Perspective Of Vision, Motion Planning, And Motion Control for Quadruped Robots

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Abstract. In recent years, robot technology has made great progress, especially quadruped robots. Quadruped robot is a bionic robot that imitates the movement of quadruped animals. For quadruped machines in complex environments, our group first investigate the control of quadruped robots in complex situations. It is found that the current quadruped robots can achieve better motion control under various complex conditions, but there are still limitations. Its structure includes the trunk and four legs located in front and behind the trunk. Each leg has the same structure, including the thigh, calf, and foot. This paper summarizes the research on foot structure design and foot tip trajectory optimization of quadruped robot. Machine Vision is a branch of artificial intelligence that is developing rapidly. Simply put, machine vision is to use machines instead of human eyes to make measurements and judgments. The following passage discusses about two main kinds of algorithm, while making analytic and comparisons among others and why to choose these two out in the machine vision part of quadruped robots. By summarizing and analyzing the research status, this paper proposes some challenging and valuable future research directions.

Keywords: Quadruped robot; complex situations; foot tip trajectory; motion simulation; machine vision.

1. Introduction

In recent years, robot technology has made great progress, especially quadruped robots. Quadruped robot is a bionic robot that imitates the movement of quadruped animals. Its structure includes the trunk and four legs located in front and behind the trunk. Each leg has the same structure, including the thigh, calf, and foot. Compared with wheeled and tracked mobile robots, quadruped robots have remarkable flexibility and strong terrain adaptability, can walk on most of the ground, and have excellent obstacle surmounting ability. These characteristics make quadruped robots have absolute advantages that wheeled robots cannot match in uncertain environments. The leg structure of quadruped robot is simple, stable, and flexible, and has a certain bearing capacity. It can assist or replace part of human work to a certain extent. It has a broad application prospect in emergency rescue, disaster relief, exploration, entertainment, military, and other fields. Therefore, quadruped robot has increasingly become a research hotspot in the robot field at home and abroad in recent years. For quadruped robot, the current research focus is on its overall structure design and motion trajectory planning.

Control method realizes the calculated foot motion trajectory on the quadruped robot entity [1]. By investigating some previous quadruped robots, our group found that quadruped robots can perfectly perform some motion control on flat terrain and under normal conditions. By sorting through the data, it has been discovered that research in this field is relatively mature. Recent research on quadruped robot control mainly focuses on control speed and accuracy in complex terrain. Terrain in a real setting comprises barriers, gaps, slopes, and other variables. The work environment may also have an impact on the robot [1, 2]. According to a survey and analysis of the literature, quadruped robots cannot reach adequate working conditions in complicated contexts. As a result, it is critical to enhance quadruped robot control in order to deal with complicated scenarios.

80% of the information people get from the external environment comes from vision. Machine vision simulates the visual function of human eyes by computer, extracts information from images or image sequences, and recognizes the shapes and movements of three-dimensional scenes and objects in the objective world. One of the purposes of machine vision research is to find the laws of human vision, so as to develop an image understanding system from image input to natural scene analysis. For a machine vision system, the input is a gray array representing the projection of a three-dimensional scene. There can be several input arrays, which can provide information in different directions, different perspectives and different moments. The desired output is a symbolic description of the scene represented by the image. Usually, these descriptions are about the category of objects and the relationship between objects, but they may also include information such as surface spatial structure, surface physical features (shape, texture, color, material), shadow and light source location. Generally speaking, the expected function of vision machine is to utilize and impose the environmental constraints of the scene, capture images, analyze these captured images, identify certain objects and features in each image, and initiate subsequent actions to accept or reject the corresponding objects. Finally, the machine vision processing flow is shown in Figure 1.

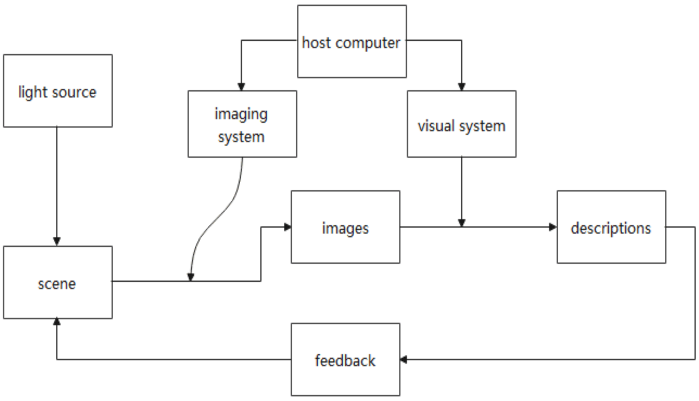


Fig. 1 Machine vision processing flow

2. Motion control of quadruped robot in complex situations

Zico Kolter created a quadruped robot with a hierarchical control system that can traverse difficult terrain [3]. They carried out experimental assessments that demonstrated the robot's strong ability to navigate a range of difficult terrains while employing their control system. They conducted comprehensive studies to show the value of these topographic aspects in control systems. In tests, the quadruped robot was able to go through uneven sand dunes and stones, but the most challenging terrain was rocky, with impediments up to 10 cm in height. The Little Dog quadruped robot is seen in Figure 2.

