Hybrid Quadruped Robot – Mechanical Design and Gait Modelling

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Abstract. The study aimed to develop a walking mobile robot and model its four-legged gait. At first, a review of existing structures was conducted and then the robot's purpose and design parameters were specified. On this basis, the kinematic structure and the geometry of the robot's legs were determined. After that, a numerical model of the quadruped robot was built in MD Adams. Mechanical structure of construction was designed and relevant drawings of individual parts were made using Inventor. General algorithm of four-legged gait used for this robot was specified. Simulations of the model's actions in MD Adams were performed to determine the kinematic and dynamic properties of the movement. Among others, walking on wheels and on feet, using the lateral surfaces of wheels, were examined and results have been presented.

Keywords: wheel-legged robot, hybrid robot, simulations.

1 Introduction

The issue of four-legged gait had been addressed by many researchers. One of them was Hildebrand [2], who analyzed different ways of horse's motion. Quadruped robot's gait has been widely studied [9, 10]. The popularity of this topic results from a fairly obvious advantage possessed by the walking machines over the more popular and simpler in construction wheeled and tracked machines. Their superiority lies in the process of moving. Robots with legs can move in much more difficult terrain and get where the wheeled and tracked robots cannot, for which only half of the earth's surface is available.

In recent years, walking robots have been becoming more widely applied in various fields. It is worth to mention, the Boston Dynamics constructions, BigDog and its bigger brother AlphaDog (LS3) [7]. Their amazing movement abilities and usage in military cargoes transport incline thinking, that in the near future walking robots will find wider and more practical applications than before. However, it cannot be forgotten, that wheeled robots are superior to walking ones as far as movement speed on flat and even surface is concerned. Because of this, appropriate is combining features of these two classes of robots and creating a hybrid robot equipped with both wheels and legs. Also this topic has already been exploited by

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many researchers, which resulted in construction of a wide range of wheeled robots with high mobility [8]. Within this group, the robot Roller-Walker is worth attention [1]. It has the ability to rotate wheels to the side and to walk on theirs lateral surfaces, using wheels as feet.

2 Wheel-legged Robot "Wonderworker"

This paper discusses the problem of modelling the gait of a mobile quadruped robot. In order to determine the algorithm and conduct tests a wheel-legged robot named **W**onde**rw**orke**r** (**W**heels **R**otating **W**alking **R**obot) has been designed. The robot can perform a variety of tasks such as transport, surroundings examination, field measurements, inspection and diagnostics. An important area of this robot's application can be military tasks such as: seeking, inspecting and neutralizing mines and improvised explosives, reconnaissance, area observation and active support of combat operations. In regard to the applications that have been intended for the robot, several requirements were identified: the ability to move in various terrains and to generate different types of gaits, as well as the adaptability to changing terrain and overcoming obstacles [4]. Based on these assumptions, the kinematic diagram and geometry of the machine have been determined [5]. The design of the robot was patterned on other constructions including the Roller-Walker. However one of Wonderworker's advantages over Roller-Walker are driven wheels which allow it to move more efficiently up the slope. Moreover, far larger wheels have been applied, which turned to the function of feet will prevent problems with movement on muddy or loose surfaces.

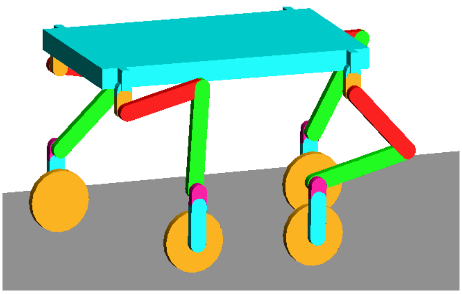

Fig. 1 Robot's model built in MD Adams [3]

Determining the robot's kinematics and geometry allowed building dynamic model in MD Adams (Fig. 1). Individual components were created and had relevant material and mass properties assigned. Then, components were connected using kinematic pairs. It was also necessary to model contact type kinematic pairs between wheels and ground [3].

