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V. KHOMENKO [1], A. MELNYK [2], P. HENAFF [2],
G. KUZMIN [3], V. BORYSENKO [3]
[1] « Versailles Saint Quentin-en-Yvelines University», LISV EA-4048, France
[2]«Cergy – Pontoise University», ETIS UMR8051, ENSEA-CNRS, France
[3] «Donetsk National Technical University»
slava.khomenko@gmail.com artemmelnyk@gmail.com

EXPERIMENTS IN MEASUREMENT OF RHYTHMICAL MOVEMENTS OF ANTHROPOMORPHIC ROBOTS OR HUMANS

Human body has nonlinear dynamics and many degrees of freedom. In this study, we propose a wearable sensors network for quantitative measurements of anthropomorphic robots and human movements. It has been shown that the proposed network of acceleration sensors and force sensors is able to capture main characteristic of a body during the fundamental physical interaction activities of a human being. Thus, jumping, vertical flexion-extension, walking and handshaking were studied in our experiments. Wearable sensors network is combined with the Kinect sensor by Microsoft to obtain the bodies segments positions and orientations, articulation angles. Experimental results show the effectiveness of the idea of combining Kinect and sensor systems.

Key words: accelerometer sensor, Microsoft Kinect, force sensitive resistor, handshake, jump, walk, flexion-extension movement, anthropomorphic robot, human.

Introduction. The robotics is a comparatively recent field of science and technology. That was established in the midst of the last century. Manufacturing or industrial robots were doing a large amount of production tasks including in a 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. Both are designed to make everyday tasks: vacuum cleaners, security guards, robots to care for the animals, assistants for people with disabilities. The further progress in humanoid robotics depends on the solving of fundamental problems like cognitive mechanisms in human being: learning, adaptation, memory, developmental capacities. These properties are required when robots interact with humans and their environment physically and socially. These problems still remain open.

Aspects of the interpersonal physical interaction.The origin of nonverbal communicative humans skill like shake of the hand goes in extreme antiquity. Along this time for nowadays this ritual enter reciprocally in ubiquitous humans live. Nowadays, the developing of the human science gives rise of all-side studying this social phenomenon. We set the starting point according to research of Schiffrin (1974) who developed an argument that handshakes serve the necessary and important social function of regulating and maintaining human interactions. In the nearest future, the circle of human’s interpersonal communication will unlock by a new agent – humanoid robot. This phenomenon is based on the rapid progress in that many different fields of computer and engineering science since last two decades. The robot came as a servant or a partner to live or work with human beings, and this enforce the relevant question of interaction between human and robot in over environment. There is a discussion about security, ethical end esthetical problems and real role of robot in works of Dautenhahn et al. (2006) andWalters et al.(2006). Review of existing systems for measure the parameters of physical interpersonal interaction. The multitude of researches was carried in this new branch of Human-Robot Interaction domain (HRI).The Physical Human-Robot Interaction (pHRI) is an essential branch of classical research HRI. This review can be started fromJindai and Watanabe (2007), Yamato et al. (2008), authors used a magnetic sensor (FASTRAK) for the measurement of a human hand position and angle, and a force sensor for the measurement of a human force,the joint angle is measured by the pulse signal from the rotary encoder installed in the servomotor. Human handshake motions are measured using the 3-dimentional motion capture system (VICON). Five reflection markers (righthand, rightwrist, right elbow, right shoulder, and left shoulder) are attached to the subjects. These positions are measured using ten cameras. An approach to estimate the motions from their sources (skeletal muscles) is used by Kwon and Kim (2011).Thus, is employed surface electromyography (SEMG) to estimate body motions.A telerobotic system used inKarniel et al. (2010), this system have the interrogator is engaged in a task of holding a robotic stylus and interacting with another party (human, artificial, or a linear combination of the two). A haptic device was used in simulations human handshakes interface via a metal rod in Giannopoulos et al. (2011). Bainbridge et al. (2010) used temperature sensors, tactile sensors, and cameras to interpret a human’s feelings towards a social interaction, include the handshaking ritual, with the robot.

