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Free Locomotion Gaits for a Four Legged Machine

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ABSTRACT

The human interaction with new kind of machines has made possible the development of new technics to drive and control devices in the robotics field. Specifically, on the control systems for walking machines there are several problems to be solved. Some of these problems are the free locomoction gaits. In this paper are shown the basic principles involved in the desing of free gaits to develop a control system for a walking machine. The locomotion method shows an interesting phrasing to solve the stability problem at the beginning of locomotion from any initial configuration of the robot. The real-time control method is used by a human to operate the robot using a virtual reality representation in the control station machine. The application of these principles makes possible an advance to develop an efficient system that permits us to drive easily this kind of machines.

KEYWORDS: Walking machine, legged locomotion, Real-time control

INTRODUCTION

The design and development of walking machines is expanding quickly. The main reasons are the advantages of this kind of machines over wheel or tracked vehicles in rough terrain as: greater mobility, better isolation from terrain irregularities, less environment demage, better energy efficiency, and new potencial applications as underwater tasks, industrial foresty, inspection in nuclear environment, planetary exploration, and so on. Nevertheless, walking machines offers a more complex control for locomotion than the traditional vehicles. For walking, the legs have to lift at the end of their effective stroke, return, and place to begin another support stroke. Due to this leg characteristics the problem of legs and body coordination arises. This phasing problem is termed gait.

Many walking machines have been already built. Some of them are huge vehicles as the Shutherland Hexapod [Sutherland, 1984] or the the CMU-AMBLER [Bares, 1989], OSU-ASV [Waldron], Melcrab-2 [Koyachi, 1990] wich present some problems for practical locomotion. Other walking machines are small, like those insect type as the six legged vehicle designed by Brooks at MIT [Brooks, 1989]. This kind of vehicles cannot carry almost any payload. There are also some medium size vehicles, as the TITAN-I [Hirose, 1984], the, 1986, Rimho [Jiménez, 1992] and Katharina [Schmucker, 1998] wich can carry a reasonable payload and do not have the problem of size.

Up to the present, many researches on gaits for legged robots have built simulators to understand how locomotion is performed in machines and its relationship to animal locomotion. Likewise, simulation technology is becoming a great tool at the same time as computers power increases. In the case of walking robots, it is very useful for the design, construction, and control of each part of the robot. New computers make possible to research new strategies for walking, by simulating a sensor system and an imaginary robot´s states to plan a locomotion in real time.

THE FREE LOCOMOTION KNOWLEDGE

The problem to select all possible movements and get the sequencial moves for the locomotion process without loss of stability or significant decrease in the robot´s mobility has led us to research the free locomotion problem [Vargas, 1994] and a control system for walking robots [Vargas, 1998]. In this research the process for walking is considered to be movement under static stability. So, when the robot walks there are at least three legs supporting the body, and the projection of the centre of gravity of the body (GC) in a horizontal plane is on the supporting polygon (see Fig. 1).

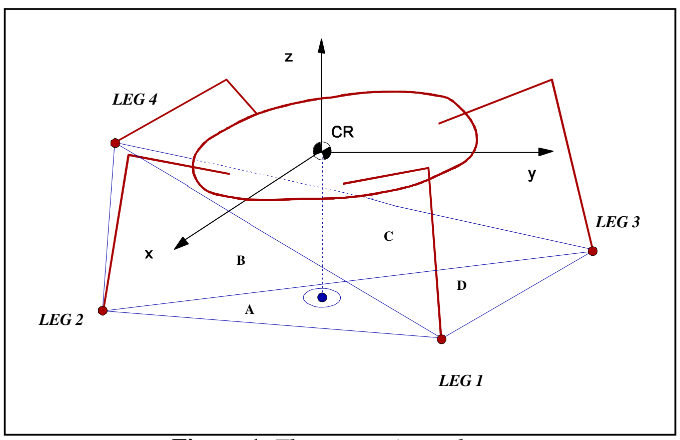

Figure 1. *The supporting polygon*

To evaluate stability we use the stability margin, wich is defined as the minimum distance between the vertical projection of the centre of gravity of the body, on a horizontal plane, and the border of the support polygon.
The cross of verteces (CV) is a new locomotion parameter defined in thes research. It is used for a number of purposes: to place the projection of the GC in a final position for the start of a new step, to finish the global step of the robot, and to decide the trajectories for the legs and the robot´s body. The security radius permit us to avoid the calculation cost of the real position of the robot´s centre of gravity. We consider that the centre of gravity is within the circumference of the security radius. The centre of this circumference is in the centre of gravity of the body (CG), and the error in the real position may be considered in any locomotion direction. We have confirmed by experiments that a real robot shows good stability for a defined security radius [Vargas, 1993]. In this way, the work space of the robot has been evaluated to permit only movement close of the real conditions, and avoid possible interference and impacts with the legs or the terrain when the robot is walking.

