Autonomous Socially Assistive Robotics in Pediatric Clinical Practice

by

D. José Carlos Pulido Pascual

A dissertation submitted by in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Computer Science and Technology

Universidad Carlos III de Madrid

Advisors:
Prof. Dr. Fernando Fernández Rebollo
Prof. Dr. Raquel Fuentetaja Pizán

Tutor:
Prof. Dr. Fernando Fernández Rebollo

January 2020
This thesis is distributed under license
“Creative Commons Attribution – Non Commercial – Non Derivatives”.
Autonomous Socially Assistive Robotics in Pediatric Clinical Practice
José Carlos Pulido Pascual
Ph.D. Computer Science and Technology
Thesis advisors
Dr. Fernando Fernández Rebollo
Dra. Raquel Fuentetaja Pizán

Contents

1. Introduction
2. State of the Art
3. Objectives
4. Design of the child-robot interaction (cHRI)
   • Principles of Design
   • cHRI Models and Framework
   • Principles of Evaluation
5. Autonomous SAR for physical rehabilitation
6. NAOTherapist Evaluation
   • Intensive Bimanual Therapy (HABIT)
7. Adaptation of Infant-Robot Interaction
   • Fixed Threshold-based Approach
   • Adaptive RL-based Approach
   • Evaluation of Approaches
8. Conclusions and Future Lines

Background & Scope
Design Phase
NAOTherapist
IR Interaction
USC
Closure
1. Introduction
2. State of the Art
3. Objectives

Background & Scope

Introduction > Foundations

Hands-off cHRI rehabilitation framework

An interdisciplinary approach

A) Enhance pediatric neurorehabilitation interventions

B) by maintaining a prolonged motivation during sessions

C) in which a charming robot interacts socially with patients

D) whose decisions are made autonomously by itself

A) Socially Assistive Robotics
B) Neurorehabilitation
C) Artificial Intelligence
D) Autonomous Motivation

u3m | Universidad Carlos III de Madrid
Ph.D. Computer Science and Technology
Neurorehabilitation

Introduction > Foundations > Neurorehabilitation

First Foundation: Neurorehabilitation

- **Infant Brain Damage** is a serious condition that happens after some complication during pregnancy or birth of the baby [Levine et al. 1984]
  - Cerebral Palsy and Obstetric Brachial Plexus Palsy → physical impairments
- In the first years of life, more psychomotor changes are experienced [Bijou 1976]:
  - Early diagnosis and intervention
  - Start the neurorehabilitation treatment as soon as possible
- Neuroplasticity → An **intense and continuous training** favors the establishment of new connections [Dobbing 2004] [Leocani et al. 2006]
- Treatments are **prolonged over the children’s life**

- Identified problem:
  "These routine and repetitive exercises may lead to demotivation and loss of interest" [Calderita et al. 2014]
Introduction > Foundations > Gamification

- Learning technique that implements game mechanisms in non-game contexts [Fleming et al. 2017]
- Towards a playful perception, positive reinforcement and immersion of the patient [Deterding et al. 2011]
  - Promotes participation
  - Improves motivation, concentration and productivity
  - Dopamine release facilitates learning

- Identified problem:
  
  "A gamified therapy may not break communication barriers between the patient and the therapist" [Dawe et al. 2019] [Karner et al. 1943]
The lack of autonomy can bring out the system limitations and teleoperated solutions do not provide any workload release of professionals’’ [Belpaeme et al. 2013]

- Identified problem:

  “The lack of autonomy can bring out the system limitations and teleoperated solutions do not provide any workload release of professionals” [Belpaeme et al. 2013]

- Provide assistance to human beings through social interaction [Feil-Seifer et al. 2005]

- Stimulate better responses and a proactive behavior from pediatric patients [Feil-Seifer et al. 2009] [Lee et al. 2012]

  ✓ Reduce significantly risk factors
  ✓ Promote active training
  ✓ Facilitate communication

- Third Foundation: Socially Assistive Robotics (SAR)
Artificial Intelligence

Introduction > Foundations > Artificial Intelligence

A SAR platform is considered autonomous when:

- The interaction offered does not require an external operator
- Self-explanatory, easily deployable and configurable for non-expert users
  \cite{Feil-Seifer2005}

Key aspect → Task/Action selection

- Model of the use case
- Decision-making algorithm

Identified problem:

