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The Bipedal Robot a Kinematic Diagram Development

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Abstract:

Due to the fact that in order to ensure the movement of a walking robot it is necessary to solve the problem of maintaining balance, there is a need to develop a kinematic diagram of the robot, and also to decide how the resulting tilts, rotations and vibrations will be compensated. This article presents the development of a kinematic diagram of a bipedal walking robot. In this robot, arm movements will compensate for unbalancing leg movements.

Key words: Mobile robot, Bipedal walking robot, Musculoskeletal apparatus, Degrees of freedom, Balance.

Introduction

Currently, robots of various types are being developed [1]-[10]. They can be zoomorphic [11]-[13] and anthropomorphic [14], [15]; they can imitate an entire object (human, animal, insect) [16], [17] or only part of it [18]-[20]. Robots vary in size: they can be large and small [21], [22]. And here various theories, methods, approaches can be used [23]-[29].

For various tasks, robots are designed that are similar to humans in their musculoskeletal structure. When creating a bipedal robot, it is assumed that its movement will be similar to that of a human, that is, it will move by rearranging its legs, that is, by walking.

However, here the task of maintaining balance arises, since the center of gravity of this robot will shift. His movement will be divided into the following stages: 2 legs on the support surface (on the ground) and a step. The step, in turn, is divided into the following phases: lifting one leg, moving it to the next place, placing it in this place and transferring the body weight.

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Thus, there is a need to maintain balance by the robot, that is, to compensate for the movement of the legs at the expense of other biological links. This entails the task of developing a kinematic diagram of a bipedal walking robot.

This task can be broken down into several stages. First you need to study the needs, that is, determine the goals and tasks that the robot must perform. This could be stable movement, overcoming obstacles, climbing stairs, etc. Next you need to select a configuration. Then carry out a kinematics analysis. This includes analysis of stride, joint movement and weight transfer during walking. It is then advisable to carry out modeling and simulation. The next step is to design the mechanism. This may include joints, motors, sensors and other necessary elements. And at the last step, testing and optimization are carried out.

In this article we consider the development of the kinematic diagram of a two-legged, two-armed robot.

Related works

Currently, plenty of scientists consider robot kinematic model development [30]-[37]. Let us look at some of them.

Researchers in [31] present a new variable curvature kinematic modeling approach for soft continuum robots by taking the external forces into consideration, achieving both accurate motion simulation and feedforward control of the robot.

Authors in [32] propose a novel kinematic model with angular positioning deviation of each rotary axis, modeled as a function of the command angle and rotation direction.

The paper [33] explain the application of kinematic modeling of four wheel omni directional robots as track tracking controllers and microcontroller based movement control.

Scientists in [34] consider the kinematic modeling and control of hyper-redundant robots inspired by the octopus arm. They propose a discrete multi-segment model in which each segment is a 6-DoF Gough-Stewart parallel platform.

An auxiliary reference position of the mobile platform is calculated based on the kinematic model in [35], and the motion of the mobile platform and robot arm can be decoupled to handle its redundant degrees of freedom.

Authors in [36] based on the authors' robot excavator designs, the forward motion kinematics and computer simulation models are described and developed. Kinematic

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characteristics with respect to digging operations were simulated. Kinematic constraint models were also established to eliminate any contact between the robot excavator and pile shaft. The findings provide a fundamental basis of designing and controlling the robotic excavators for pile construction in practice.