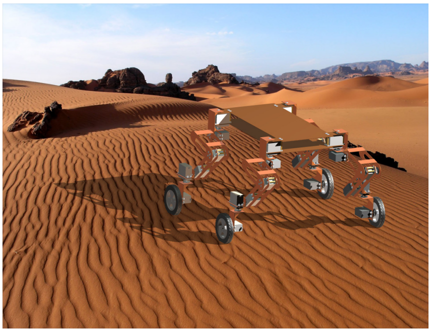

Fig. 2 Robot's view in 3D - driving position with widely placed wheels [4]

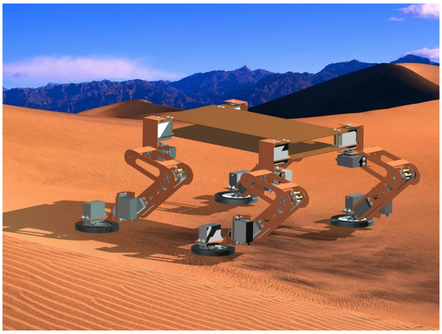

Fig. 3 Robot's view in 3D while walking on feet (typical for mammals position of legs) [4]

Individual components were designed in 3D using Inventor. Figures 2 and 3 show 3D views of the whole Wonderworker robot with four designed legs attached, in two positions [4].

3 The Control Algorithm – Model of Four-Legged Gait

Walking is a very common way of moving on land. It is achieved by limbs conversion sequence, repeated from time to time, called the period of gait. This is a complex way of moving and its implementation in robots requires an accurate control algorithm. Walking is characterized by many parameters and exists in many variations. In addition to the different postures, walking can be divided according to the length of stance phase for individual legs. For quadrupeds, symmetrical gaits among others can be distinguished (Fig. 4). They are characterized by an identical time of stance phase for each leg, while asymmetric gaits do not meet this condition [11]. Another feature of the gait is the order of limbs conversion. For four-legged gaits six sequences can be distinguished. When it comes to walking robot's control, one should pay attention to the possible shapes of the trajectory of feet relative to the body. The most commonly used are triangular (Fig. 5), trapezoidal and rectangular trajectories [11].

To realize walking of Wonderworker, posture typical for mammals, quadruped crawl with a triangular trajectory of step and the sequence of legs conversion: left front, right rear, right front, left rear, were selected. It was also assumes, that the period of gait consists of 12 equal parts and the swing phase for each leg takes 2/12 of the period. As a result, the length of step was divided into 10 parts [11].

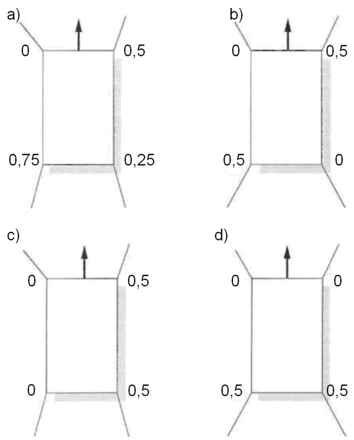

Fig. 4 Symmetrical gaits: a) quadruped crawl, b) trot, c) pace, d) bound [11]

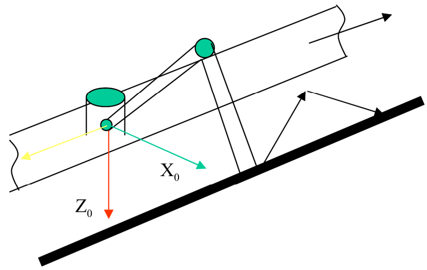

Fig. 5 The triangular motion trajectory of leg's end [3]

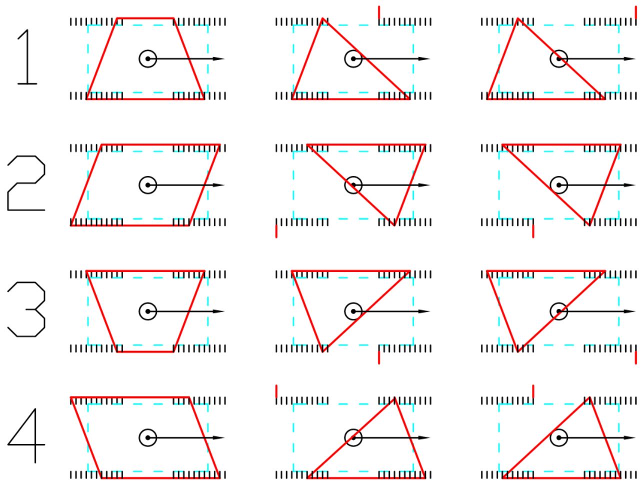

Fig. 6 Successive support polygons analyzed for robot's gait [3]