"Changes in the model or use case still require expert knowledge of modeling"
\cite{Gonzalez2018}
1. Introduction
2. State of the Art
3. Objectives

Background & Scope

Non-contact Rehabilitation Robotics

State of the Art > Non-contact Rehabilitation Robotics

- The area of robotic rehabilitation has historically been based on **physical contact** [Maciejasz et al. 2014]

- **Target individuals**
  - **Pediatrics:** brain injury, autism, diabetes, education, hospitalization [Dawe et al. 2018]
  - **Adults:** post-stroke [Mataric et al. 2007]
  - **Elderly:** dementia, companion, active ageing [Fasola et al. 2013]
**SAR Rehabilitation in Pediatrics**

State of the Art > SAR Rehabilitation in Pediatrics

<table>
<thead>
<tr>
<th>Authors</th>
<th>Robot</th>
<th>Participant</th>
<th>No.</th>
<th>Cond</th>
<th>Age</th>
<th>Autonomy</th>
<th>Perception</th>
<th>Adaptation / Configuration</th>
<th>Long-term</th>
<th>Clinical Setting</th>
<th>Clinical Results</th>
<th>Gamified Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brisben 2005</td>
<td>Cosmobot</td>
<td>6 CP</td>
<td>4-10</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Roberts 2012</td>
<td>Manoi</td>
<td>20 TD</td>
<td>18-23</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Rios R. 2013</td>
<td>LEGO</td>
<td>1 CP</td>
<td>7</td>
<td>✗</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Suárez-M. 2013</td>
<td>Urion</td>
<td>6 CP</td>
<td>3-7</td>
<td>✗</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>X</td>
<td>X</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Kozyavkin 2014</td>
<td>Etreum</td>
<td>6 CP</td>
<td>4-9</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Fridin 2014</td>
<td>NAO</td>
<td>4 CP</td>
<td>5-14</td>
<td>✗</td>
<td>✓</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Kozyavkin 2014</td>
<td>NAO</td>
<td>12 ASD</td>
<td>7-10</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Adawiah 2015</td>
<td>NAO</td>
<td>2 CP</td>
<td>5-14</td>
<td>✗</td>
<td>❌</td>
<td>✗</td>
<td>✗</td>
<td>✔</td>
<td>✗</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Rodriguez-Lera, 2013</td>
<td>OTRobot</td>
<td>4 TD</td>
<td>25-52</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Carrillo 2018</td>
<td>NAO</td>
<td>9 CP</td>
<td>-</td>
<td>✗</td>
<td>✓</td>
<td>✔</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

**Autonomy in SAR**

State of the Art > Autonomous Human-Robot Interaction

- **Main HRI challenges to control the interaction:**
  - Execute the most appropriate action according to the state perceived
  - Long-term user adaptation

- **Robot control techniques**
  - **Non-Autonomous**
    - Scripted behavior [Kozyavkin 2014] [Malik 2014] [Adawiah 2015]
    - no unexpected events handling
  - Teleoperated [Brisben 2005] and Wizard of Oz [Suárez-M. 2013] [Carrillo 2018]
    - require human intervention
  - **Autonomous/Partially Autonomous**
    - Subsymbolic representation [Baxter et al. 2013]
      - missing knowledge
    - Learning-based adaptation [Greczek 2014] [Fridin 2014]
      - many examples to converge
    - Symbolic representation based on state machines [Roberts 2012] [Rodriguez-Lera, 2018]
      - Costly to keep the coherency
Discussion

State of the Art > Discussion

- SAR rehabilitation robotics is still in an early stage with a promising future
- Low level of autonomy in most of the platforms
- No work explicitly applies gamification and/or reward techniques
- Few experimental evidence:
  - Small sample size
  - Few long-term studies
  - No clinical results
  - No implantations due to lack of continuity
Objectives

Introduction > Objectives

Main goal:

Design and evaluate child-robot interaction models and frameworks for non-contact rehabilitation to augment pediatric interventions

1. Design a child-robot interaction framework for non-contact rehabilitation that integrates the four foundations and all the previous fundamentals:

<table>
<thead>
<tr>
<th>Autonomy</th>
<th>Perception</th>
<th>Adaptation / Configuration</th>
<th>Long-term</th>
<th>Clinical Setting</th>
<th>Clinical Results</th>
<th>Gamified Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