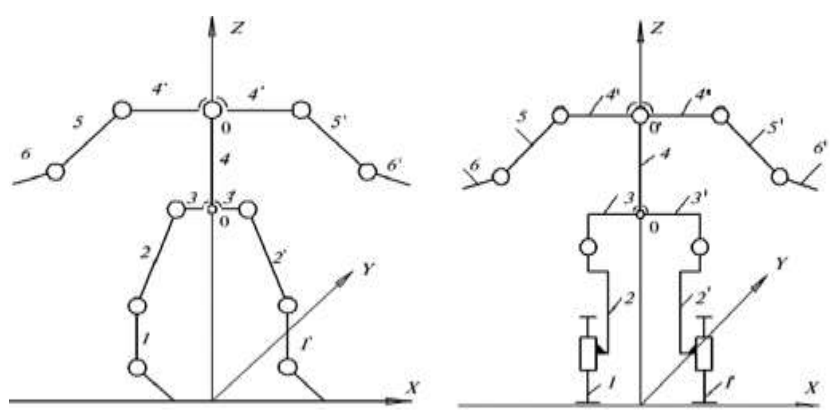
Article [37] examines lower limb joint angles during walking and running by using Inertial Measurement Units. The geometry and kinematic parameters were calculated. The geometric model of a human leg hydraulic exoskeleton was presented. Joint angle data acquired during experiments were used in the mathematical model. The proposed model allows for calculating the position of the human leg and actuators' characteristic points.

As you can see, there are a huge number of works describing kinematic model for a mobile robot development. Further in our article we will consider the development of a kinematic model of a bipedal walking robot.

The robot walking part a kinematic diagram development

Any bipedal walking robot (BWR) consists of two large mechatronic units - the musculoskeletal apparatus (MSA) and the body with arms. The MSA consists of two legs, each of which consists of a lower leg and a thigh; the hip joint is used as the body of the MSA. The MSA leans on the movement surface with the foot, which has either a rigid connection with the lower leg, or is connected to the lower leg with a rotational pair.

Currently, there are two groups of BWRs - with rotational kinematic pairs in the leg joints and with translational kinematic pairs in the leg joints (Figure 1).



a – with rotational kinematic pairs in the leg joints;
b – with translational kinematic pairs in the leg joints

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Figure 1: Bipedal walking robot schemes

During transverse vibrations, the robot tilts to the side - left or right, and during longitudinal vibrations - forward or backward. Depending on the nature of the vibrations of the body, which are supposed to be dampened (balanced) by the movement of the hands, the directions of the axes of rotation of the hands are selected (Figure 2).

Rotation of the BWR arm around the X axis dampens longitudinal vibrations, and rotation of the arm around the Y axis dampens transverse vibrations. To study the nature of the robot's oscillations, a mechanical model of the BWR is compiled.

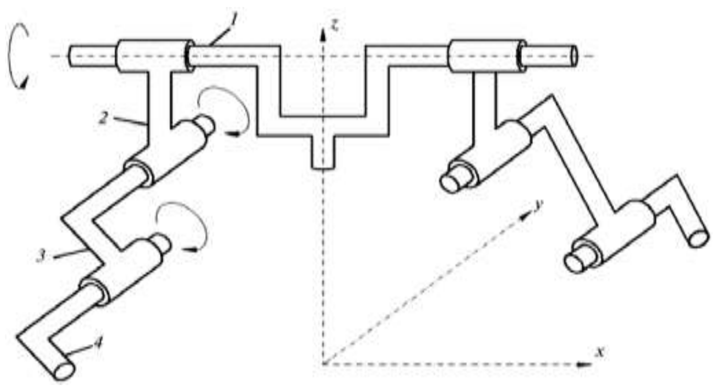

Figure 2: Rotational axes location of hand kinematic pairs example

The MSA has fifth-class rotational kinematic pairs in the leg joints, the mechanical model has the form shown in Figure 1a. A mechanical model of a standing BWR, in which the leg joints of the MSA have translational kinematic pairs, is shown in Figure 1b.

External forces applied to a mechanical model cause mechanical stresses, vibrations and deformations. The dynamic properties of a walking system depend not only on its structure, but also on the configuration of the robot, as well as on external influences. When describing the process of oscillations propagation along the BWR skeleton using a mechanical model with concentrated masses, the number of these masses is limited depending on the task (Figure 3).