THE CONTROL SYSTEM

The free gaits algorithms use a control structure that consist of two levels: Control Station Leve and Machine Level. These two levels work in separate computers connected via an RS-232. All twelve joints in the machines are driven by DC servomotors. Each motor is controlled by a dedicated microcontroller that provides the interface between motor drives and processors. Apart from the proprioceptive sensors employed on the actuation control system there are four contact sensors (one for each leg). These sensors determine 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 gaits are based in the diagram shown in the Figure 2.

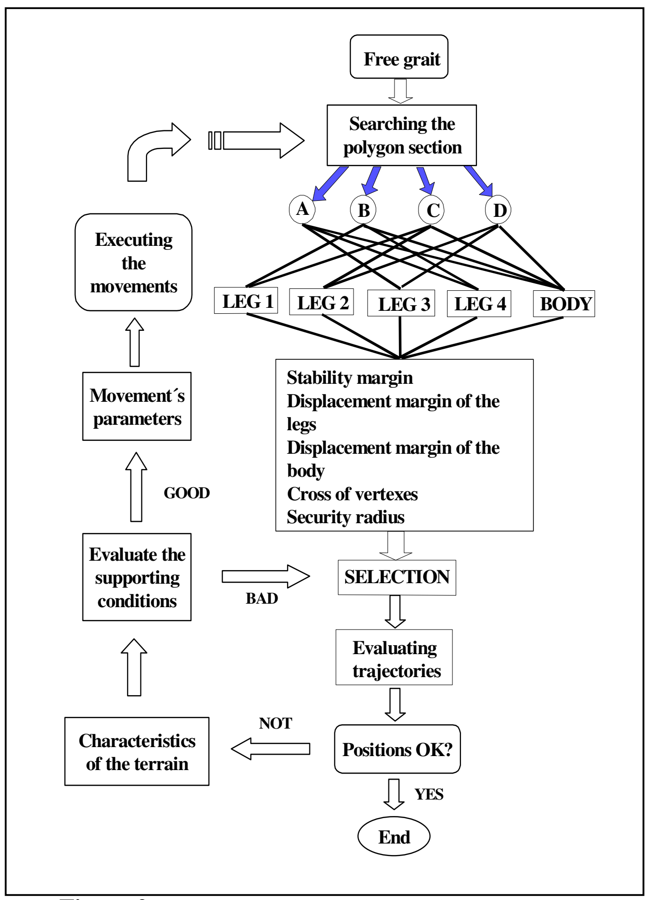

Figure 2. *Diagram to desing the free locomotio gaits*

An interesting possibility is to plan a locomotion mission over diferent terrain using simulation. The locomotion plan is supervised for the gait and attitud controllers. In this way, new conditions are analized to get new experience in the walking process and improve to the controllers. These experiments are useful for locomotion control in real-time. The environment control implements the combination of the real and artificial environments with the intention of proving information to the human operator. The man/machine interface enables the operator to drive or select free locomotion in order to get the walking machine into a required position and orientation. We define to 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 provide information about the place in wich the robot is walking (TV camera) and the irregularities of the terrain (ultrasonic sensors).

The techinical design also establishes the relationship between the sensors and the actuators in order to control the global configuration of the walking robot. The free locomotion actions are based on the locomotion knowledge. Experiments shows good stability and mobility in a real machine for practical locomotion in real time.

EXPERIMENTS

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

1. Forward: This king of locomotion enables the robot to walk in 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 a walk is not fixed, and the sequence obtained in some cases are repetitive and some times not, depending of the evaluation of the internal and external parameters.
2. Turning: This king of locomotion permits us to walk the robot on a circumference trajectory. The gravity centre of the body is moved at the same time as the orientation is changing. The locomotion begins from any initial configuration.

Forward gait

In the case of forward locomotion, we have tested the stability for different wave-crab angles. Figure 3 shows the trajectories obtained when the robot made five steps on an irregular terrain with an incremental direction of 30 degrees. The trajectories show that the free locomotion gaits get good results for the robot displacement. The following empirical equation for the trajectories of the legs has been obtained by simulation, and later verified by experiments:

$$dX_{leg} = \left(1 - \frac{1}{3\,N_{step}}\right)\Delta X_{leg}\,\cos\sigma - \left(1 - \frac{1}{3\,N_{step}}\right)\Delta Y_{leg}\,sin\sigma \qquad ...(1)$$

$$dY_{leg} = \left(1 - \frac{1}{3\,N_{step}}\right)\Delta X_{leg}\,sin\sigma + \left(1 - \frac{1}{3\,N_{step}}\right)\Delta Y_{leg}\,\cos\sigma \qquad ...(2)$$

Where σ is the orientations of the body in the horizontal plane (XY); ΔX_{leg} is the partial increment in the X direction of the leg; ΔY_{leg} is the partial increment in the Y direction of the leg; dX_{leg} is the total displacement of the leg in the X direction; dY_{leg} is the total displacement of the leg in the Y direction; Nstep is the step number.