2. Development of functional prototypes intended to cover certain needs that are of interest to health professionals (user-centered methodology):

   I. Pediatric physical rehabilitation - NAOTHERapist
   II. Infant motion encouragement - IR Study at USC

3. Evaluate the feasibility of this framework in real healthcare scenarios with a significant sample of participants

4. Design of the child-robot interaction (cHRI)

   - Principles of Design
   - cHRI Models and Framework
   - Principles of Evaluation

Design Phase
Contributions to cHRI

Design of the cHRI > Outline

1. Principles of Design

2. Request-Return-Reward (R³) model

3. Framework for Hands-off Rehabilitation

4. Creating a Gamified SAR-based Use Case

5. Principles of Evaluation

Principles of Design

Design of the cHRI > Principles of Design

- Taxonomy of requirements to conform to the clinical guidelines
- Most of these principles arise from:
  - Literature [Fasola et al. 2013]
  - Interviews with healthcare professionals
  - Personal experience

1. Therapy requirements:
   - Goal-directed
   - Gradual and Balanced
   - Personalized
   - Constraint Induced
   - Game-like Tasks

2. Therapy execution:
   - Interactive
   - Supervised
   - Adaptive
   - Adequate Social Distance

3. Therapy engagement:
   - Attitude
   - Positively Reinforced
   - Promoting Bonding and Empathy
**Request-Return-Reward (R³) cHRI Model**

Design of the cHRI > R³ cHRI Model

- **Effort-based Reward training** -> **50% more efficient** in solving a task [Bardi et al. 2013]
  - **Request** includes all those actions of the robot necessary for the patient to understand the task: verbally and non-verbally
  - **Return** relates to the perception capabilities to determine the correct achievement of the task
  - **Reward** reinforces the patient, so that the best rewards are a consequence of a great performance

---

**General Framework for Hands-off Robotics Rehabilitation**

Design of the cHRI > Framework for Hands-off Robotics Rehabilitation

[Diagram of HRI Architecture]

- **Decision Support**
  - **AI System**
    - **User model**
    - **Configuration**
    - **Execution**

- **Robotic Platform**
  - **Interactive Agents**
  - **Perception**
  - **Action**

- **Information System**
  - **Environment**
  - **Interaction**
  - **Patient**
Creating a Gamified SAR-based Use Case

Design of the cHRI > Applying Gamification to SAR

<table>
<thead>
<tr>
<th>Aspect</th>
<th>SAR diagnostic</th>
<th>ICP (Diparesis)</th>
<th>Spacetraps and heroes</th>
<th>Therapeutic goal</th>
<th>Improve range of mobility and handling</th>
</tr>
</thead>
</table>

**Game-like activities:**
- Little games: imitation game (proprioception and ROM)
- Big games: functional tasks “eating together”

**Immersion:**
- Narrative: The robot comes from another planet and it emitted its spaceship
- Role-play: The patient helps the “recovery” of the robot
- Theatrical Prop: Background cloth with stars

**Instruments:**
- Rewards: Dance, choreography
- Challenges: Quests proposed by the robot
- Levels: Different difficulties
- Score: Unlock new behaviors

---

Principles of Evaluation

Design of the cHRI > Evaluation

**Phase**
- Pre-evaluation
- Evaluation
- Post-evaluation

**Material**
- Patient Pre-qualification Interview
- Therapist Pre-qualification Interview
- Anthropometric, video and/or speech data acquisition
- Patient Post-qualification Interview
- Therapist Post-qualification Interview
- Motion metrics
- Video annotations

**Evaluation Factor (USUS)**

- **Utility**
- **Social Acceptance**
- **User Experience**
- **Societal Impact**

- Interviews
- Questionnaires
- Discussion groups
- Objective data:
  - Session logs
  - Motion metrics
  - Video annotations
5. **Autonomous SAR for physical rehabilitation**

6. NAOTherapist Evaluation
   - Intensive Bimanual Therapy

---

**Autonomous SAR for Physical Rehabilitation: NAOTherapist**

- NAOTherapist is a cognitive robotic architecture to develop hands-off rehabilitation sessions with a social robot for patients with physical impairments.
- Towards novel motivational physical rehabilitation procedures.
- Address the decision making using Automated Planning [Ghallab et al. 2004].
- Adaptation using rule-based expert knowledge.
  - Gamified sessions
  - Autonomous
  - Adaptive
  - Configurable by physicians
  - Easily Extensible
  - Hardware Independent

