Research on a Movable Microcontroller-based Four-Legged Walking Robot System

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Abstract

In this study, a four-legged walking robot with legs is selected so that it can be applied to different surfaces, and studies on gait, structure and control were reviewed, with a greater emphasis on stable walking. What is important about walking is to ensure stability so that the center of gravity (or ZMP) is within the polygon formed by the legs supporting the ground. For this purpose, a mathematical model for kinematics and inverse kinematics suitable for the robot's leg joints was established. The motion trajectories of the torso and each foot were generated using third or higher order functions, and the angular values of each leg joint were obtained through their relative motion and an inverse kinematics model programmed in MATLAB. The angular value obtained as above was applied to ADAMS, a dynamics simulation software, in the form of a spline. The ADAMS model used at this time was constructed by importing 3D CAD CATIA data from an actual produced dog-shaped robot, creating constraints and joints for each joint and providing contact relationships between the toes and the ground. ADAMS simulation results confirmed that the planned walking pace was sufficiently stable. These gait patterns were again applied to the robot itself to confirm its walking ability, and the distance sensor was installed to improve the robot's navigation ability by equipping it with obstacle detection and response capabilities.

Keywords

ADAMS, 3D CAD, robot, four leg and motor

1. Introduction

Recently, the role and importance of robots has increased and expanded into our everyday lives. Research on different types of mobile robots is constantly evolving, and robots with legs are classified into bipedal, three-legged, four-legged and multi-legged robots according to the number of legs. Below them, four-legged robots walk on two legs. Legs Compared to robots, it is generally better able to adapt to its environment and can walk more efficiently than robots with many legs. In order to implement the stable walking of a four-legged robot, first study the data and research results on observing animal walking, adopt or develop an appropriate theory among the existing theories to ensure the stability of walking, and apply it to the robot at. A stable control algorithm must be created.

Accordingly, the subject of this study was a four-legged walking robot that has excellent adaptability to the environment, is capable of various walking movements and is suitable for performing various tasks by moving objects.

2. Body

Among the various running patterns in animals, walking is the most common pattern. When walking, the robot has no special acceleration force and at least three legs are in contact with the ground, and at some point all four feet are in contact with the ground. The order of the feet is shown in Figure 1. In tigers, a weight of 1.2 times body weight is exerted vertically on the forefeet; when walking, a weight of 0.9 times body weight is exerted. hind feet. And when you slow down or stop, there is a large force on the front feet, and when you speed up, there is a large force on the back feet.

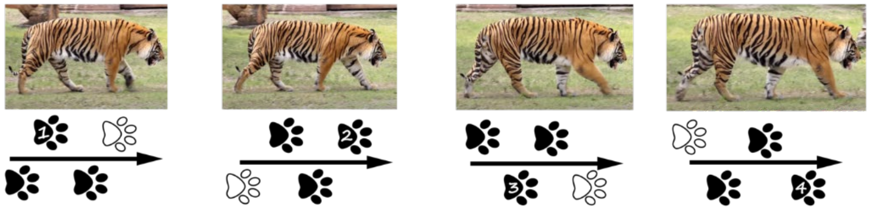


Figure 1. Tiger walking

The trot is also one of the most stable gaits because, like the diagonal walk, the center of gravity is always in the middle between the feet on the ground. A characteristic feature of this gait is that the limbs fall apart and touch the ground, while the animal's body tends to hop a little. It tends to sink between hits and bounce back the next time it makes contact with the ground. If you focus on the diagonal limbs in the video, you can see them moving at the same time. Figure 2 shows the trot of a horse. As shown in Figure 2, when a four-legged animal walks, the left forefoot and the right hindfoot are arranged diagonally, and the right forefoot and the left hindfoot move in pairs, and when walking, two feet touch the ground or all four feet touch the ground once . Touch it and get started. The speed of trotting is somewhere between walking and sprinting, and people walk at different speeds.

