Analysis of Fall Detection, Autonomous Reset and Other Technologies for Quadruped Robots

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Abstract. Traditional industrial robots are widely used in automobile assembly, automobile spraying, and other fields, but they have certain limitations in some fields with high precision requirements. Research on quadruped robots not only addresses the disadvantages of traditional robots, but also combines with other technologies to form a more advanced production model. This article starts from the two aspects of fall detection and reset planning of quadruped robots, and explains that compared with traditional robots, quadruped robots have higher accuracy and a more complete system, and their integration of deep learning technology allows quadruped robots to complete operations in more complex environments. This article reviews the current development status of quadruped robots and explains their future development direction, promoting the development of this field through the collaboration of multiple technologies.

Keywords: quadruped robot, deep learning, reset planning, fall detection

1 Introduction

In this era led by technology, intelligent manufacturing has become a new synonym. Integrating technologies such as the Internet of Things, big data, and artificial intelligence, and with information technology as the core, intelligent manufacturing runs through the entire production process, realizing a fully controllable advanced production model, making manufacturing self-aware, self-decision-making, self-execution, and self-learning. Traditional manufacturing processes are fixed and less flexible, while smart manufacturing is mainly data-driven and can continuously and iteratively optimize production capabilities, improve production efficiency, while avoiding high risks. In the process of highly integrated development of digitalization and intelligence, industry giants such as Yushu Technology and UBTECH have made huge breakthroughs in the field of intelligent robots and developed various humanoid and quadruped robots. In this field, precision, efficiency, and modularity reflect the wider application and higher application value of this type of robot in technology.

Compared with traditional robots, quadruped robots can adapt to many complex environments and have the potential for multi-functional operations based on their bionic movement mechanism and good control capabilities. Moreover, researchers were inspired by the movement gaits of goats, turtles, and other creatures, and conducted in-depth research on how to control quadruped robots to adjust their own structures during movement to maintain a stable state [1].

However, the current quadruped robots have reached a certain level of movement ability, load-

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carrying capacity, and various work coordination capabilities on hard roads, but they face huge challenges in some specific scenes and extreme environments. For example, soft beaches will greatly reduce the stability of the robots. What's more, it is difficult for quadruped robots to complete some difficult actions and put them into practical applications with the current level of accuracy. In response to this problem, this article summarizes the detection function and autonomous reset method of a quadruped robot when it falls. It also introduces how to get inspiration from the bionic mechanism and combine related technologies and models to realize the function. First, plan the placement of the detection device based on the structure of the quadruped robot, and then use sensors to detect the robot. This article mainly introduces the IMU sensor and RGB camera to detect whether the robot is in a fallen state. Then, when introducing the reset function, it starts with quadrupeds and other creatures, and also analyzes the reset process of crustaceans. Deep learning also has specific manifestations in this field, combining deep convolutional neural networks and feature frameworks for research. Finally, the future development of fall detection and reset technology for quadruped robots is summarized and projected.

2 Development stage of quadruped robots

Traditional industrial robots are automated devices oriented to industrial scenarios, replacing manual labor in completing some high-intensity tasks according to set procedures. Such industrial robots can be seen everywhere in corporate factories. The robotic arms on the assembly line can replace human labor to complete some simple sorting tasks. In the field of automobile welding, this type of robot is the most mature application scenario. In addition, there are also application fields such as automobile painting and hardware polishing. However, this type of robot has great limitations. Fixed scenarios and weak interaction capabilities make them gradually eliminated. Compared with those industrial robots that lack flexibility, quadruped robots emerged at a historic moment. This is not only caused by people's gradually increasing needs, but also a trend caused by technology leading this era. They fill the gap of traditional industrial robots that do not have the ability to perceive independently, and enable multi-technology collaboration through the Internet of Things to expand the scope of production.

