MOBILITY ANALYSIS OF HUMAN GAIT AS UNDERACTUATED MECHANICAL SYSTEM

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Summary A model for a walking mechanism is proposed. The model has nine links representing the body and leg parts. It is a class of underactuated mechanisms and it is analyzed for a leg in the stance and swing phases of a step. Some of the joints are actuated and the others are non-actuated and modelled like a spring between the links associated to the joint. The actuated joints are different in the stance phase from the actuated joints in the swing phase. The feasibility of the gait is demonstrated by selecting the appropriated actuated joints in each phase and taking account of the kinetic energy of the body.

INTRODUCTION

An underactuated system has more degrees-of-freedom (DOF) than control signals [1]. Normally the control signals are torques or forces applied on mechanism's joints by actuators. Several dynamic studies and control designs for these systems are developed.
Design of prosthetic and robotic hands is one of the major application fields [2][3] on control of underactuated systems. Another field of application is walker robots. Analysis of bipedal walking like mechanical systems focus on two main cases: human and bird walk. Study of human walking examines ranges of motion of joints, links movements and loads with the aim of designing prostheses or to design bipedal walking robots.
The study of bird's gait seeks to know the characteristics of motion for different species, dimensions of the links and ranges of motion. They are used for comparative characterization between species, for equilibrium, energetic and evolutionary analysis.
This paper proposes a simplified model of the legs of a bipedal walker. The dimensions of the links are assimilated to the human lower limb.

MODELO

This model treats the human legs and body like a mechanism. It is formed by nine links, one for the body (hip and chest) and four for every leg: thigh, calf, foot and toe.

Mobility of the model
It is calculated the mobility of the model for single (Fig.1) and double (Fig. 2) support conditions in correspondence with the stance and swing phases of the gait [4]. It was eliminated some links and joints that don't take part in the movement. In the case of simple support the model has 8 links and 7 joints and is open kinematic chain type. For double support the model type is a closed kinematic chain with 7 links and 7 joints.
Using the Grübler's mobility formula [5]:

$$F = \lambda(n - j - 1) + \sum_i f_i \qquad (1)$$

In single support the model has 7 DOF and 4 DOF for double support.

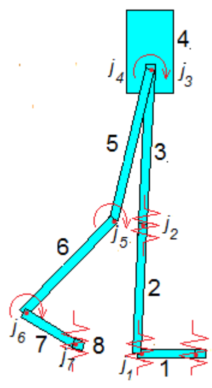


Fig. 1. Apoyo simple.

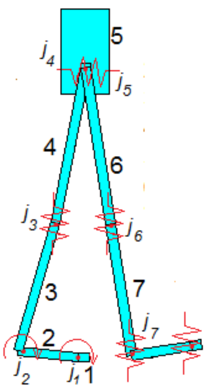


Fig. 2. Doble apoyo.

Underactuated system

For each support condition, it was proposed a number of actuators less than the mobility calculated. This is an underactuated mechanical system. The choice of the number of actuators or control signal and the actuated joints was based in clinical and physiological studies [4][6]. The typical Denavit Hartenberg method, used in robotics, was applied in order to simulate de kinematic behaviour of the model [7]. The goal is the feasibility of the gait without toe shuffling.

GAIT SIMULATION

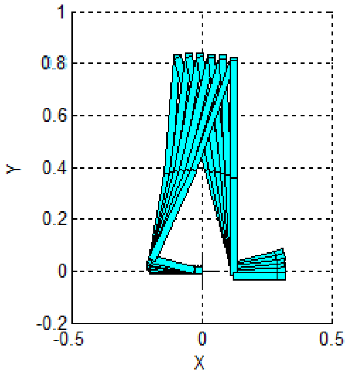
In human gait, each leg makes two phases at each step. The stance phase and the swing phase.

Taking under consideration the right leg, the stance phase begins when the right heel touches the ground and has three secondary phases: early, medium and late stance. In the former the body is supported on both feet and the support is translated from the left leg to right leg. The second part starts when the left leg goes off the ground and ends when the left heel touches the ground. In this part of the right leg has the full support of the body. In the third part, again, there is double support condition. The end of this part is also the end of the stance phase and occurs when the right toe lefts the contact with the ground. In the swing phase, the right leg is in the air and moves like a pendulum back and forth. During this phase the body is supported by the left leg.

The swing phase is approximately 60% of the time step, corresponding to 10% for each interval of double support and 40% for support on one leg. The swing phase is 40% of step.

The joints switch from actuated to a non-actuated and vice versa accordingly with the changes from a gait phase to another. Figures 1 and 2 show the model with its actuated and non-actuated joints. An actuated joint is showed with a circular arrow like a torque action. The movement of links associated with non-actuated joints is defined like spring action. These joints have a spring symbol in the referred figures.

Figure 3 shows the results of simulations of the gait under the above considerations.



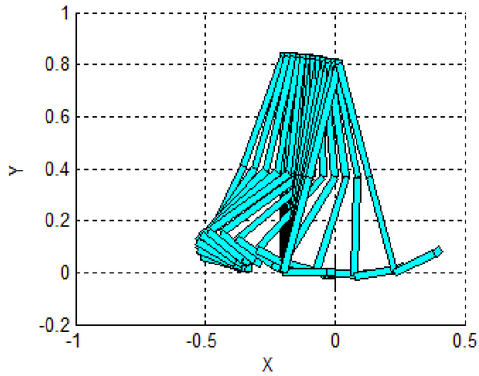


Fig. 3 Results in gait simulation: a) Stance phase. b) Swing phase.

CONCLUSIONS

The model proposed shows the feasibility of a like human bipedal gait. The underactuated condition showed a movements with elegancy and similar to the real. Furthermore, a underactuated system is efficient compared with one totally actuated because the first has less actuators.

The simulations showed better performance when the model when the model includes a initial kinetic energy in the body. This energy was introduced like an initial velocity of this link.

References

[1] Aneke, N.P.I. Control of underactuated mechanical systems. Technische Universiteit Eindhoven, 2003. Proefschrift. - ISBN 90-386-2684-3

[2] Routhier, F., Rancourt, D., and Gosselin. Design of a hand prosthesis based on kinematics principles in Proceedings of the 1995 MyoElectric Controls/Powered Prosthetics Symposium Fredericton, New Brunswick, Canada: August, 1995.

[3] Balasubramanian, R. and Dollar, M. Variation in Compliance In Two Classes of Two-Link Underactuated Mechanisms. 2011 IEEE International Conference on Robotics and Automation. Shanghai International Conference Center May 9-13, 2011, Shanghai, China.

[4] Chuansi Gao et al. Gait Muscle Activity during Walking on an Inclined Icy Surface. J. Industrial Health. Vol. 46, pp 15–22. 2008.

[5] Tsai, Lung-Wen. Robot analysis: the mechanics of serial and parallel manipulators. John Wiley and sons. NY. 1999.

[6] Rose, J. Clinical Gait Analysis Biomechanics & Etiology of Common Walking Disorders. Slides presentation. Department of Orthopaedic Surgery. Stanford University School of Medicine.

[7] Ollero, A. Robótica: manipuladores y robots móviles. Editorial Marcombo S. A. Barcelona. 2001.