Human-Robot Emotional and Musical Interactions

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Outline of the presentation

• Emotional robotics
• Musical robotics
• Wearable bioinstrumentation
The pyramid of life

- Increasing population
- Stable population
- Decreasing population
The pyramid of life is becoming more and more unstable.

- **1930 – the past**: Over 65 <5%
- **2005 – the present**: Over 65 about 20%
- **2050 – the future**: More than 30% of the population in Japan will be over 65 years old!!!

http://www.ipss.go.jp/index-e.html
Seamless mobility

Natural communication

Safety technology

Pseudo-lite

Environmental information structuring

Pseudo-lite (outdoor)

Robot as physical agent

RFID tag

RT furniture

Interaction with physical environment

Position identification

Autonomous environment recognition

Seamless mobility
Emotional robot WE-4RII
Paul Ekman’s classification of emotions

Ekman’s list of basic emotions (1970):

- Anger
- Fear
- Surprise
- Happiness
- Disgust
- Sadness

The facial expressions of the 6 primary emotions are common to all cultures.
FACS
(Facial Action Coding System)

- Face elements

- Glabella
- Root of Nose
- Eye Cover Fold
- Lower Eyelid Furrow
- Infraorbital Furrow
- Nostril Wing
- Infraorbital Triangle
- Nasolabial Furrow
- Philtrum
- Chin Boss
Emotional models

1. Miwa’s model
2. Kismet’s model
3. Circumplex model
4. Plutchick’s Wheel of Emotions
Previous Studies

WE-2 (1995) - Motion Perception
WE-3 (1996) - Depth Perception
WE-3R (1997) - Light Perception
WE-3RII (1998) - Facial Expression
WE-3RIII (1999) - Tactile and Audition
WE-3RIV (2000) - Olfaction
WE-3RV (2001) - Facial Color
WE-4 (2002) - New Models
Mental Model for Humanoid Robot

External Environment

Robot

Motion Reflex

Motion

Intelligence

Behavior

Internal Environment

Sensing

Recognition

Expression

Personality

Emotion

Mood

Need

Consciousness

Autonomic Reflex

Motion

Sensing

Personality

Emotion

Need
WE-4RII
emotional expressions

Happiness
Doing exercise using a dumbbell
WE-4RII
consciousness

Showing the Red Ball

REar RSide Vision LSide LEar

Loughborough University
The robot works, but…

• What about the people interacting with the robot?
• Is s/he enjoying the interaction?
• What about her/his emotions?
Interacting with humans at musical level

Musical Robots
WF-4 and WAS-3
Long term research objective

natural and intuitive human-robot complete musical interaction
Waseda Flutist Robot N.4 Refined VI

WF-4RVI (2010)

DOF Configurations

<table>
<thead>
<tr>
<th>Component</th>
<th>DOF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lungs</td>
<td>2-DOF</td>
</tr>
<tr>
<td>Vibrato</td>
<td>1-DOF</td>
</tr>
<tr>
<td>Eyes</td>
<td>3-DOF</td>
</tr>
<tr>
<td>Arms</td>
<td>14-DOF</td>
</tr>
<tr>
<td>Lips</td>
<td>3-DOF</td>
</tr>
<tr>
<td>Fingers</td>
<td>12-DOF</td>
</tr>
<tr>
<td>Neck</td>
<td>4-DOF</td>
</tr>
<tr>
<td>Tonguing</td>
<td>1-DOF</td>
</tr>
</tbody>
</table>

Total: 41-DOF
Waseda Flutist Robot N.4 Refined VI

Anthropomorphic Flutist Robot WF-4RIV
Musical Performance

The Flight of The Bumble Bee
WAseda Saxophonist No.3

**Eyes / 2-DOF**

**Lips / 2-DOF**

**Lung**

**Pump / 1-DOF**

**Valve / 1-DOF**

**Oral cavity / 1-DOF**

**Tongue / 1-DOF**

**Waist / 1-DOF**

**Air Flow**

**Hands / 19-DOF**

**Right / 179 [mm]**

**Left / 185 [mm]**

**WAS-3**

計 / 28-DOF
Anthropomorphic Saxophonist Robot WAS-2 Musical Performance

Sing Sing Sing

Louis Prima
Big issues (2)

- What about the people interacting with the robot?
- Is s/he enjoying the interaction?
- What about her/his emotions?