The control methods of quadruped robots can be divided into two categories: model-based control and model-free control. Wang et al. proposed areas where these two models are relatively applicable when studying quadruped robots on the lunar surface[2]. The former can combine existing physical methods and mathematical models with feedback systems to achieve high-precision control of the robot's motion trajectory planning; the latter summarizes experience through deep learning and reinforcement learning without model reference, and can also be combined with neural network control to more accurately adjust motion trajectory parameters, greatly improving the robot's adaptability in complex environments.

Obviously, when studying the fall and reset process of a quadruped robot, it is necessary not only detect the fall process based on some specific models, but also need a model-free intelligent algorithm to improve the accuracy during reset and plan a relatively reasonable motion trajectory. For example, some robot operating structure models and motion control and gait planning algorithms can help quadruped robots improve their accuracy.

3 Kinematics theory of quadruped robots

3.1 Body structure (degrees of freedom, joint connections)

The current structure of quadruped robots is often similar to canine robots because their appearance is highly similar to that of dogs, and the dimensions and other parameters of the feet are also designed by referring to the limbs of dogs[3]. As shown in Figure. 1, the quadruped robot climbing stairs obviously has a high degree of stability, thanks to the rational connection of various joints and multiple degrees of freedom, which allows the robot to have quite a few paths to complete corresponding movements.

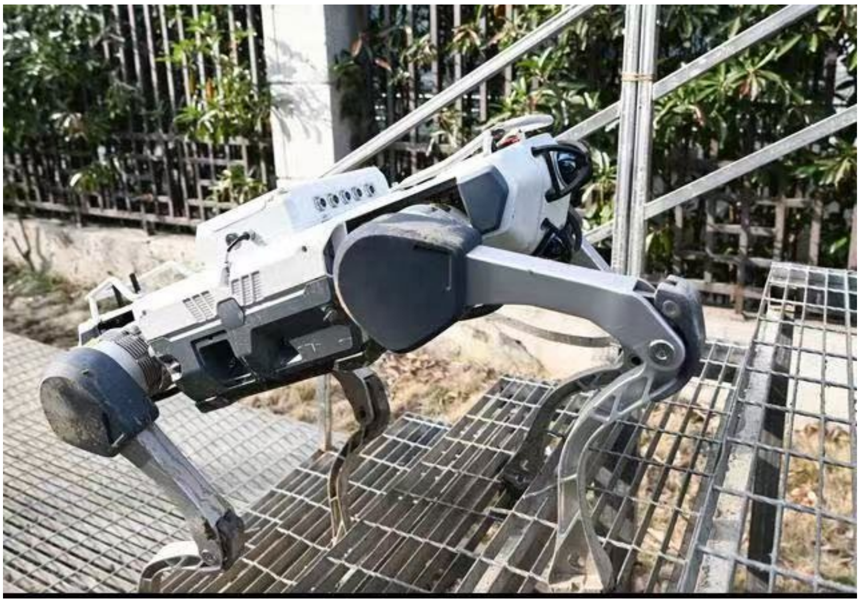

Fig. 1: Quadruped robot climbing stairs[3]

Different from the limbs of dogs, the robot's "thighs" and "calves" can bend to a wider range, and each leg has two joints to maintain balance in various standing postures. This way of standing with inner knees and elbows also further increases its stability.

The stable structure of the quadruped robot foot was also studied and summarized in the bionic mechanism mentioned by Pei et al [4]. Referring to the folds of protein bristles on the toes of gecko feet, the feet of quadruped robots can also use similar structures to have an adhesive structure to increase the friction between the feet and the contact surface, which is very important for the stability of the robot.

3.2 Fall detection function

Fall sensing. Based on the existing model, sensors can detect the real-time motion parameters of the machine, such as attitude angle, angular acceleration, contact status with the ground, etc., to determine whether the robostate. At the same time, it is also necessary to avoid false triggering due to ground impact, that is, to make subsequent reset actions when the robot is not in a fallen state.

