CONTROL SYSTEM OF A QUADRUPED WALKING ROBOT

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ABSTRACT

This paper presents a control system for a quadruped walking robot. The walking robot named RIMHO has been developed to obtain expertise in legged locomotion. A brief description of the robot and its model is shown. A description about the relationship between the machine level and the control station level is presented. The paper also shows experimental results of a new free locomotion gait for forward motion and turning. At present, the new real-time control method is used to operate the robot by a human operator using a virtual reality representation in the control station. In this way, a three dimensional graphic representation in real time is used to test the effectiveness of the locomotion.

INTRODUCTION

Simulation technology is becoming an increasingly important tool as computer capabilities increase. In the case of walking robots, it is very useful for the design, the construction, and the control of each part of the robot. The new computers make it possible to research new strategies for walking, by simulating a sensor system and imaginary robot states to plan a locomotion solution in real time. The walking machines present some advantages over the wheeled vehicles in rough terrain, e.g. greater mobility, better isolation from the terrain irregularities, reduced possibility of environmental damage, and better energy efficiency. These advantages make the free locomotion gaits potentially adequate for some emerging applications such as planetary exploration, underwater tasks and industrial forestry or agriculture. Up to the present, many researchers on gaits for legged robots have built simulators to understand how locomotion mayä be achieved in machines and its relationship with animal locomotion. In this sense, this paper shows a new knowledge about free locomotion gaits by using a three dimensional graphic simulator as an interface with a human operator in the control station.

DESCRIPTION OF THE WALKING ROBOT

The quadruped walking robot named RIMHO is a robot that can be classified as an insect type. This robot has not been developed for any specific application, although it is intended for application in hostile environments, and at present is used as a test bed for different aspects related to walking vehicles [1]. Fig. 1 shows the arrangement of the legs in the robot´s body, the actuation of each leg is based on a three dimensional cartesian pantograph mechanism [2], which consists of four links that provide three degrees of freedom. So, the direction of the displacement for each degree of freedom is on a cartesian coordenate system fixed in the body. The body of the RIMHO is 735 mm long, 710 mm wide and 344 mm high. The machine's weight is 65 kg, and can carry a 25 kg. payload. The chassis and links are mostly aluminium. The leg positions are controlled by a personal computer. There are incremental optical encoders of 500 pulses per revolution attached to the motor shaft (12 in all). The RIMHO has a height step of 240 mm, and has been designed to do omnidirectional movements under the supervision of a control station.

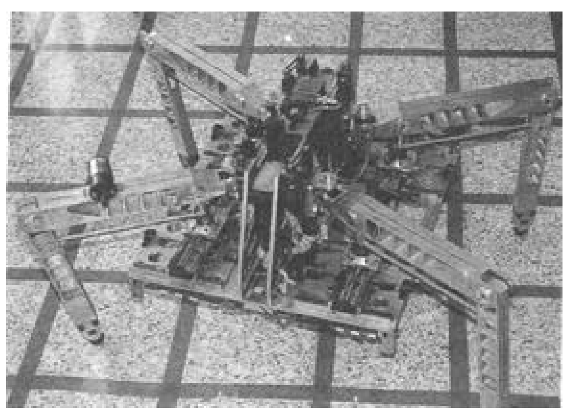

Fig.1 The RIMHO walking machine

KINEMATICS MODEL

The objetive of keeping the robot´s body in a position and orientation desired at any instant of time, has carried us to determine the kinematic model of the walking robot. The Kinematics equation are quite

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simple if it is assumed that each part of evrey leg is a rigid body, and each legis supported in a contact point on the ground. For the solution of the Kinematics inverse problem we have placed a reference system fixed on the Geometrical Center of the body, and four auxiliary reference systems distributed in the body (one for each leg). Fig.2 shows the coordinated systems and the vectorial relationship used in the model. The geometry of one leg, Fig.3, permits us to define the point A placed on the joint to produce displacement in the horizontal plane (XY), and the point B on the joint to make vertical movements [3].