Marc Raibert developed quadruped walking algorithms for difficult terrain and sloping surfaces [4]. A gait coordination system that controls inter-leg communication starts leg state transitions at the level of the individual leg to create a steady gait. In the simulation, the BigDog moves up and down rough slopes with up to a 60-degree gradient. It makes it possible to move from walking on flat ground to walking on slopes or slopes, and it can tolerate sudden variations in terrain height brought on by rocky or uneven terrain. Figure 3 depicts Big Dog scaling a fictitious rubble heap.

Fig. 2 Little Dog across rocky terrain [3]

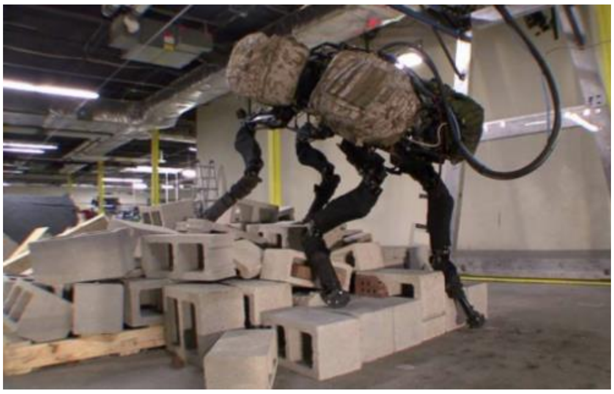
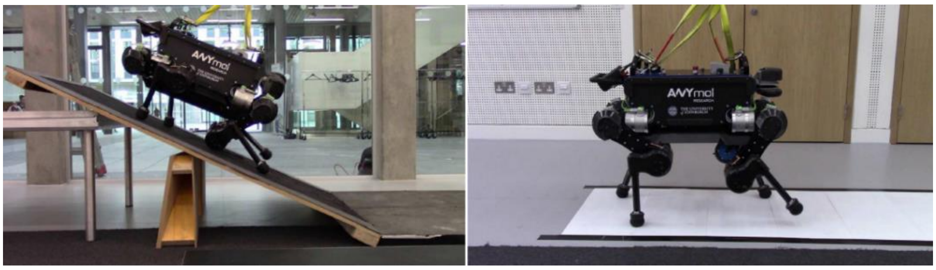


Fig. 3 BigDog climb a rubble pile [4]

Gerardo Bledt's PR-MPC (Policy Regularized Model Predictive Control) [5] considerably improves the present controller. The strategy entails employing straightforward physics-based heuristics to optimize ground response forces and footstep placements in order to normalize forecasts. Based on gait planning and the controller model, they performed force control and model predictive control of the balance controller, respectively. Increased range of motion gives the robot the capacity to create large yaw movements. Figure 4 illustrates how the robot in the stair climbing experiment successfully reached the top.

Fig. 4 Quadruped robot climbs stairs [5]

Xin proposed a Cartesian impedance controller that is analytical, and a QP optimization algorithm as a semi-analytical motion quadruped robot controller [6]. A Cartesian impedance controller can estimate environmental disturbances as well as track the desired end effector trajectory. They put the proposed controller to the test in both low-friction environments and on difficult terrain. The robot can navigate ramps of 30 degrees and fake ice by demonstrating this method. Figure 5 illustrates how ANYmal navigates slopes and ice.



(a) walk on slope (b) walk on ice

Fig. 5 ANYmal walks on slopes or ice [6]

A passive Whole-Body Control (WBC) was tried and confirmed by Shamel Fahmi [7]. The purpose of the planned WBC is to maintain the balance of the quadruped robot when it is passively engaging with its surroundings (whether running, walking, or standing). Quadruped robot motion tasks can be separated into trunk tasks and swing tasks. The trunk job uses a Cartesian-based impedance controller with a feedforward term to primarily regulate the trunk's orientation. The swing task alters the trajectory of the swing foot to place it in the appropriate location. Due to the exploitation of the robot's entire dynamics, the proposed WBC can produce more dynamic motions.

A self-contained control architecture was proposed by Michele Focchi [8] for quasi-static walking over steep terrain. By calculating the ground reaction force at the standing foot, they were able to calculate the desired CoM acceleration and the angular acceleration of the robot base, and they described a method for preventing discontinuity in the contact forces computed by the QP-based controller when breaking or making contact. The findings show that torque management of quadruped robots may prevent sliding despite the high slope of the ground by directly manipulating the GRF.

The Mini-Cheetah Vision robot, created by Thomas Dudzikis, needed to be able to change its posture in response to variations in slope by determining a plane for foot position and adjusting body pitch correspondingly, all without knowing the terrain beforehand [9]. A group of hierarchical motion controllers that govern the robot take the intended CoM path and determine the joint torques to be applied to the robot. Together, the Whole-Body Impulse Control (WBIC) and Regularized Predictive Control (RPC) controllers have been proven to completely harness the benefits of both, including WBIC's processing of complete system models and RPC's predictive capabilities.

In order to respond to disruptions, Edrisi Farid adjusts the quadruped robot's position by combining sensor feedback [10]. An IMU, a three-axis gyroscope and a three-axis accelerometer are required for this technique. A Switched Extended Kalman Filter (SEKF) is created to combine perceptual data with the data from these sensors. The quadruped robot's pose and the zero bias of the gyroscope can both be precisely estimated via SEKF. Switching rules are employed in this filter to distinguish between the robot's EKF measurement model when it is moving slowly or quickly. Finally, the robot body's attitude is altered using a platform beneath ramp disturbances. Figure 6 illustrates the disruption caused by pitch angle.

