



# Human-like walking bipedal robots

Juanjun Lin<sup>1</sup>, Gurvinder S Virk<sup>2</sup> and Hernando Leon Rodriguez<sup>3</sup>

<sup>1</sup> South Westphalia University of Applied Sciences Campus Soest, Luebecker Ring 2 59494 Soest, Germany

<sup>2</sup> University of Gävle, Faculty of Engineering and Sustainable Development, SE-801 76 Gävle, Sweden

<sup>3</sup> Nueva Granada Military University, Faculty of Industrial Engineering, Carrera 11 #101-80 Bogota, Colombia

**Abstract:** The paper develops a human-like gait controller for a 7 degree of freedom bipedal robot system during straight walking; the robot system comprises 2 legs (each with hip, knee and ankle joints) and a torso. Human walking data is collected using a specially designed and developed harness, and analysed to identify key patterns in human walking. The data is used with theoretical dynamical models to simulate the human-like walking by developing appropriate gait control strategies. The controller is also tested on a prototype exoskeleton robot leg.

## 1. Introduction

Research into robot systems has been gradually shifting from the area of industrial robots, which has become firmly established (but which has hardly changed for 25 years) towards new non-industrial areas since the early 90s; this trend has been increasing exponentially over recent years. Whereas industrial robots require high speed repeatable manipulators able to perform various manufacturing tasks with great precision, the new applications require the robots to be mobile (in a variety of environments), have high cognitive capabilities and be able to interact closely with humans to perform a wide range of assistive tasks. This new area of robotics is commonly referred to as service robotics, and the primary aim is to realize assistive robots able to help humans perform everyday tasks (daily living). Since the new robots are required to provide support to human users they need to be able to operate in the same environments as the humans. Because of this close linkage to human support tasks, many countries have been developing humanoid robots, arguing that such bipedal systems will be able to operate in the same manner as humans in the various environments, and that the solutions could be designed by mimicking humans. Some of the notable humanoid robots which have been realized recently are shown in Figure 1.

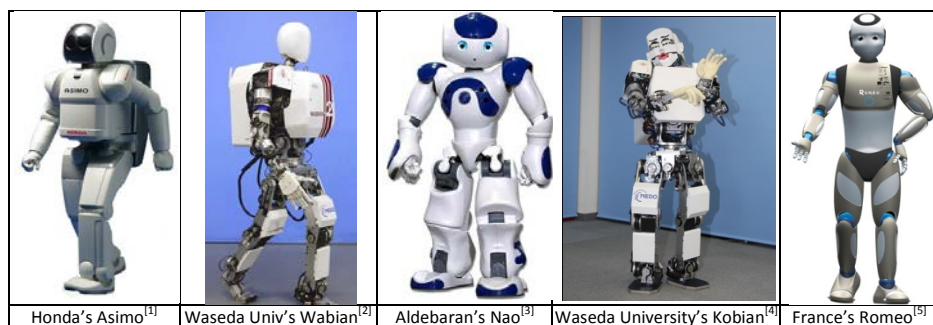


Figure 1: Humanoid robots developed across the world

The main thrust of the work has been to develop robust and reliable electromechanical bipedal systems by studying the dynamics to realize sophisticated control strategies and to produce a variety of walking motions based on human walking. Methods for designing walking strategies include the following:

1. floor reaction control: here force irregularities in the robot due to uneven floor conditions are absorbed to prevent falling. For example, if the tip of the robot's toe steps on a rock, the actual center of ground reaction shifts to the tip of the toe, and the floor reaction controller causes the toe to rise slightly, returning the center of ground reaction to the desired target.
2. ZMP control: zero moment point (ZMP) is defined as the point where the total inertial force of the robot is zero and ZMP control maintains the biped's walking stability by controlling the actual ZMP point against a desired trajectory.
3. Model-based and non-model based methods which control the centre of mass to determine "optimal" walking patterns via theory or some reinforced learning approach (e.g QLearning).

The walking performance of most of these bipedal robots needs improving to allow more effective locomotion in everyday scenarios, and one approach for doing this is to mimic human walking. This paper studies humanoid robots and uses human walking data to design human-like gait controllers of a bipedal system. Theoretical simulations and testing of the designed gait controller on an exoskeleton leg system are planned to realize efficient bipedal walking control strategies.

The paper is set out as follows: Section 2 presents the details of the humanoid robot model considered; Section 3 describes the workplan for collecting the human walking data; Section 4 presents the controller design studies to determine the human-like walking controller; Section 5 describes the exoskeleton leg to be used for testing the walking gaits experimentally and Section 6 ends with conclusions from the work.