- What about the interaction with other musicians and artists in a small group?
- And hat about the interaction within a big orchestra?
Common need: Understand the human being

Wearable sensing
Main Scientific interest

• Observation, analysis, and understanding of the human being
  • extreme and exquisite example of robotic system,
  • clarification of the basic mechanisms underlying human's control of their bodies
  • extremely important and helpful tool for the society for realizing better health-care systems, human-support devices, teleoperation methods, and so on.
Main Research Activities

- **OBJECTIVE:**
  - to develop a **Wearable Bio-instrumentation System** capable of monitoring and integrating the human motion with several physiological indices

- **Core research tool** for understanding the basic mechanisms underlying human’s control of their bodies

- **Ultimate objective:**
  - to improve and enhance the quality of life of elderly and disabled people
Research approach and activities

1. Hardware
2. Software/Firmware
3. Applications
Research approach and activities

1. Hardware

- WB-4 and WB-4R Inertial Measurement Units
- WB-EMG wireless sensor
Industrial cooperation → WB Evolution

WB-1 2004
WB-1R 2005
WB-2 2006
WB-2R 2007
WB-3 2008
WB-4 2010
WB-5? 2014

Best Paper Finalist Award, ROBIO 2007
Best Paper Award, AIM 2009
Best Paper Finalist Award, IRIS 2010
Best Presentation Award, WWLS 2010
Best Paper Finalist Award, ROBIO2010
Best Paper Award, ROBIO2012
WB-4 Wireless IMU

- Bluetooth module: Zeal-C01 (Musenka Company)
- Li-Polymer battery: KPL501717 (3.6V@80mAh, Kayo Inc.)
- WB-4 IMU power consumption: 3.0V@80mA
- Continuous working time: 1 hour
- Data: ±8 [G], ±1600 [deg/s] @200Hz
# WB-EMG Sensor Specifications

<table>
<thead>
<tr>
<th>Circuits</th>
<th>WB-EMG Board</th>
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</thead>
<tbody>
<tr>
<td>Gain</td>
<td>2800</td>
</tr>
<tr>
<td>PCB Size (mm)</td>
<td>30.5x17.5x11mm</td>
</tr>
<tr>
<td>Voltage Supply</td>
<td>3.7V (Poly Li-ion battery)</td>
</tr>
<tr>
<td>Sampling Rate</td>
<td>1KHz</td>
</tr>
<tr>
<td>Resolution</td>
<td>12-bit</td>
</tr>
<tr>
<td>Low Frequency Cutoff</td>
<td>19Hz</td>
</tr>
<tr>
<td>High Frequency Cutoff</td>
<td>457Hz</td>
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<tr>
<td>Transmission Frequency</td>
<td>2.4 GHz (Bluetooth)</td>
</tr>
<tr>
<td>Power line Noise Rejection</td>
<td>Amplifier Common-Mode Rejection Driven Right Leg</td>
</tr>
<tr>
<td>DC Input Rejection</td>
<td>Passive Differential Filter</td>
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<tr>
<td>DC Offset Removal from INA</td>
<td>Feedback Integrator</td>
</tr>
<tr>
<td>Movement Artifact Rejection</td>
<td>Input Filter, Feedback Integrator</td>
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<tr>
<td>IC Packages</td>
<td>8-MSOP, 14-TSSOP</td>
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<tr>
<td>Passive Components</td>
<td>16</td>
</tr>
<tr>
<td>Active Components</td>
<td>2</td>
</tr>
<tr>
<td>Components Count</td>
<td>18</td>
</tr>
</tbody>
</table>

ICMA2013, best student paper finalist
Research approach and activities

1. Hardware

2. Software/Firmware

- Orientation estimation
- Wavelet Based EMG Denoising
- EMG-driven muscle model
Quaternion-based Extended Kalman Filter

\[ K_k = \bar{P}_k H_k^T \left( H_k \bar{P}_k H_k^T + R_k \right)^{-1} \]
Effect of R-Adaptive algorithm

- Perfect bias canceling
- No dynamic error rejection
- Dynamic error rejection
- No drift

