Sim-to-Real Hierarchical Planning and Control System for Six-Legged Robot

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Abstract. Legged robots have attracted much attention both from industry and academia. Despite the recent progresses in robotics, planning and control in complex environments are still great challenges for legged robots. Generally, constructing the planning and control system for legged robots requires complex designing and parameter tuning. To reduce resource consumption and potential risk in this process, a sim-to-real hierarchical planning and control system is proposed in this paper. The proposed hierarchical system can improve the data efficiency and reduce the training cost utilizing the reinforcement-learning-based framework. Several experiments are conducted to demonstrate the feasibility and effectiveness of the proposed method.

Keywords: Sim-to-real · Robot control system · Hierarchical system

1 Introduction

Legged robot is a challenging research topic in the field of robotics. It has potential applications in military and civilian fields, such as military reconnaissance, intelligent manufacturing monitoring and disabled assistance [1–4]. Compared with tracked and wheeled robots, multi-legged robots have advantages in adapting to complex unstructured environments [5–7]. However, the planning and control system for the multi-legged robot is more complex due to its "multi-input, multi-output and multi-end-effector" property [8]. Compared with bipedal and quadruped robots, six-legged robots have better stability, bearing capacity and adaptability [9].

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In recent years, the field of multi-legged robot has made great progresses. Particularly when utilizing simulation environment, reinforcement learning methods have shown potentials in planning and control for unstructured environments [10]. For instance, with an end-to-end approach, a policy network can be trained to control the torques of the robot with different height maps as input [11,12]. In addition, sim-to-real framework facilitates the planner to learn the boundary of the motor skills of the robots [13].

To improve the adaptability and the intelligence of six-legged robots in diverse environments, a hierarchical planning and control system is proposed in this paper. In this two-layer framework, the bottom layer performs local motion planning and balance control, while upper layer adaptively learns the capabilities of the robot and generates global trajectory considering the capability embeddings of the robot. In the training process of the proposed framework, a Sim-to-Real pipeline is employed for efficiency and safety, where the robot is modeled in the simulator to train the policy for the planning and control system.

2 Methods

2.1 Sim-to-Real Training Framework

To simulate the kinematics and dynamics motion of the robots, the model of the six-legged robot is created in the simulator. In this process, the identified parameters of the real robot directly influence the accuracy of the simulated model. As shown in Fig. 1, the physical model reflects the topological motion characteristics of the six-legged robots, and the control policy is optimized in the simulation environment by utilizing reinforcement learning methods. Since a gap between reality and simulation still exists, data from the real-world data are utilized during training. The learned control policy network can be deployed on a real robot and evaluated in indoor and outdoor environments.

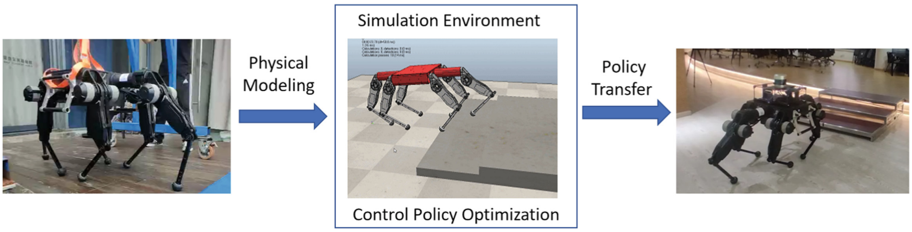

Fig. 1. Sim-to-real legged-robot policy learning process. Policy learned in the simulation environment can be transferred to a real robot.

2.2 Hierarchical Planning and Control System

To improve the accuracy and the robustness of the control policy for the six-legged robot, a hierarchical architecture is presented to integrate planning and control modules. As shown in Fig. 2, the hierarchical adaptive planning framework is designed, which has the advantages of efficient and accurate computation for global planning. This hierarchical structure contains a bottom and an upper layer. The bottom layer is responsible for the balance and local motion control of the six-legged robot, and the upper layer learns the capabilities of the bottom controller and provides the guiding trajectory by considering the surrounding height map and the target location. In the training process, the control module consists of an active compliance control method based on the whole-body dynamics model and an impedance control method for a single leg based on the foot-ground contact stiffness identification model.

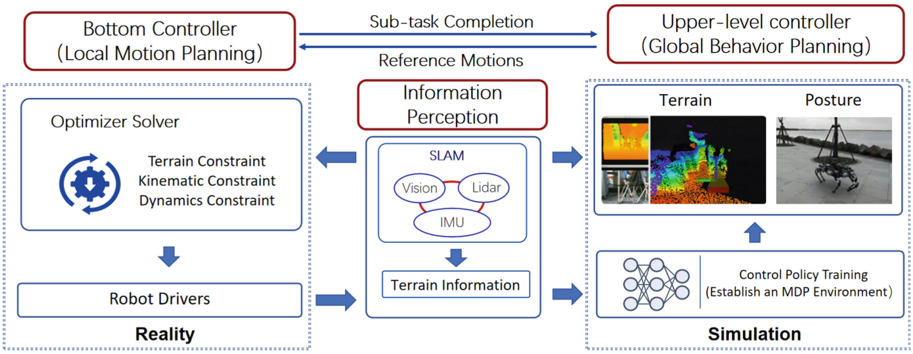

Fig. 2. The overall framework of proposed hierarchical planning and control system. The bottom-level controller is designed to control the robot's motion in real time according to the instructions from upper-level policy learned in the simulation environment.

