Adaptive behavior of electromechanical anthropomorphic robots during physical interaction with environment and with human being

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The paper present results of the Ukrainian-French scientific activity between Donetsk National Technical University and French partners in the field of human-robot and robot-environment interactions. The first part of the research shows adaptation of robotic arm movements to the dynamics of interacting person who imposes its own rhythmicity. The adaptation algorithm is based on rhythmic oscillator inspired by biology. The second part of the research considers adaptation of a biped robot internal vibration modes to the environment during flexion-extension vertical movements. These vibrations are extremely unwanted; they appear during robot motion by reason of internal flexibilities in articulations, backlashes and friction and can cause the fall of the robot. It is shown that their efficient attenuation can be achieved by using auto-adaptive oscillator that acts on the robot's knee articulations.

Introduction

Robotics is a relatively young domain of science and technology. It was formed in the middle of the last century. Industrial robots solve large amount of production problems including in hostile environment like nuclear or chemical station. Special robots were created for surgery, underwater or space exploration. Domestic, entertainment or assistive robots are relatively new. They are designed to perform routine tasks: vacuum cleaners, security guards, robots to care for the animals, assistants for people with disabilities.

In humanoid robotics, further progress depends on the success in solving more fundamental problems like cognitive mechanisms in human being: learning, adaptation, memory, developmental capacities. These properties are necessary when robots interact with humans and their environment physically and socially. These problems still remain open.

This paper presents results in the control of rhythmicity in physical interaction between human and robot arms and between a biped robot and the ground.

This work is performed in the framework of Dnipro Ukrainian-French research project Donetsk National Technical University — University of Cergy-Pontoise[1]".

Human-robot interaction

The problem of interaction between human and robot becomes relevant since as the robot is regarded as a servant or a partner to live or work with human being Attention of the world scientific community is focused nowadays on the important and difficult problems of interaction between the human and the robot (pHRI), [1] authors present a complete map of the areas of interaction.

Most of the scenarios of interaction between people are repetitive or rhythmic. This is the base of several research fields in human robot interaction threw different modalities: verbal-speech, visual-gestures or mimic, physical-shaking hands or touch, collaborative-walking or dancing. In animals, rhythmic movements are generated and controlled with special low level cellular structures localized in the spinal cord. These neural structures called central pattern generators (CPG) are based on intrinsic rhythmic neurons that can be modeled as non linear oscillators. Their

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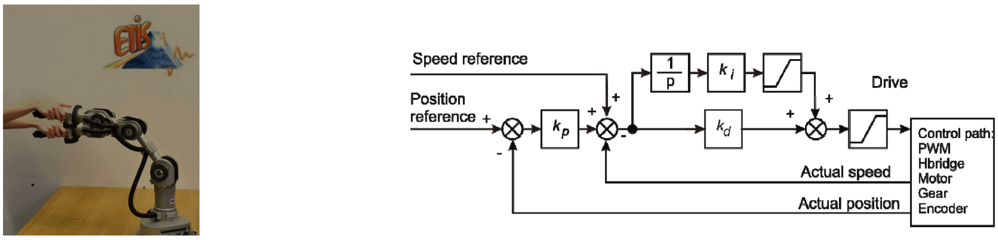
[1] Scientific research grant Dnipro 2011-2012 "Bio-inspired models of humanoid robots in rhythmical interaction with their environment."

learning properties allow a flexible and dynamic coordination of the motor synergies when the body interacts with the environment.

In one example of rhythmic pHRI, we study the handshake situation between a man and a robot.

Setup experiment

The research was carried on the manipulator Katana of the type 6M180, figure 1, a. Each axis of this robot is driven with a DC motor and is separately controlled. The cascade control loop includes the proportional integral (PI) speed controller and the proportional (P) position controller. They are implemented in a particular firmware. As it's shown on the figure 1, b, the PI controller of the inner loop is adjusted with ki and kd parameter, while the parameter of the P controller of the outer loop is in the Katana robot.



a) b)

Figure 1. Manipulator Katana 6M180: (a) scheme of interaction; (b) low-level control

Model of neural controller

The neural controller based on CPG, has been implemented according to the intrinsic rhythmic neuron model of Rowat-Selverston [2] and the architecture proposed in [3], figure 2, a. The model cell has two differential equations, one (1) for the membrane potential V, derived from current conservation, and one (2) for the lumped slow current q, derived from current activation:

$$\tau_m \frac{dV}{dt} = -((fast(V,\sigma_f) - q + I_{inj}) \tag{1}$$

$$\tau_s \frac{dq}{dt} = -q + q_\infty(V) \tag{2}$$

τ_m membrane time constant; τ_s slow current activation time constant σ_f the conductivity of fast current can be considered to be the sum of a leak current and an inward calcium current; I_{inj} is the injected current; $fast(V;\sigma_f)$ is an idealized current-voltage (IV) curve for the lumped fast current $fast(V;\sigma_f) = V - A_f tanh((\sigma_f/A_f)V)$; A_f width of the N part of IV curve parameter.