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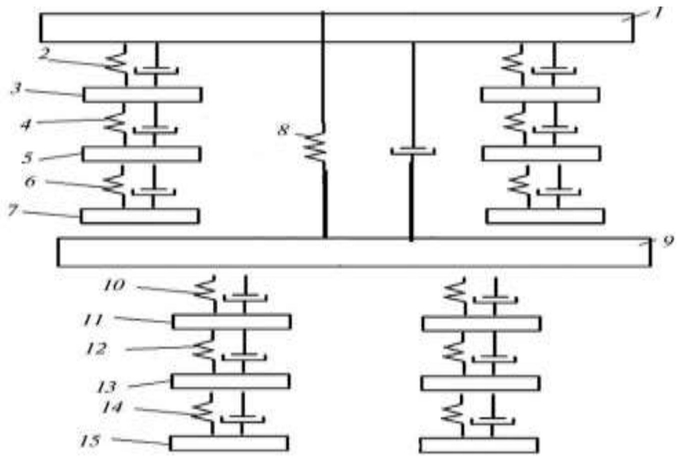

1 – collarbone; 2 – shoulder joint; 3 – shoulder; 4 – elbow joint; 5 – forearm; 6 – wrist joint; 7 – wrist; 8 – spinal column; 9 – pelvis; 10 – hip joint; 11 – hip; 12 – knee joint; 13 – lower leg; 14 – ankle joint; 15 – foot

Figure 3: Mechanical model of a standing BWR with rotational kinematic pairs in the leg joints

When the BWR moves with vertical vibrations, angular and horizontal vibrations occur. To study motion processes that cause oscillations, differential equations are drawn up.

To describe the dynamics of the BWR hands movement under influence in two mutually perpendicular planes – the lower leg and foot move along the vertical X axis, and all other parts of the BWR together with the thigh move along the Y axis, perpendicular to the plane of the drawing (Figure 1b).

This mutually perpendicular direction of movement is reflected in the mechanical model shown in Figure 2.

When drawing up a differential equation to take into account possible fluctuations of the BWR when walking, it is necessary to take into account both permanent disturbances and random ones.

The housing design must allow three drives to be placed on it. For greater maneuverability of the kinematic scheme and the ability to perform any work with the hands, it is advisable in the shoulder joint to be able to rotate the arm relative to the two axes X and Y, then the diagram will look like that shown in Figure 4.

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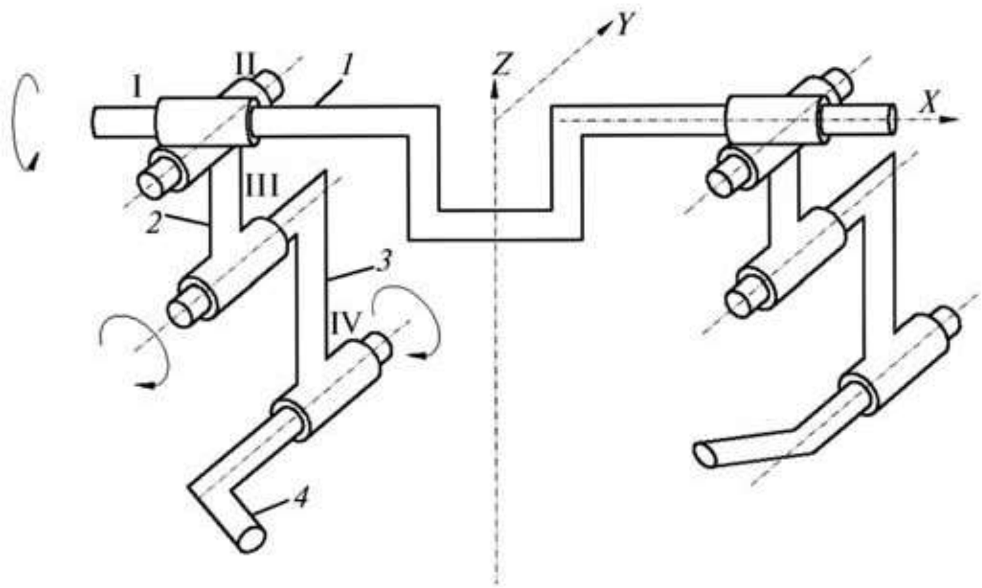

1 – collarbone; 2 – shoulder; 3 – forearm; 4 – wrist

Figure 4: Kinematic diagram of the BWR body with arms with increased maneuverability

The design becomes more complex, since two actuators are required in the shoulder joint, which leads to a more complex control system for the BWR (Figure 5).