---

[Published in Cognitive Systems Research]

[Universidad Carlos III de Madrid]
NAOTherapist Implementation

NAOTherapist > Outline

1. Model of Use Case
2. Interaction Flow of the Gamified Use Case
3. Cognitive Architecture: Decision Making
4. Perception: Motion Tracking
5. Graphical User Interface

Model of Use Case

NAOTherapist > Automated Planning Model

Welcome

Training

Reward

Farewell

Unexpected situation

- detect-patient
- identify-patient
- greet-patient
- Start-training

- Mirror
- Memory
- Inverse memory
- Teaching NAO
- Dance with NAO
- NAO says

- Finish-exercise

- Finish-training?
- Give-reward
- High
- Mid-High
- Mid-Low
- Low

- Say-good-bye
- Finish-session

- claim-attention
- pause-session
- resume-session
- cancel-session
Interaction Flow of Mirror Game

NAOTherapist > Use Case

- R³ cHRI model: Request-Return-Reward
- Gamification: Immersion

How is this interaction flow controlled?

Cognitive Architecture: Decision Making

NAOTherapist > Cognition: Decision Making > Overview

Decision support compares the perceived state of the world with the expected one and provides the next coherent action.

Published in Cognitive Systems Research

Ph.D. Computer Science and Technology
Perception: Motion Tracking

An anthropometric model of the patient in terms of range of mobility of each joint according to human beings.

Graphical User Interface

Removing the engineer from the configuration process.
5. Autonomous SAR for physical rehabilitation
6. **NAOTherapist Evaluation**  
   - Intensive Bimanual Therapy

---

**Chronology of Evaluation**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>First Contact</th>
<th>Long term adherence</th>
<th>Intensive therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical settings</td>
<td>✘</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Participants</td>
<td>117</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Condition</td>
<td>TD</td>
<td>DBP/CP</td>
<td>DBP/CP</td>
</tr>
<tr>
<td>Sessions</td>
<td>1</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Frequency</td>
<td>✓</td>
<td>✓</td>
<td>weekly</td>
</tr>
<tr>
<td><strong>System</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autonomy</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Perception</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Adaptation</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
</tr>
<tr>
<td>Configuration</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
</tr>
<tr>
<td>Gamification</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
</tr>
<tr>
<td><strong>SAR-based Activities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reward</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
</tr>
<tr>
<td>Mirror</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Memory</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
</tr>
<tr>
<td>NAO says</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
</tr>
<tr>
<td>Dance w NAO</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
</tr>
<tr>
<td>Teach me</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
</tr>
</tbody>
</table>
First Insights with Patients

NAOTherapist Evaluation > First insights with patients

VIDEO

Ev. 3 – Intensive Therapy

5. Autonomous SAR for physical rehabilitation

6. NAOTherapist Evaluation
   • Intensive Bimanual Therapy
Ev. 3: Hand-Arm Bimanual Intensive Therapy (HABIT) Study

NAOTherapist Evaluation > Ev. 3: HABIT Study

- **First summer camp in Spain** that follows the HABIT methodology
  - 13/07 – 02/08: Monday to Saturday
  - 21 days, 5 hours/day
  - 10 patients with Infantile Cerebral Palsy
  - 1 or 2 expert volunteers for each patient
  - 10 consecutive sessions with NAOTherapist

- **Objective**: increase motivation and patient engagement through varied game-like activities contributing to generate a playful environment

  Dealing with the *novelty effect*

Ev. 3: 2-Step Session Procedure

NAOTherapist Evaluation > Ev. 3: 2-Step Session Procedure

- **A. SESSION CONFIGURATION (THERAPIST)**
  1) Select the gamified rehabilitation activities:
     - Mirror
     - Nao says
     - Memory
     - Dance with me
     - Inverse Memory
     - Teach me
  2) Adapt the activities to the patient
  3) Execute the session and save it in patient’s profile

- **B. SESSION EXECUTION (PATIENT)**
  - 2 - 4 activities 20 - 30 min
  - Welcome Story
  - Gamified Activity
  - Personalized Reward
  - Farewell Story

No engineer was required during the study.
Ev. 3: HABIT Evaluation Procedure

Pre-evaluation

Evaluation

Post-evaluation

Ev 3: USUS Evaluation Indicators

Objective: Evaluate each of the indicators with the administered materials
**Ev. 3: Usability / Effectiveness**

