Computational Intelligence and Games for at home Rehabilitation

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Summary

- Research activity in AIS-Lab
- Games and rehabilitation
- Game engines
- IGER – Intelligent Game Engine for Rehabilitation
- HCI in a Patient Station
- Modeling interaction through Stochastic automata
Applied Intelligent Systems Lab

- Many students (> 120 since 1994)
- Few staff
- Lot of work

Application driven: algorithms that can work in a reasonable time.
CHT, Randomized CHT, estimate of the center fail when partial occlusions occur. Write the probability that a point belongs to a circle with position $C$ and radius $R_C$. Minimized in 1.7ms in 2008.

$$p(C, R_C) = \frac{t}{\ln[1 + \exp(t \cdot R_C^2)]} \cdot \frac{1}{1 + \exp[t \cdot (\rho_i^2 - R_C^2)]}$$

Probability density of $\pi$ belonging to a circle as a function of its distance from the center ($R_C = 15$)

- Frosio, Borghese - Real-time accurate circle fitting with occlusions. Pattern Recognition 2008
How to track 6dof with a stick?

Frosio, Borghese, 6dof tracking, with axial markers, Submitted Med. Eng. and Comp. + patent pending
Density reduction with filtering

EVQ – Soft clustering with setting of para and fast processing (Ferrari, Ferrigno, Piuri, Borghese. Reducing and Filtering Point Clouds with Enhanced Vector Quantization. *IEEE Trans. on Neural Networks*. 2007 (1:10 points reduction).
Learning and multi-variate function approximation

HRBF networks with adaptive allocation of units on the grid. Local computation of the coefficients. Uniform error over the whole domain.


Recent generalization to SVR

Target function

SVR ($\sigma = 0.05$)

SVR ($\sigma = 0.015$)

\[ f(x) = \sum_{i=1}^{n} \beta_i k(x, x_i) \]

Time consuming. Optimize For ($\varepsilon$), $\sigma$, $C$, max value of $\beta$.

Circle dots are SVs. Shall we need all? $\Rightarrow$ Pruning

Approximation adding scales

Simple optimization problems
Other applications

Alamia, Borghese, Creating long gait animation sequences through Reinforcement Learning

Rossini, Quadri, Borghese Clever Pacman Fuzzy RL applied to games

java pacman.PacmanMAIN
Digital Radiography

Work on real machines and saw the final product (for dentists, but we did not become rich!).

Soft-tissue filtering

3D local tomography
http://www.my-ray.com/


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• Increase of rehabilitation need.
• Prolonged intensive rehabilitation allows recovering and/or maintaining health conditions.
• National health providers are facing budget cuts.
ICT recent developments have made possible facing the challenge
The scenario

A sitting room with a TV screen sufficiently large and some space to move
A kinect and/or a balance board for tracking

We start thinking of the PC as an embedded system (just power on/off)
Gesture + voice commands.
The REWIRE hierarchy (3 levels)

- **Data mining**
- **Management**

- **Data analysis**
- **Configuration**
- **Community**

- **At-home rehabilitation**
- **Play games**
- **Data recording**
- **Communication with hospital**
Why games?

- Our aim is to create *videogames for rehabilitation*

- Rehabilitation will benefit from games...
  ... for increased motivation
  ... for decreased repetition
  ... for a more comfortable experience
  ... for fun!
Commercial games close to rehabilitation

- Engaging (create even addiction)
- At home

Why not to use these games to guide rehabilitation?

Similar concepts apply to Wii Sports
Games proposed for rehab

RGS – Rehabilitation Gaming System (Cameirao et al, 2010)

- Used in some domains
- At home

Why not endorse these games to guide rehabilitation?
Novel game engines are required

These approaches do not close the loop

Shall we afford the patient to do rehabilitation alone? These approaches seem far for providing a virtual therapist.

How can we avoid maladaptation? How can we avoid boreness? Intensive rehabilitation would be allowed at home. Correct execution of the exercises should be guaranteed.
The game technology: Low-cost rush

Nintendo Wii
19-Nov-2006

Sony PS3 Cam
23-Oct-2007

Wii Balance Board
01-Dec-2007

Unity: 3D Game Engine
Since 2006, now partially open source, version 3.5

Sony Move
15-Sept-2010

Microsoft Kinect
10-Nov-2010
SDK released
9-March-2011

Panda3D: 3D Game Engine
Since May 2008, open source, version 1.8.0

OpenGo
June-2011

Trackers at low cost with high performance and motion data
High level interactive graphics
The requirements

**Functional Specifications**
- Configuration (Rehab)
- Adaptation (Rehab, some)
- Monitoring
- Data acquisition (Rehab)

**Technological Specifications**
- Easy interface (commercial)
- Engaging (commercial)
- Variety
- Multiple devices

Commercial games lack functional specifications for rehabilitation and multiple device support.

