Multimodal Interaction with Robotic Devices: Assistive Technologies Applications

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IEETA – Instituto Engenharia Electrónica e Telemática de Aveiro

Outline

- Introduction
- Intelligent Wheelchairs (IWs)
  - Concept, Prototypes and Interfaces
  - IntellWheels Project
- Users Profiles and Adapted Interfaces
  - System Architecture
  - Multimodal Interface
  - IntellSim - IntellWheels Simulator
  - Wheelchair Control
  - Data Analysis System
  - Extending the concept: Serious Games for cerebral palsy users
- Conclusions and Future Work
- Publications and Awards
Introduction

- Motivation
  - Growing importance given to
    - Autonomy and independence
    - People with disabilities
    - Elderly individuals
  - Unexplored research subject
    - Automatic configuration and parameterization of Intelligent Wheelchairs
    - Users/patients characteristics to adapt IWs interface

Introduction

- Objectives
  - Data Analysis System (DAS)
    - Analysing multimodal data
    - Patients with distinct disabilities
    - Automatic characteristics classification
  - Real data gathering system
  - Data gathering process
  - Multimodal interface (flexible command language)
  - Realistic simulator
  - Experiments with real patients to validate the approach
Introduction

- Applying data analysis within a multimodal interface it is possible to adapt an intelligent wheelchair to the user
  - User profiling provides relevant information when automatically adapting an intelligent wheelchair to users with severe disabilities
  - It is possible to provide an automatically generated command language adapted to the user for driving the IW
  - Data analysis system provides equal or even better adapted command languages for driving an IW than human specialists

Intelligent Wheelchairs

- IW Concept
  - Smart Chairs / Robotic Chairs
  - Locomotion device to assist a handicapped user
  - Autonomous navigation system
  - Controlled by computer
  - Sensors and actuators
  - Communication with other devices
  - Intelligent interface with the user
    - joystick, voice based control, facial expressions, eye tracking
Intelligent Wheelchairs

Projects and Prototypes

- Madarasz [1986]
- Omnidirectional IW [1993]
- Two legs IW [1994]
- NavChair [1996]
- Tin Man I [1995]
- Tin Man II [1998]
- FRIEND’s Project [1999]
- LURCH [2007]
- Robochair [2009]
- VAHM [2010]
- ARTY [2012]
- SDA [2012]

Portuguese Projects

- ISR Wheelchair [2002]
- Enigma [2007]
- Palmiber [2010]
- Magic Wheelchair [2011]

Interfaces using different input devices

- CNBI [2011]
Intelligent Wheelchairs

- Characteristics
  - Usability
  - Accessibility
  - Safety
- Adaptation to a single user or a group
- Automatic configuration and parameterization of IWs to their users’ characteristics is an unexplored subject
- Lack of experimental results with real users

IntellWheels Project

- Institutions
  - UP/UA/UM
  - LIACC
  - IEETA
  - INESC-TEC
  - ESTSP/IPP
  - APPC
- Objective
  - Develop an IW platform
  - Easily adapted to any commercial wheelchair
  - Controlled by a multimodal interface
  - Adapted to any person with special mobility needs
IntellWheels Project

- Hardware Prototype
- Inputs: joystick, keyboard, head movements, voice
- Sensorial System: IR sensors; sonars; camera; encoders
- Simple Localization, Navigation and Planning
- Communication and Cooperation
- Simple Wheelchair Simulator
- Basic Multimodal Interface

Project Evolution

Today
IntellWheels Project

User Profiles and Adapted Interfaces

Inspired in the Phases of Knowledge Discovery

- Objectives
- Methods
- Results
- Discussion
- Conclusions

Real and Simulated Intelligent Wheelchair

Data Analysis System

User Profiling

Confusion Matrix Deployment

Input Devices
System Architecture

Multimodal Interface

- Fully integrated
  - Data Gathering System and new Simulator
- Flexible
  - User defined input sequences
  - Freely associated to wheelchair output actions and interface actions
    - Blink left eye + Say “Go” -> Turning Left
  - Friendly Graphical User Interface
Multimodal Interface

- **Input Modalities**
  - Voice Commands
  - Joystick Movements
  - Gamepad
  - Head Movements
  - Facial Expressions

Multimodal Interface

- **User Profiling**
  - Module integrated in the Multimodal Interface
  - Simple interactive tests that do not involve the IW
  - Evaluates user capability to use different inputs
**Multimodal Interface**