NAOTherapist Evaluation > Ev. 3: Usability / Effectiveness

**Progress:** comparing expected vs patient’s pose (anthropometric model)

Most of the patients got a progress between 5% and 15%

---

**Ev. 3: User Experience / Emotion**

NAOTherapist Evaluation > Ev. 3: User Experience / Emotion

SAM (Self-Assessment Manikin) scale

[Geethanjali et al. 2017]

Patients felt very happy, quite calm and with great control of the situation
**Ev. 3: Results**

NAOTHERAPIST EVALUATION > EV. 3: RESULTS & DISCUSSION

<table>
<thead>
<tr>
<th>Usability</th>
<th>Social Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness</td>
<td>Effort Expectancy</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Attitude towards using technology</td>
</tr>
<tr>
<td>Learnability</td>
<td>Self-Efficacy</td>
</tr>
<tr>
<td>Robustness</td>
<td>Attachment</td>
</tr>
<tr>
<td>Utility</td>
<td>Reciprocity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>User Experience</th>
<th>Societal Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodiment</td>
<td>Quality of life</td>
</tr>
<tr>
<td>Emotion</td>
<td>Working conditions</td>
</tr>
<tr>
<td>Human-oriented perception</td>
<td></td>
</tr>
<tr>
<td>Feeling of security</td>
<td></td>
</tr>
</tbody>
</table>

**Ev. 3: Enriching Experience**

NAOTHERAPIST EVALUATION > EV. 3: ENRICHING EXPERIENCE

Ep 3. Intensive therapy

- First evaluation in intensive therapy
- Lesson learned: “Every effort has its rewards”
**Evaluation Summary**

- 244 children (21 patients)
- 429 sessions (206 clinical)
- 11 relatives
- 20 experts
- 3 clinical settings
- 11 publications

**Infant-Robot Interaction Study**

7. Adaptation of Infant-Robot Interaction
   - Fixed Threshold-based Approach
   - Adaptive RL-based Approach
   - Evaluation of Approaches
**IR Study: Motivation**

- Early detection, prevention and intervention of possible developmental delays
- Infant Motion encouragement promotes a typical and healthy development

✓ Will they be able to mimic a goal-oriented task?
  **Principles of “Mirror Neurons”**
  - “Kick the ball”

- Recruitment:
  - 12 participants = 6 months

---

**Study 1: Fixed Threshold-based Approach**

- Evaluation setup:
  - Four inertial APDM sensors on both arms and legs
  - A NAO humanoid robot
  - Two suspended toy balls

- Session steps:
  1. Baseline (2 min)
  2. Demo (3 kicks)
  3. Contingency (8 min)
  4. Baseline (2 min)

- Metric: *right leg acceleration*
- **Reward activation threshold**: set to 3.0 m/s²

---

[Fitter, Funke, Pulido et al. 2019]
*Published in IEEE Robotics & Automation Magazine*
**Study 2: Adaptive RL-based Approach**

- **Objective:** Implement adaptation methods to improve SAR interaction
- **Reinforcement Learning approach** to adjust the level of difficulty (threshold)

![Contingency Timeline](image)

- **Reward activation threshold ($\theta$): adaptive after each segment**

<table>
<thead>
<tr>
<th>Level of Difficulty</th>
<th>Reward 1</th>
<th>Reward 2</th>
<th>Reward 3</th>
<th>Reward 4</th>
<th>Reward 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**RL actions:** UP, STAY, DOWN

- Can the robot influence the baby’s behavior so that s/he reaches higher accelerations?
The robot was able to encourage the infant to produce higher accelerations to get better rewards!
8. Conclusions and Future Lines

Conclusions

- Main goal:

  The design and evaluation of child-robot interaction models and frameworks for non-contact rehabilitation to augment pediatric interventions

  - The system conforms to the clinical guidelines, complies with the mandatory objectives and is useful for health professionals
  - The interaction provided by the robot guarantees an active engagement improving the patient’s experience
  - Integrating mechanisms of gamification in therapy improves motivation and, therefore, adherence to treatments
  - The autonomy provided is so robust that no engineer is required
  - SAR-based adaptation systems are able to influence on the users’ behaviors

