BIPED GAIT OBSERVER AND ANALIZER SYSTEM

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Abstract

In this paper, a tool is presented that allows the observation of the gait employed by human beings. The obtained information provides data of joint position, velocity and acceleration. Also, it makes possible to estimate the minimum number of degrees of freedom necessary to imitate human agility and locomotion, and to compare it with a theoretical point of view. Finally, this work can be used to evaluate the performance of a biped robot kinematics, dynamics and control, because it makes easier a validation process between a biped robot and a human being.

1. Introduction

During the last decades researchers all around the world have been working on machines that can replace humans in hazardous jobs. The design, development and control of walking machines have been a very important activity at *Instituto de Automatica Industrial CSIC* during the last decade [4,5,8]. Most recent advances in this area try to design autonomous human-like robots and reproduce locomotion and agility so that they can have the same dexterity while performing human tasks.

The optimum number of degrees of freedom of a biped robot [1] depends on several considerations, i. e., the final use of the biped. A biped robot is a potential solution to the need for locomotion in constrained spaces, however it must be able to stand statically while performing useful tasks [2 -3]. Four degrees of freedom per leg (abduction and flexion in both hip and ankle) are enough to obtain a functional biped robot, that is, to maintain the centre of gravity inside the *stability margin* (on uneven surfaces or in the case of external forces tending to topple the biped). However, additional degrees of freedom are required if the biped robot has to achieve human agility.

It is possible to analyze directly the human locomotion system using adequate instrumentation [8]. Many methods of kinematics measurement are based on image processing. The old method of cinematography still retains the advantages of its high resolution, high speed, and the absence of interference with the measurement subject. The disadvantages are the requirements of manual, time-consuming evaluation and digitization. Usually, systems use two cameras to observe lights attached to anatomical reference points on the subject's body. Some works, have been done using cameras with a sample rate of 30Hz [6] and others with higher speed [7], up to 300Hz, so it is known that a higher speed gives better results. Several different configurations are studied while trying every phase of walking mode, skipping mode and climbing mode.

2. 3D Vision Acquisition System

A high speed (up to 300Hz) opto-electronic system (Selspot II) which utilises active light sources is used for determining actual positions of objects in space. These positions can be presented in Cartesian coordinates and can be calculated into speed and acceleration. This system uses active light sources, such as infrared light emitting diodes (LEDs), which are applied to the points of an object that are of interest, i. e. the joints of a human leg (see figure 1). The LEDs are powered by a LED control unit which turns on the light sources sequentially.

There are two cameras, both consisting of a detector, analogue pre-amplifier, analogue amplifiers for *X* and *Y* position and A/D converters. They sense the intensity of light from the light source and record the position of the LED. The camera interface module receives position information to deliver it to the Selspot control module, which communicates with an external computer.

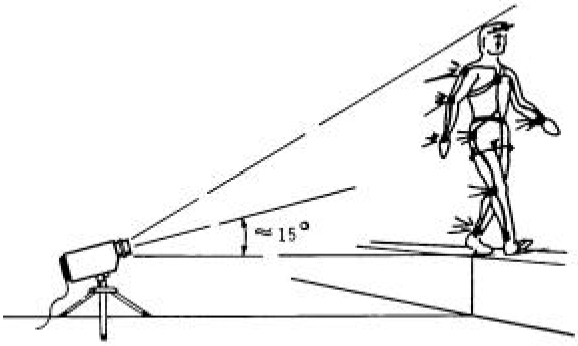

Figure 1. Leds placement on human body.

3. Pre-processing

Data from Selspot must be pre-processed before using it, because there are some sources of errors: reflection, focusing – edge effect and problems with constraints on movements. Reflection can be diminished using non-reflecting materials, but also cameras adequately placed. Focusing – edge effect are due to the fact that one of the image cameras may be too close to edge, and 3D position is miscalculated. Constrained movement errors arises because some positions put out of sight some leds, for example one leg can hide other leg leds from one of the cameras. Figure 2 shows some a typical data with errors, it is possible to recognize TZP points because you have zero on x, y and z simultaneously and focusing edge effect errors can be detected by a high rate change between samples.

```
POS X     POS Y   POS Z     Errors

-219.899 -515.953 -195.077
-219.995 -516.115 -194.55
-221.257 -516.021 -195.826
-219.899 -515.953 -195.077
-222.379 -515.962 -196.72
-231.196 -503.37  -187.755 ← focusing
                              edge effect
0.0      0.0      0.0     ← TZP
0.0      0.0      0.0     ← TZP
0.0      0.0      0.0     ← TZP
0.0      0.0      0.0     ← TZP
-212.109 -492.723 -191.532 ← focusing
                              edge effect
-220.672 -514.387 -195.457
-222.841 -515.864 -196.913
-223.978 -515.872 -197.448
-225.587 -516.392 -198.767
```

