A Quadruped Walking Robot as Educational Robot

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Abstract: *Walking vehicles, comparing to traditional mobile platforms, offer superior mobility over natural terrain. The use of legs is convenient for locomotion on soft and accidental ground where the performance of wheels and tracks are considerable reduced. From educational point of view, to study the kinematics and the control theory of this kind of robots could be interesting. This paper presents a prototype of mobile platform with four legs, which could be used for educational purposes.*

Keywords: Mobile robot, Legs, Educational purpos

I INTRODUCTION

The fascination of mobile robots has continued since the famous science fiction of Karel Capek and Isaac Asimov, the beginning of legged robots in the early eighties and the humanoids at the end of the nineties up to the actual American Mars mission with the robots Spirit and Opportunity. The success and the failure are discussed. Mobile robot systems have been investigated and developed at high-specialised laboratories in research institutes, universities and companies. A number of service or personal robots have found their way into our world.

The performance of traditional mobile robots largely results from the structured nature of their operating enviroments. Robotic mobility over highly broken and unstable terrain requires walking machines. Even though for many applications, traditional wheeled platform provide sufficient robustness and energetic performance, in the long run, sistem capable of operating in the widest variety of terrain conditions, will be legged robots [2].

Nonetheless, walking machines present many difficulties from an engineering point of view. Unlike traditional mobile robots, the control of these platforms requires a thorough understanding of their dynamics.

In this context, studying the kinematics and the control theory of this kind of robots could be very interesting from the educational point of view. The paper presents a prototype of walking robot, which could be used for educational purposes.

II DESCRIPTION OF THE FOOT LEGS

The quadruped-walking robot QWR (Fig. 1) is constituted by: chassis, four identical legs, locomotion system, command - action system and source of energy.

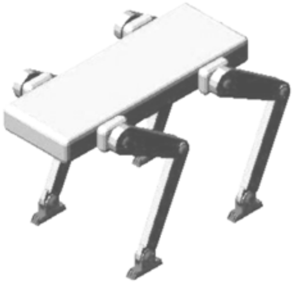

Figure 1
The CAD model of quadruped-walking robot

We can say that QWR is the similar of the structural point of view with the robot with parallel topology (mobile platform is identical with chassis, fixed element is identical with soil and legs is identical with open kinematical chains (connexions)).

The leg mechanisms are a RRR structure, where every kinematics pair is actuated as shown in Fig. 2.

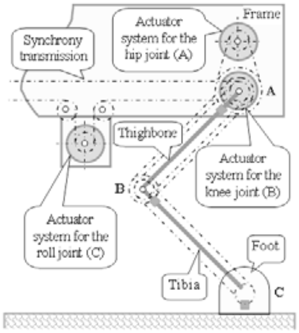

Figure 2
Scheme of one-foot leg

The A kinematics pair is called hip joint, the B is called knee joint, and the C is called the foot joint. The base element of the A joint is the frame of QWR, and the leaded element is called thighbone. For the B joint, the thighbone is the base element and the leaded element is called tibia. For the C joint, the tibia is the base element, and the foot represents the leaded element. The A, B, and C joints actuator systems, are placed on the frame, have AC servomotors with rotor disk and harmonic drive gear [4].

The movements from the motor shafts arrive to the three joints through the synchrony transmissions. The A and B joints servomotors are equipped with an incremental rotation encoders, that send the reject signal needed to achieve the programmed movements for walking, by a supervising control system. The C joint servomotor tachometer sends the appropriate signal to achieve the programmed speed for wheeled locomotion. The C joint is equipped with a force sensor that sends a signal to the control system about the instantaneous load of the leg, to decide the next step of the control program. Also, a vibration sensor is mounted on the frame. This sensor sends a signal to the control system about the natural terrain quality, to adapt the movement regime of the system.

The electronic control system is placed on the frame and has an on board computer as central unit.

The control software is based on the mathematical algorithms, structured by specific movement sequence routines.

