization' to 'active interaction.' While adding tactile sensors adds a level of complexity to the system, it is the inevitable step for humanoid robots to progress from being a simple mobile platform into a smart agent with dexterous manipulation capabilities.

4. Conclusion

This paper elaborates on the main technologies facilitating the adaptation of humanoid robots in real time in dynamic unstructured environments. By examining three more specific dimensions (the evolution of control paradigms, the physical limitations of hardware configurations, and the state reconstruction of sensing systems), we develop a whole closed loop system for processing environmental feedback information. Research has shown that as Industries 4.0 works towards the stage of Embodied AI, the essential challenge for humanoid robots has changed fundamentally. It has shifted from the task of traditional static trajectory reproduction to that of seeking real time balance between dimension high nonlinear dynamics and unpredictable environmental interactions. At the control level, we have seen that rivalry between the two mainstream paradigms, model based optimal control and data-based learning control, as well as a deep integration of these two paradigms. Model Based Approaches Using particularly Model Predictive Control combined with centroidal dynamics full physical properties are transformed into real-time constraints for stability with hard base math. Nevertheless, they face computational bottlenecks to disturbances that have not been modeled. On the other hand, data driven strategies typical of reinforcement learning demonstrate amazing capabilities of adaptation and human like intuition. Despite this, they find it difficult to bridge the gap between the simulated world and the actual world. Current trends lead to the view that the optimal resolution to this conflict is hybrid architectures, which use the safety boundaries of model-based control for determining learning strategies. As concerns hardware and perception, then, this research opens up the importance of 'morphological computation.' This concept means hardware is no longer simply an execution container or execution environment for algorithms. Instead, its configuration design, the structure being minimalist underactuated or a foot design that is capable of active terrain reshaping inherently offloads control tasks at the physical level. Simultaneously, the change in the sensor configuration from series of single modal to multi-source heterogeneous fusion of vision, inertia, and touch, and the change in the state estimation algorithms from Kalman filter to neural network, have solved the problem of the loss of state during intense motion and slipping conditions. In summary, existing technological breakthroughs in humanoid robot not derived from one point of eruption. Instead they are derived from the efficient synergy and unification of three things: the information flow of perception, the decision flow of control, and the energy flow of the hardware.

Looking at the future, the progress of humanoid robots will be accomplished from the current point of 'locomotion adaptation' to higher levels of 'cognitive interaction' and 'extreme efficiency.' Its

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development path will play out as the co-design of the software and hardware and the deep evolution of embodied AI. First, at the control and algorithmic level, future advances will be based on joining 'transparency' and 'generalisation.' Although hybrid control architectures have been successfully employed in the first experiments, how to give deep neural networks their physical interpretability is an unsolved challenge. Ensuring they have verifiable safety in the extreme operating conditions is nonetheless difficult. Meanwhile with the development of the large model technology, their end to end general control policies will replace specialized controller designed for specific terrains. This will allow robots to exhibit zero shot transfer capabilities across cross domain scenarios (from snow to stairs). Secondly, in regard to hardware evolution, 'biological fusion' will be an important word. There will be no restriction for rigid motors any longer to act as actuators. Instead, they will be evolved to artificial muscles or joints with variable stiffness that have high explosive power and intrinsic compliance. This evolution at the hardware level will fundamentally reduce the improvement of high frequency feedback control, achieving efficient energy utilization. Furthermore, perception systems will change their face from 'geometric reconstruction' to 'semantic understanding'. Advances in the edge power of AI will allow robots to move past detecting an obstacle ahead, however. They will instead comprehend the material, properties and possible interaction methodologies of the obstacle, thus being able to realize the transition from pure obstacle avoidance to complex dexterous manipulation. Finally, the lines between hardware and software will be blurred even further. Evolutionary based co design will become the norm, i.e. the robot's physical structure and control brain will evolve in synergy in the virtual environments. This process will eventually produce the next generation embodied AI terminals with an authentic sense of environmental adaptability, operation dexterity, and inherent safety. Thus, we will really get the vision of moving from controlled laboratories to the wide open world.