Bipedal dynamical phenomena: jumping, flexion-extension and walking.Noninvasive measurement methods started to develop at the end of the XX century (1990’s) with big proliferation of MEMS sensors Yang and Hsu(2010), Liu et al. (2010), Channells et al. (2006), Mayagoitia et al. (2002), Willemsen et al. (1991). There are commercially available sensors used in biomechanics and science of human movements. Usually these sensors combine linear accelerometers, magnetometers and gyroscopes with the Kalman filter inMoriya et al. (2004) and Beravs et al. (2011). These sensors are always very expensive due to the technology costs. As the Kalman filter includes integration and differentiation, it can create errors that accumulate with time. Also, such measurement systems have a very limited band pass that does not exceed 10-20 Hz. In real life situations, frequencies up to 200 – 300 Hz are needed. In recent works we find accelerometer-only measurement systems but they require 5 and more accelerometers per body mounted in orthogonal way see Fong and Chan (2010), Cardou and Angeles (2007), Cardou(2010), Qin et al. (2009), Yoganandan et al. (2006), Yang et al. (2005), Zappa et al. (2001).

The approach proposed in this article uses 2 triaxial accelerometers mounted along the principle axis of a body in a movement. Using this setup, it is possible to measure up to 2 angular and 3 linear accelerations of the considered body.

Setup experiment. The human’s arm is instrumented by MEMS accelerometers BMA180 and force sensitive resistors on the hand CP 0150, as shown on fig. 1. The current values of accelerations are processed in real time by a microcontroller and sent asynchronously each 6,6ms via serial bus to the registration software after filtering and transformations of coordinate systems.

Figure 1 –Anthropomorphic arm coordinate systems and image of a human hand equipped by triaxialacceleration sensor and KATANA 450 robot of the ETIS laboratory, France with FSR sensors installed.

The upper arm (UA), the forearm (FA) and hand formed the serial linked 3-DOF robot-like object. The sensors network is formed by two accelerometers on the upper arm link and forearm link which measured the pairs of corresponding accelerations $\boldsymbol{r_{UA1}}$, $\boldsymbol{r_{UA2}}$ and $\boldsymbol{r_{FA1}}$, $\boldsymbol{r_{FA2}}$. The hand (H) is equipped with two force sensitive resistors $\boldsymbol{f_{H1}}$ and $\boldsymbol{f_{H2}}$. It is assumed the wrist and elbow stiffness and damping phenomena $\boldsymbol{C_W}$, C_E, D_W, D_E. The pelvis (r_{PE}), is equipped with one accelerometer, thereby the thigh with two (r_{TH1} and r_{TH2}) accelerometersas shown on Fig. 2. The system is studied under three cases of movements: jumping up and landing down on foots on a place, vertical flexion-extension and walking. The last two types of movements are tested for fast and slow realizations.

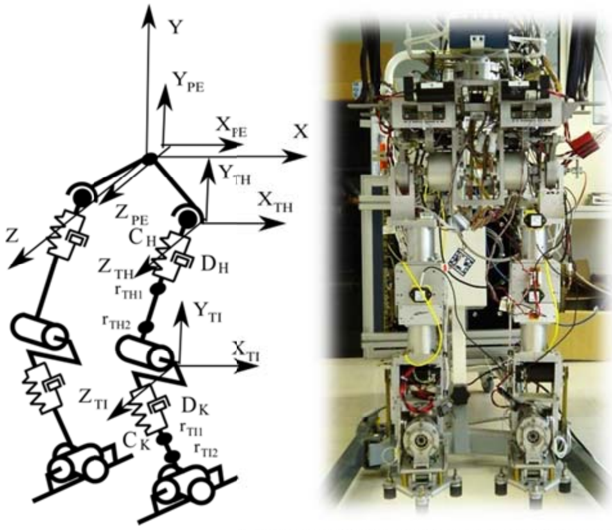

Figure 2 – Anthropomorphic biped locomotion system and ROBIAN robot of the LISV laboratory, France with acceleration sensors installed