For the selected type of gait with predetermined motion parameters, analysis of the body's centre of gravity movement relative to the ends of the limbs while walking was performed to determine the stability. The result was obtaining a sequence of support polygons and positions of the centre of gravity (Fig. 6) [11]. The diagram should be analyzed from left to right, row by row. The dashed line outlines the body, while the point in the middle stands for the centre of gravity. Thick lines indicate support polygons. Short segments of thick vertical lines show locations where leg has just left the ground or where in a second it is going to make contact with the ground. Successive views of support polygons indicate that the robot should maintain static stability at every moment of walk. The reason is the fact that, the body's centre of gravity stays always within the current support polygon. This is true for considerations without taking into account the dynamic relations and influence of legs' masses on position of the robot's centre of gravity. Furthermore, at some points the centre of gravity is dangerously close to the boundary of the polygon, which may lead to a loss of balance [3].

A good solution to the mentioned problem is monitoring the state of the robot, in order to enable the control system to react properly and avoid an overturn. Placing pressure sensors in the wheels (feet) of the robot would also be very helpful. They would allow keeping proper load on each leg, thus helping to maintain the balance [3].

4 Simulations of Robot's Walk

Using the presented earlier dynamic model in the MD Adams, a number of simulations were carried out. Among others, walking on wheels was modeled (Fig. 7). Leg's trajectory of motion relative to the body achieved through inverse kinematics is shown in Fig. 8.

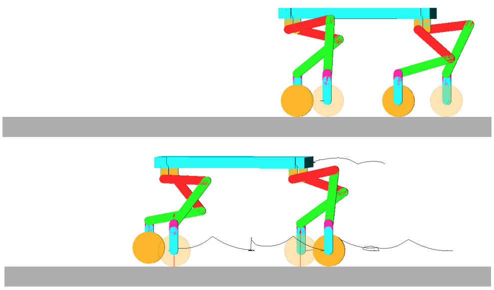
a)
b)

Fig. 7 View of walking on wheels – with a marked motion tracks of the body and wheels of front left and rear right legs [6]

The horizontal line at the height y = 75 mm (Fig. 9), indicates the expected positions of wheels during the stance phase. For each leg in this phase, the wheel is lower than it should. This means that while walking, the body and legs' attachment points to the body are too high. Thus there are moments when one of legs at the end of the swing phase does not reach the ground. The reason is the fact that, trajectories between the predefined points are circles' arcs (Fig. 8). As an example of the error, in Fig. 9 the arrow marks the point of maximum deviation for the left front leg [6].

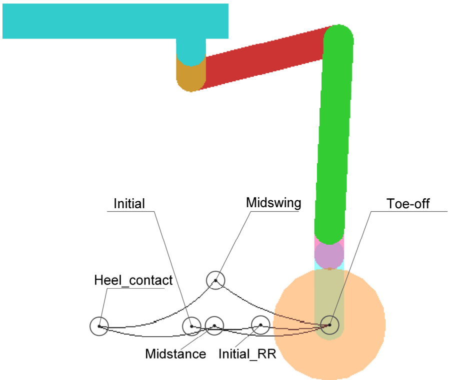

Fig. 8 Motion trajectory of the leg relative to the body, while walking on wheels [6]

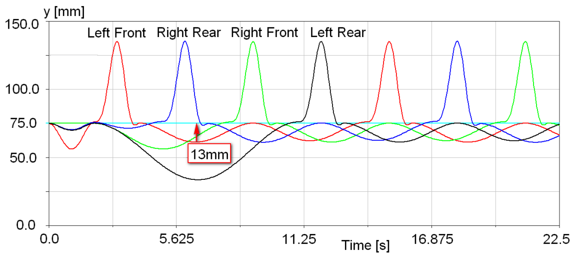

Fig. 9 Graph of positions, along y-axis, of centres of wheels for particular legs while walking, according to fixed body [6]

Moreover, gait with the use of wheels in function of feet was developed (Fig. 10). The reconfiguration of the robot from its initial position, where it stands on wheels, to the position where all wheels are rotated to the position of feet takes 14 s. Sequentially for successive legs, wheels change to positions of feet during the first second of swing phase, while moving from point toe-off to point midswing (Fig. 8) [3].