Fig. 6 Attitude Balance of a Quadruped Robot on a Slope [10]

Quadruped robots occasionally concentrate on minimizing the number of control calculations in order to more effectively navigate complicated environments. The quadruped robots created by Md. Moin Uddin Atique can run at around 15.5 cm every second. over a variety of surfaces, including Formica board, asphalt, rocky dirt, and cement floors [11]. This robot's ability to be remotely controlled from the Android operating system and its automated obstruction-avoidance function make it effective at reaching any desired location. The quadruped robot is seen strolling on the ground in Figure 7(a). When comparing the simulation results of flexibility and rigidity when traversing difficult terrain, Wenkai Huang's flexible quadruped robot illustrates how the robot's flexible legs improve its stability while moving [12]. The actual motion results are superior to the rigid simulation results, but when compared to the flexible simulation results, the robot motion error is greater than the simulation results due to a number of issues, including where the center of gravity is, assembly mistakes, and artificial flaws in the creation of flexible legs. A quadruped robot with flexible legs is seen walking in moist ground in Figure 7(b).

(a) android operating system [11] (b) Equip Flexible Legs [12]

Fig. 7 Measures to reduce the amount of control computation

3. Research on Structural Design

As the most important action execution component of a foot robot, leg structure directly affects the overall performance of the foot robot. Feng Junhua, Qu Xin and others believe that in the current research environment, quadruped robots mainly have the following four-foot structures [13]. Figure 8 shows the leg structure of a quadruped robot widely used at present. This type of robot can realize the movement of hips, thighs and calves, which makes the robot have strong adaptability to uneven ground and strong obstacle surmounting ability. Figure 9 shows another form of leg structure. The crotch buffer joint is formed through the buffer mechanism, which increases the number of joints and buffer performance, thus increasing the workspace of the leg structure at the foot end, enhancing the environmental adaptability, effectively relieving the impact of the robot's foot end when it touches the ground, and improving the stability and reliability of the robot's operation. Figure 10 is another example of the leg structure of a quadruped robot, compared with [14].

For the leg structure shown in Figure 8 and Figure 9, the installation mode of the steering gear in the robot leg structure shown in Figure 10 is simpler, which makes the leg structure more compact on the whole and has low moment of inertia, which is also conducive to the control of the robot leg structure, and can also improve the stability of the leg structure in the movement process. The leg structure of the robot shown in Figure 11 is DELTA type leg structure, which is quite different from the above three leg structures. The DELTA leg structure is simple. Only three motors and three groups of connecting rods are needed to realize the three-dimensional movement of the foot by controlling the rotation angle of the motor respectively, which improves the flexibility of the robot's leg movement and simplifies the robot's leg structure [15]. However, the leg structure of this type of robot has a large width due to the setting mode of three groups of connecting rods, which is not conducive to the miniaturization of the robot. Due to the blocking of the robot body, the lifting height of the foot has certain limitations, resulting in the low obstacle surmounting ability of the robot. Therefore, further research on its structure is needed to overcome the above defects [16].