The Force Sensing Resistors (FSR) are a polymer thick film device which exhibits a decrease in resistance with an increase in the force applied to the active area surface. Its force sensitivity is optimized for use in human touch control of electronic devices. FSRs are not a load cell or strain gauge, though they have similar properties according to Interlink Electronics (2011). FSRs should not be used for accurate measurements of force because sensor parts may exhibit 15% to 25% variation in resistance between each other seeInterlink Electronics (2011).In this paper, they are used for qualitative assessment of the forces acting on the hand of human, as in the wrist there is a great suppleness.

The base-station has a 16-bit micro-controller for data sampling using a 14-bit analog-to-digital converter (ADC) integrated into the BMA180 sensor Fig. 3. The data is transmitted via I2C digital bus.

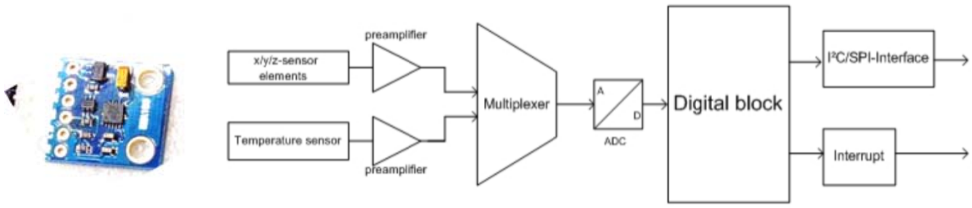

Figure 3– Digital acceleration sensor BMA180and its block scheme (extracted from datasheetBosh Sensortec (2009))

The FSR is composed of two substrates divided by an adhesive spacer, Fig.4a. The more one presses, the more of those active area dots hit the semiconductor, and that does the Ohmic resistance decreasing. Resistance as a function of force for a typical force sensing resistor is depicted at Fig. 4b, referring to it the low force end of the force-resistance characteristic, a switch like response is evident. This turn-on threshold, or 'break force" that swings the resistance from greater than 100 kΩ to about 10 kΩ (the beginning of the dynamic range that follows a power-law) is determined by the substrate and overlay thickness and flexibility, size and shape of the actuator, and spacer-adhesive thickness (the gap between the facing conductive elements). Break force increases with increasing substrate and overlay rigidity, actuator size, and spacer adhesive thickness. Eliminating the adhesive, or keeping it well away from the area where the force is being applied, such as the center of a large FSR device, will give it a lower rest resistance (e.g. stand-off resistance) according toInterlink Electronics (2011).

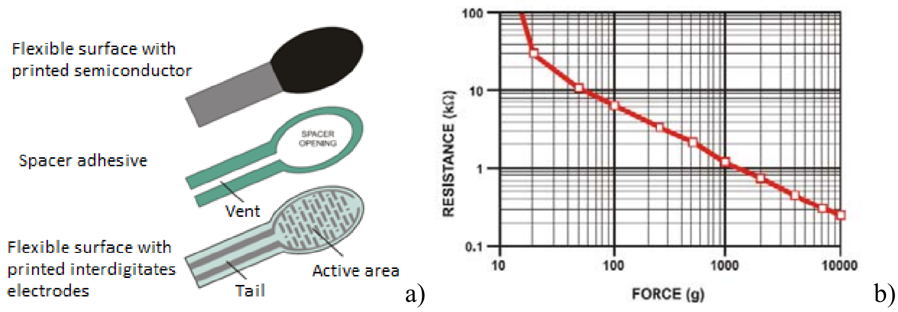

Figure 4 – Construction, main characteristic and basic connection circuit (extracted from Interlink electronics FSR guideInterlink Electronics (2011))

