Large-scale Network Survivability Mathematical Association Model under Set Pair Analysis Theory

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Abstract. With the expansion of the application field of robots, the use of eight-legged bionic robots to assist or replace human operations in various complex and extreme terrains is constantly being explored. This paper uses octopus as a bionic object, designs an eight-eccentric wheel walking platform, and studies its dynamics, kinematics and trajectory planning. This paper first investigates the development history and research status of multi-legged robots in many countries, analyzes the shortcomings of octa-legged robots, and proposes improved solutions on this basis. Through the bionic of the octopus structure, the Catia software is used to design and establish a three-dimensional model of the octopus-like eight-eccentric wheel robot. By importing the three-dimensional model into the dynamic analysis software Adams for simulation, after adding constraints, driving, torque and contact force, the various functions of the platform are simulated to obtain linear wheel walking, rotary motion, linear leg walking, the parameters of jumping motion and obstacle-crossing motion are drawn into tables for intuitive analysis, and virtual prototype simulation is used to verify the correctness of the established model and trajectory planning.

The research in this paper lays a theoretical foundation for the development and application of this eight-eccentric wheel bionic robot.

Keywords: Octopus, eight-legs, Bio-robot, Motion Simulation.

1. Introduction

1.1. The background of the subject and the purpose and significance of the research

In the process of human exploration and transformation of the world, there are many dangerous occasions, such as rescue and disaster relief, polar exploration and planetary exploration. It is often dangerous to use manual operations in these occasions, and mobile robots help humans to achieve safe and efficient realization. Operations in these high-risk situations [1]. Mobile robots can be classified into wheeled robots, crawler robots, and footed robots according to the movement mode. In the above-mentioned dangerous situations, footed robots are more widely used. This is because footed robots have lower requirements for walking on the road compared to wheeled robots [2, 3]. The number of feet of a footed robot is usually greater than or equal to four feet, and the common ones are four feet, six feet, and eight feet [4].
Due to the advantages and characteristics of footed robots, the current research on footed robots is often combined with bionics. The term bionics was first proposed by Jeck Ellwood Steele in 1960. Bionics is mainly based on the structure, characteristics and behavior of organisms and combined with relevant knowledge of such disciplines as architecture, mechanics and materials science to provide new design ideas and working principles for solving specific problems and designing specific products. Because bionics integrates multiple disciplines, it can solve practical problems in our lives from a more novel and comprehensive perspective [5]. The combination of foot robot and bionics allows us to study the physiological structure and motion mechanism of various footed creatures so that the manufactured bionic foot robot has the advantages of flexible movement, good stability and adaptability to a variety of terrains.

Most of the bionic foot robots that have appeared are hexapod bionic mobile robots. This kind of hexapod bionic robots usually imitate spiders or crabs to work, and they often work in the form of leg motion or wheel-leg switching. The hexapod robot has a rich gait and redundant limb structure, flexible movement, high reliability, and contact with the ground through discrete feet, making obstacle crossing more convenient and flexible [6]. On this basis, people gradually began to study eight-legged robots. The degree of redundancy of eight-legged robots is higher than that of six-legged robots. It can achieve higher-precision motions and there are more ways to achieve the same motion. The structure is more complicated than that of hexapod robots. At this stage, the research on octopod robots is not enough.

1.2. Research status

1.2.1. Quadruped robot. The most famous quadruped robot in the early stage is called The Walking Truck, which was designed by an American Ralph Mosher in 1968 to help land soldiers carry supplies and equipments. Limited by the technological level at that time, the mechanical efficiency of this robot is relatively low. Weighing 3,000 pounds (1,400 kilograms), the robot can travel only 5 miles (8 kilometers per hour). It is driven by hydraulic pressure and requires operators to operate, so strictly speaking it is not as intelligent as we often say [7].

Another famous four-legged robot is the Big Dog, which was built by Boston Dynamics with Foster-Miller, the NASA Jet Propulsion Laboratory, and the Harvard University Concord Field Station. The Big Dog is 3 feet (0.91m) long, 2.5 feet (0.76m) tall, weighs 240 pounds (110kg), travels at four miles (6.4 km/h), carries 340 pounds (150 kg) and can climb slopes of up to 35 degrees. The Big Dog is hydraulically driven and uses a number of sensors and computers to coordinate calculations, which allows it to quickly adjust its posture and prevent itself from falling down. Unfortunately, due to the excessive noise of its gasoline engine, it was deemed unsuitable for military use, and the Big Dog project was terminated in 2015 [8, 9].