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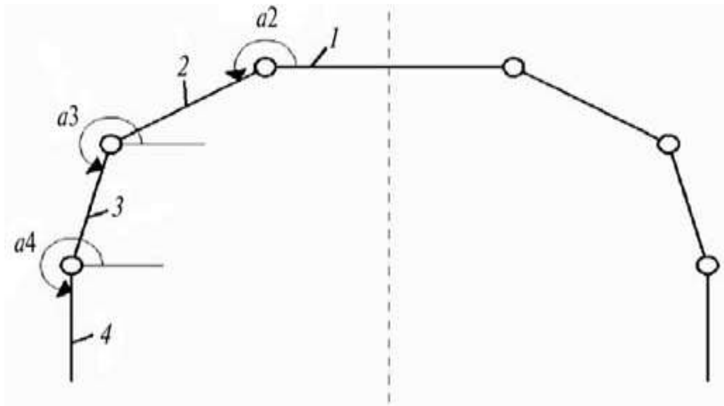

1 – the collarbone is rigidly connected to the body, i.e. it is motionless; 2 – shoulder; 3 – forearm; 4 – wrist

Figure 5: Spatial manipulation system with thew 5th class rotational pairs

If we use hands as a device to maintain a stable state of the joint movement at the moment when it stands on one leg, then in this case it is enough to have one rotational movement in each joint around the Y axis. Then the movement of all links (shoulder, forearm and hand) will occur in the plane of the drawing, and the diagram will have the form shown in Figure 5.

Thus, we have three controlled drives, and they rotate relative to the common Y axis (perpendicular to the plane of the drawing). This scheme of the body with arms can be installed on the MSA of the BWR with both rotational kinematic pairs in the leg joints and translational pairs in the leg joints (Figure 6).

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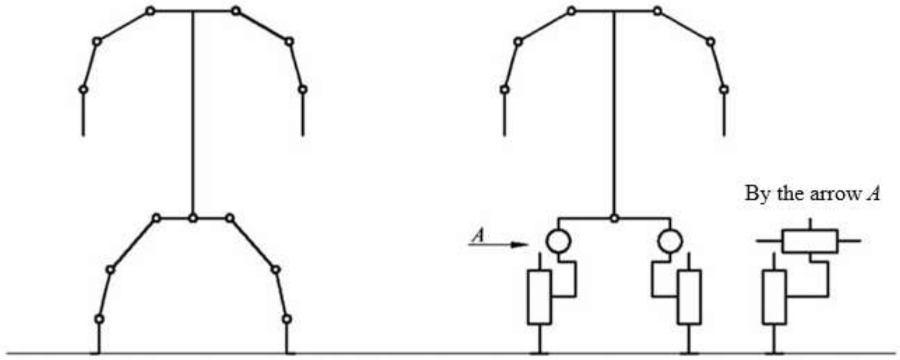

Figure 6: Manipulation system on the BWR musculoskeletal apparatus

In both cases, by moving hands you can maintain a stable state of the robot while walking. The angles of rotation of the arms must be consistent with the movement of the MSA legs.

Conclusion

Developing a kinematic design for a walking robot is a complex process that requires the integration of knowledge from mechanics, electronics, programming, and other areas.

When we develop a kinematic design, it is important to consider aspects such as balance, control and degree of freedom of movement. We should also pay attention to the materials used to create the components, their strength and lightness.

In this article we considered the development of a kinematic diagram of a bipedal walking robot. The necessary kinematic pairs are considered, the coordination of movements of the arms and legs is given. We also took into account the need to maintain balance when moving this robot. To do this, we note, that it is necessary to coordinate the movements of the arms and legs. In this case, we consider a combination of translational and rotational movements. Naturally, when using such a combination, it is necessary to take into account the degrees of freedom of the arms and legs of the designed robots. Moreover, we believe that the additional capabilities of rotational movements contribute to better maintaining the balance of the developed robot.

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