The movement strategy depends on the number of the legs of the walking locomotion system.

III THE FORCE DISTRIBUTION IN THE LEG MECHANISMS

The system builds by the terrain on which to do the displacement and the walking robot, which has three legs in the support phase, is determinate static. The problem of determination of reaction force components is made in simplifying assumption, namely the stiffness of the walking robot mechanical structure and terrain [5].

The complex behaviour of the earth may not be described than by an idealization of its properties.

The surface of terrain which the robot walks on is defined in respect to a fixed coordinates system O_1XYZ annexed to the terrain (Fig. 2), by the parametrical equations X = X (u, v); Y = Y (u, v); Z = Z (u, v), implicit equations F(X, Y, Z) = 0, or explicit equation Z = f(X, Y).

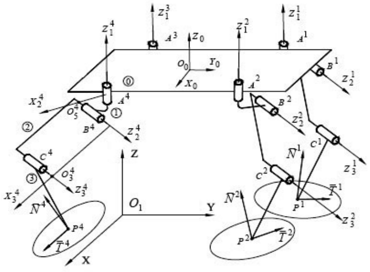

Figure 2
The Hartenberg-Denavit coordinate system and the reaction force components

These real, continuous and uniform functions with continuous first partial and ordinary derivative, established a biunivocal correspondence between the points of support surface and the ordered pairs (u, v), where $\{u, v\} \in R$.

Not all partial first order derivatives are null and not all Jacobians

$$\frac{D(X, Y)}{D(u, v)}, \frac{D(Y, Z)}{D(u, v)}, \frac{D(Z, X)}{D(u, v)} \tag{1}$$

are simultaneous null.

On the entire surface of the terrain, the equation expressions may be unique or may be multiple, having the limited domains of validity.

The normal component N of reaction force at the P^i contact point of the i leg with the terrain is positioned by the direction cosine:

$$\cos\alpha^i = \frac{A_i}{\sqrt{{A_i}^2 + {B_i}^2 + {C_i}^2}}$$

$$\cos\beta^i = \frac{B_i}{\sqrt{{A_i}^2 + {B_i}^2 + {C_i}^2}} \tag{2}$$

$$\cos\gamma^i = \frac{C_i}{\sqrt{{A_i}^2 + {B_i}^2 + {C_i}^2}}$$

in respect to the fixed coordinated axes system, where:

$$A_i = \begin{vmatrix} \dfrac{\partial Y^i}{\partial u_i} & \dfrac{\partial Z^i}{\partial u_i} \\ \dfrac{\partial Y^i}{\partial v_i} & \dfrac{\partial Z^i}{\partial v_i} \end{vmatrix} \quad B_i = \begin{vmatrix} \dfrac{\partial Z^i}{\partial u_i} & \dfrac{\partial X^i}{\partial u_i} \\ \dfrac{\partial Z^i}{\partial v_i} & \dfrac{\partial X^i}{\partial v_i} \end{vmatrix}$$

$$C_i = \begin{vmatrix} \dfrac{\partial X^i}{\partial u_i} & \dfrac{\partial Y^i}{\partial u_i} \\ \dfrac{\partial X^i}{\partial v_i} & \dfrac{\partial Y^i}{\partial v_i} \end{vmatrix} \tag{3}$$

The tangential component of reaction force, i.e. friction force, is comprised in the tangent plane at the support surface.

The equation of the tangent plane in the $P^i\left(X_{P^i} \quad Y_{P^i} \quad Z_{P^i}\right)$ point is:

$$\begin{aligned} & X^i A_i + Y^i B_i + Z^i C_i - \\ & - X_{Pi} A_i - Y_{Pi} A_i - Z_{Pi} A_i = 0 \end{aligned} \tag{4}$$

The straight-line support of the friction force is included in the tangent plane:

$$\frac{X^i - X_{Pi}}{l_i} = \frac{Y^i - Y_{Pi}}{m_i} = \frac{Z^i - Z_{Pi}}{n_i} \tag{5}$$

If the surface over which the robot walked is plane, it is possible that the robot may slip to the direction of the maximum slope.