In addition to the monitoring function of sensors, the increasing maturity of visual technology has made the perception function more powerful. This technology has a wide range of applications and has made a lot of progress in agricultural irrigation and other fields. Martin et al. mentioned the diversity of this technology when summarizing assistive robots that help the elderly prevent falls [5]. Compared with sensors, vision technology only requires cameras to complete the monitoring function, improving the flexibility of the user group. In this technology, three types of cameras, single camera, multi-camera, and depth camera, can be selected according to different needs.

For quadruped robots, the dual detection of vision technology and sensors can greatly improve its error tolerance. Sometimes, when the sensor fails, vision technology can correct the error of undetected falls and pass the signal to the reset system.

Data collection platform. At present, the most common data collection method prioritizes the smallest state space and collects the robot's status data in real time through IMU+contact sensors.

Kim et al. mentioned the specific embodiment of this technology in this field when studying autonomous vehicles [6]. The IMU sensor can monitor acceleration, angular velocity, and other parameters to determine the vehicle's position. However, it will produce large errors when processing the integrated acceleration to estimate the driving distance.

Lee also used IMU technology in studying fall detection methods [7]. Through the IMU sensor and RGB camera, the robot can move to the corresponding position when it detects a fall signal, conduct multiple inspections with the camera, and then improve accuracy through image collection and analysis.

When applied to quadruped robots, the technology's high adaptability provides an important basis for the robot's fall detection function. If large errors are found during the experiment, RGB cameras and other technologies can also be used to assist, thereby improving accuracy.

3.3 Reset planning

The reset planning of a quadruped robot refers to the process of sensing its own state after a fall, identifying and planning the movement trajectory, and autonomously returning to a stable standing posture. In this process, the state space must first be clarified to obtain specific parameters to provide data for subsequent planning, and then the optimal gait planning can be carried out based on these data.

The state space of robots can be roughly divided into four categories. Among them, the most basic position state can be divided into three mutually perpendicular planes, X, Y, and Z, in a three-dimensional space. The position information of the robot can be accurately described through these three planes. Attitude state is a very important state quantity in kinematics. It includes roll angle, pitch angle, yaw angle, and other parameters that can further describe the real-time dynamics of the robot, making subsequent reset operations more accurate. The biggest difference between the motion state and the previous two states is that it has six dimensions, whichcombine linear velocity, angular velocity, and other velocity parameters. The contact state is one of the indispensable states. Although it has only one dimension, it can accurately determine the number of legs touching the ground through binary coding.

Gait planning is often based on IMU sensors to determine the status and then output gait instructions. In different environments, switch to different gaits according to the terrain type and robot status. Of course, bionic mechanisms also have great reference value in gait planning.

Zhang et al. studied the process of self-recovery of some four-legged animals after falling and found that they usually have three methods when resetting [8]. For example, some small mammals (cats, dogs) will use the method of spinal curvature, mainly relying on their own gravity to complete the reset action. Insects without spines are obviously not suitable for this method. They mainly rely on their limbs and tails to support themselves back to a standing position. There are also some crustacean insects; due to their weak limb strength and disadvantages in spinal function, the first two methods are not applicable. But due to the particularity of their body shape, they can adopt a special set of mechanisms to help themselves reset. Thanks to their curved carapace, when they are in a fallen state, only the center point is in contact with the ground. At this time, the shell can shake violently due to gravity, creating a resonance effect. When the vibration reaches a certain frequency, the flip reset can be completed. Fig. 2 shows the process of crustacean resettlement.

Fig. 2 Crustacean organism reset process[8]

According to the different state spaces, the gait planning of the quadruped robot can be roughly divided into four steps after referring to the above technology and experience. The first is attitude detection. The IMU sensor is used to monitor the roll angle of the robot (the dividing value is about 60°). At this time, the joints need to be fixed to make the subsequent process relatively easy; then the center of gravity of the robot should be transferred to the side that has not fallen, which is conducive to the activity of the joints on the side of the fall; then the body is flipped with the leg touching the ground as a fulcrum until it returns to a standing state; finally, the center of gravity is adjusted to make it enter a relatively stable state.