3 Experiments

Based on the proposed intelligent system, a variety of six-legged robots have been developed and applied to different scenarios, as shown in Fig. 3. The mechanical structure of the high-load six-legged robot is designed based on the bionics of an octopus. The mechanism and motion topology of the robot are complex, hence the design of the controller is a complicated task. With the support of the proposed hierarchical system, the robot can be modeled and trained in the simulator, and then the system with the learned policy can be deployed to the real robot for real-time execution. In terms of the guide-dog robot, the employment of the sim-to-real framework can avoid the potential risks caused by unexpected behaviors in policy training and physical human-robot interaction.

For skiing and skating robots, the uncertainty and complexity of the environment is the major challenge for the planning and control system of the robots. Hence in the training process, the environment characteristics are parameterized to generate diverse training scenarios for better adaptability of the system. On the other hand, the data of the robot and the environment is collected and

(a) High-load robot (b) Guide-dog robot (c) Skiing robot

Fig. 3. The experiments of several six-legged robots based on the sim-to-real planning and control system. The effectiveness of the proposed system has been verified in different application scenarios.

transferred into the simulator to improve the fidelity of the simulation and represent the variability of the environment. According to the above experiments and applications in various scenarios, the adaptability and the universality have been demonstrated on the planning and control for legged robots.

4 Discussion and Conclusion

A sim-to-real hierarchical planning and control System for the six-legged robot is proposed in this paper. The implementation and experiments show the feasibility and effectiveness of this framework in practical scenarios. In the future, more work can be done to increase the efficiency of each module. For instance, the efficiency of data utilization during training and the accuracy of model construction can affect the performance of this system.

References

1. Usha, M.N., Priyadharshini, S., Shree, K.R., Devi, P.S., Sangeetha, G.: Military reconnaissance robot. Int. J. Adv. Eng. Res. Sci. **4**(2), 237036 (2017)
2. Zhang, Z., Chen, S.: Real-time seam penetration identification in arc welding based on fusion of sound, voltage and spectrum signals. J. Intell. Manuf. **28**(1), 207–218 (2017)
3. Xiao, A., Tong, W., Yang, L., Zeng, J., Li, Z., Sreenath, K.: Robotic guide dog: leading a human with leash-guided hybrid physical interaction. In: IEEE International Conference on Robotics and Automation, pp. 11470–11476 (2021)
4. Al-dabbagh, A.H., Ronsse, R.: A review of terrain detection systems for applications in locomotion assistance. Robot. Auton. Syst. **133**, 103628 (2020)
5. Bartsch, S., Manz, M., Kampmann, P., Dettmann, A., Hanff, H., et al.: Development and control of the multi-legged robot mantis. In: International Symposium on Robotics, pp. 1–8 (2016)
6. Wellhausen, L., Hutter, M.: Rough terrain navigation for legged robots using reachability planning and template learning. In: IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 6914–6921 (2021)

7. Tennakoon, E., Peynot, T., Roberts, J., Kottege, N.: Probe-before-step walking strategy for multi-legged robots on terrain with risk of collapse. In: IEEE International Conference on Robotics and Automation, pp. 5530–5536 (2020)
8. Fang, L., Gao, F.: Type design and behavior control for six legged robots. Chin. J. Mech. Eng. **31**(1), 1–12 (2018)
9. De Santos, P.G., Cobano, J.A., Garcia, E., Estremera, J., Armada, M.A.: A six-legged robot-based system for humanitarian demining missions. Mechatronics **17**(8), 417–430 (2007)
10. Nie, B., Gao, Y., Mei, Y., Gao, F.: Capability iteration network for robot path planning. Int. J. Robot. Autom. **37**(3), 266–272 (2022)
11. Qin, B., Gao, Y., Bai, Y.: Sim-to-real: six-legged robot control with deep reinforcement learning and curriculum learning. In: International Conference on Robotics and Automation Engineering, pp. 1–5 (2019)
12. Erden, M.S., Leblebicioğlu, K.: Free gait generation with reinforcement learning for a six-legged robot. Robot. Auton. Syst. **56**(3), 199–212 (2008)
13. Hwangbo, J., et al.: Learning agile and dynamic motor skills for legged robots. Sci. Robot. **4**(26), eaau5872 (2019)