VR rehab is not created with good game design practices in mind.

A new approach is needed to fulfill all requirements.

Intelligent Game Engine for Rehabilitation (IGER)
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• «A *game engine* is a system designed for the creation and development of *video games*.””

(Wikipedia)
The game engine

Assets: environments, models, avatars
Scripts: flexible logic.
An example: Panda3D

- Panda3D is an open-source game engine
  - Built from a collaboration between the Carnage Mellon University and Disney
  - Still active and growing today!
  - Written in c++, with python bindings

Unity is the most diffused alternative
Why using a game engine?

- Instead of creating a single game, or multiple different games, we obtain a framework for creating many games!
Research activity in AIS-Lab
Games and rehabilitation
Game engines
**IGER – Intelligent Game Engine for Rehabilitation**
HCI in a Patient Station
Modeling interaction through Stochastic automata
IGER

the Intelligent Game Engine for Rehabilitation
IGER

- **Intelligent**
  ... as it is provided with computational intelligence algorithms

- **Game**
  ... as it supports and encourages play

- **Engine**
  ... as it is a software system designed for creation and development

- **Rehabilitation**
  ... as its focus is on rehabilitation, unlike other game engines
What we have added to a classic Game Engine (through scripting language)

- Multiple device support
- Natural user interfaces
- Heavy parametrization and configuration
- Monitoring
- Adaptivity
- Controlled variability
- Virtual therapist
- Input abstraction layer
- On-line *Adaptation* to the patient
- On-line *Monitoring* of the patient’s posture
- Off-line *Configuration* of the games and exercises
Game as a proof of concept

Catching fruit with a virtual basket – balance coordination: body shift, steps. Kinect and/or balance board (video: MonitoringVideo.wmv).
Definition of a weekly rehab program: mix of exercises for increasing force and coordination.

Possibility to progress along the degree of difficulty. Standing -> Body shift -> Walking step -> Dual tasks

The **level** of the exercises should be defined (intensity, amplitude....).

**How can we translate this into games?**

Single game may address more than one cluster. E.g. Falling fruit standing, with a shift forward or lateral, with a step, holding something real or virtual in hands.
Configuration GUI

Game: Fruit Catcher
Input: Balance Board
N repetitions: 5
N trials: 10

Parameters:
- Fruit Range:
  - R: 10 to 200
  - L: 10 to 200
- Fruit Dimension: 1 to 5
- Fruit Gravity: 0.5g to 5g

Visual Result
Score: 100
Explore more the offended body side (more frequent)

Shorter range of falling on that side.

Smaller range of movement in the offended body side.
Smaller range of falling fruit.
Lower frequency of falling fruit.

....
We have to avoid maladaptation (constraints on posture have to be defined)
On-line game adaptation

Therapist point of view: Exercise intensity / amplitude
(amplitude of motion, speed...)

Game designer point of view: level of challenge.
• Aim 1: Cater to the patient’s limits
• Aim 2: Avoid repetivity
• Aim 3: Increase challenge (too easy!)
• Aim 4: Avoid frustration (too hard!)

We want to maintain the proper challenge level

Video: adaptationVideo.wmv
Previous attempts – Colombo et al. 2007

Colombo et al. 2007 J. NeuroEng. and Rehabilitation

Configuration

Simple adaptation (100% tasks completed -> larger range)

Heuristic adaptation (50% mean velocity + 90% all tasks -> change in level of difficulty)
Previous attempts – Cameirao et al. 2010

- Characterization of the game in psychometric terms
  - Speed    Interval    Range    Size
- Performance = f(S, I, R, Z) has to be estimated. Such function is a second degree polynomial (1 + 4 + 6 + 4 = 15 parameters)
- 12 stroke patients + 10 normal subjects played the game with 256 combinations of 4 values for each parameters to estimate the regression parameters.
- The model was identified with the data on normal subjects and only S, I, R were determinant with S-I, S-R and I-R interaction resulting into 1 + 3 + 3 + 3 = 10 parameters.
- The resulting model was fitted to the patients.
- Fitted on the not paretic arm. Rehabilitation of the paretic arm.
  - Fitting it to the paretic arm would have required re-estimate often the parameters.
Previous attempts – Zimmerli et al. 2012

