Vibration Reduction of Walking Biped Humanoid Robot Using Energy Harvester

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Abstract

There is always a problem of vibration to the swinging leg of the biped humanoid robot associated with its walking. Therefore it is proposed a new technique in this research not only to reduce this vibration energy, but exploit it (or harvesting it). The process consists of using piezoelectric generators to harvest the vibration energy and hence make reduction to the vibratory motion and at the same time using this energy to supply a storage system or a load (electrical device).

Keywords: *Energy Harvesters, Biped Humanoid Robot, Vibration Control*

1. Introduction:

When a biped humanoid robot is walking, the swinging leg vibrates. This is because the connecting frame between the leg and pelvis is deflecting and the reduction gear is slightly compliant. While the vibrations are not large, they disturb the precise landing position control of the foot. If the position control accuracy is not within ± 3 mm, the performance of the landing position controller is diminished. Therefore, the vibration reduction is fundamentally necessary for the landing position controller [1].

P.W.M. van Zutven [2] indicates that with the primary goal to give the research field of humanoid robotics a new impulse, the three technical universities in the Netherlands (Delft, Eindhoven and Twente) together with Philips have developed the humanoid robot TUlip. This robot is intended as key experimental platform for research on walking, dynamical analysis, control and artificial intelligence of humanoid robots. Using TUlip as a test bed, his work presented focuses on the modeling and identification of humanoid robots, as well as on analysis of stability of bipedal walking.

LI Zhao-Hui, HUANG Qiang, LI Ke-Jie [3] show that a humanoid robot has high mobility but possibly risks of tipping over. Until now, one main topic on humanoid robots is to study the walking stability; the issue of the running stability has rarely investigated. The running is different from the walking, and is more difficult to maintain its dynamic stability. There objective is to study the stability criterion for humanoid running based on the whole dynamics.

Dorian Scholz, Martin Friedmann, Oskar von Stryk [4] indicate that the generation of fast and robust locomotion is one of the crucial problems to be solved for a competitive autonomous humanoid soccer robot. During the last decades many different approaches to solve this problem have been investigated. They described a simplified yet powerful approach for generation of locomotion for an autonomous humanoid robot. It is based on an open loop trajectory generation with an overlying gyroscope-based closed loop postural stabilization. Unlike other widely used approaches in humanoid robotics the trajectory generation is completely decoupled from the stabilization algorithm, thus simplifying design, implementation and testing of either algorithm.

2. Theory

Energy harvesting raises the possibility of self-powered systems which are ubiquitous and truly autonomous and without human intervention for energy replenishment [5].

The Schematic diagram of the leg as shown in Figure 1. indicates the rolling vibration to the swinging leg, and the possibility of dealing with it as a simple pendulum.

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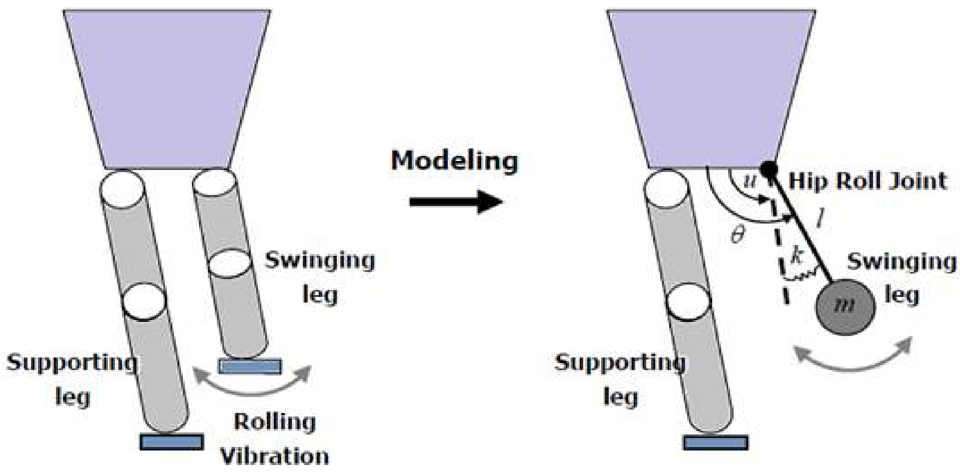

Figure 1. A schematic diagram of the leg [1]

As shown from Figure (1), u is the desired angle of hip joint, θ is the actual angle of hip joint, m is the point mass of a leg, l is the distance from the hip joint to the mass center, and k is the torsional stiffness of the spring. Therefore the equation of motion of the system is derived as shown in equation (1):

$$J\ddot{\theta} = -D\dot{\theta} - k\theta + T \tag{1}$$

Where: D = damping coefficient, T = excitation torque

Now the signal represents a vibratory motion (mechanical energy) which can be converted into electrical energy throughout different energy converter devices. The aim of this research is to exploit this energy (store it for example using the battery) rather than damp it out.