Generally, the sliding result is a rotational motion superposed on a translational one.

The instantaneous axis has an unknown position.

Let

$$\frac{X-U}{\cos\alpha_r}=\frac{Y-V}{\cos\beta_r}=\frac{Z}{\cos\gamma_r} \tag{6}$$

the equation of instantaneous axis under canonical form, in respect to the fixed coordinate axes system.

The components of speed of the P^i point, on the fixed coordinate axes system with OZ axis identical with the instantaneous axis, are:

$$\begin{aligned}\overline{V}_X &= -\omega Y\,\bar{i}\\ \overline{V}_Y &= \omega X\,\bar{j}\\ \overline{V}_Z &= \overline{V}_0\end{aligned} \tag{7}$$

The projections of the P^i point speed on the axes of fixed system O_1XYZ, are:

$$\begin{Vmatrix}V_X\\ V_Y\\ V_Z\end{Vmatrix}=R\begin{Vmatrix}V_x\\ V_y\\ V_z\end{Vmatrix} \tag{8}$$

where R is the matrix of rotation in space. The carrier straight line of P^i point speed, i.e. of the tangential component of reaction force, has the equations (9).

$$\frac{X-X_{Pi}}{V_X}=\frac{Y-Y_{Pi}}{V_Y}=\frac{Z}{V_Z} \tag{9}$$

and is contained in the tangent plane to the terrain surface in the point P^i:

$$V_X\,l+V_Y m+V_Z n=0 \tag{9'}$$

To determine the stable position of the walking robot, which leans upon 3 legs, on some shape terrain, it is necessary to solve a nonlinear system, which is formed by:

- the transformation matrix equation

$$\begin{Vmatrix}1\\ X_{0P_i}\\ Y_{0P_i}\\ Z_{0P_i}\end{Vmatrix}=AA_0A_1{}^iA_2{}^iA_3{}^i\begin{Vmatrix}1\\ X_{4P_i}\\ Y_{4P_i}\\ Z_{4P_i}\end{Vmatrix} \tag{10}$$

- the equilibrium equations are

$$\sum_{i=1}^{n}\overline{R}_i+\overline{F}=0 \tag{11}$$

$$\sum_{i=1}^{n}\overline{M}_{(R_i)}+\overline{M}=0 \tag{12}$$

which expressed the equilibrium of the forces and moments system which acted on the elements of walking robot.

IV LOCOMOTION STRATEGY

'Gait is the leg phasing part of the coordination problem.' [6]. In other words, we can say that, a gait defines the form and the characteristics of a body displacement. The gaits can be divided in three basic types: static gaits, marginally static gaits and dynamic gaits. In a quadruped robot three of the legs must be on the ground for a static gait. Dynamic gaits, on the other side, don't have this limitation because, as long as equilibrium is maintained, the number of legs on the ground can vary from 0 during a jump to the total number of existing legs. The stability margin (Fig. 3) of a gait is the minor of the minimum distances of the mass center to the border of the supporting polygon for all the robot configurations. With this study we can test the sensibility of the gaits to disturbance of the mass center.

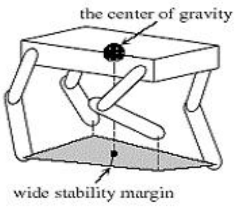

Figure 3
The support polygon

To pass from stopped configuration to the turning configuration or to start of walking configuration or inverse, the movement of the involved legs into the configuration operation is similar to the movement that performs one step, but the support legs are maintained blocked, in order to keep the frame position and orientation during the operation time. The programmed routines elaborated to implement the configuration operations into the control software are based the leg's inverse geometrical model. The Axz reference system is chosen with the origin into the hip joint, with the sense of abscise axis oriented into the frame moving direction and with Az axis oriented after the vertical line in A point towards the terrain (Fig. 4).