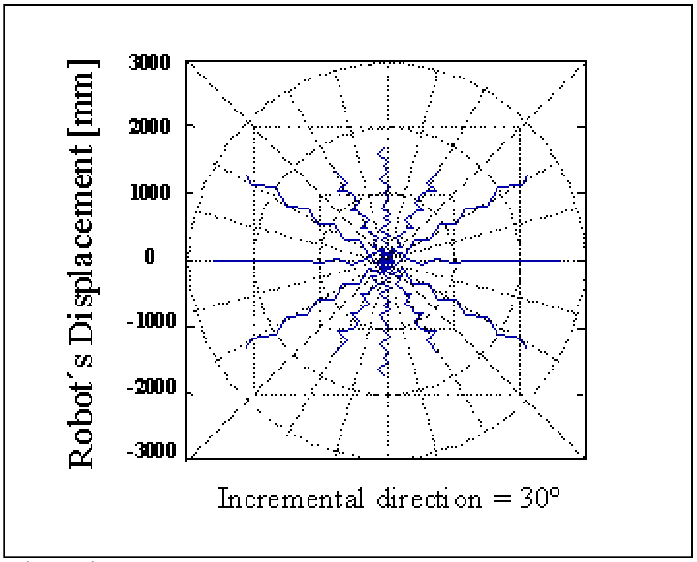

Figure 3. *Trajectories of the robot for different directions, five steps*

The stability margin of the robot for a wave crab angles in the range from 0 to 360 degrees was controlled in each instant time (See figure 4).

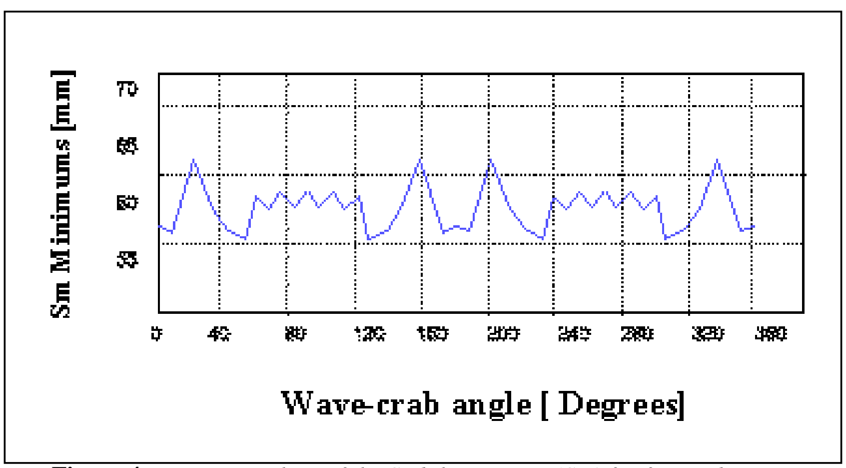

Figure 4. *Minimum values of the Stability margin (Sm) for forward gait*

Turning gait

We consider that the disposition of the legs in the body and the work space limits are the most important parameters to determine the minimum radius for free turning gait. We defined two types of turning mode: Lateral and frontal .

The sequences observed in the robot for the turning modes are non-peridic. In according with the locomotion parameters, the stability of the robot was maintained in each instant time. Figure 5 shows initial and final configuration simulated for a frontal turning.

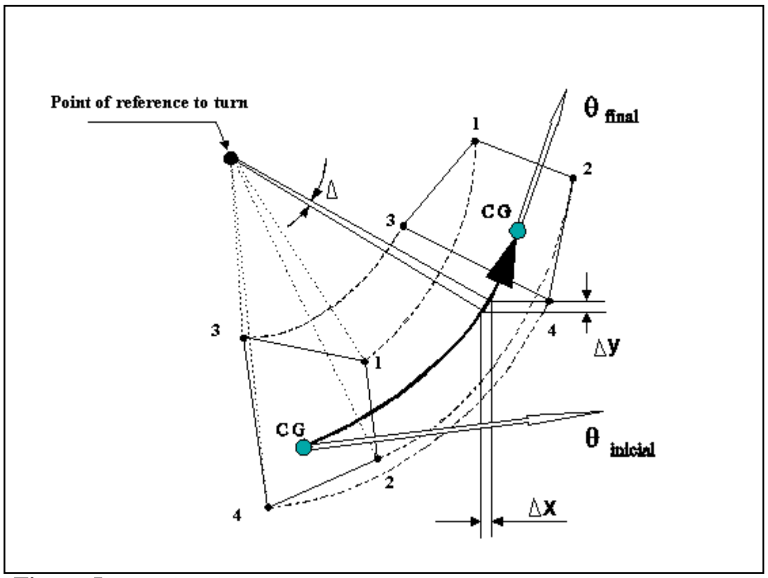

Figure 5. *Initial and final supponting polygon for frontal turning free gait*

CONCLUSIONS

The control method proposed in this paper shows some results that makes possible to design free locomotion gaits to drive easily a walking machine. The strategy to form a free locomotion process for real-time is one of the reasons the control works efficiently for practical locomotion, however we consider that this strategy can be extended to other walking machines, taking care of the geometry, work space area, and the mobility parameters defined in this research.

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