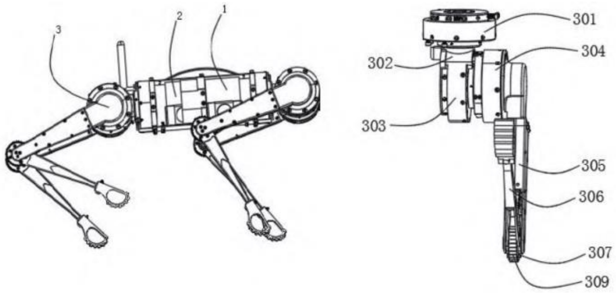


Fig. 8 MIT Cheetah Robot

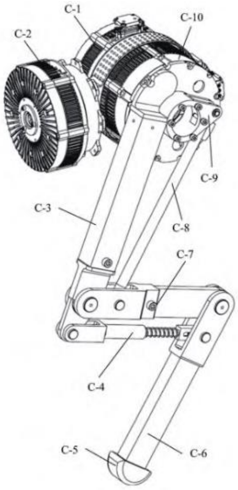


Fig. 9 Two joint leg structure

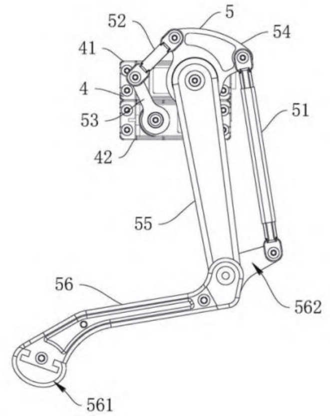


Fig. 10 Single joint leg structure

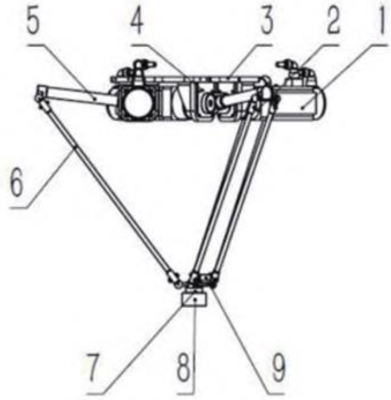


Fig. 11 Simple leg structure

At present, the academia believes that quadruped robots must meet the following basic conditions: 1) stable walking; 2) It has strong terrain adaptability. In practice, most of the walking mechanisms of foot robots use linkage mechanisms. In the following Figure 12, a quadruped walking robot is designed based on the linkage mechanism. Its internal structure is simple and reasonable, and it is easy to use and maintain. It is composed of prime mover, transmission device and working device. The prime mover is a micro motor, and the working part is a leg mechanism. The torque output by the motor reduces the speed through the meshing connection between the small gear and the big gear, and drives the gear coaxial with the big gear to rotate. Because of the meshing between the gears, the rotation is transmitted to the leg mechanism coaxial with them to drive the leg movement. There are 6 gears driving quadruped movement. The figure shows 3 gears driving the front and rear biped movement on the right side, and 3 gears driving the front and rear biped movement on the left side. The layout and structure are the same as those on the right side [17].

Fig. 12 Simple quadruped robot as a whole

4. Research on Trajectory planning

Unlike traditional wheeled or tracked robots, foot robots can lift their legs off the ground for a short time to cross some discontinuous obstacles and move in places that are difficult for traditional robots to reach. At present, some institutions are committed to developing quadruped robots with excellent performance [18]. For example, in 2004, Boston Power Company of the United States developed a large quadruped robot Bigdog, which demonstrated its adaptability to complex terrain such as sloping mountains, soft snow, smooth ice, etc; Based on Bigdog's technology, Spot replaces the hydraulic drive with the motor drive. With the help of the mechanical arm, it can open the door and go up and down stairs; MIT Cheetah3 of MIT can climb stairs without vision sensor [19]; Anymal of Anybotics Company uses integrated joint modules to reduce power consumption and improve sports performance; The Go1 of Yushu Technology in China and the "vanishing shadow" of Yunshen Technology also show good performance in motion control in complex environments. With the improvement of quadruped robot's motion performance, the requirements for quadruped robot to adapt to various working environments also appear. How to explore and move in the unknown environment has become a research hotspot. The stability angle of the quadruped robot body is calculated according to the terrain to realize the stable walking of the robot, but it increases the difficulty of solving the stability angle; The workspace based central pattern generator (CPG) method can simulate the attitude adjustment of animals after lateral impact, which depends on the rapidity of the robot control system; The virtual model method can decouple and control multiple degrees of freedom of the robot, but the model parameters are difficult to estimate accurately, resulting in large differences between simulation and physical testing; Exhaustive method can analyze 24 kinds of walking gait of robot, and select the most appropriate gait for different terrain, but this method is not robust; The method of using sensors to obtain the terrain of foot contact points to adjust the robot's attitude has the disadvantage that it can only detect the terrain touched, and still depends on the rapidity of the robot control system [20, 21]. The above research always relies on the rapid response and adjustment of quadruped robot to adapt to the impact of unknown terrain on the robot, which cannot fundamentally reduce the impact on the robot. For this reason, Chai Qi, Yang Jie and others put forward a method for optimizing the foot tip trajectory of quadruped robot facing unknown terrain, which integrates ideal foot tip trajectory under different terrain segments to obtain foot tip trajectory adapted to various terrain.

Take Stanford's quadruped robot Doggo as the research object. Doggo adopts a parallel leg structure. Each leg has two degrees of freedom. Two motors control one leg to rotate around the shoulder, changing the equivalent angle and length of the leg. As shown in Figure 13, the connecting line from the foot end to the shoulder is the effective length L0 of the parallel leg, and the included angle between L0 and the negative direction of Z-axis is φ, the two motors of the robot legs apply torque respectively τ 1 and τ 2. The equivalent force of the contact point between the foot end and the ground is F, the support force of the ground to the foot end is N, and the friction force of the ground to the foot end is f. The included angle between the ground and the horizontal plane is η

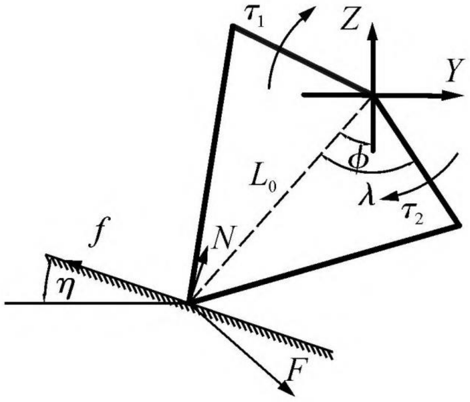


Fig. 13 Angle calculation

When the foot track is fixed, the amplitude of the foot support force N is only related to the sum of the output torques of the two motors. The sum of the quadrature axis currents of the two motors can be used to characterize the foot support force N [22].