The learning rule inspired by the work of [4] is proposed in order to change both the amplitude (3) and frequency (4) of movement by varying the intrinsic properties of the coupled cells.

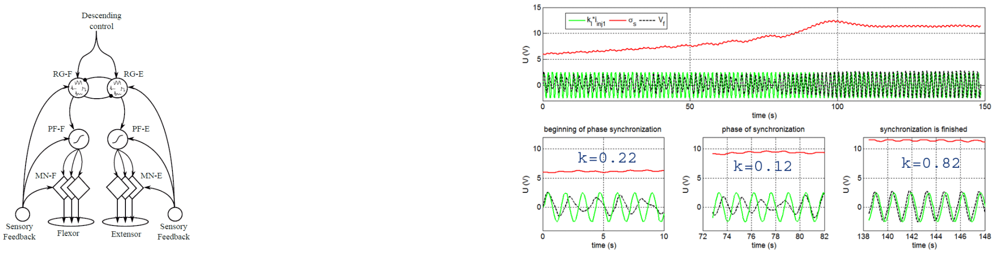
$$\frac{dA_f}{dt} = -\mu(\frac{1}{\epsilon}I_{inj})^2(V^2 - (\frac{1}{\epsilon}I_{inj})^2) \tag{3}$$

mu amplitude's learning step; ϵ learning parameter.

$$\frac{d\sigma_s}{dt} = -\lambda\frac{2}{\tau_m}\sqrt{\sigma_s}I_{inj} \tag{4}$$

σ_s the conductivity of slow potassium current; λ frequency step learning.

Model of a pair of cells with reciprocal inhibition form the Rhythm Generator level of CPG architecture was implemented. Figure 2, b shows neurons parameters during learning of the human's rhythm of interaction.



a) b)

Figure 2. (a) The model's of one joint controller and its motion patterns scheme, CPG with three levels: Rhythm Generator, Pattern Formation and Motor Neuron levels [3]. (b) behavior of rhythmic neuron parameters in the CPG during synchronization experiment. Curves from left to right: start synchronization; during synchronization; reached synchronization. Gamma parameters is the correlation coefficient k between the signal of interaction force measured in the joint and the neuron activity V.

Experimental results

Experiment of the handshaking between human and robot was carried by several types of experiments with the same scenario fig. 3. Phase 1 — the robot is driven by an initial periodic motion. Phase 2 — the human disturbs the rhythm of the robot by slowing or accelerating the movement while the neural controller learns to change the pace of the robot so that it is consistent with that imposed by man. Phase 3 — the robot keeps the new rhythm generated by the neural controller.

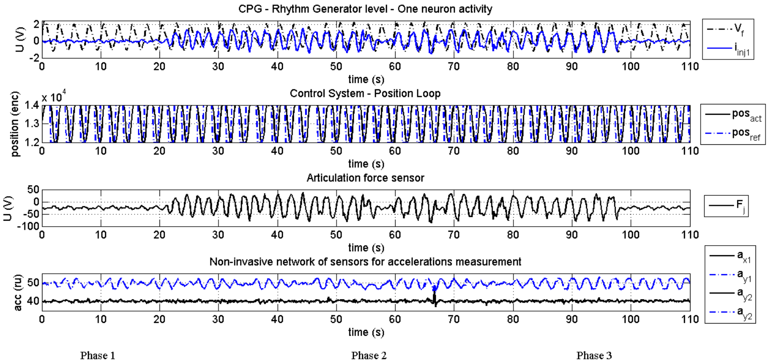


Figure 3. Results of handshaking between human and robot.

Robot-environment interaction

Robot-environment interaction is a very large domain, especially for humanoid walking robots [5]. One of fundamental aspects of this research is to predict the dynamical reaction of robot legs in contact with ground. This reaction phenomena can be measured using an accelerometer-based method proposed before [6].

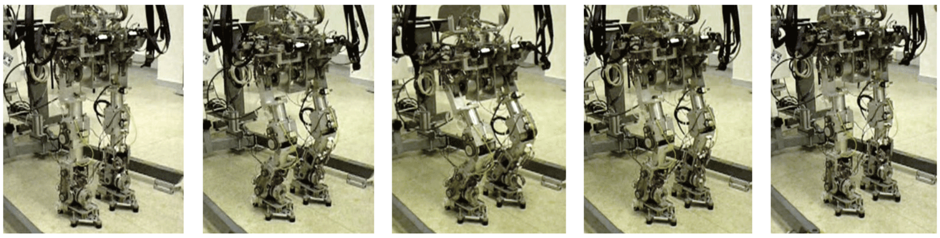


Figure 4. ROBIAN[2]biped robot flexion-extension vertical movements.