<table>
<thead>
<tr>
<th>Robot</th>
<th>Participant</th>
<th>No.</th>
<th>Cond</th>
<th>Age</th>
<th>Autonomy</th>
<th>Perception</th>
<th>Adaptation / Configuration</th>
<th>Long-term</th>
<th>Clinical Setting</th>
<th>Clinical Results</th>
<th>Gamified sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAOTherapist</td>
<td>&gt; 200 CP OBPP TD</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>u3m</td>
<td>Universidad Carlos III de Madrid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ph.D. Computer Science and Technology
**Future Lines**

1. Improvements are projected around patient adaptation systems
2. Activity recognition
3. Facilitate the task of modeling new activities to health professionals
4. Extending the target population
5. Deepen the ethical and security aspects
6. Create a final product

**Contributions: JCR Journal**


---

* *USC* symbol refers to the studies carried out during my international internship at the Interaction Lab of the University of Southern California.
Contributions: Conferences & Workshops

- **2018**
  - **Adaptation of the Difficulty Level in an Infant-Robot Movement Contingency Study:** José Carlos Pulido, Rebecca Funke, Javier García, Beth A. Smith and Maja Matarić, on the 3rd Iberian Robotics Conference, (ROBOT 2017), on in proceedings of the 19th Workshop of Physical Agents (WAF), pp. 70-83, Madrid (Spain), November 2018. (LSCI)

- **2017**
  - **Classifying Infant Motor Development using Day Long Movement Data from Wearable Sensors:** David Goodfellow, Ruoyu Zhi, Rebecca Funke, José Carlos Pulido, Maja J. Matarić, Beth A. Smith, on the 2018 KDD Workshop in Machine Learning in Healthcare and Medicine, London (UK), August 2018. (LSCI)

- **2016**
  - **Enhancing a Robotic Rehabilitation Model for Hand-Arm Bimanual Intensive Therapy:** Enrique García Estévez, Irene Díaz Portales, José Carlos Pulido, Raquel Fuentetaja and Fernando Fernandez, on the 3rd Iberian Robotics Conference, (ROBOT), Rehabilitation and Assistive Robotics special session, Seville (Spain), November 2017.

  - **NAOTherapist: Autonomous Assistance of Physical Rehabilitation Therapies with a Social Humanoid Robot:** José Carlos Pulido, José Carlos González and Fernando Fernández, in proceedings of the International Workshop on Assistive & Rehabilitation Technology (iWART), pp. 15-16, Elche (Spain), December 2016.

- **2015**
  - **Playing with Robots: An Interactive Simon Game:** Mısra Turp, José Carlos Pulido, José Carlos González, Fernando Fernández, in proceedings of the Workshop on Social Robotics and Human-Robot Interaction (RSIM), CAEPIA 2015 Albacete (Spain), 2015.

  - **Therapy Monitoring and Patient Evaluation with Social Robots:** Alejandro Martín, José Carlos González, José Carlos Pulido, Ángel García-Olaya, Fernando Fernández and Cristina Suárez-Mejías, in proceedings of the 3rd Workshop on ICTs for improving Patients Rehabilitation Research Techniques, REFAB 2015 Lisbon (Portugal), 2015.

  - **Planning, Execution and Monitoring of Physical Rehabilitation Therapies with a Robotic Architecture:** José Carlos González, José Carlos Pulido, Fernando Fernández and Cristina Suárez-Mejías, in proceedings of the 26th Medical Informatics Europe conference (MIE), Studies in Health Technology and Informatics, vol. 210, pp. 339-343, Madrid (Spain), 2015.

- **2014**
  - **Goal-directed Generation of Exercise Sets for Upper-Limb Rehabilitation:** José Carlos Pulido, José Carlos González, Arturo González-Ferrer, Javier García, Fernando Fernández, Antonio Bandera, Pablo Bustos and Cristina Suárez, in proceedings of the 5th Workshop on Knowledge Engineering for Planning and Scheduling (KEPS), ICAPS conference, pp. 38-45, Portsmouth (New Hampshire, USA), 2014.

  * LSCI symbol refers to the studies carried out during my international internship at the Interaction Lab of the University of Southern California

Awards & Honors

- **First prize in the VI edition of “Implicados y Solidarios” de Bankinter**
- **First prize in eHealth 2017: Best initiative in robotics**
- **Third national prize Santander YUZZ 2016**

Current entrepreneurship programs:
Thank you for your attention!