Quadruped robots often adopt the trot gait and walk gait. The process of the Trout gait is shown in Figure 14. First, the left hind leg HL and the right front leg FR step together. After half a step cycle T, the right hind leg HR and the left front leg FL step together again. Walk walks step by step in the order of FL-HR-FR-HL. As shown in Figure 14, the robot foot end track is divided into two parts: swing phase ①, and the robot foot end is in a suspended state; Support phase ②, the foot end contacts the horizontal ground, and the support robot moves parallel to the ground. The foot end trajectory of quadruped robot often adopts cycloid trajectory, and the velocity and acceleration of cycloid trajectory at the alternate position of swing phase ① and support phase ② are zero. During the transition from the horizontal ground to the uphill surface, the swing phase has not ended, and the foot tip speed has not dropped to zero before it contacts the uphill surface, causing impact; When transiting from the horizontal ground to the slope, the direction of the support phase is different from that of the slope, which is also easy to cause impact. In order to achieve zero speed and acceleration when swing phase ① and support phase ② alternate on the slope, adopt the method shown in Figure 14 to adjust the foot end track of support phase to be parallel to the slope. In order to reduce the impact on the foot end of the robot on the uphill and downhill surfaces, the foot end trajectories under the three conditions in Figure 15 are fitted. As shown in Figure 16, the support phase is divided into three sections: the uphill support phase, the horizontal support phase and the downhill support phase, and the constraints of the robot leg trajectories on the Y and Z axes are obtained. Under this condition, the velocity constraint and acceleration constraint in Y and Z directions are both 0, so the displacement distance is calculated to plan the path [23].

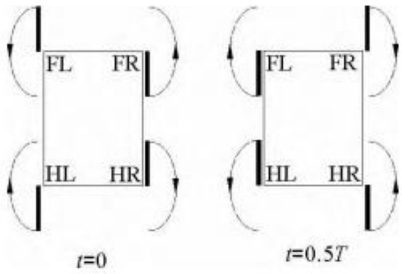


Fig. 14 Step process selection

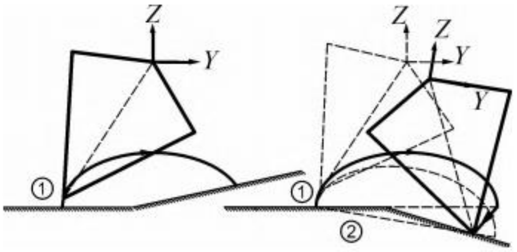


Fig. 15 Schematic Diagram of Tilt Angle Offset

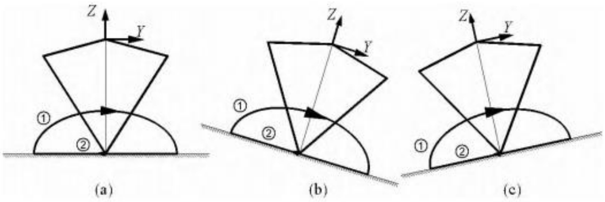


Fig. 16 Gait planning in three cases

some researchers and others proposed a constraint method of zero torque point under diagonal gait in order to make quadruped robot show more stable motion performance in the process of terrain free motion, combined with the motion characteristics of diagonal gait. The fuselage trajectory of the robot under walking and diagonal gait is optimized online by using the quadratic programming optimization method. The optimized fuselage trajectories under the two gaits are mapped to the whole-body state with the same mapping relationship. Combined with the planning control framework, the robot's motion state and trajectory tracking under the two gaits are verified through simulation. The simulation results show that the robot's position, speed tracking effect and body posture stability are better than those of diagonal gait, and the robot can follow the planned trajectory to maintain stable motion under both gait types.

5. Machine vision

5.1. Inertial position algorithm based on monocular vision

How can a robot learn to see the road? Firstly, our group draw out the conclusion, it depends on algorithm: inertial positioning algorithm based on monocular vision (visual positioning technology+terrain recognition technology). Then its eyes can recognize and map terrain in real time, and the accuracy of terrain recognition is less than 2cm [24].

But why our group do not use binocular vision? Indeed, in terms of measurement accuracy and noise resistance, binocular vision undoubtedly performs better than monocular vision. However, there are certain difficulties when using binocular vision.Binocular ranging works by calculating the parallax of two pictures to determine the distance of the front target, which is then processed by a target identification algorithm. The first challenge with binocular vision systems is the size of the calculation and the high performance standards of the computer hardware.Another difficulty lies in the registration effect of binocular vision. Although stereo matching algorithm can be used in the ranging process to improve the ranging accuracy, the principle of ranging itself requires that the error between two lenses should be as small as possible. If the errors of two lenses are about 5% respectively, it will be much more difficult to adjust the algorithm in the later stage, and the certainty cannot be guaranteed.

Figure 17 shows the different pictures captivated by the camera.