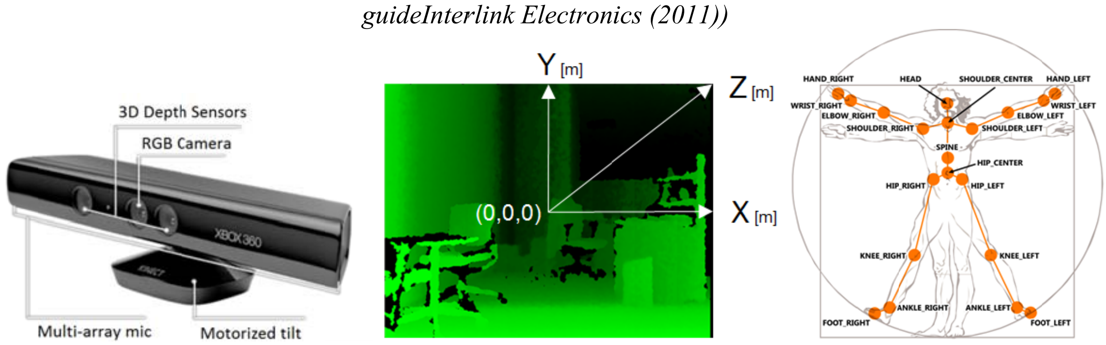

Figure 5 – Kinect sensor general view and its coordinate systems (extracted from Microsoft MSDN and MATLAB® 7.11.1 documentations)

Results and Analyze. Research of the handshaking between two human being is provided by one experiment with three different handshakes with following recurring scenario: Phase 1: Visual contact is established and participations in the test persons brings their hands to shake. Phase 2: Physical contact is made and the participants are in the first phase of the interaction, unconsciously synchronizing their movements. Phase 3: Movements are mutually synchronized and there is a handshake. Phase 4: The successful completion of the handshake and physical connection is broken and hands freely moves to the body.

The results are shown in fig. 6 by tree subplots of data sets from arm equipped sensors according to fig 1. First subplot selectively shows the values of forearm acceleration. Second subplot present the values from two hand placed FSR. Third subplot details the hand displacement measured using Kinect sensor. The participants move their hands to shake [18–18.5 s] until physical contact which confirmed by force sensor. During next time range [18.5–19.5 s] humans interact physically between them and unconsciously synchronizing their movements. At time [19.5–22.5 s], there is a handshake with a stable rhythm. After t=22.5s, rhythmic movement is interrupted by the end of handshake act. The handshake duration average value is 3,6 s with a standard deviation 0,577. Maximum accelerations values attempt to 3G, and this is unknown information from any source which we are referred.