Figure 2. Data with errors

Pre-processing should manage these errors. Constrained movement errors produce a ‘x’, ‘y’, and ‘z’ zero position output, something that it is impossible if this reference point is placed outside of working place. As well as these zero data, a focusing - edge effect is produced on nearby points, in other words, erroneous data are around these zero points. A fix data algorithm has been designed to repair these data. First, it should detect these triple zero points (TZP). Second, a Zero-phase forward and reverse digital filter, should be applied to actual data. Then, apply a zero mask to n_m points before the first TZP on a TZP frame and to n_m points after the last TZP on the same frame. After this pre-filtering and masking process, a correct value for TZP points using a linear interpolation either splinnes must be estimated. After that, data is better, however it must be filtered to smooth it Pre-processing algorithm can be resumed in these lines:

1. Detect TZP points (P_{ij} = (0, 0, 0) where ***i*** is le number and ***j*** is instant data)
2. Pre-filter data with a zero-phase forward and reverse five order Butterworth digital filter. Cut-off frequency should be chosen higher than the dynamic bandwidth expected.
3. Apply a zero mask to n_m points before the first TZP on a TZP frame and to n_m points after the last TZP on the same frame.
4. Estimate TZP points using linear or splines interpolation.
5. Smooth final data with a post-filtering process. A zero-phase forward and reverse filter can be used. Cut-off frequency should be chosen similar of pre-filtering cut off frequency.

4. Kinematics

Direct Kinematics is computed by a software package, *BIGOBAS (Biped Gait Observer and Analyzer System)*, developed at the *Instituto de Automática Industrial (CSIC)*, that is described in section 6. It determines Denavit-Hartemberg parameters from link lengths and relative positions of one to the following. It computes each joint angle and determine angle restrictions by analyzing the simulated motion.

$$T = G(q) \qquad (1)$$

Hence, it depends on the initial position of the leds and their capture by the Selspot II system. Links are then jointed with rotational joints, so Denavit-Hartemberg parameters are then immediately obtained.

5. Dynamics

For computation of biped dynamics it is necessary the knowledge of some factors as: inertia, weight, size, and centers of mass of links. Some works has been done in this field [9] and its possible to resume these data in a table:

Segment	Seg. Weight	Cent. mass	Rd. Gyration
Foot	0.0145*m	0.5*l_{foot}	0.475* l_{foot}
Shank	0.0465*m	0.433* l_{shank}	0.302* l_{shank}
Thigh	0.100*m	0.433* l_{thigh}	0.326* l_{thigh}

Where
m = total mass of body,
l_{foot} = foot length,
l_{shank} = shank length,
l_{thigh} = thigh length.
Therefore, dynamics can be calculated by

$$t = D(q, \ddot{q}) + C(q, \dot{q}) + G(q) \qquad (2)$$

Forward dynamics is obtained with ***q*** known values.

6. Description of BIGOBAS

A *software package*, *BIGOBAS*, works as a Graphical interface, reproducing on the screen the time evolution of joint coordinates, velocity and acceleration. Also, it runs a simulation process of the motion of a user-designed human-like leg. *BIGOBAS* performs the calculation of 3D kinematics and dynamics of a particular mechanical system.

The process of observation and analysis begins capturing data from the motion of a human leg. Several Light Emitting Diodes are applied in different human leg locations (i. e. joints) and captured by the motion analyzer to obtain joint trajectories. From these data, *BIGOBAS* simulates on the screen the movement of the leg, linking one joint to the following and obtaining an anthropomorphic leg structure. The simulation process uses MATLAB with SIMULINK (The MathWorks, Inc.) to animate the motion of the leg and to reproduce the human gait. Figure 3 shows an instantiation of the simulation process of a four-degrees-of-freedom human leg.

Once the human gait has been observed, *BIGOBAS* obtains the leg's joint trajectories in internal coordinates and their angular velocities and performs direct kinematics to compare the external joint trajectories and velocities obtained with those ones the Selspot system observed.