**Brain Computer Interface**

```
\[ \bar{X}_{EEG} = \frac{1}{k} \sum_{i=1}^{k} EEG_i \]
\[ \bar{X}_{Gyr} = \frac{1}{k} \sum_{i=1}^{k} Gyr_i \]
```

**Hjorth Parameters**

- Activity (Ac) – measure of the mean power of the signal. It is measured using the standard deviation of the signal.
- Mobility (Mo) – represents the mean frequency in the signal.
- Complexity (Co) – Expressed as the number of the standard slopes actually seen in the signal during the average time required for one standard amplitude deviation.

```
S_{Ac}^i = \frac{1}{l} \sum_{i=1}^{l} (S_i^i - \bar{S}^i)
S_{Mo}^i = \frac{S_d^i}{S_{Ac}^i}
S_{Co}^i = \frac{S_{dd}^i}{S_{Ac}^i}
```

**IntellSim – Realistic Simulator**

- USARSim (Unified System for Automation and Robot Simulation)
- Using Unreal Tournament 2004 (UT2004)
  - Unreal Engine 2.5 and the Karma physics engine
  - Unreal Editor 3 to develop new objects and environments
IntellSim – Realistic Simulator

- Simulated wheelchair modelled using 3D Studio Max
- Imported to Unreal Editor as separated static meshes (*.usx)
- Model has fully autonomous caster wheels and two differential steering wheels
- Sensors in simulation
  - 16 sonars
  - laser range finder
  - encoders
  - camera

IntellSim – Realistic Simulator

- IntellWheels Serious Game
  - Patient challenge and motivation
  - Flexible circuit definition
  - Collectable objects mark the intended path
  - User drives wheelchair collecting the objects
  - Performance measured in real time
- System gathers data
  - Collected objects, time, sensors values
  - Input devices data, control type
User Profiling Experiments

- 34 cerebral palsy users
- Levels IV (23%) and V (77%) GMFM
- Mean of 28 years old (7.7 std)
- Head Movements, Voice, Joystick

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<thead>
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<th>Manual wheelchair</th>
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<table>
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<table>
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<td></td>
<td>no</td>
</tr>
<tr>
<td></td>
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</table>

IntellSim Experiments

- A circuit was created in the simulator
- Two floors linked by a ramp
- With obstacles and different kinds of illumination and noise
- Should collect 15 blue balls by passing near them
IntellSim – Realistic Simulator

IntellSim Results

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>n</th>
<th>Mean</th>
<th>Median</th>
<th>Std</th>
<th>Min</th>
<th>Max</th>
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<td>16.6</td>
<td>7</td>
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<td>12</td>
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<td>8</td>
<td>6</td>
<td>6</td>
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<td>23</td>
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<tr>
<td>Number of objects collected</td>
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<td></td>
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<td>Voice commands</td>
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<td>11.7</td>
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<td>2</td>
<td>15</td>
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<tr>
<td>Head movements</td>
<td>31</td>
<td>13.8</td>
<td>15</td>
<td>2.7</td>
<td>3</td>
<td>15</td>
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</tbody>
</table>

Wheelchair Control

- Manual, Automatic and Shared algorithms
- Comparative evaluation
Wheelchair Control

Manual Wheelchair Control

Original
\[
\begin{align*}
R &= y - x \\
L &= y + x
\end{align*}
\]

Proportional
\[
\begin{align*}
R &= \begin{cases} 
-\theta + \frac{\pi}{4} & \text{if } 0 \leq \theta \leq \frac{\pi}{2} \\
\theta - \frac{\pi}{4} & \text{if } \frac{\pi}{2} \leq \theta \leq \pi \\
-\theta - \frac{\pi}{4} & \text{if } -\pi < \theta < -\frac{\pi}{2} \\
\theta + \frac{\pi}{4} & \text{if } -\frac{\pi}{2} \leq \theta < 0
\end{cases} \\
L &= \begin{cases} 
\frac{-\theta + \pi}{4} & \text{if } 0 \leq \theta \leq \frac{\pi}{2} \\
\frac{\theta - \pi}{4} & \text{if } \frac{\pi}{2} \leq \theta \leq \pi \\
\frac{-\theta - \pi}{4} & \text{if } -\pi < \theta < -\frac{\pi}{2} \\
\frac{\theta + \pi}{4} & \text{if } -\frac{\pi}{2} \leq \theta < 0
\end{cases}
\]