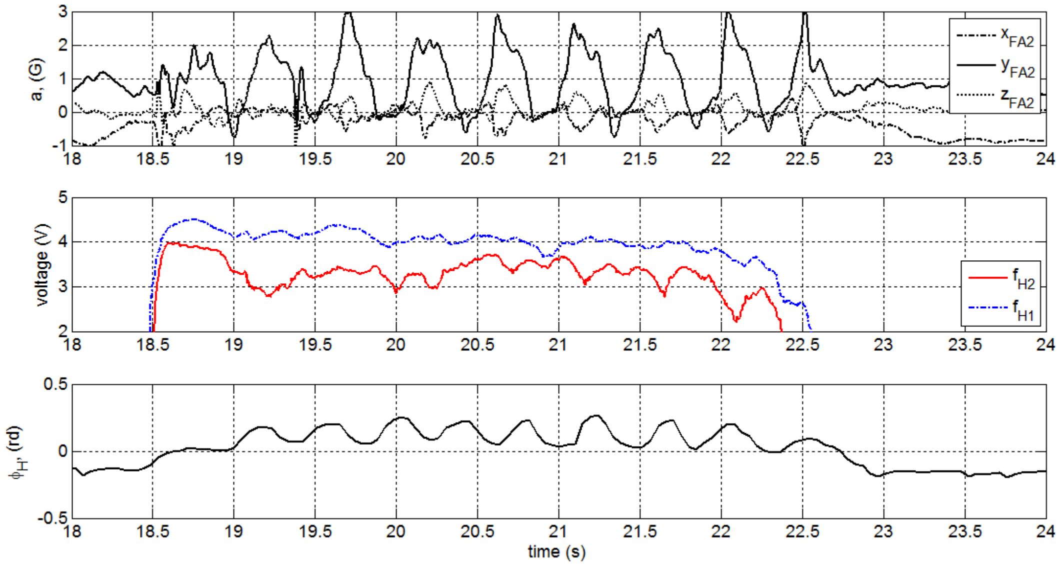

Figure 6 – Two man shaking hands

Acquired signals have been processed with Matlab FFT functions for the frequency domain data analysis. A power spectrum decomposition results of the upper arm and forearm accelerations and force sensors are shown in fig.7. We limit the spectrum analysis of arm movement to 12 Hz and it result for forearm joint indicates the fundamental frequency of examined handshake is 2 Hz for y_{FA2} acceleration. Furthermore, the frequency 4,2 Hz is in the spectrum for x_{FA2} acceleration and 6,2 Hz for y_{FA2} acceleration. The spectrum analysis of second forearm accelerometers gives similar results, namely the fundamental frequency is 2 Hz for y_{FA2} acceleration, the frequency 4,2 Hz is in the spectrum for x_{FA2} acceleration with increased amplitude and 6,2 Hz for y_{FA2} acceleration with increased amplitude. Frequency analysis of the accelerometer data from shoulder gives similar results to the 2 Hz and 6 Hz accented but smaller amplitude.

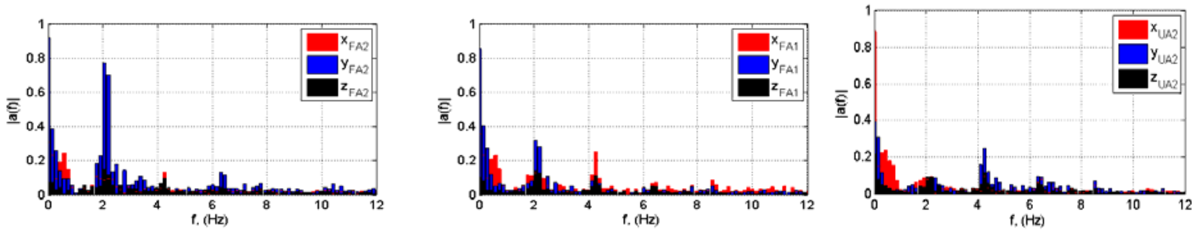

Figure 7 – Spectrograms of the handshaking between two men

The jumping is an action that can engender to very high accelerations of members of a humanoid body. We've observed a second order dynamics (fig. 8) during landing of a 100 kg person. The amplitude acceleration achieves 8G, this value is quite stable and repeats from one experiment to another for the same person. The person try's to absorb the shock by bending a little its knees.

Due to the damping of the person's legs and abdomen, the pelvis amplitude is quite smaller comparing to the thigh (fig. 8).The Kinect is able to represent person's members orientations (fig. 8) and positions during jumping. As one an see, the movement is really rhythmical, but the information on high order dynamics is not accessible via the Kinect data. That's because his band pass if quite limited comparing to the accelerometer sensors data (10 times, 300Hz for accelerometer comparing to 30Hz Kinect).

The jump deigns from the flexion of knees [0,2-0,7 s]. At the time of 0,7s the person rapidly deflects knees (push) that sends her in air. Knees are not bend no more until the time of contact [1,25 s]. The person tries to attenuate the shook by staring bending the knees but this time slower than in the previous push case. It acts as the controlled compliance.The total duration of the considered jump is 1,8 s, the stay in the air is 0,1 s.