The presence of ambient vibrations makes it possible to scavenge mechanical energy. Harvesting ambient vibration energy through piezoelectric (PE) means is a popular energy harvesting technique which can potentially supply the available power [5].

3. Experimental Work

According to the piezoelectric direct effect, piezoelectric material can generate electrical energy from a mechanical vibration. To collect the energy, a piezoelectric element is attached on a vibrating structure, and an interface circuit is connected to the piezoelectric element to transfer the generated energy to the load [6]. The circuit representation of a piezoelectric generator is shown in Figure 2.

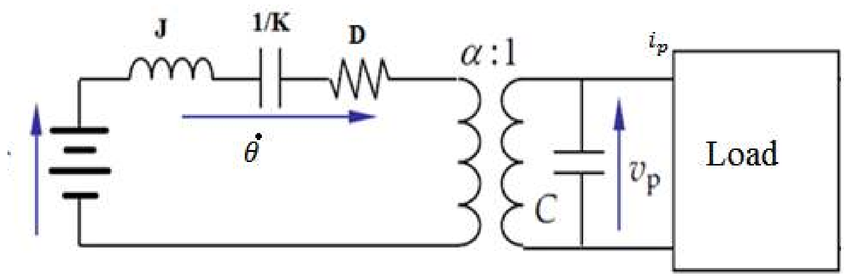

Figure 2. The circuit representation of a piezoelectric generator

It should be noted that torque **T** and velocity $\dot{\boldsymbol{\theta}}$ are equivalent to a voltage source and a flowing current in the mechanical impedance respectively.

Now for simplicity, this system can be modeled as a one degree-of-freedom system of a mass moment of inertia **J**, a spring **K** and a damper **D**. Assuming the system is operated in the linear region, the differential equation of this electromechanical system can be expressed as shown in equation (2),(3):

$$J\ddot{\theta} = -D\dot{\theta} - K\theta - \alpha v_p + T \tag{2}$$

$$i_p = \alpha\dot{\theta} - C\dot{v}_p \tag{3}$$

Where α is torque-voltage coupling factor, C is the clamped capacitance of the piezoelectric element, v_p is piezoelectric voltage, *i.e.* the voltage across the piezoelectric element and θ is the displacement of the host structure. The piezoelectric element generates AC voltage from the vibration. To store the energy in the DC form, a rectifier, *i.e.* AC/DC converter is required to connect the storage buffer at the piezoelectric element.
Putting equation (2) and equation (3), in the frequency domain and assuming the load is purely resistance load **R** where ($i_p = \frac{v_p}{R}$) :

$$[-J\omega^2 + Dj\omega + k]\theta = T - \alpha v_p \tag{4}$$

$$v_p = \frac{j\alpha R\omega}{(1 + jRC\omega)}\theta \tag{5}$$

Note: Remembering that the load may be a storage buffer or any other kind of useful load, say for example a power supply to a micro system where the power supplies from chemical energy sources are undesirable due to limited shelf life and replacement accessibility [7].
Now substitute the piezoelectric voltage v_p of equation (5) into equation (4) and derive for vibration:

$$[-J\omega^2 + Dj\omega + k]\theta = T - \frac{j\alpha^2 R\omega}{(1 + jRC\omega)}\theta \tag{6}$$

So the peak frequency response of the angular vibration θ will be:

$$\frac{\theta}{T} = \frac{\sqrt{1+(RC\omega)^2}}{\sqrt{[k-(J+RDC)\omega^2]^2+[(kRC+D+\alpha^2R)\omega-JRC\,\omega^3]^2}} \tag{7}$$

Equation (7) is very important to analysis the frequency response of the angular vibration.
The generated power using the piezoelectric generator can be represented as:

$$P = \frac{{v_p}^2}{R} \tag{8}$$

From equation (5):

$\theta = \frac{(1+jRC\omega)}{j\alpha R\omega} v_p$, substituting into equation (4) and drive for voltage of load:

$$\frac{v_p}{T} = \frac{\alpha R\omega}{\sqrt{[k-(J+DRC)\omega^2]^2+[(D+kRC+\alpha^2R)\omega-JRC\,\omega^3]^2}} \tag{9}$$

The power therefore will be:

$$P = \frac{R\alpha^2\omega^2T^2}{[k-(J+DRC)\omega^2]^2+[(D+kRC+\alpha^2R)\omega-JRC\,\omega^3]^2} \tag{10}$$

4. Results and Discussion:

Using the above mentioned technique it is therefore the main important purposes of this work (i.e. Vibration reduction, and Energy exploitation) will be possible.
It is also required to indicate the effect of the torque-voltage coupling factor $\boldsymbol{\alpha}$ on the frequency response of the vibratory system, where the increment in this factor is helpful to reduce the amount of vibration especially near and in the natural frequency as shown in Figure 3.