Intuitive
\[
\begin{align*}
\rho, 0 \leq \theta \leq \pi/2 & \rightarrow \rho, \theta = \theta \\
\rho, \theta \geq \pi/2 & \rightarrow \rho, \theta = \pi/2 - \theta
\end{align*}
\]

Wheelchair Control

Introduction | Intelligent Wheelchairs | User Profiles and Adapted Interfaces | Conclusions & Future Work

Wheelchair Control

Manual Wheelchair Control

Adapted CSUQ (Final Score) Results

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Orig</th>
<th>Prop</th>
<th>Intui</th>
<th>Orig At</th>
<th>Prop At</th>
<th>Intui At</th>
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<tbody>
<tr>
<td>Mean</td>
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<td>63.4</td>
<td>80.6</td>
<td>64.6</td>
<td>72.8</td>
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<td>Median</td>
<td>52.4</td>
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<td>85.7</td>
<td>61.9</td>
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<td>Std. Dev.</td>
<td>23.6</td>
<td>24.6</td>
<td>17.4</td>
<td>22.7</td>
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<tr>
<td>Min</td>
<td>22.2</td>
<td>14.3</td>
<td>33.3</td>
<td>25.4</td>
<td>14.3</td>
<td>33.3</td>
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<tr>
<td>Max</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>95.2</td>
<td>98.4</td>
</tr>
</tbody>
</table>

Adapted CSUQ – Final Score (n=8 cerebral palsy patients)

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Orig</th>
<th>Prop</th>
<th>Intui</th>
<th>Orig At</th>
<th>Prop At</th>
<th>Intui At</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>72.9</td>
<td>77.9</td>
<td>88.7</td>
<td>86.7</td>
<td>84.9</td>
<td>83.9</td>
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<tr>
<td>Median</td>
<td>81.7</td>
<td>88.1</td>
<td>99.2</td>
<td>96.0</td>
<td>98.4</td>
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<tr>
<td>Std. Dev.</td>
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<td>19.8</td>
<td>20.6</td>
<td>23.5</td>
<td>24.5</td>
</tr>
<tr>
<td>Min</td>
<td>30.2</td>
<td>25.4</td>
<td>46.0</td>
<td>41.3</td>
<td>36.5</td>
<td>39.7</td>
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<tr>
<td>Max</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Wheelchair Control

- Automatic Wheelchair Control

Objective of following a predefined circuit without the need of user intervention

Wheelchair Control

- Manual
- Automatic
- Shared - Aid Level

Wheelchair Control

- Shared Wheelchair Control

- Estimate user intention based on joystick position
  - If user joystick position difference to automatic joystick position greater than threshold: user command
  - Otherwise: use weighted average of the automatic control and manual control

- Weights based on the aid level provided to the user

Wheelchair Control

- Manual
- Automatic
- Shared - Aid Level
Wheelchair Control

- Shared Wheelchair Control
  - Aid level of 100%
  - Aid level of 50%
  - Manual with obstacle avoidance

<table>
<thead>
<tr>
<th>Adapted CSUQ – Final Score (n=8 cerebral palsy users)</th>
<th>Head Movements (wiimote)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statistics</strong></td>
<td><strong>Aided 100%</strong></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>82.7</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>88.9</td>
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<td><strong>Std. Dev.</strong></td>
<td>21.0</td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td>39.68</td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td>100</td>
</tr>
</tbody>
</table>

Multiple Comparisons LSD – Head movements shared controls (p values)

<table>
<thead>
<tr>
<th></th>
<th>Aided control 100%</th>
<th>Aided control 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aided control 50%</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>Obstacle Avoidance</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Data Analysis System

- Enable multiple input devices
- Maximize user performance driving the IW
- Adapt IW to users with distinct disabilities
- Associate distinct input sequences to the same command
- Fast response to user commands
- Intuitiveness between associations (input sequences and commands)

Data Analysis System and User Profiling

\[
rec_i = \frac{n_i}{\sum_{k=1}^{m} n_{ik}} \quad prec_i = \frac{n_i}{\sum_{k=1}^{m} n_{ki}}
\]

\[
F_{\beta} = \frac{(\beta^2 + 1) \times prec_i \times rec_i}{\beta^2 prec_i + rec_i}
\]
Data Analysis System

Input Device Advisor
- An input device is advised if overall accuracy, using the F-measure, is higher than a threshold.
- Or a subset of the possible combinations with the set of available input devices:
  - wiimote
  - gamepad
  - joystick
  - microphone for voice commands
  - BCI for the facial expressions