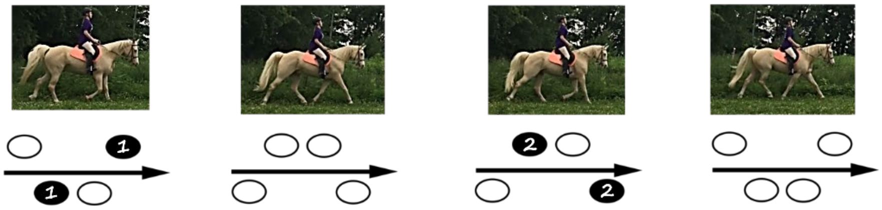


Figure 2. Horse's trot

The gallop is the fastest gait; Each step can cover more ground than other gaits, but it is also very energy intensive and less useful for long-distance travel. The walk is a development of the canter and its natural progression, except that the canter becomes a four-beat gait. Each step is equidistant from the others and is always followed by a moment of pause at the end. The two hind legs hit the ground first with slightly different timing, while the two front legs land immediately afterwards in the same pattern.

Cantering is also where we see the greatest compression and extension of the trunk, with the strongest compression occurring as the front legs rise and the longest extension occurring just before the front legs land. Depending on the exact time of landing of all limbs, there are two types of gallop: a traverse and a rotating version.

In the cross canter, the foot drop follows a diagonal pattern with left or right canter like in canter. The transverse canter is the more natural development of the gallop and is primarily used by horses and other herbivores. Figure 3 shows the gallop of a horse.

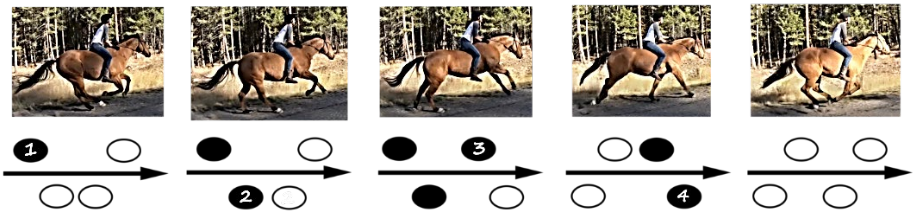
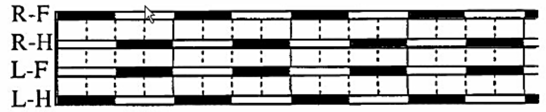


Figure 3 is a Horse's gallop

Duty factors for representative static and dynamic gaits are shown in Figure 4.

(a) Walk ($\beta = 0.75$)



(b) Trot ($\beta = 0.50$)

(c) Gallop ($\beta = 0.30$)

Figure 4. Walking pattern of typical gait

When walking statically, in a natural state in which no special external force is applied, the walking robot always falls at the edge of the support surface. As the robot's center of gravity leaves the support area, the robot falls in an arc around the edge of the support area due to the rotational moment caused by gravity. To quantify this stability, McGhee and Frank proposed using the stability margin as the minimum distance between the position where the center of gravity is projected onto the horizontal plane and the edge of the polygon formed by the leg on the same horizontal plane, as shown in Figure 5.

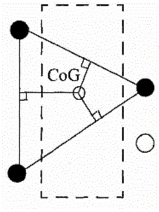


Figure 5. Definition of the stability margin

Margin of stability is also a standard for measuring a robot's stability while walking and a measure of how much force the robot can withstand without falling.

As a standard for assessing dynamic stability in walking, the Zero Moment Point theory is an extended theory of stability in static walking.

Zero Moment Point is a point on a plane where the sum of moments due to all forces acting in the system is zero.
In bipedal walking, as shown in Figure 6, the position is illustrated by Equation (1).

$$x_{zmp} = \frac{F_{1z}x_{e1} + F_{2z}x_{e2}}{F_{1z} + F_{2z}} \qquad (1a)$$

$$y_{zmp} = \frac{F_{1z}y_{e1} + F_{2z}y_{e2}}{F_{1z} + F_{2z}} \qquad (1b)$$

Furthermore, if the above equation is generalized to the case of any n-group robot, it looks like this.

$$x_{zmp} = \frac{\sum_{i=0}^{n} N_i x_{ei}}{\sum_{i=0}^{n} N_i} \quad , \quad y_{zmp} = \frac{\sum_{i=0}^{n} N_i y_{ei}}{\sum_{i=0}^{n} N_i}$$