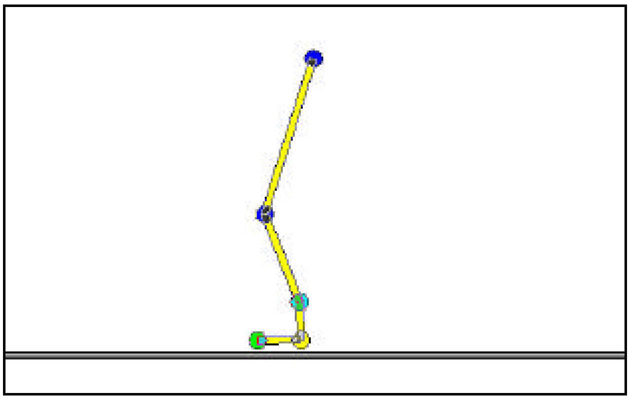

Figure 3. Simulation of human gait.

The simulation process can reproduce now the movement of the robotic leg and compare it with the previously analyzed human gait.

Introducing information of every link (i. e. center of mass coordinates, inertia tensor and mass of the link), *BIGOBAS* performs direct dynamics for the selected human leg.

Different changes in the structure of the leg can be made so as to find the simplest configuration that can reproduce the agility and soft gait of the human leg. Any joint can be eliminated to decrease the number of degrees of freedom of the leg.

Experimental results from the study of a robotic leg are shown below.

7. Experimental Results

Many different configurations of anthropomorphic legs can be analyzed using the *BIGOBAS* software package. In this paper we will discuss the observation and analysis of a leg of four degrees of freedom. The human leg moves two steps forward and two steps backwards while the Selspot II system captures the trajectories of five led diodes, fixed at hip, knee, ankle and toe. By means of the observation of the motion of the leg through the *BIGOBAS* simulation, an anthropomorphic leg structure is proposed and internal joint angles are computed. Figure 4 shows the evolution of the internal joint coordinates obtained, and figure 5 shows the evolution of internal joint velocities.

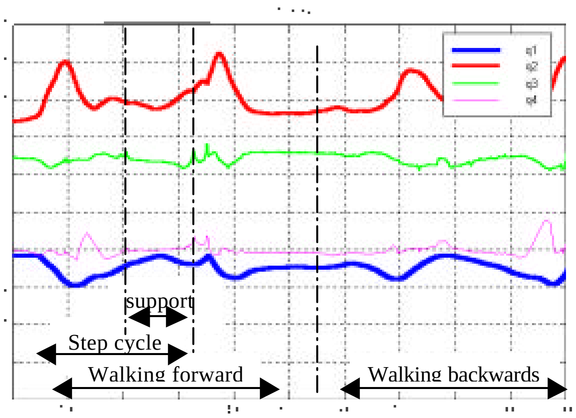

Figure 4. Joint angles evolution for a four-dof-leg.

The evolution of the internal joint angles can be analyzed as shown in the Figure 4. If we denote the time between two succesives contacts of the leg with the floor as a *step cycle*, it can be clearly observed that there are two sub-phases on each step cycle. The first one, in which the leg is on the air, and the second one, when the leg is supporting for balance. Figure 5 shows that during this second phase, joint velocities are almost zero. Also it is important to note that is the ankle who has the highest speed values during one leg step.

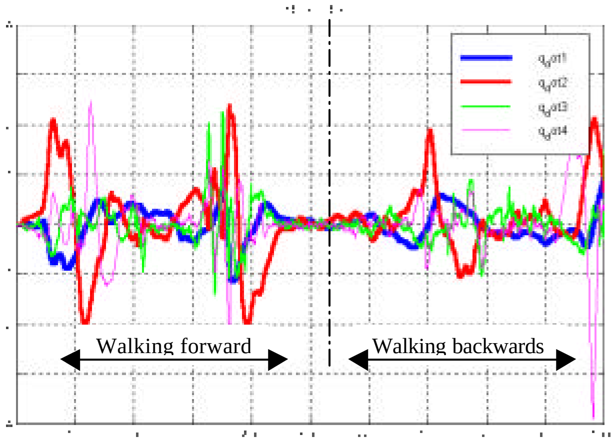

Figure 5. Joint angular velocities evolution for a four-dof leg.

Figure 6 shows the external joint x-coordinates evolution obtained from Selspot II analyzer and they are to be compared with figure 7 which shows the external joint x-coordinates obtained from direct kinematics of joint angles of figure 4. Figures 8 and 9 show the same as figures 6 and 7 but they show z-coordinates. Figures 10 to 13 show external joint velocities .