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[2] LISV laboratory of Versailles Saint Quentin-en-Yvelines University

Our experiments done on the biped robot ROBIAN have shown vibrations that appear during walking of the robot and at the beginning of the contact with ground. To study nature of these vibrations and to compensate the observed phenomena, we consider flexion-extension vertical movements of the robot that are basic rhythmic motions and easy to control without dangerous situation for the robot balance (figure 4).

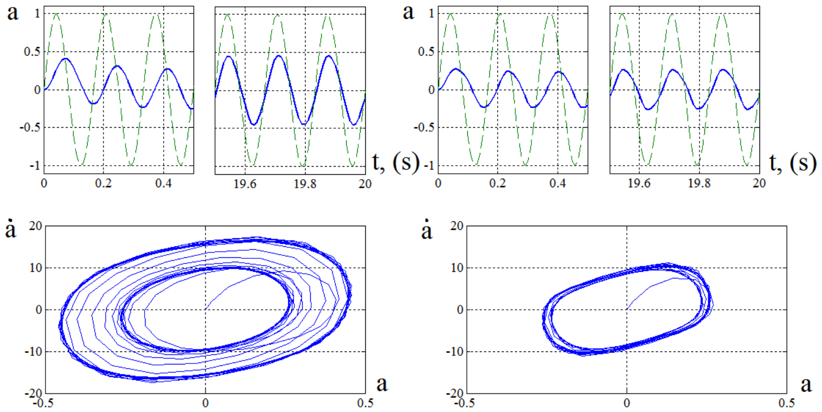
We have implemented an auto-adaptive Hopf oscillator in the real time-controller of the robot according to the next mathematical model discussed in [4] and [7]:

$$\begin{cases} \frac{dx}{dt} = (-\mu - x^2 - y^2)x - \omega y + KF(t) \\ \frac{dy}{dt} = (-\mu - x^2 - y^2)y - \omega x \\ \frac{d\omega}{dt} = -KF(t)\frac{y}{\sqrt{x^2+y^2}} \end{cases} \qquad (5)$$

x, y state variables of the oscillator; μ parameter relating to the steady state amplitude of oscillations; ω frequency of the oscillator; K coupling strength; $F(t)$ time periodic perturbation.

Simulation results

Results of simulations for coupling of the Hopf oscillator to sinusoidal signals are presented on the figure 5. There is an optimal coefficient for every frequency and we have established experimentally that the relation between the coupling strength K of the oscillator and its optimal synchronization frequency ω is linear for the interested range of frequencies.



a) b)

Figure 5. Synchronization of the Hopf oscillator with sinusoidal input signals for different coupling strengths: (a) $K = 40$; (b) $K = 100$.

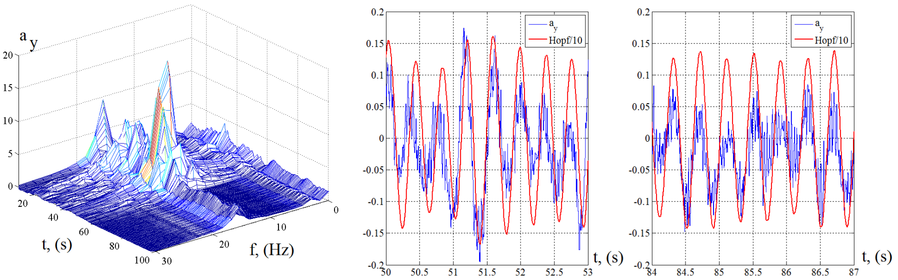
Experimental results

Experiments for the flexion-extension movements (figure 6) have shown a good adaptation of the Hopf oscillator to the vibrations of the biped robot pelvis. The oscillator acts on the pelvis movements by actuating knees joints.

After the time t = 60 s, the perfect synchronization is achieved and residual vibrations do no perturb the robot movements any more.

Conclusion

Phase synchronization between a robot arm and the human being in case of rhythmic physical interaction using a model of CPG based on rhythmic neurons are obtained. Results show that our



a) b)

Figure 6. 3D surface spectrogram (a) of vibrations of the biped robot pelvis: vertical acceleration a. Synchronization curves (b) of the Hopf oscillator signal with vibrations of the biped robot pelvis. From left to right: non optimal and optimal synchronizations.

bio-inspired robot controller is able to capture the frequency of rhythmic movements of human by a learning rule based on plasticity mechanisms.

Further improvement should be done in objective to reduce the time of synchronization and improve the adaptation of the amplitude of the robot arm movement to the human gesture. Also, experiments with people having dissimilar behavior will be considered. We plan to establish different scenarios of interaction with several controlled degrees of freedom of the robot, and to test different architectures the CPG.

The Hopf auto-adaptive oscillator showed its efficiency t compensate mechanical vibrations due to the robot interaction with the floor during basic rhythmic movement like large flexion-extension. The ability of the oscillator to adapt its own frequency to the rhythmical modes of mechanical dissipative system is demonstrated. We will further test this approach during walking of the robot with different patterns.

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