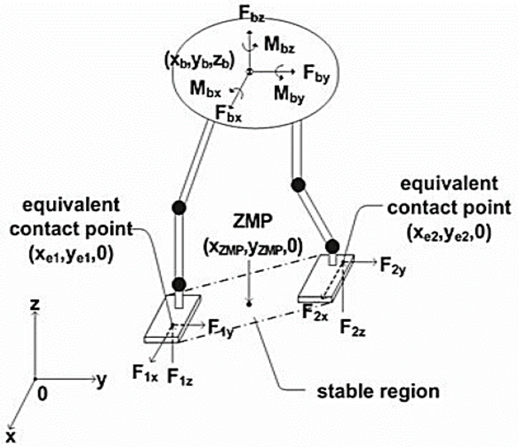


Figure 6. Application to general biped robots

Figure 7 shows a virtual model created by 3D modeling the robot itself using CATIA, a CAD program, based on the robot manufactured in our laboratory.

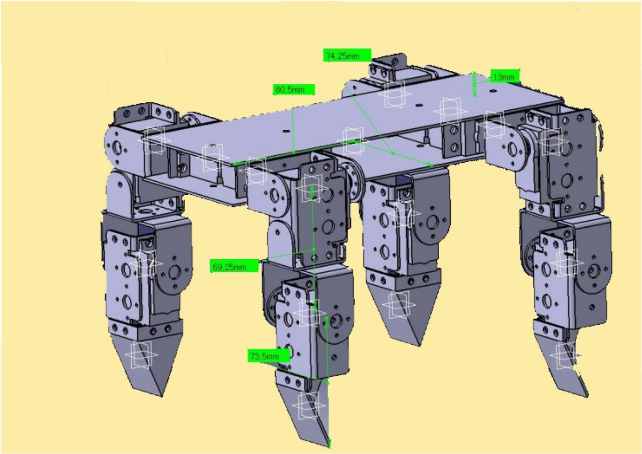


Figure 7. CATIA model

When creating information walking patterns, movements were created that correspond to walking between the patterns of four-legged animals. The legs were moved sequentially, and the order in which the legs moved was RR (RearRight) → FR (FrontRight) → RL (RearLeft) → FL (FrontLeft). The walking speed was set at 0.73, the stride length was 23 mm, and the cycle time was 3 seconds. Table 1 shows the progression of walking over time.

Table.1. Walking pattern with time

time[s]	0-0.5	0.5-1	1-1.5	1.5-2.5	2.5-3.5	3.5-4.5	4.5-5.5
movement	Early posture	FL Early Move location	RL early Move location	RR swing	FR swing	RL swing	FL swing

Figure 8 shows the absolute movement of the upper body. After taking the starting position, the upper body did not move in the Z-axis direction, but only in the forward direction (X-axis).