References

[1] de Lima, C. R., Khan, S. G., Tufail, M., Shah, S. H., & Maximo, M. R. O. A. (2024). Humanoid Robot Motion Planning Approaches: A Survey. Journal of Intelligent & Robotic Systems, 110(2), 86.
[2] Ibraev, S., & Sultan, D. (2025). A Review of Control Strategies for Robotic Systems with Embedded Sensors. Engineering, Technology & Applied Science Research, 15(6), 29536–29544.
[3] Hu, C., Xie, S., Gao, L., Lu, S., & Li, J. (2023). An overview on bipedal gait control methods. IET Collaborative Intelligent Manufacturing, 5(3), e12080.
[4] Carpentier, J., & Wieber, P.-B. (2021). Recent Progress in Legged Robots Locomotion Control. Current Robotics Reports, 2(3), 231–238.
[5] Karsai, A., Kerimoglu, D., Soto, D., Ha, S., Zhang, T., & Goldman, D. I. (2022). Real-Time Remodeling of Granular Terrain for Robot Locomotion. Advanced Intelligent Systems, 4(12), 2200119.
[6] Ficht, G., & Behnke, S. (2022). Direct Centroidal Control for Balanced Humanoid Locomotion (No. arXiv: 2208.04757). arXiv.
[7] Xu, W. Q., Yang, F. Y., & Li, Q. D. (2025). Stable walking planning of biped robots based on angular momentum. Electronic Science and Technology, 38(08), 87-93.
[8] Rossini, L., Ruscelli, F., Rouxel, Q., Tsagarakis, N., & Hoffman, E. M. (n.d.). Experimental Validation of Open-Loop Walking based on Whole-Body Model Predictive Control.
[9] Zamboni, R., Owaki, D., & Hayashibe, M. (2021). Adaptive and Energy-Efficient Optimal Control in CPGs Through Tegotae-Based Feedback. Frontiers in Robotics and AI, 8, 632804.
[10] Lin, J. Y., Hu, X. C., & Zhang, C. (2020). Generation and analysis of motion trajectories for biped robots based on CPG mechanism. Machinery Design & Manufacture, (02), 256-259.
[11] Roychoudhury, A., Khorshidi, S., Agrawal, S., & Bennewitz, M. (2023). Perception for Humanoid Robots. Current Robotics Reports, 4(4), 127–140.
[12] Wang, Z., Yan, H., Wang, Y., Xu, Z., Wang, Z., & Wu, Z. (2024). Research on Autonomous Robots Navigation based on Reinforcement Learning. 2024 3rd International Conference on Robotics, Artificial Intelligence and Intelligent Control (RAIIC), 78–81.

DOI: 10.54254/2755-2721/2026.BJ31659

[13] Radosavovic, I., Xiao, T., Zhang, B., Darrell, T., Malik, J., & Sreenath, K. (2023). Real-World Humanoid Locomotion with Reinforcement Learning (No. arXiv: 2303.03381). arXiv.
[14] Hernandez-Vicen, J., Martinez, S., Garcia-Haro, J., & Balaguer, C. (2018). Correction of Visual Perception Based on Neuro-Fuzzy Learning for the Humanoid Robot TEO. Sensors, 18(4), 972.
[15] Gong, Y. L., & Tao, Z. B. (2025). Feedback gait control method for biped robots for the escalator scenario. Industrial Control Computer, 38(07), 56-58.
[16] Mikolajczyk, T., Mikołajewska, E., Al-Shuka, H. F. N., Malinowski, T., Kłodowski, A., Pimenov, D. Y., Paczkowski, T., Hu, F., Giasin, K., Mikołajewski, D., & Macko, M. (2022). Recent Advances in Bipedal Walking Robots: Review of Gait, Drive, Sensors and Control Systems. Sensors, 22(12), 4440.
[17] Kyle, J., Yim, J. K., Hart, K., Bergbreiter, S., & Johnson, A. M. (2023). The Simplest Walking Robot: A bipedal robot with one actuator and two rigid bodies (No. arXiv: 2308.08401). arXiv.
[18] Wang, Y., Li, W., Togo, S., Yokoi, H., & Jiang, Y. (2021). Survey on Main Drive Methods Used in Humanoid Robotic Upper Limbs. Cyborg and Bionic Systems, 2021, 2021/9817487.
[19] Bin, T., Yan, H., Wang, N., Nikolić, M. N., Yao, J., & Zhang, T. (2025). A survey on the visual perception of humanoid robot. Biomimetic Intelligence and Robotics, 5(1), 100197.
[20] Wang Xiaoyun. (2020). Research on robot pose correction method based on vision and IMU fusion. Journal of Heilongjiang University of Technology (Comprehensive Edition), 20(03), 84-88.
[21] Fu Miaomiao & Shen Hongwei. (2021). Research on automatic control of robot attitude based on laser and visual perception. Laser Journal, 42(05), 138-142.
[22] Liu Xiaogang & Zhang Bin. (2019). Research on robot laser sensing positioning technology based on neural network. Laser Journal, 40(11), 127-130.
[23] Gao, S., Dai, Y., & Nathan, A. (2022). Tactile and Vision Perception for Intelligent Humanoids. Advanced Intelligent Systems, 4(2), 2100074.