"Kotetsu" developed by the University of Tokyo in Japan is also a classic quadruped robot. The robot dimensions are 340mm in length, 190-250mm in width, 350mm in height, 250mm in front and hind legs, 120-180mm in left and right legs, and 5.2kg in total weight. It adopts high-power actuators and legs with small moment of inertia, so that it can respond to the movement quickly. The robot is controlled by CPG method, which is simple and efficient, so it has good adaptability to the environment [10].

1.2.2. Hexapod robot. In 1976, Robert McGhee from the United States designed OSU Hexapod, a Hexapod robot that can walk automatically. Each of its legs has three degrees of freedom, and the robot can move laterally and overcome obstacles in addition to moving forward [11].

Another well-known hexapod robot is Asterisk, a limb manipulator developed by Sakakuchi University in Japan in 2005. Asterisk has six limbs, each of which has four degrees of freedom. By basically arranging the limbs from the center of the body in six directions, Asterisk can achieve uniform working space and mobility in all directions. This means Asterisk can walk on uneven ground as well as use its legs as hands to move around areas such as the ceiling, expanding the robot's range of motion and making it useful in areas such as search and rescue operations and plumbing [12].
Another famous hexapod robot is "Aqua", jointly developed by York University and McGill University in Canada. This robot can work in amphibious environment. The overall size is: 500×650×130mm, weight 18kg, it has good sealing, using semi-circular arc foot walking in accordance with the triangular gait on land, using slurry foot underwater, can realize sinking, reversing and other functions [13,14].

1.2.3. Eight-legged robot. NASA's Spidernaut is a typical eight-legged spider-like robot. Each leg has three degrees of freedom. The first is the hip, which is a simple rotating joint, and the other two are rotating joists driven by a linear actuator. And its feet can withstand forces of more than 250 pounds, which allows it to climb [15].

The other is Scepion, an eight-legged Scorpion robot developed by the University of Bremen in Germany. The robot is equipped with sensors such as Angle sensor, current sensor, tilt detection gyroscope, infrared distance sensor and other sensors, which makes it equipped with powerful detection and feedback functions. At the same time, each joint is driven by an independent DC servo motor to ensure that it has a strong control ability, which enables it to autonomically adapt to unknown roads and complete functions such as obstacle crossing and climbing [16].