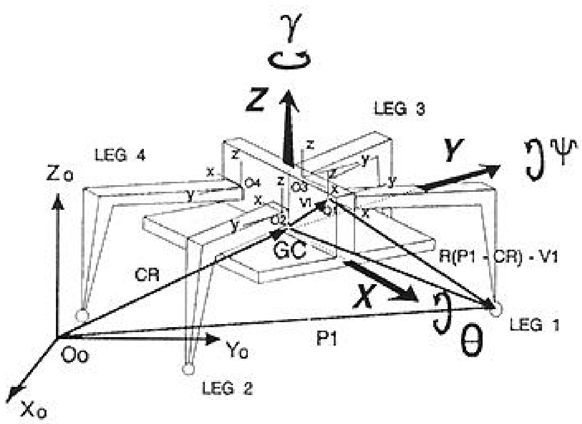

Fig. 2 The coordinate system and vectorial relationship for the RINHO

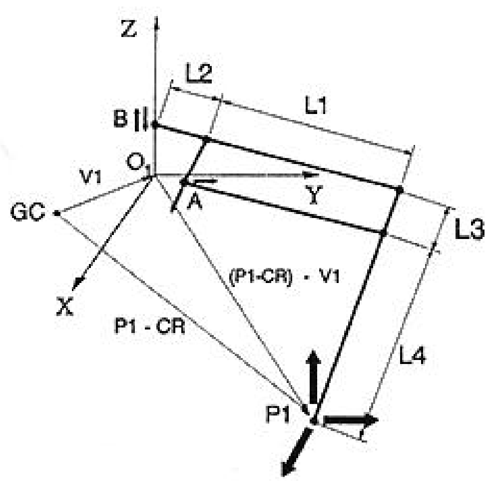

Fig. 3. Geometric parameters for the mechanism of the leg 1

The reduced equation for the twelve joints (three for each leg) to solve the kinematics inverse problem may be expressed as,

$$\begin{pmatrix} X_A \\ Y_A \\ Z_B \end{pmatrix}_I \begin{bmatrix} \frac{L2}{L5} & 0 & 0 \\ 0 & \frac{L3}{L5} & 0 \\ 0 & 0 & -\frac{L2}{LI} \end{bmatrix} \left\{ \begin{bmatrix} \cos\gamma\cos\varphi & -\sin\gamma\cos\theta\cos\varphi - \sin\varphi\sin\theta & \sin\gamma\cos\theta\cos\varphi - \sin\varphi\sin\theta \\ \sin\gamma & \cos\gamma\cos\theta & -\cos\gamma\cos\theta \\ \sin\varphi\cos\gamma & -\sin\varphi\, c\sin\gamma\cos\theta & \sin\theta\sin\gamma\sin\varphi - \cos\theta\cos\varphi \end{bmatrix} \begin{pmatrix} P_X - CR_X \\ P_Y - CR_Y \\ P_Z - CR_Z \end{pmatrix} - \begin{pmatrix} V_X \\ V_Y \\ V_Z \end{pmatrix} \right\}$$

Where $L_5=L_1+L_2=L_3+L_4$; $L_1=L_4=400$ mm; $L_2=L_3=100$ mm; P_i is a vector from the fixed inertial system Oo to the endpoint of the leg i; i={1,2,3,4}; CR is a vector from the fixed inertial system to the geometrical center of the body; V_i is a vector from the geometrical center of the body to the origin O_i of each leg; the angles _, _, _ define the roll, pitch, and yaw angles respectively for the orientation of the body on the inertial coordinate system O_o. Eq. 1 shows three different actions for walking in an instant of time: linear motion of a leg, linear motion of the body, and rotation motion of the body. The movements of the legs for locomotion are designed to small velocity, 25 mm/s to move up and down, and 100 mm/s as the highest speed to step forward motion.