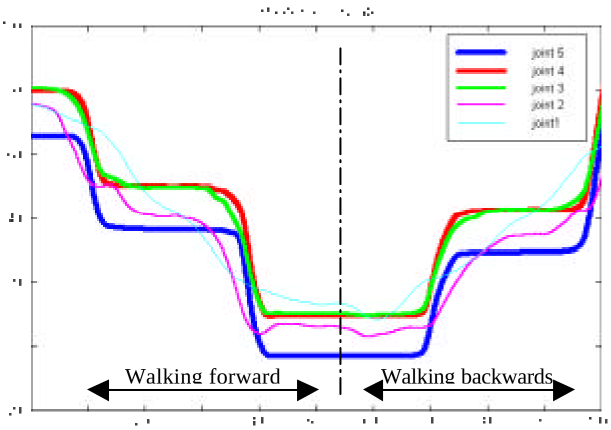

Figure 6. Joint extern x-coordinates evolution obtained from Selspot II analyzer.

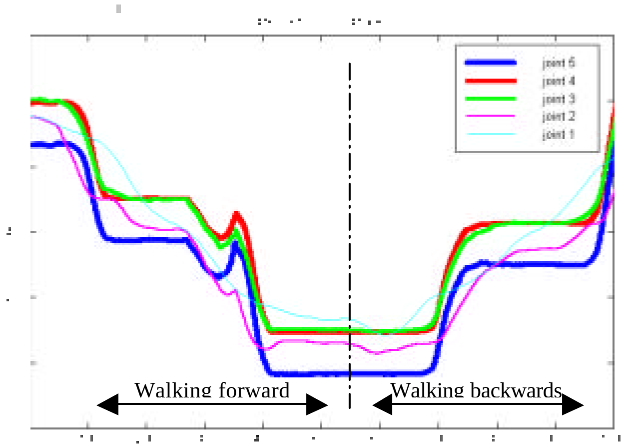

Figure 7. Joint extern x-coordinates evolution obtained from Direct Kinematics.

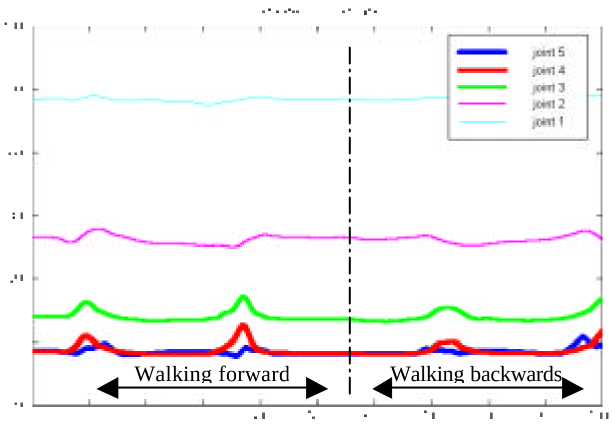

Figure 8. Joint extern z-coordinates evolution obtained from Selspot II analyzer.

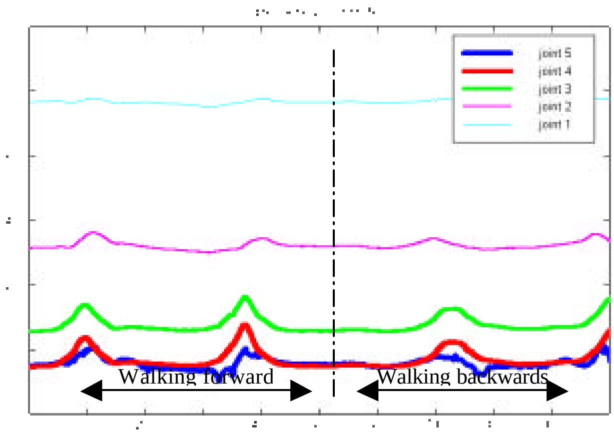

Figure 9. Joint extern z-coordinates evolution obtained from Direct Kinematics.

Figures 6 to 9 show that the cinematic model adopted for the leg follows the behavior of the human leg with a high precision. Also the relative positions of each link during the step cycle can be easily observed and analyzed. The differences between the figures 8 and 9 correspond to the foot link, and they are due to the small link length used to compute joint angles. This problem is being solved.