2. Model design and motion simulation

2.1. Model Design
In order to complete this walking platform with the knowledge of bionics, we looked up a lot of materials, and initially decided to choose spiders or crabs as the biomimetic objects. However, after in-depth study of their movement mode, we found that because their legs are axismetrically distributed along the axis line of the body, it is difficult to realize omnidirectional movement through the use of eccentric wheel. Therefore, we needed to find another leg distribution structure to make it easier to control omnidirectional movement with an eccentric wheel. Finally, we found that the tentacle distribution of octopus just met the requirements, because the eight tentacles of octopus are almost uniformly distributed around the head of the octopus, and this distribution makes the omnidirectional movement of the platform possible. As shown in the figure 1 and figure 2, the eccentric diameter of the walking platform is 134mm, the eccentric distance of the wheel shaft is 32.5mm, and the total height of the walking platform is 205mm. The chassis of the walking platform adopts equilateral octagonal, and the center of gravity of the eccentric wheel on the chassis is called circular array distribution. This distribution borrows from the octopus and its eight-legged structure. On the one hand, this distribution can improve the stability of the body; on the other hand, due to the redundancy of the number of feet, its motion mode is richer than that quadruped robots and hexapod robot, which means that the same movement corresponds to more eccentric movement points. The eccentric wheel is driven by a brushless servo motor, which makes the speed control more flexible and accurate. At the same time, the advantages of the brushless servo motor, such as fast response, light weight, large torque and small moment of inertia also make it more suitable for this walking platform. Since eight eccentric wheels are used as the output mechanism, we can realize the omnidirectional movement of the horizontal plane by controlling the different speeds of the eight eccentric wheels. At the same time, we can also realize the platform rotation and climbing over obstacles by controlling the eccentric speed and steering difference. If the servo motor outputs large instantaneous torque, the platform can also realize the jumping function. The laser radar is installed in the middle of the platform for positioning and navigation. Meanwhile, because the laser radar can only scan the objects in the horizontal plane, the laser radar is installed at the limit height of obstacle crossing of the platform of 10cm through calculation, so that the obstacles that cannot be surmounted can be well scanned for avoidance. At the same time, ultrasonic sensors with steering gear are distributed on the edge of the upper platform where the laser radar is located. These ultrasonic sensors can not only detect the distance between the obstacles and the platform, but also because the ultrasonic sensors are at angles with each other, so we can set a threshold value of the width of the obstacles to the chip. If the calculated width of the obstacle returned by the three ultrasonic sensors
in the forward direction exceeds the set threshold, it means that the obstacle has a large width. At this
time, the energy lost to bypass the obstacle is more than to climb over the obstacle, so it is better to
choose to climb over the obstacle. And because the ultrasonic sensor is connected with the steering gear,
it can scan up and down, so that it can sense the height of the obstacle, and choose whether to climb
over the obstacle or jump over the obstacle through calculation. The most prominent feature in this
design is the use of eight eccentric wheel structure instead of the traditional sense of the foot, each
eccentric wheel has only one degree of freedom, and most of the feet are two or three degrees of freedom,
which simplifies the control of the platform movement. At the same time, the advantage of controlling
the single degree of freedom also makes the platform respond faster to commands and the delay is
shorter. In addition, when using the same power source, the power loss caused by the use of an eccentric
wheel is smaller than that of using a traditional foot mechanism as the actuator.

Fig 1. A 3D model of the platform.

Fig 2. Multiple views of the platform.

2.2. Simulation
As shown to the platform of the eight eccentric numbered, below shows how to implement different by
controlling the speed of different control function.
2.2.1. **Wheeled linear motion.** In this kind of motion, eight wheels are driven simultaneously to achieve continuous straight motion. However, since the distribution of the eight eccentric wheels is circular, the steering of different wheels is required, which is different from the traditional axisymmetric wheel motion mechanism. As shown in the figure 4, the rotating speed of No. 1, 2, 3 and 4 wheels is set as $x$ (300d*time in simulation) to rotate clockwise, and the rotating speed of No. 5, 6, 7 and 8 wheels is set as $-x$ (-300d*time in simulation), so that the platform can move uninterruptedly in one direction. Similarly, as long as the rotation speed of different sets of wheels is adjusted, the mechanism can move continuously in other directions. This straight line movement is carried out along the direction of the longest diagonal of the octagon. If the platform is to move in other directions that are not the longest diagonal, only the factor of the upper Angle needs to be taken into account.

![Fig 3. Division of wheels.](image)

2.2.2. **Rotational motion.** This movement is usually used to assist the lidar in terrain scanning or in situ steering, in which case the torque is simply adjusted to rotate it around the platform axis. Specifically, the rotation can be achieved by balancing the forces and torques of three pairs of opposite wheels (as shown in the figure 1, 5, 2, 6 and 3, 7 wheel groups) and balancing the forces and torques of the remaining pair of opposite wheels. In this simulation, the platform can rotate clockwise around the axis only by adjusting the eight wheels to rotate clockwise at the same speed.

![Fig 4. The relationship between displacement and time (Wheeled linear motion).](image)
2.2.3. Intermittent straight motion (leg motion). The realization of this movement is actually to split the eight wheels into two groups of four wheels for each group, and the two groups of wheels move alternately to realize the leg movement. Specifically, the No. 1, 4, 5, and 8 wheels in Figure 1 are programmed into one group, and the No. 2, 3, 6, and 7 wheels are programmed into another group. The first group rotates once and a half to make the platform move forward by a certain distance. At this time, the first group is lifted to the highest point, while the wheels of the second group are rotated for one and a half turns to make the platform move forward for a certain distance, and the second group is lifted to the highest point. At this time, the first group is driven to rotate once, and then the second group is driven to rotate once and so on to achieve intermittent linear motion.