During the human landing its legs act like a spring-mass dampers. They have a well-defined proper frequency (fig. 9) of 10,2 Hz. The acceleration frequency is essentially lower (fig. 9) for the pelvis (fig. 9), its value is equal to the half of the leg frequency. It means that high frequency contact shock oscillations are essentially attenuated at this point of the body. Only each second wave affects the upper human body who acts like a mechanical filter. The 4.9 Hz is probably a dynamics of the upper body.

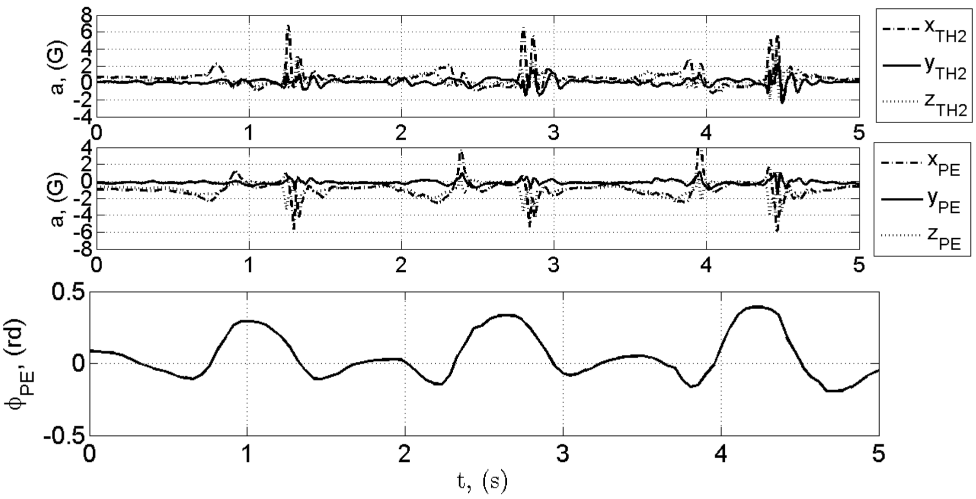

Figure 8 – Jumping of a human

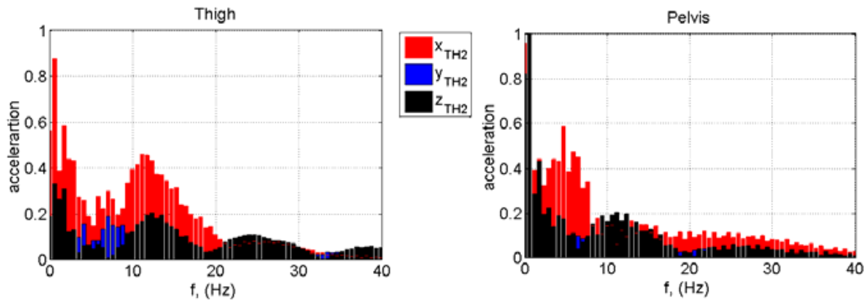

Figure 9– Spectrograms of jumping of a human

Flexion-extension experiment consists in periodical bending knees with vertical lifting and lowering of the upper body (fig. 10). Kinect sensors permits to see that when descending, the upper body declines forward t=[0 - 1,5 s] and contrary when lifting the body restores its initial orientation t=[1,5 – 2 s]. At the same time, accelerometers show high frequency vibrations 6,37 Hz at the extreme points of the movement (beginning of flexion-extension) for slow and 16,6 Hz for fast movements.Maximum accelerations values do not exceed 3G. The frequency of flexion-extension varies from 0,5 Hz (normal) to 1 Hz (fast).