Control Advisor
- Emerged from the experiments with cerebral palsy users.
  - Several patients have different movement abilities.
  - Not precise enough for driving a wheelchair in a safe manner.
- Several alternatives for the shared control:
  - Aid level of 100% - if the overall accuracy is included in \([0, x]\)
  - Aid level of 50% - if the overall accuracy is included in \([x, y]\) where \(0 < x < y < 1\)
  - Manual with obstacle avoidance - if the overall accuracy is in the interval \([y, 1]\)
Data Analysis System

- **Command Language Advisor**
  - **Command Language (CL)**
    - set of associations of input sequences to commands
    - allowing a user to drive the IW
  - Formally is a function
    \[
    CL : S \rightarrow C
    \]
    \[
    S_i \rightarrow C_j
    \]
    \[i \in \{1, ..., n_S\}, j \in \{1, ..., n_c\}\]
    \[n_S\] is the number of available input sequences
    \[n_c\] is the number of available commands

Sequence of inputs \(S_i: f^{(1)}, f^{(2)}, f^{(3)}, ..., f^{(N_i)}\)

\[
t_{S_i} = \sum_{k=1}^{N_i} t^{ID}_{j(k)} + t_{timeout(i)}
\]

- time to select the inputs
- timeout

\[
T_c = \sum_{j=1}^{C_j} t_{S_j}
\]

- total time for all the commands

\[
T_{c_{eff}} = \sum_{j=1}^{C_j} \text{eff}(t_{S_j})
\]

\[
\text{eff} : [0, +\infty[ \rightarrow [0, 1]
\]

\[
t_{S_i} \mapsto \frac{1}{t_{S_i} + 1}
\]
Data Analysis System

■ Command Language

- Efficiency
- Recognition
- Intuitivity

Sequence $S_i$ recognition value

$$regS_i = \prod_{k=1}^{N_i} F^{ID}_{j(k)}$$

Total recognition value of a set of commands

$$T_{reg} = \sum_{j=1}^{C} regS_j$$
Data Analysis System

Command Language

Maximizes the function composed by the total time efficiency, total recognition and intuitiveness

$$\arg \max (\alpha T_{eff} + \beta T_{reg} + \gamma T_{int})$$

User Profiling Experiments

- 11 cerebral palsy users
- Level IV (27.3%) and V (72.7%) GMFM
- Voice Inputs
  - “Go”, “Front”, “Forward”, “Back”, “Right”, “Left”, “Turn”, “Spin” and “Stop”
- Joystick and the Head Movements
Data Analysis System

Input Device Advisor

<table>
<thead>
<tr>
<th>Patient</th>
<th>Buttons</th>
<th>Joystick</th>
<th>Wheel</th>
<th>Microphone</th>
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<tbody>
<tr>
<td>P1</td>
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Control Advisor

<table>
<thead>
<tr>
<th>Patient</th>
<th>Aid 100%</th>
<th>Jeystick Aid 50%</th>
<th>Obstacle Avoidance</th>
<th>Aid 100%</th>
<th>Wheel</th>
<th>Obstacle Avoidance</th>
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<tbody>
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<td>x [0.68]</td>
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<td>x</td>
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<td>x</td>
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Data Analysis System

**Command Language Advisor**

Mean of DAS evaluation higher than mean of evaluation of the command language recommended by specialist (p value = 0.002)

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**Extending the concept**

**Another Robotic Devices**

Paralympic Boccia
Believed to have Ancient Greek origins, this is a tactical target sport played by individuals in wheelchairs. The games are played in teams, in pairs or as individuals. The sport is similar to bowls or table tennis.

The aim
To get the ball closest to the jack over a series of ends.

The court
The court consists of six throwing boxes behind a throwing line to the court.

Field of play
The court consists of six throwing boxes behind a throwing line to the court.

Special rules
Balls propelled by rolling, throwing or kicking. If a player is unable to throw or kick, they can use a ramp and where necessary assistance is allowed for passing balls or positioning the ramp prior to a play.

Assistants
Non-valuable areas for the jack ball to reenter.