2.2.4. Jumping movement. In fact, this movement is to give each wheel an instantaneous large torque, so that the platform to jump, the specific implementation is to make each wheel can achieve a full rotation in 0.2 seconds, control the rotation time can control the jump height and the distance forward.
2.2.5. Obstacle crossing. As shown in the figure 8, the combined action of ultrasonic sensor and laser radar can detect the distance of the platform from the obstacle. At this time, by gradually adjusting the position and posture as shown in the figure, the movement over the obstacle can be realized.

3. Discussion of the resulting results

3.1. Wheeled linear motion.
The realization of this kind of motion is to determine the rotation direction of all the eccentric wheels when moving in one direction, and then apply the same speed, so that at the same time, there will be a
point on the eight eccentric wheels that is in contact with the ground, and the distance between the point and the axis of the eccentric wheel is equal, which ensures the smoothness of the motion. The velocity curve of linear motion is shown in the figure 9. They're all sinusoidal periodic with time. This is because the linear velocity of the eccentric wheel and the contact point on the ground is positively related to the distance between the contact point and the axis line. This control method is relatively simple, and the speed and direction of motion can be controlled only by controlling the speed and steering of the eccentric wheel. The disadvantage is that it is not flexible to switch the direction of motion in the process of motion, because the speed cannot change abruptly. When changing the steering of the eccentric wheel, it is necessary to reduce the speed of the wheel to 0 and then start it in reverse, which leads to the deviation of the trajectory from the predetermined trajectory under the action of inertia.

![Velocity Curve](image)

**Fig 9.** The relationship between velocity and time.

### 3.2. Rotational motion.
This kind of motion is essentially the same as the linear motion of the wheel. It only needs to allocate the eight eccentric wheels according to the direction of torque to choose positive and negative rotation.

### 3.3. Intermittent linear movement (leg movement).
The realization of this motion is created by alternating motion of two groups of eccentric wheel, its advantage is that only when a group of eccentric exercise after another set of wheels to sports, make this can be done in a group of four eccentric movement can switch another set after the completion of the four eccentric (four eccentric axis of diagonal intersection in attachment) to complete the movement direction of switching. The other advantages are that the switching is more convenient than the foot robot, and the joints need to be adjusted are greatly reduced compared with the foot robot, which reduces the power loss transmitted by motion, reduces the response time of the system, and makes the response of the system more flexible. The disadvantage is that this kind of foot movement has requirements on the direction of motion, and can only move towards the perpendicular direction of the octagonal edge line and the angular bisector direction of the eight interior angles. In the movement of a random Angle switching need many times to change direction to achieve.

### 3.4. Jumping movement.
This kind of movement is generated by applying instantaneous large torque, and the foot robot can also use similar principle to complete the jump. However, the advantage of the eccentric wheel walking
platform is that its transmission chain is short, and the driving torque converted from the same jumping torque to the rotating shaft is relatively small, and its response to the motion is faster than that of the general foot robot.

3.5. Obstacle crossing.
This kind of movement is realized by adjusting the posture of the walking platform after scanning the terrain, so as to achieve the purpose of crossing step by step. This obstacle crossing mode is simple to control, has a variety of choices for the position and posture of obstacle crossing, and has a fast response. However, the disadvantage is that the foot robot has certain requirements for the width of the obstacle, while the foot robot has low requirements for the width of the obstacle.

4. Conclusions
This paper uses the data to design an eccentric wheel walking platform, and uses ADAMS to simulate the movement. The designed virtual prototype can achieve a variety of functions and work well in various environments where human beings are not suitable for work, such as emergency rescue and disaster relief, interplanetary exploration, etc. It can be said that this walking platform can be adapted to a variety of different working conditions, a wide range of applications, bright development prospects.

This design is mainly based on the design theory of six-eccentric robot [17] and eight-legged robot. The six-eccentric is extended to eight-legged robot, and the layout is in accordance with the circular distribution of the traditional eight-legged robot to improve stability and motion diversity.

However, it is a pity that due to the limited time and ability of the author, the physical model was not made according to the virtual prototype. If there is an opportunity in the future, I will continue to make the physical model for more in-depth and comprehensive research.

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