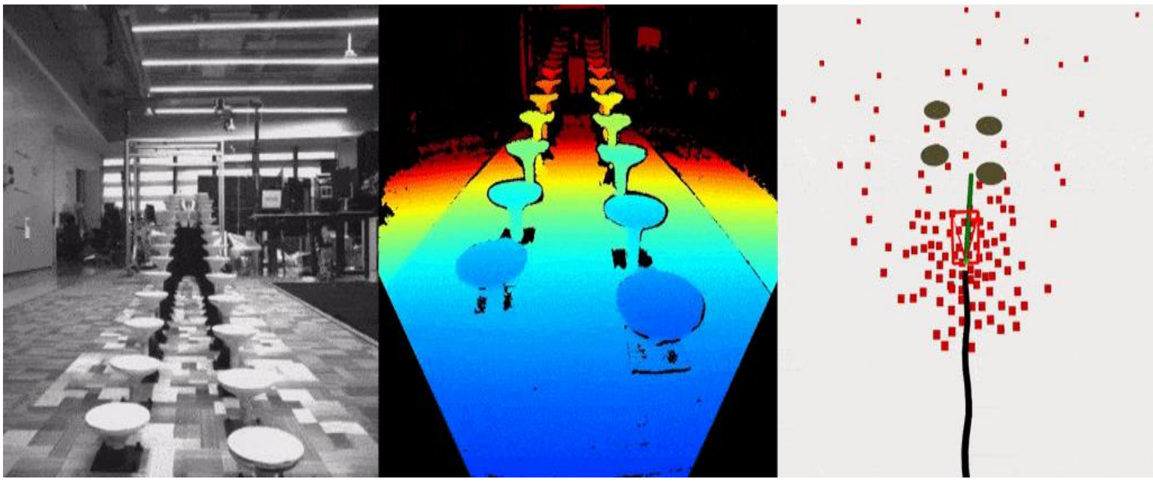


Fig. 17 Different pictures captivated by the camera

The developing conditions of monocular system:Due to its portability, affordability, and simplicity in terms of hardware setup, the usage of simply a monocular camera has attracted a lot of attention. However, their use in practical robotics is constrained by the monocular vision system's inability to restore the measuring scale. Recently, our group've seen that it's becoming more and more common to use inexpensive inertial measurement units (IMUs) to support monocular vision systems. The key benefit of this monocular inertial system (VINS) is that it can measure the roll angle and pitch angle and has a metric scale.This makes navigational tasks feasible that call for measurement state estimate. Additionally, the use of IMU measurement may compensate for visual track loss brought on by changes in lighting, textureless regions, or motion blur, greatly enhancing the effectiveness of motion tracking. Nowadays, using VINS to navigate in GPS-shielded locations is rather common (for example, underground, space or indoors). With the increasing application of such sensors in mobile devices, the research axis of VINS is gradually turning to finding efficient solutions in real time on devices with limited resources Furthermore, with the recent improvement of mobile CPUs and GPUs, interest in more powerful multi-camera VINS is also growing.[25]. However, all of these benefits come at a price For the monocular VINS, it is well known that accelerated excitation is required to make the scale observable This means that the monocular VINS estimator cannot start from a static state but from an unknown moving state Aware of the fact that the intuitive inertial system is very non-linear, our group find a great challenge in initializing the estimator The existence of two sensors also makes the external calibration of the cameraIMU very important Finally, to eliminate long-term drift within an acceptable processing window, a complete system including visual inertia must develop odometer, loop detection, navigation and optimize globally. Strategy: Today, researchers have solved all of the above problems using VINS-Mono, a powerful and versatile visual inertial state estimator [26]

The achievements of this system can be summarized as follows:

- The vigorous initialization process can boot the system from an indeterminate initial state
- Optimized and tightly coupled monocular inertial odometer featuring external camera IMU correction and IMU offset estimation.
- Detect online loops and move tight joints.
- Optimized global attitude map with four degrees of freedom.

•Real-time performance demonstration of UAV navigation, large-scale positioning and augmented reality mobile applications.

•Open source version for PC version fully integrated ROS and iOS version running on iPhone6s and above.

Figure 18 shows the block diagram of the proposed monocular inertial state estimation pipeline.

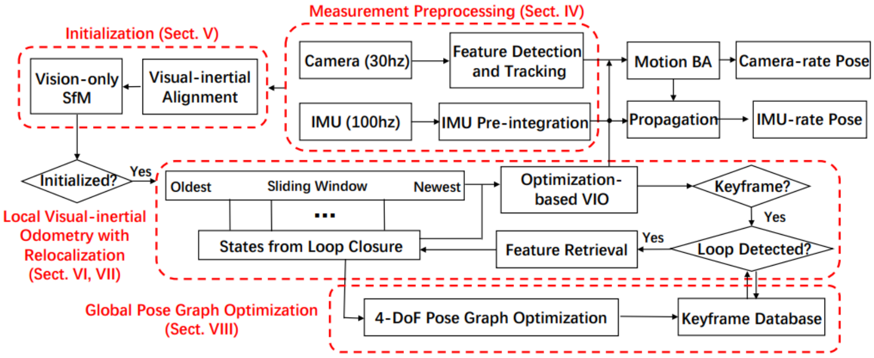


Fig. 18 A block diagram of the proposed monocular inertial state estimation pipeline.

Although many issues have been resolved by the technologies now in use, there are still numerous potential areas for future research. The observability of monocular VINS may be diminished or even destroyed as a result of complicated movement and a challenging working environment. To restore the accuracy and robustness of the system, one study area focuses on creating online techniques to assess the observability of monocular VINS and online real-time motion planning. The usage of several devices on a big scale in the opposite direction necessitates online adjusting of virtually all internal and exterior sensor settings.

In the following passage, I focus mainly on the first matter and give a possible solution already been proposed in other areas.