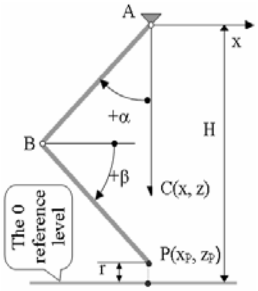

Figure 4
The leg's configuration based on the inverse geometrical model

Into the inverse geometrical model is supposed that the support polygon's corner points P (x_P, z_P) are defined. The unknown variable is the orientation angles α and β of the thighbone and tibia elements. They are determined for the C (x, z) leg's extremity, situated on the vertical line that crosses through the P support point, at r height from 0 reference level. It is specified that the level 0 is the reference level, which will be chosen at H distance from the hip joint. According to the algorithm from [3] the angles are determined with the relations:

$$\alpha = \arcsin \frac{u}{l_{AB}} \quad \beta = \arcsin \frac{v}{l_{BC}} \tag{13}$$

the u and v function with the relations:

$$v = \frac{b}{a} - \sqrt{\frac{b^2}{a^2} - \frac{c}{a}}$$

$$u = -\frac{x}{z} \cdot v + \frac{x^2 - z^2 + l_{BC}^2 - l_{AB}^2}{2 \cdot z} \tag{14}$$

and the coefficients with the relations:

$$\begin{aligned} a &= 1 + x^2 / z^2 \\ b &= \left[1 + \left(x^2 - z^2 + l_{BC}^2 - l_{AB}^2\right) / \left(2 \cdot z^2\right)\right] \cdot x \\ c &= \left[\left(x^2 - z^2 + l_{BC}^2 - l_{AB}^2\right) / (2 \cdot z)\right]^2 + x^2 - l_{AB}^2 \end{aligned} \tag{15}$$

If we know the l_{AB} and l_{BC} length, the H height and the foot height r, after we determine the C point coordinates with the relations:

$$\begin{aligned} x &= x_P \\ z &= z_P - r = H - r \end{aligned} \tag{16}$$

the algorithm in (15), (14), (13) order is used to uniquely obtain the orientation angles α and β values.

During the configuration, the leg's extremity goes through a fragmented trajectory (Fig. 5).

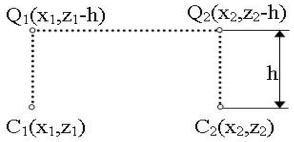

Figure 5
A fragmented trajectory

This trajectory has the C_1 as the start point and the C_2 as the stop point, in successive positions of the legs extremity, before an after the configuration operation.

The fragmentary trajectory contains the C_1Q_1 lift segment, the second horizontal movement segment Q_1Q_2, and the third to put down Q_2C_2. The start and stop points coordinates are determined using the relations (16), if we know the coordinates of the support points P_1 and P_2 between which we make the transition. We obtain the Q_1 and Q_2 point's coordinates from C_1 and C_2 points if we translate the axis with the h height as in Fig. 5. This algorithm associates to each coordinate pair, one angle pair.

In the walking locomotion, the system is permanently reconfigured. This process depends on both the stepping leg's movement and on support leg's movement. Because, at the walking locomotion there are cyclical repeated movements, we can predetermine offline the joints ranges for the whole duration of the cycle and store these results in a database. In this case, the commands to generate the stepping movement are reduced to reading the database and sending this movement information to the axis regulator to be executed.

Conclusions

The use of legs is convenient for locomotion on soft ground where the performance of wheels and tracks are considerable reduced. It is recognizes that four legs are required to obtain good static stability for a legged vehicle.

In this context, studying the kinematics and the control theory of this kind of robots could be very interesting from educational point of view. Another important study is the study of the stability margin; study the adaptation of gaits to variations in the ground slope; detection and avoidance of obstacles with the help of sensors (force, ultrasonic and infrared sensors) and its applications in dynamic gaits.

The autonomous programmable quadruped system could be a useful tool for trainers and researchers in mechatronics, robotics, computers and communication.

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