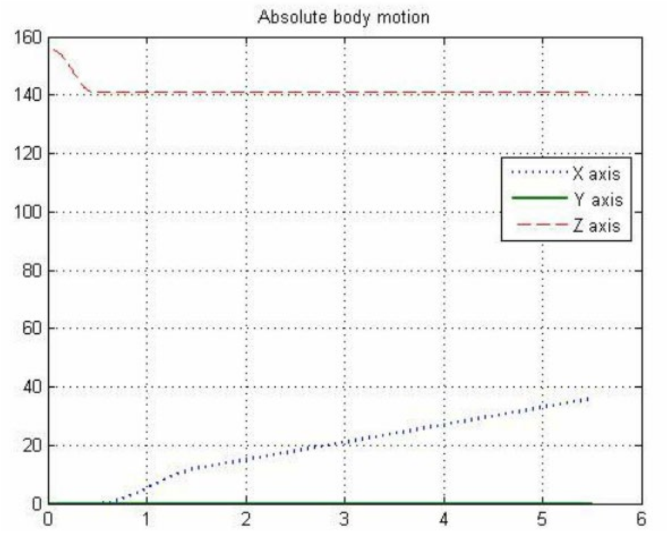
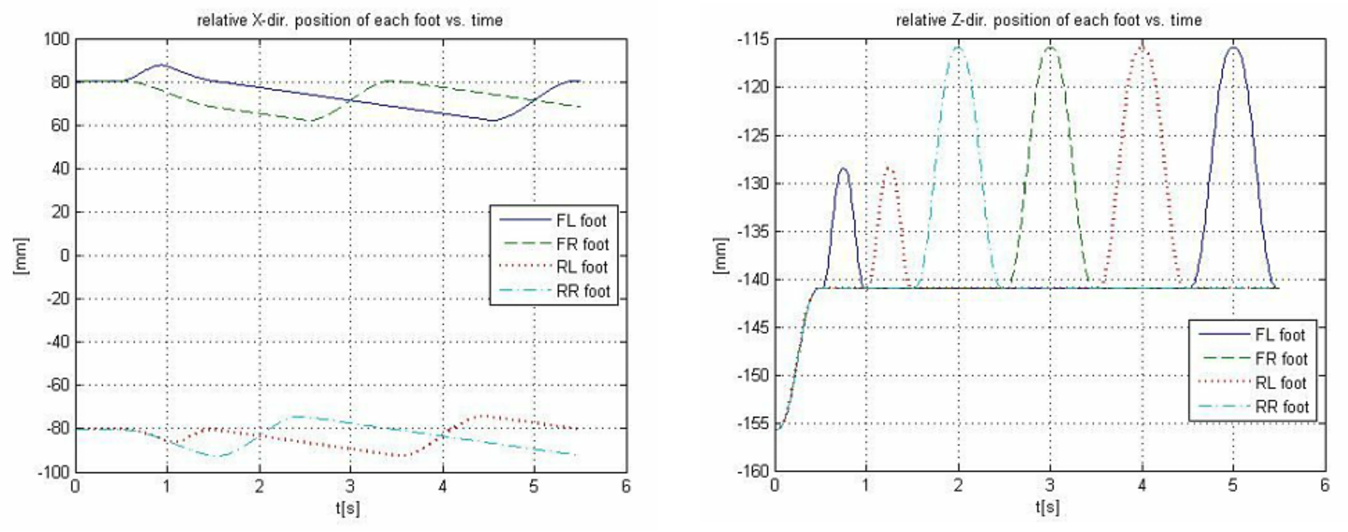


Figure 8. Absolute body motion (walk)



(a)

(b)

Figure 9. Relative position of each foot (walk): (a)X-dir. (b)Z-dir.

The relative movement of the torso and each toe in the X and Z axis directions is shown in Figure 9.

Figure 10 is the actual model made in our laboratory. Each leg consists of a 3-axis pitch-roll-pitch, and the first two axes are orthogonal at one point using a gimbal structure. And a hierarchical control method was introduced.

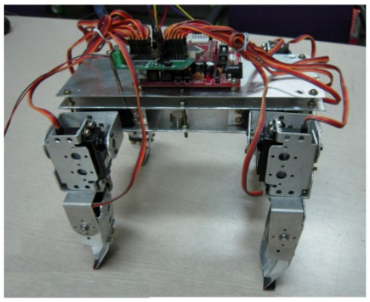


Figure 10. Photo of the actual robot

3. Conclusion

Existing research results on four-legged walking were examined and analyzed. Based on the walking of four-legged animals, a stable robot walk was developed and verified through simulation. In addition, an experimental four-legged walking robot system was fabricated and experiments were conducted on basic movements such as walking, obstacle detection and reaction.

When planning the movement of the toe based on the movement of an animal, it is very important to use a smooth curve with a cubic function or more, and when building a mathematical model to calculate the exact joint, derive an inverse kinematic solution angular value corresponding to the path the toe This has been confirmed. Meanwhile, the plan was to achieve the animal's general duty factor by designing the running patterns to go forward and forward.

The walking movement was planned assuming that the robot's body moves parallel to the ground. On the other hand, the dynamic analysis includes friction with the substrate and there is slippage on the contact surface. The stability was predicted by kinematic analysis and the stability of the stage was checked by dynamic simulation of the pattern created on this basis. This showed that stability prediction was possible by comparing kinematic analysis and dynamic analysis. The manufactured four-legged robot has the advantage of being small, cheap and easy to manufacture, but especially the RC servo motor for joint drive has the disadvantage of insufficient position and speed control.

In the future, there is a need for research in the field of running technology that can move autonomously to the destination while avoiding obstacles through the use of faster and more sophisticated DC servo motors and PC-based control units.

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