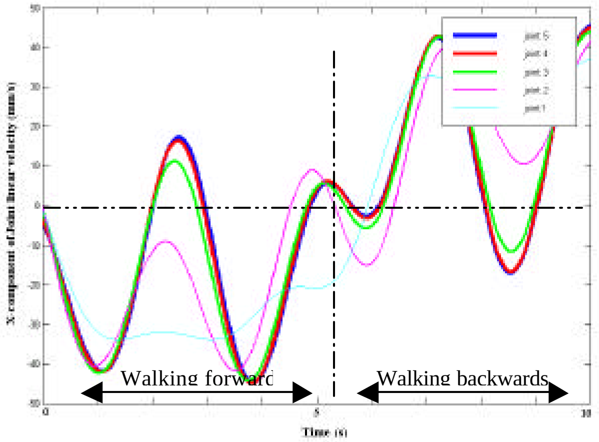

Figure 10. Evolution of x-component of joint extern velocity obtained from Selspot II analyzer.

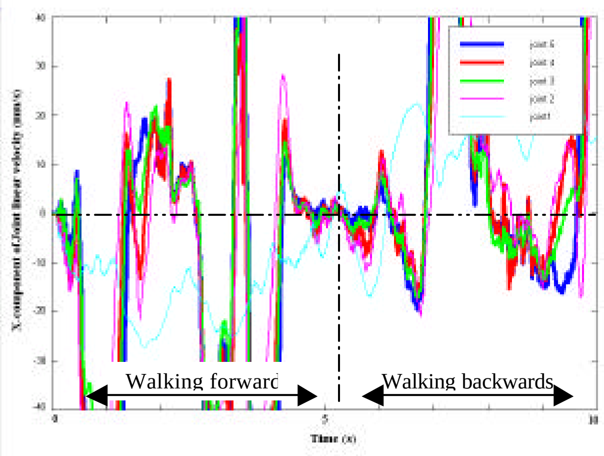

Figure 11. Evolution of x-component of joint extern velocity obtained from Direct kinematics

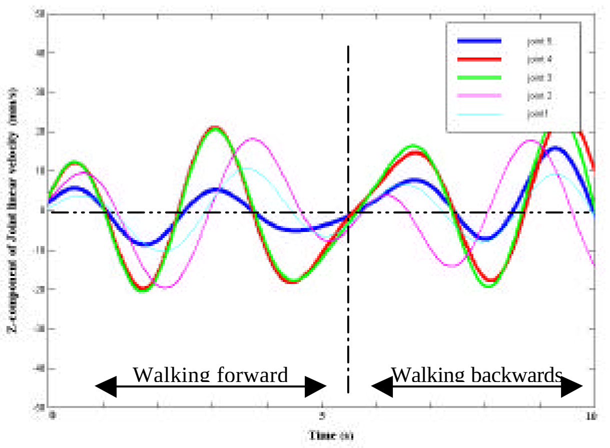

Figure 12. Evolution of z-component of joint extern velocity obtained from Selspot II analyzer.

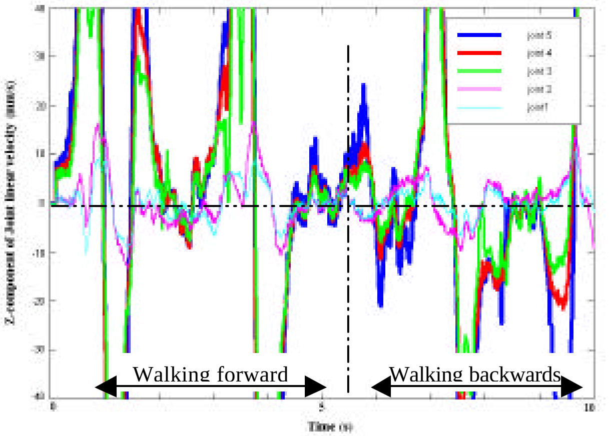

Figure 13. Evolution of z-component of joint extern velocity obtained from Direct kinematics

The evolution of joint linear velocity obtained from computation, results a noisy value that must be filtered, and this is being done. However it is possible to appreciate the similarities between both curves, the one obtained from Selspot data capture and this one.

Experimental results show that the system for observation and analysis of biped locomotion is a helpful tool for the research. Different human models can be proved trying to design the more suitable architecture for a robot that could imitate the human motion, stability and agility.

8. Discussion and Conclusions

These results show promise for further work. It is possible to obtain some information of human been as: Denavit–Hartemberg parameters, movement constrains, kinematics and dynamics, that can be used to build an anthropomorphic robot. Computed torque control may be used because joint torques can be predicted.

BIGOBAS is a powerful tool because of its flexibility and scalability. It makes it possible to analyze and simulate any leg of any number of degrees of freedom and compare their performance.

Also, there are some problems to overcome. One of the most important is to diminish computer processing load in order to obtain a real time observer.

Acknowledgement

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