THE CONTROL SYSTEM STRUCTURE

The control system structure consists of two levels: Control Station Level and Machine Level. These two levels work in separate computers connected for the serial port RS-232. All twelve joints in the machine are driven by DC servomotors. Each motor is controlled by a dedicated microcontroller that provides the interface between motor drivers and processors. Apart from the proprioceptive sensors employed on the actuation control system, there are four contact sensors (one for each leg). These sensors detect whether the foot is on the ground or not, and permit us to modify the decision for walking according to the internal and external locomotion parameters. The automatic free locomotion decisions are based on the structure control shown in Fig. 4. An interesting aspect presented by the control station is the posibility to plan a locomotion mission under different terrain by simulation. The planned locomotion is supervised by the gait and attitude controllers. In this way, new conditions are analyzed to gain new experience in the walking process and to improve the controllers. This experience is useful for locomotion control in real time.

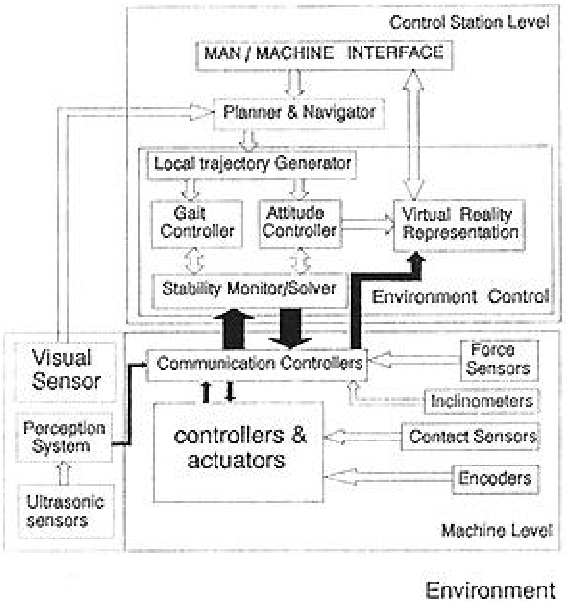

Fig. 4 The RIMHO Control System

The environment control implements the combi-nation of the real and artificial environments with the intention of obtaining sensations in the human operator. The man/machine interface makes it possible for the operator to drive or select the free locomotion mode in order to get the walking machine in a position and orientation wished for walking in different conditions. We define two classes of sensors:

1.Internal. These sensors are used to measure the internal characteristics of the robot (position, internal forces, orientation, and state of the legs).
2.External. These sensors essentially inform about the place where the robot is walking (TV camera) and the irregularities of the terrain (ultrasonic sensors).

The technical design also establishes the relationship between the sensors and actuators to control the global configuration of the walking robot. The free locomotion actions are based on a new locomotion knowledge developed by simulations and experiments with the walking robot. The free locomotion algorithms produce adaptive non-periodic gaits from any initial configuration of the walking robot. This aspect is important for walking automatically on different terrains. The formulation of the free locomotion algorithms [4] used in the gait controller is different from other kinds of formulations proposed previously [5], [6]. It provides good stability and mobility in the machine for practical locomotion in real time.

EXPERIMENTS WITH THE WALKING ROBOT

The free locomotion experiments have been analyzed for the two types of gaits: Forward and turning.

1. Forward: This kind of locomotion permits the robot to walk on a straight line. The walking directions obtained in our experiments take values from 0 to 360 degrees, wave- crab angle. The initial geometry at the beginning of the walk is not fixed, and the sequences obtained in some cases are repetitive or not, depending of the evaluation of the internal and external parameters.
2. Turning: This kind of locomotion permits the robot to walk on a circular trajectory. The gravitational center of the body is moved at the same time as the orientation is changed. This kind of locomotion begins from any initial configuration.

FORWARD GAIT

In the case of forward locomotion, we have tested the stability for different wave-crab angles in real conditions. Fig.5 shows the trajectories obtained when the robot made five steps on irregular terrain with an incremental direction of 30º.

The trajectories show that the free locomotion gaits give good results for the robot displacement. The following empirical equations for the trajectories of the legs have been obtained by simulation, and later verified by experiments in the walking robot.