## 2. Humanoid walking robot model

The biomechanics of human walking have been well studied and is known to have more than 30 degrees of freedom (dof) (see for example [6]). However using such high order models requires considerable computational effort to study the dynamics as well as being very complex; it turns out that such high orders are unnecessary and realistic approximations can be obtained using much lower-order models (and 5-7 dof systems have been extensively studied). A 7 dof dynamic model (3 dof per leg and 1 dof for the torso) has often been used for straight walking, as shown in Figure 2.

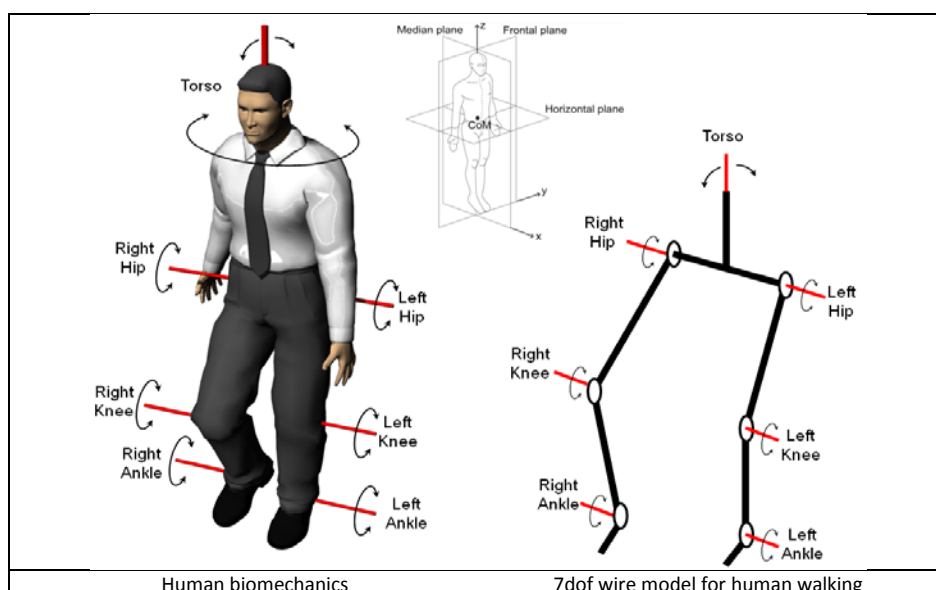


Figure 2: Simplified human walking biomechanics and 7dof biped model

The 7 dof bipedal system can be considered as 7 links connected forming the two legs and a torso, the legs each comprise a thigh, shin and foot, with forces applied at the hip, knees, ankles and the torso to derive a walking control strategy. Lagrangian dynamics are often used to model bipeds as this provides a simple

method to obtain the dynamical equations for the complex systems by expressing them in terms intuitively used for mechanical systems and eliminating the need to consider the constraint forces between the joined links, and it also lends itself to the design of control systems. The dynamics of the biped can be described by the angles of rotation of the 7 links and their velocities in the various phases of the walking cycle (double and single support phases). In the analytical and numerical considerations, the general structure of these is well-known (see for example [7]-[10]) and has the following form:

$$D(\theta)\ddot{\theta} + C(\theta, \dot{\theta})\dot{\theta} + G(\theta) = T(\theta)$$

where  $T$  is the torque matrix;  $C$  is the centrifugal force matrix;  $G$  is the gravity matrix;  $D$  is the inertia matrix and  $\theta, \dot{\theta}$ , etc represent the 7-joint angle vector, joint angle velocity vector, etc. The detailed dynamical model is being derived for the simulation studies and controller designs to be done in Matlab/Simulink.

## 3. Human walking data

To assist in the design of the human-like walking gait of the 7dof system, human walking data will be collected. This will be carried out by designing a data gathering harness that can be strapped onto a person and will collect real-time hip, knee and ankle joint angles for both legs as well as the torso angle during normal straight walking; the harness will be similar to the system that has been designed and developed by Honda for assisting elderly persons in their gait management so that 5-7dof systems may be realised (see Figure 3). Walking data will be collected from several persons, and studied to establish any important patterns that need to be represented in the robot walking strategies.

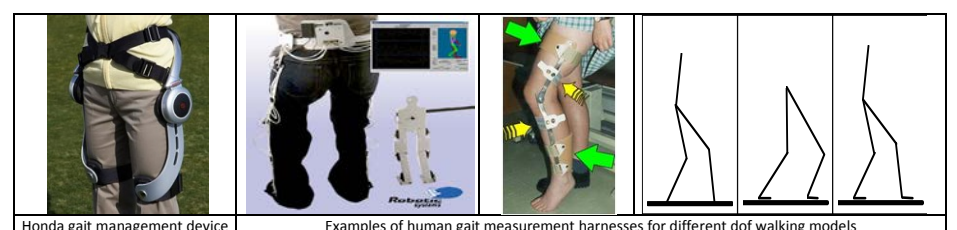


Figure 3: Human gait measurement harnesses based on the Honda gait management robotic device

## 4. Human-like gait controller design

For the gait controller design, a multi-input/multi-output Matlab/Simulink simulation environment will be established so that various scenarios can be modelled and tested dynamically. The torques for all the joints can be set to drive the walking pattern as required, and a variety of controllers can be designed to realise walking gaits to mimic human walking, both of the dynamical model and an exoskeleton leg robot.