![Graph showing the effect of R-Adaptive algorithm. The graph compares the roll angle over time for different conditions: σ=100, σ=0, and R-adaptive. The x-axis represents time in seconds, and the y-axis represents roll angle in degrees. The graph illustrates the effectiveness of the R-Adaptive algorithm in reducing dynamic error and drift.](image-url)
**Denoising: Baseline Adaptive Denoise Algorithm (BADA)**

**Successes**
- Reduction of false activations 92% vs original signal and 10% vs Standard Dohono Technique
- No negative impact the signal original shape

**Limitations**
- Heavy Computational Load of Wavelet Algorithm -> difficult to implement Real Time
- Firmware currently implemented only on MATLAB

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Proposed EMG+IMU Driven Musculoskeletal Model

**IMU**

Joint angles: $\theta(t)$

**EMG**

$a(t)$

$L^MT(\theta,t)=f(\theta,t)$

Muscle Contraction Dynamics + Hill Model

$F^E_{MT}(\theta,t)$

NRMSE=7.3 ± 1.0

Normalized Root Mean Square Error

Model Parameters (Estimated from Calibration)

**Successes**

- Fast (i7 Dual Core Intel <0.2s for 30s exercise) with only 1% NRMSE degradation -> possibility of Real Time Analysis
- Synchronized IMU + EMG

**Limitations**

- Firmware currently implemented only on MATLAB
- EKF optimized only for the upper limbs
Research approach and activities

1. Hardware
2. Software/Firmware
3. Applications

- Human-Robot interaction
- Healthcare
- And many many more…
Original Mental Model

- External Environment
  - Sensing
  - Recognition
  - Sensing Personality Emotion Need
  - Sensing

- Robot
  - Motion Reflex
  - Emotion Mood Consciousness Need
  - Autonomic Reflex

- Internal Environment
  - Motion
  - Expression Personality Emotion Need
  - Motion
Modified Mental Model

External Environment

Sensing

Recognition

Motion Reflex

Internal Environment

Sensing

Personality

Emotion

Need

Autonomic Reflex

Expression

Personality

Emotion

Need

Motion

Robot

Intelligence

Behavior

Emotion

Mood

Consciousness

Need
Human-Robot Interaction Example:
Stress management
Interaction System General Structure

**Performance rule**

Modulation of the musical output of the robot by an artist's performance

**Artist** → **Performance rule** → **Robot**

Performance feedback
Human-Robot Interaction Example:

Performance Start Synchronization

Artist → Performance rule → Robot
Dance performance: very strong expression of instinctive motion based on musical performance.
Human-Robot Interaction Example: Directing a musical robot

Conductor

Music

Tempo Calculation

Beat Segmentation

Mood Discrimination

Normal, Legato, Marcato

Tempo

MIDI Controller

Robot (WF4-RVI)

WB-4

Data Preprocessing

Ictus Detection

Tempo Calculation

MIDI Controller

WF-4RVI
Musical Interaction
Hungarian Dance

Johannes Brahms
Traditional training model

Current universal evaluation model
Methodology proposal

To develop a general **skill evaluation system**

- separated from the training devices
- objective and quantitative based on motion analysis
- adaptive to various training devices, surgical applications and clinical practice

Diagram:

- **Subject**
  - Instrument / human motion measurements
  - Expert doctor
  - Quantitative feedback
  - Training platforms
  - Motion analysis and skill classification
Medical applications – Laparoscopy (1/3)

Novices, differently from the experts, use the right forearm only during the second part of the exercise.

Qualitative analysis
Novices, differently from the experts, use the right forearm only during the second part of the exercise.
Medical applications – Laparoscopy (2/3)

**Quantitative analysis**

Muscles present different behavior in different exercises

** p<0.01
Medical applications – Laparoscopy (3/3)

**Successes**
- General system able to provide both qualitative and quantitative results
- Application in a complete curriculum for laparoscopic training

**Limitations**
- EKF optimized only for the upper limbs
- Current HW setup invasive and uncomfortable
Take home message
Take home message

• We need to work hard for developing better robots

• More important, we need to work harder for understanding ourselves 😊
Human-Robot Emotional and Musical Interactions

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