An end
Passage of play which features six bowls per athlete, pair, or team.
Extending the concept

- Develop a Boccia intelligent robotic ramp
  - Virtual environment
  - Real environment
- Adaptation of the multimodal interface
- Creation of different scenarios for training and testing

Scenarios

- Bolt
  - Conduct a ball from an initial to a final point
Scenarios

- Tactics
  - Several objectives along a route

- Insert objects (multiplayer)
Scenarios

- Soccer with CRI (multiplayer)

- Boccia Ramp – pointing to targets
Conclusions and Future Work

- Many IWs prototypes are being developed
  - User adaptation is often neglected
  - Rigid Interfaces adapted to a single user (or user group)
- IntelliWheels project
  - High-level commands through Multimodal interface
  - Interface adapted to users’ characteristics
  - IntellSim is a realistic tool for testing and training
- Adaptation performed automatically using user profiling
- DAS generates command language adapted to the user
- Command language with better evaluation than recommended by specialists
- New methodology for starting to use an intelligent wheelchair
- Shared control with appropriate aid level may be a solution to help the daily life chores of users
Conclusions and Future Work

- Development of new inputs
  - Voice recognition with native user language and matching sounds instead of words
  - Facial expression and gesture recognition
  - Increase the input devices’ accuracy
- Extension of the experimental work
  - Other potential users of an intelligent wheelchair
  - Extensive tests with real prototype
  - Tests with other input devices
- Development of the Boccia game in real and virtual environment

Publications (Journals & Book Chapters)

- B. M. Faria, L. P. Reis, N. Lau, Adapted Control Methods for Cerebral Palsy users of an Intelligent Wheelchair, *Journal of Intelligent and Robotics Systems*, Springer, (selected for the special issue of the 13th ICARSC) [ISI] [Scopus]
- B. M. Faria, S. Vasconcelos, L. P. Reis, N. Lau, Multimodal Interface for an Intelligent Wheelchair, *J. of Disability and Rehab.: Assistive Technology*, Submitted [ISI] [Scopus]
- B. M. Faria, L. P. Reis, N. Lau, A. P. Moreira, M. Petry, L. Ferreira, Bridging the Gap between Virtual and Real Intelligent Wheelchairs, *Advanced Robotics*, Submitted [ISI] [Scopus]
Publications (Conferences)

- B. M. Faria, N. Lau, L. P. Reis, Applications of ML Algorithms for Individual Recognition and Facial Expressions Classification; VIPIMAGE 2009, Taylors&Francis, pp 233-239, Out2009, [ISI] [Scopus]
- B. M. Faria, S. Vasconcelos, L. P. Reis, Nuno Lau, A Methodology for Creating Intelligent Wheelchair Users’ Profiles, ICAART 2012, pp. 171-179, 6-8 Feb2012, Algarve, [ISI] [Scopus]
- B. M. Faria, Luis Paulo Reis, Nuno Lau, Manual, Automatic and Shared Methods for Controlling an Intelligent Wheelchair: Adaptation to Cerebral Palsy Users, 13th Int. Conf. on ARSC, April, 2013.,

Publications and Awards (Awards)

- 2nd place at Festival Nacional de Robótica, International Competition Freebots, Portugese Robotics Open, Instituto Superior Técnico, Lisbon, April 2011
- Galardão da Inclusão at the category Applied Investigation, Teatro José Lúcio da Silva, em Leiria, 3 de Dezembro de 2011, Dia Internacional da Pessoa com Deficiência, Centro de Recursos para a Inclusão Digital (CRID), Instituto Politécnico de Leiria (IPL)
- First Honor Mention/2nd Place at the Award "Ser Capaz" of Associação Salvador, Projeto Intellwheels, Espaço BES Arte & Finança, Lisboa, Portugal, 16 de Janeiro de 2012
- Honor mention, Jaime Filipe Award, "Projeto Cadeira de Rodas Inteligente com Interface Multimodal Flexivel" - Instituto Nacional para a Reabilitação, Dia Internacional da Pessoa com Deficiência, 3 de Dezembro de 2012
Acknowledgements

- FCT – Portuguese Science and Technology Foundation
  - PhD scholarship with reference FCT/SFRH/BD/44541/2008
  - INTELLWHEELS Project - Intelligent Wheelchair with Flexible Multimodal Interface with reference FCT/RIPD/ADA/109636/2009
- DETI/UA – Departamento de Engenharia Electrónica, Telecomunicações e Informática da Universidade de Aveiro
- IEETA – Instituto de Engenharia Electrónica e Telemática de Aveiro
- LIACC – Laboratório de Inteligência Artificial e Ciência de Computadores da Universidade do Porto
- ESTSP – Escola Superior de Tecnologia da Saúde do Porto, Instituto Politécnico do Porto
- APPC – Associação do Porto de Paralisia Cerebral

Questions?

Multimodal Interaction with Robotic Devices: Assistive Technologies Applications

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