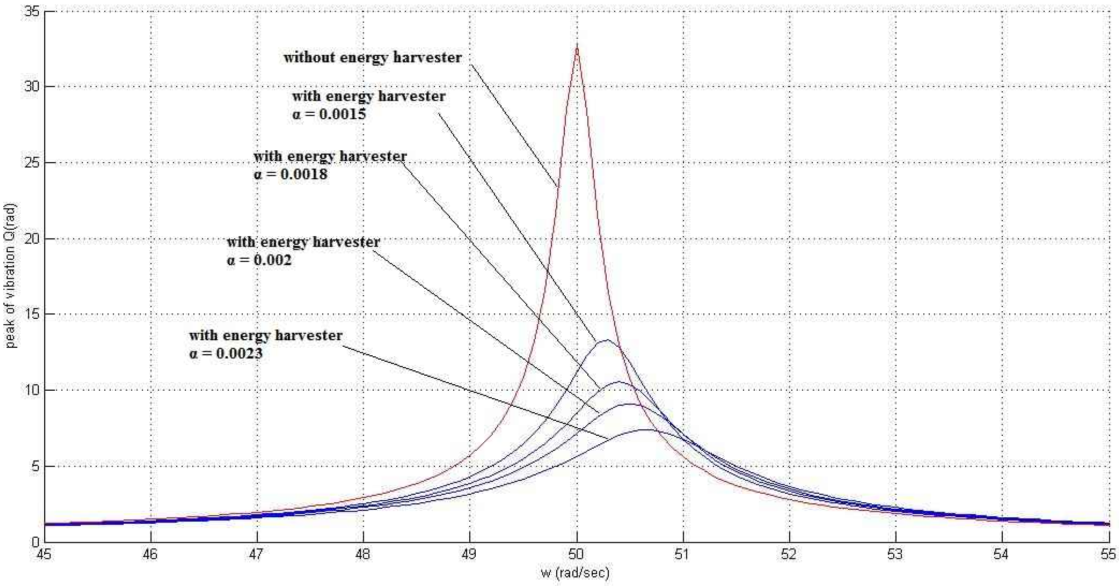

Figure 3. The frequency response of the vibratory system (robotics leg) with and without the energy harvester and the effect of the torque-voltage coupling factor (α) on the frequency response of the vibratory system; assuming as a case study: T= 2 Joule, K=500 N.s, J=0.2 kg.m^2, D = 0.07 N.m.sec.

The generated power using the piezoelectric generator depends on the amount of the output load resistance R, where the increment in the output load (i.e. decrease in R) reduces the amount of the generated power in a way as shown in Figure 4.

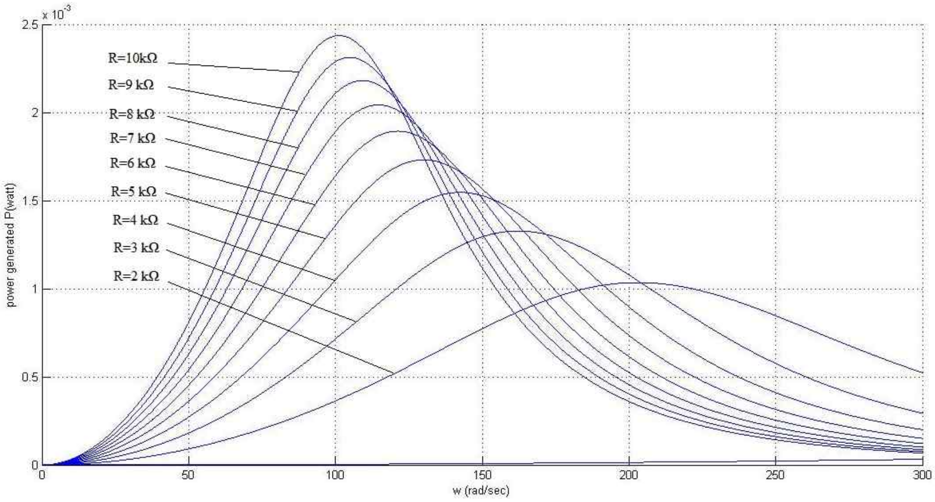

Figure 4. The generated power frequency response and load resistance effect on the amount of the power.

5. Conclusion

The results of the case study indicates the possibility of apply the piezoelectric harvesting technique to reduce the effect of the vibration of the swinging leg of the walked biped humanoid robot and at the same time store this energy or deliver it to another circuit load. The load circuit may be a driver of motors inside the robot or supply voltage after regulation to the brain or the microcontroller of the same robot. The results indicate also that the piezoelectric of the large coupling factor **(α)** reduces the vibration of the swinging leg much better than the piezoelectric small factor.

6. References

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