5.2. Real-time trajectory planning algorithm

Perception alone is not enough, it's just getting started.Adaptability is the second skill it must master.It means real-time automatic adjustment to make sure the working accuracy and robustness. We suppose that Adaptability can depends on Real-time planning algorithm of six-dimensional omnidirectional motion trajectory. (Movement in front and back, left and right, up and down three dimensions and rotation in roll, pitch and yaw three dimensions) While recognizing the three-dimensional terrain in real time, the six-degree-of-freedom trajectory including position and attitude is optimized, so that our group can better automatically adjust the pitch, sideways and steering, thus adapting to the undulating terrain.

Creation of a trajectory planning algorithm: The current quadruped robot trajectory planning approach enables users to describe the lens in a 3D virtual environment and construct the plan automatically [27]. This is typically expressed as an offline optimization problem. According to the robot dynamics model, the user-specified 3D location and camera observation direction are used to construct the time reference trajectory and control input parameters. The online outcome plan is then tracked using the feedback controller. Because trajectory planning and tracking are feed-forward and open-loop processes, they are not suited for coping with severe environmental disruptions [28], which frequently occur in chaotic settings with moving objects. they are limited to shooting static scenes.On the other hand, dynamic situations require real-time re-planning to prevent collision trajectories and get the desired photos [29].

The real-time robot route planning algorithm is forced to give up path quality for real-time execution due to the conventional trade-off between execution speed and path quality. Designing a path planning algorithm with the goal of enhancing the path quality and speed is still a difficult task. Although there are many sophisticated algorithms currently available, such as A*, D*, or Probabilistic Roadmap (PRM) methodologies, they can only be used to implement around barriers in order to identify a workable way around each chosen obstacle. This method will reduce the computing effort compared to using the fundamental algorithm on the entire map. In an effort to bridge the gap between quality and speed, researchers have proposed a novel path planning approach called sequential linear path method (SLP strategy). Any path planning method may be used as the fundamental algorithm in this technique, which can produce better outcomes in terms of computation time and path quality [30].

The SLP strategy's overall schematic was displayed in Figure 19.

The contributions of this methodology are as follows, in brief:

•Effective machining path planning system that strikes a balance between quality and speed; it computes the shortest barrier-free path to the target in real-time.

• Low-cost obstacle tracking system.

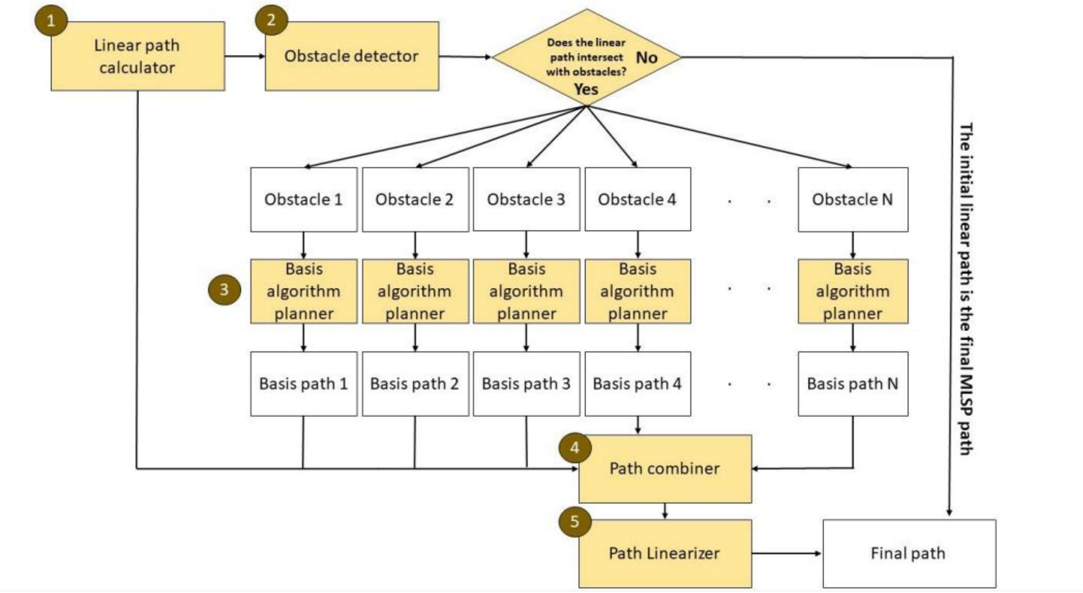


Fig. 19 The SLP strategy's overall schematic

Calculating the straight path from the beginning location to the goal point is the first step of the suggested SLP path planning method. The program then searches for obstacles that cross the straight path using the straight path as a starting point. Then, for each obstruction that crosses the straight path, the fundamental procedure is applied to determine the barrier-free way around it. Then, a barrier-free path is created from the beginning point to the goal point by combining all pathways, both linear and nonlinear. By linearizing the path as much as feasible, the path is eventually improved from the beginning point to the goal point, resulting in a variety of linear pathways. Figure 20 displays an example called MAX.