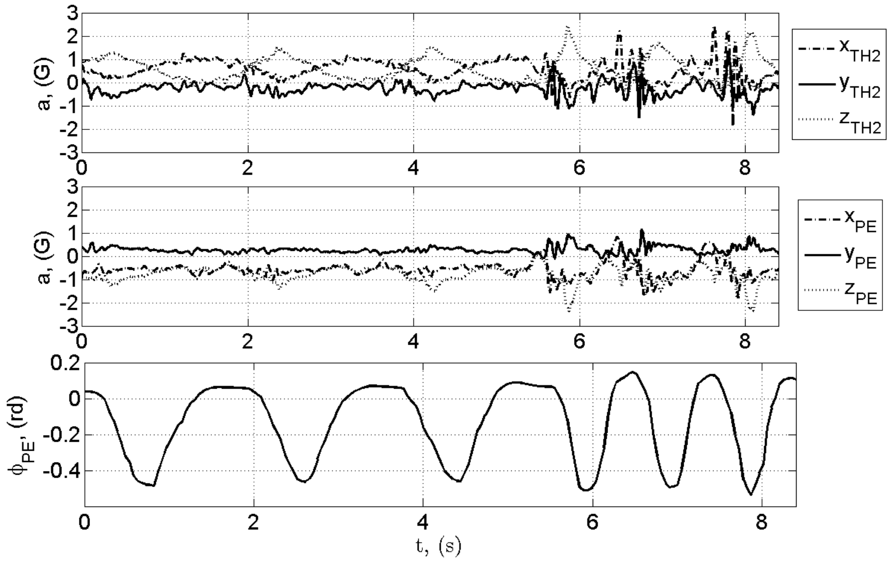

Figure 10 – Flexion-extension of a human

The walking is the most complex process among considered within this article. The frequency of experimentally studied walking varies from 0,14 Hz (slow), t= [0 – 17 s], to 0,2 Hz (fast), t = 17 – 32 s . During the slow walking accelerations of the thigh do not exceed 2 G whereas for fast walking they achieve 4G (fig. 11).

Kinect is able to capture walking gates but accelerometers present more accurately details of transient processes during lifting/posing a foot.Due to the complex high order dynamics of the process, high frequency oscillations of the person's thigh and hip are generated. For slow walking they are of 11,6 Hz and for fast walking 16,6 Hz.