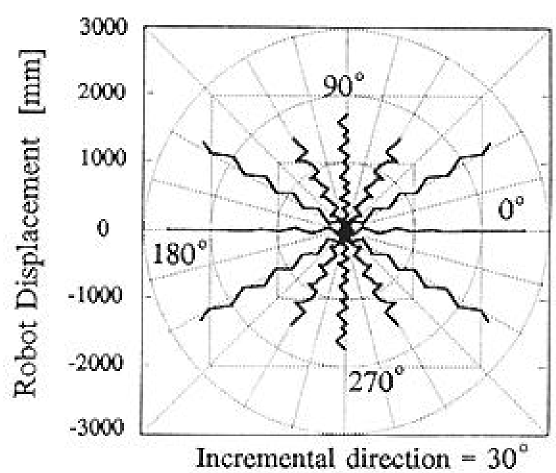

Fig. 5. Locomotion trajectories for different directions in real conditions

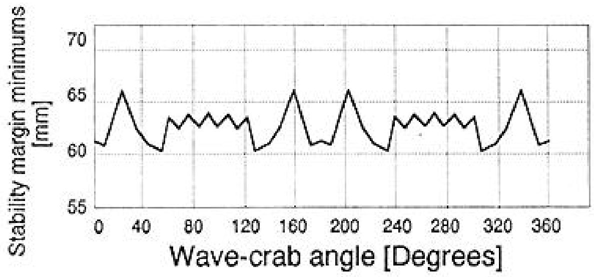

Fig. 6. Minimum values of the stability margin vs. wave-crab angles for the free forward gait

$$dX_{LEG} = \left(1 - \frac{3}{3N}\right)\Delta X_{LEG} \cos s - \left(1 - \frac{3}{3N}\right)\Delta Y_{LEG} sin s \quad (2)$$

$$dY_{LEG} = \left(1 - \frac{3}{3N}\right)\Delta X_{LEG} sin s + \left(1 - \frac{3}{3N}\right)\Delta Y_{LEG} \cos s \quad (3)$$

Where _ is the yaw angle of the robot´s body at the beginning of walk; ΔX_{LEG} is the partial increment of the leg motion in the X direction; ΔY_{LEG} is the partial increment of the leg motion in the Y direction; dX_{LEG} is the total displacement of the leg motion in the X direction; dY_{LEG} is the total displacement of the leg motion in the Y direction; and N is the step number. The stability when the robot walks often is analyzed with the behaviour of the stability margin for a wave-crab angle. The stability margin is defined as the minimum distance between the vertical projection of the gravity center of the body, on a horizontal plane, and the border of the supporting polygon [6]. The plot of the minimum values of the stability margin and the different wave-crab angles shows a good security in the walking process for different directions (Fig. 6).

TURNING GAIT

The disposition of the legs in the body and the work space limits are the most important parameters to determine the minimum radius for the free turning gait. At the moment, we have defined two types of turning modes: lateral and frontal (Fig. 7). The sequences observed in real conditions when the robot is turning are non-periodic. According to the locomotion parameters, the stability of the robot was maintained in each instant of time. The minimun radius determined in the experiments with
the robot for the lateral and front turning free gaits are 360 mm and 250 mm respectively.

CONCLUSIONS

A new control system used to drive a walking machine has been discussed. The reduced model of the walking robot shows good stability for the two free locomotion experiments in real conditions. The new free locomotion gaits are the most important innovations in order that the control system works efficiently for practical locomotion. However, this paper attempts to help the future development of a control theory for walking machines.

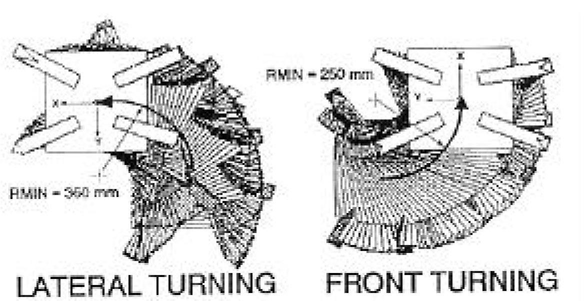

Fig. 7. History of the configuration of the robot in the lateral and front turning free gaits

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