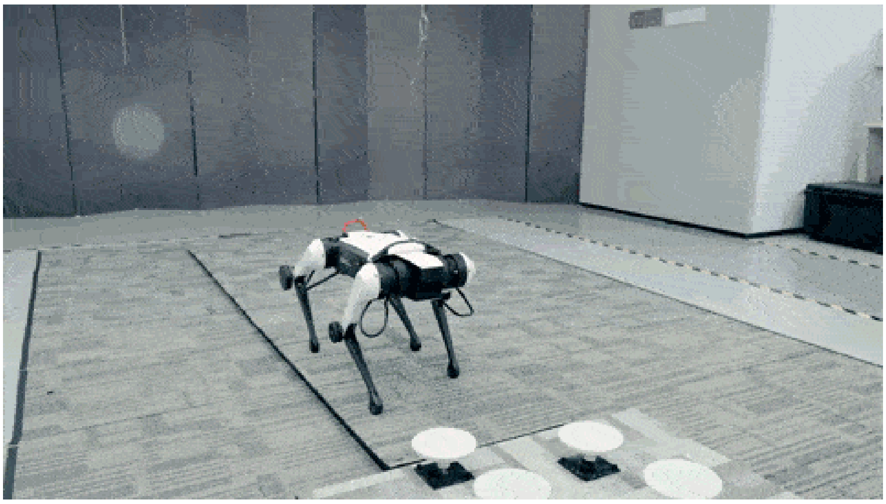


Fig. 20 An example called MAX

6. Discussion

In past studies, quadruped robots have mastered the ability to traverse special terrains. Existing quadruped robots can walk on rocky terrain, rough dry soil, and ice. The quadruped robot was also asked to do some more difficult movements, such as climbing particularly rough terrain, climbing stairs, and having some stability in the presence of disturbances. One of the research hotspots is the walking ability of quadruped robots on slopes, because slope terrain is a simple and typical special case. Most full-fledged quadruped robot prototypes have been tested in slope conditions, and some have achieved good results. But, In the control of quadruped robots in the past, the environment is basically regarded as relatively static. So that it is difficult for a quadruped robot to perceive the dynamic changes of the environment. In terms of terrain, there may be soft and wet soil and quicksand in the real environment. In this environment, the terrain is likely to be changed by the addition of quadruped robots. If the dynamic changes of the environment are considered in the future control research of quadruped robots, the motion control of quadruped robots will be faster and more accurate.

The control of the robot has a large amount of calculation and increases the overall volume and quality of the robot. One of the current solutions is to remotely connect a full-fledged intelligent system for computing. Through advanced communication technology and cloud computing technology, the function of control and operation can be separated from the body of the quadruped robot. Furthermore, the mechanical legs of the quadruped robot also adopt a flexible driving method, so that the controller can be designed to be simpler and have good stability. However, in terms of physical installation, debugging, etc., the uncertainty brought by the flexible drive is difficult to be effectively eliminated by the existing control methods.

At present, the motion of quadruped robot depends on the high-intensity mechanical design of legs. In the past research, the main research direction is active compliance technology and passive compliance technology to reduce the impact of the ground on the robot feet when the robot moves. However, if the robot needs to achieve the goal of a large number of loads, high-intensity structural design is indispensable. Therefore, in the future research, attention should be paid to the use of new high-strength materials and the lightweight of the overall structure of the robot. At the same time, the innovation of high-strength mechanical structure should also be an important development direction.

Despite years of research, there is still no universal algorithm and framework for quadruped robot control. It is still a hot topic to find efficient and universal control framework and algorithm. The combination of artificial intelligence and traditional gait planning algorithms should be considered, and the data collected by visual sensors should be used to realize real-time calculation during the robot's motion, so that the robot can achieve more efficient motion planning.

It is simple to determine each algorithm's benefits and drawbacks. We should discuss the prospect of an enhanced compound algorithm and the application of a machine version to robots after examining and contrasting them. The first and most obvious issue is how to speed up the system's reaction time and increase its accuracy. The monocular camera technique has drawn a lot of interest from the community due to its portability, affordability, and simplicity of hardware setup. However, their use in practical robotics is constrained by the monocular vision system's inability to restore the measuring scale. Recently, it has become patently apparent that adopting a low-cost inertial measurement unit (IMU) to support monocular vision systems is a trend. The second attribute it has to develop is adaptability. To assure the correctness and reliability of the job, this entails automatic correction in real time. As a result, a real-time trajectory algorithm must be added. In an effort to bridge the gap between quality and speed, researchers have proposed a novel path planning approach called sequential linear path method (SLP strategy).Secondly,The machine vision system has been extensively utilized in the areas of work environment tracking, final products monitoring, and quality control because it can rapidly obtain a huge quantity of information and is simple to automatically produce and incorporate project data and computation related data during the modern automation process.

7. Conclusion

In this paper, our group first survey the various complex situations that quadruped robots have solved so far, and based on this, our group point out the motion control method. It is found that the current quadruped robots perform well on slopes, rocks, mud and other terrains, but there are still limitations. In the future design, our group should consider the combination of artificial intelligence and traditional gait planning algorithms, and use the data collected by visual sensors to achieve real-time calculation in the process of robot movement. At the same time, the innovation of high-strength mechanical structure should also be an important development direction.In terms of the visual part of quadruped robots,the primary issue to deal with an advanced algorithm that can satiate both the accuracy and the robustness demand.Also,on this basis,as it is a real-time system,enhancing the swiftness is necessary to develop a better one.

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