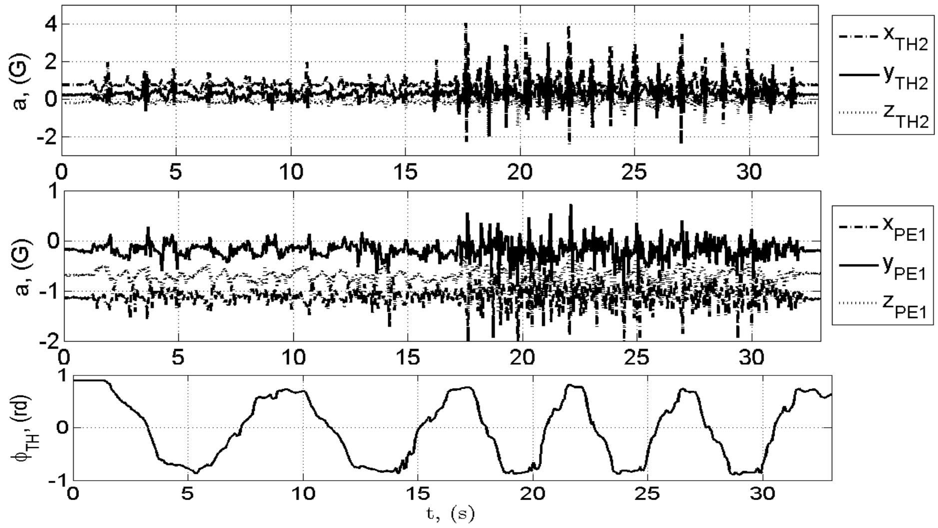

Figure 11 – Walking of a human

Conclusions. All studied human activities have high dynamics and they require precision measurement system with high range and sensitivity. Good band pass is assumed by using of accelerometers, whereas static or quasi-static actions can be estimated by using the Kinect sensor.We’ve discovered a high order dynamics in walking, jumping and vertical flexion-extension activities of a human and anthropomorphic robot. This dynamics is characterized be frequencies up to 6 – 20 Hz. At the same time, low frequencies of these movements lay between 0,1 and 2 Hz. High order dynamics can be modeled by spring-mass system and statics by simple kinematics models. The accelerometer network is used to identify dynamics of the walking biped system and Kinect is used to identify its kinematics.

Future work. In the near future we plan to use the real time multilayer neuron network for sensor fusion and realization of online identification of dynamic and kinematic parameters of the anthropomorphic robots and humans. The accelerometer sensor network and Kinect skeleton data will be used as input signals.We also plan to test the developed system in highly dynamic applications in sports, like running, tennis and martial arts.

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В.М. ХОМЕНКО [1],А.А. МЕЛЬНИК [2], П. ЕНАФФ [2], Г.О. КУЗЬМІН [3], В.П. БОРИСЕНКО [3]
[1] «Університет Версаль-Сен-Кантен-ан-Івелін», Франція
[2] «Університет Сержі-Понтуаз», Франція
[3] Державний вищий навчальний заклад «Донецький національний технічний університет»

Вимірювальні експерименти ритмічних рухів антропоморфних роботів та людей. Тіло людини має нелінійну динаміку і багато ступенів свободи. У цьому дослідженні ми пропонуємо мережу давачів, що надягається на тіло, для кількісних вимірювань величин руху антропоморфних роботів і людей. Було показано, що пропонована мережа давачів прискорення і сили здатна виміряти характеристики руху тіла під час основних видів фізичної взаємодії людини. Таким чином, стрибки, вертикальні згинання-розширення, ходьба і рукостискання були вивчені в наших експериментах. Переносні мережі датчиків прискорення в поєднанні з давачем Kinect від Microsoft застосовані для отримання положення сегментів і їх орієнтації, артикуляційних кутів і прискорень. Експериментальні результати показують ефективність ідеї об'єднання Kinect і систем акселерометричних давачів і давачів сили.
Ключові слова: акселерометр, Microsoft Kinect, чутливий до сили резистор, рукостискання, стрибок, хода, згинання-розширення, антропоморфний робот, людина.

В.Н. ХОМЕНКО [1],А.А. МЕЛЬНИК [2], П. ЭНАФФ [2], Г.А. КУЗЬМИН [3], В.Ф. БОРИСЕНКО [3]
[1] «Университет Версаль-Сен-Кантен-ан-Ивелин», Франция
[2] «Университет Сержи-Понтуаз», Франция
[3] Государственное высшее учебное заведение «Донецкий национальный технический университет»

Измерительные эксперименты ритмических движений антропоморфных роботов и людей. Тело человека имеет нелинейную динамику и много степеней свободы. В этом исследовании мы предлагаем сеть датчиков, надеваемых на тело, для количественных измерений величин движения антропоморфных роботов и людей. Было показано, что предлагаемая сеть датчиков ускорения и силы способна измерить характеристики движения тела во время основных видов физического взаимодействия человека. Таким образом, прыжки, вертикальные сгибания-разгибания, ходьба и рукопожатия были изучены в наших экспериментах. Переносные сети датчиков ускорения в сочетании с датчиком Kinect от Microsoft применены для получения положения сегментов и их ориентации, артикуляционных углов и ускорений. Экспериментальные результаты показывают эффективность идеи объединения Kinect и систем акселерометрических датчиков и датчиков силы.
Ключевые слова: акселерометр, Microsoft Kinect, чувствительный к силе резистор, рукопожатие, прыжок, походка, сгибание-разгибание, антропоморфный робот, человек.