a)
b)

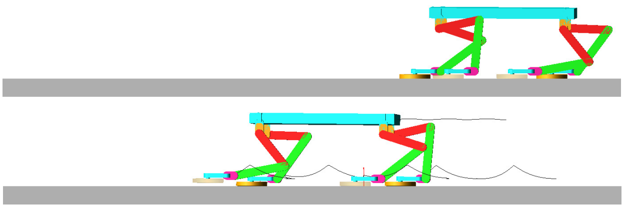

Fig. 10 View of walking on feet – with a marked motion tracks of the body and wheels of front left and rear right legs [3]

The graphs (Fig. 11, 12) show the results starting from 12 s, and they are completely correct only after 14 s, because it is as long as it takes the robot to change to the initial position. Each leg is set in appropriate phase of movement and wheels are rotated to positions of feet [3].

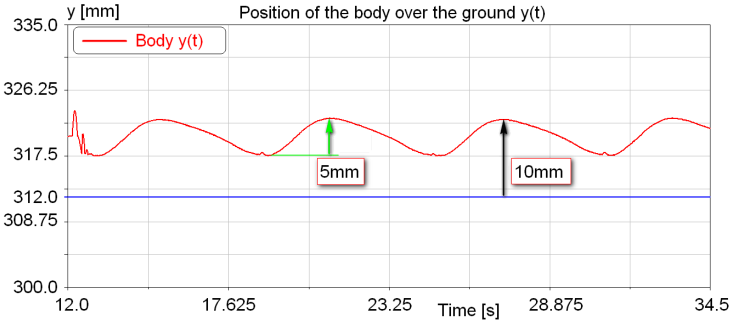

Fig. 11 The graph of the height of the body above the ground y(t), while walking on feet [3]

The problem mentioned at the simulations of walking on wheels occurs also in this case and causes the distance of the robot's body from the ground to increase by approximately 10 mm, in regard to the expected position (horizontal line in Fig. 11). However, fluctuations of the height of body's position are rare and their amplitude is not greater than 5 mm (Fig. 11) [3].

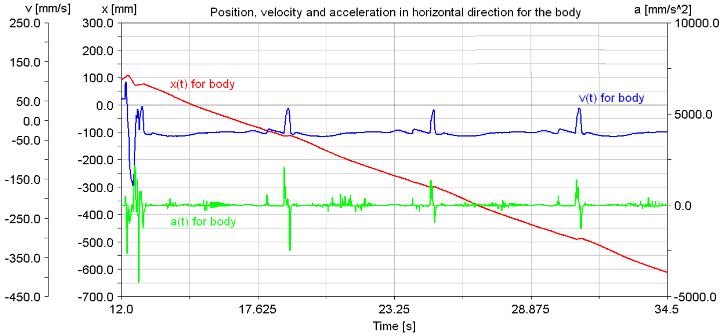

Fig. 12 Graph of position (x), velocity (v) and acceleration (a), along x-axis against time [3]

Based on the characteristics of the body's movement (Fig. 12) it is concluded that the robot traveled 700 mm in 22 s. Therefore, the absolute value of average speed is equal to 32 mm/s. It is also confirmed by average value obtained from the speed curve v(t). The body's movement speed is quite constant, there are no large fluctuations and its value never changes the sign. However, there are sudden changes in the values of velocity and acceleration [1]. The timing of these abnormalities is consistent for both. They appear about every 6 s. Thanks to that and observations of motion it have been concluded that they correspond to the phases of movement when one of the front legs is in a heel contact phase. Due to the mentioned problem of incorrect vertical positions of feet, the front leg is not touching the ground. There is a slight forward tilt and the leg gently hits the ground. In addition, there are little slips of wheels in the first moments of stance phases [3].

5 Conclusions

The type of gait shown in the simulations of walking is the best obtained during various tests of robot's motion on flat surface. Further improvements of the gait would be possible by adding more trajectory points. This would lead to small differences between the expected and achieved trajectory. As a result, smaller errors of body and legs' positions would be achieved. This would improve the stability of gait and decrease the fluctuations in speed and acceleration of body movements. In addition, the errors that occur during the initial phase should be eliminated by improving the gait's control algorithm. It would result in achieving movements, leading to the initial position of walking and rotating wheels to position of feet, being as smooth as in the repeated gait cycle.

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