## 5. Exoskeleton robot leg studies

An exoskeleton leg has been designed and built using three links to represent the thigh, shin and foot, and three linear actuators are included to drive the hip, knee and ankle joints to perform the walking motions. The exoskeleton leg is shown in Figure 4.

The mechanical design represents the lower parts of the human body and is driven by three bi-directional lightweight linear DC motors, giving 3dof to provide the motions needed for simple straight walking. The magnitudes of the maximum pushing and pulling forces that can be applied by the motors are 600 N. The main structural design consists of standard aluminium profiles representing the links (femur, calf, foot) and three rotating brackets placed in each joints (hip, knee, ankle) to mimic the basic structure of a human leg. This structure is used since it is lightweight, rated for human uses, and can be easily interfaced with standard industrial connectors and components. The criteria for sizing the structure has taken into consideration stresses, dimensions of "normal" human legs and minimizing the size and weight of the overall structure.

The leg is controlled by three Phidget DC cards with feedback provided by encoders placed in each joint. The control system has a graphic user interfaces for manual input motions and also its able to use PID control to follow human walking trajectories by using a Phidget spatial 3/3/3/ sensor.

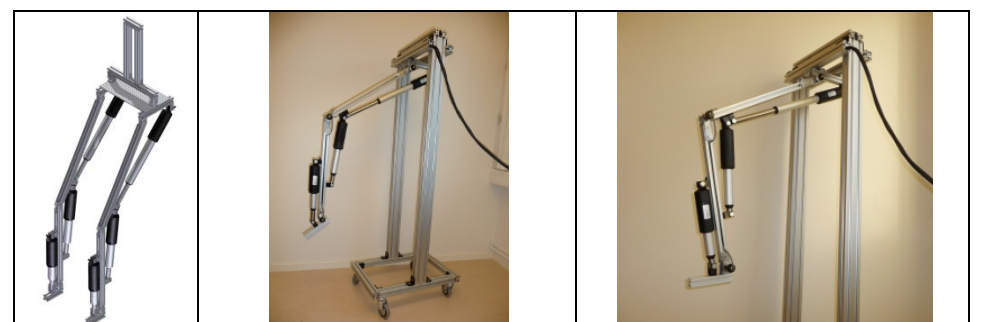


Figure 4: Three-link exoskeleton legged system for testing human-like walking strategies

## 6. Conclusions

The paper has presented the initial stages of a project aimed at designing a human-like walking gait controller for a 7 dof bipedal robot system. Theoretical and experimental work is planned to specify the key gait patterns in human walking by collecting real human walking data and using this in the controller design. The dynamical model of the 7dof system will be used to develop the robot gait controller to mimic human walking and the final controller will also be tested on an experimental exoskeleton robot.

## 7. References

- [1] Asimo robot, Honda, <http://asimo.honda.com>
- [2] Wabian robot, Waseda University, [www.takanishi.mech.waseda.ac.jp/top/research/wabian/index.htm](http://www.takanishi.mech.waseda.ac.jp/top/research/wabian/index.htm)
- [3] Nao robot, Aldebaran, <http://www.aldebaran-robotics.com/>
- [4] Kobian robot, Wasada University, <http://www.topnews.in/humanoid-robot-overcomes-emotional-hurdle-2169802>
- [5] Romeo robot, [www.projetroleo.com/index\\_en.html](http://www.projetroleo.com/index_en.html)
- [6] Winter DA, Biomechanics and the motor control of human movement, Fourth Edition, John Wiley, 2009.
- [7] Mester G, and Rodic A, Contribution to the simulation of humanoid Kondo robot, Int J Eng, Tome IX, Romania, 2011.
- [8] Braun DJ and Goldfarb M, A control approach for actuated dynamic walking in bipedal robots, IEEE TRO, 25(6):1 292- 303, Dec 2009.
- [9] Olensek A & Matjacic Z, Human-like control strategy of a bipedal walking model, Robotica, Vol26, pp295-306, 2008.
- [10] Rolf C, Nikolaj F, Rico H, Heine H, Asger M, Mads S & Louis S, Modelling and control of a biped robot, Aalborg Univ, Denmark, 2007.