4 Deep learning core technology

4.1 Background of deep learning

Deep learning (DL) uses multiple neural systems to extract features from the content recognized by machine learning (ML). Peter et al. first mentioned the wide application of DL in industrial fields such as robot control and grasping, and then focused on an overview of the deep convolutional neural network (CNN) proposed by researchers such as Krizhevsky[9]. The CNN model shows a lower error rate than other models and has high application value in speech recognition, image processing, and other functions. In the emerging field of autonomous vehicles, this technology has high adaptability. For example, combining DL with navigation technology can monitor the surrounding environment to complete the network. Using environmental characteristics as input, the signal is converted into an electrical signal output, and the robot can be controlled in different complex environments.

4.2 Application of deep learning in the field of quadruped robots

Deep learning has taken root in the field of quadruped robots, and both motion control and environmental perception are inseparable from the application of this technology. Of course, deep learning is also often used in other fields. Intelligent robots, such as warehousing robots and navigation robots, need it to improve production efficiency.

For canine robots such as quadruped robots, the most common approach is to learn bionic mechanisms. Summarize the rules by studying the fall and recovery process of canine creatures. Peng et al. were inspired by the cognitive process of animals and established a framework based on the animals' perception of the environment [10]. For example, a feature space established based on the animal's vision and touch. The quadruped robot will form a contact model based on the touch on different surfaces. Through this model, various parameters of the ground can be identified, and a neural network will be established after obtaining the parameters.

It can be seen that DL has formed a complete framework system for quadruped robots. This system adapts to each other in the robot's touch to the ground, and can complete the corresponding monitoring and reset functions without the need for a model.

5 Outlook

At present, quadruped robots play a huge role in important scenarios such as road rescue and personnel rescue. Sensing technologies such as bionic mechanisms and IMU have provided a lot of experience in the research of quadruped robots. At the same time, researchers are also committed to studying the combination of deep learning and various model systems to improve the detection accuracy and reset sensitivity of quadruped robots in different environments. Among them, deep convolutional neural networks have been widely used in this aspect.

In the future, the fall and reset detection technology of quadruped robots is expected to make further breakthroughs. On the one hand, deep learning is still in the research stage, and further research in the future will definitely bring more theoretical guidance to this technology. On the other hand, researchers are in the experimental stage of multi-technology integration. If various technologies can be connected in series, it may be a substantial breakthrough for this field.

What deserves more attention is that the future development of reinforcement learning such as robot control strategies, can greatly improve the control accuracy of robots. In general, quadruped robots will focus on the multi-module integration of deep learning and reinforcement learning technologies in the future to achieve higher precision. This is consistent with the pursuit of precision, efficiency, and modularization, and is conducive to advancing this field to a higher level.

6 Conclusion

This article summarizes that in the context that traditional industrial robots have matured, technologies such as fall sensing and reset functions of quadruped robots are overcoming difficulties. When studying the fall state of the robot, in addition to using traditional sensors for monitoring, this article also mentions that high-tech technologies such as IMU sensing technology, camera technology, and RGB cameras improve monitoring accuracy. In terms of reset technology, this article mainly summarizes the application of bionic technology through the combination of various sensing technologies. Then he mentioned the application and advantages of deep learning in quadruped robots, which have extremely high adaptability in fall sensing and reset planning.

This article also summarizes that in future development, quadruped robots will be more widely used, and mentions that deep learning and intensity learning technologies will play an increasingly important role in the various functions of quadruped robots. Of course, these technologies can be further researched and improved in the future. They can also be improved in aspects such as the shape and installation ability of the quadruped robot to reduce the risk of falls and eliminate the need for reset planning. These technologies can also be used to improve stability and accuracy during reset, which is beneficial to production development and rescue work.

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