- Physiological models: Fitt’s law
- Performance = \[ \text{Time} = a + b \log_2(1 + \frac{\text{Distance}_\text{moved}}{\text{Width}}) \]
  - 2 parameters. Distance in the frontal plane between start and target.
- 3 conditions
  - \( T = 2 \times \text{Time} \) (Easy)
  - \( T = \text{Time} \) (Medium)
  - \( T = 0.5 \times \text{Time} \) (Hard)
- No adaptation
Our psychophysics approach  
(based on Quest – Watson & Pelli 1983)

Let us consider a set of trials that can have as an outcome: success / fail and that depends on a variable $x$ (e.g. the position). We want to set a value of $x^* = T$ such that the rate of success $R = R^*$. 

Let us write $y = p_T(x)$ – $x$: input variable (e.g. Position), $T$: threshold (on position, determines the range) $y$: outcome.

1) The Psychometric function, $p(.)$, has the same shape under all variable values. It translate along the variable possible values. 
\[ p_T(x) = \psi(x - T) \] with $T$ the actual threshold

2) $T$ does not vary from trial to trial

3) Individual trials are independent.
Prior Knowledge

- We may have experiments that give some information which can guide in the selection of an initial threshold value (e.g. Knowledge of the therapists, trials in the hospital).
- We can identify the most adequate value for $T$ and assign a statistical distribution to it, typically Gaussian.

$$f_T(T) = G(T, \sigma)$$

This codes an a-priori information on the threshold on the position (the range) and it does not depend on the outcome of the trials.
From the data observed, we can write the likelihood of the data, given a threshold $T$: $f_{D|T}(D \mid T)$

Considering the a-priori distribution of $T$, we can write the Bayes theorem and find the optimal threshold, considering also the data, as the maximum of:

$$T_{next} = \max_T \frac{f_T(T \mid D)}{f_D(D)} = \frac{f_T(T)f_{D|T}(D \mid T)}{f_D(D)}$$

The data here are sequences of success / fail: $D = \{S, S, F, S, F \ldots\}$ $T_{next}$ is the threshold for the next trial (experiment)
Implementation of Quest

\[ T_{next} = \min_T (Q(T)) = \min_T \left\{ \ln f_T(T) + \ln f_{D|T}(D \mid T) - \ln f_{D}(D) \right\} \]

\( T_{next} \) is chosen such that \( D \) tends to a given success rate.

\( Q(T) \) Quest function =

\[ Q(T) = \ln f_T(T) + \sum_{i=1}^{n} \ln(p_{result|T}(x_i)) \]

Responses are statistically independent

Given a threshold \( T \), the probability of having a

- Success is \( p(x_i) \)  \( \Rightarrow \)  \( \ln(p(x_i)) \)
- Failure is \( 1 - p(x_i) \)  \( \Rightarrow \)  \( \ln(1 - p(x_i)) \)
Translational invariance property

\[ Q(T) = \ln f_T(T) + \sum_{i=1}^{n} \ln(p_{\text{result}}|T(x_i)) \]

The function \( p_T(.) \) is translational invariance, therefore we can write it in the more convenient form:

\[ Q(T) = \ln f_T(T) + \sum_{i=1}^{n} \ln(\psi(x_i - T)) \quad \text{success} \]

\[ Q(T) = \ln f_T(T) + \sum_{i=1}^{n} \ln(1 - \psi(x_i - T)) \quad \text{failure} \]

At each trial the log of the function \( p(x) \) (or \( 1-p(x) \)), centered in \( T-x \), is added.
Which shape for $p(.)$?

- In psychophysical Weibull distribution is used and log of intensity is considered.
- In games we adopt a Logistic probability function with a linear region defined as a function of $T_{ini}$.
- Most games have range of the targets and speed of movement. We prioritize on speed.
- A more complex statistical framework that considers statistical interactions between the input variables is future work.
On-line game adaptation

Therapist point of view: Exercise intensity / amplitude
(amplitude of motion, speed...)

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Video: adaptationVideo.wmv
Monitoring

- On-line monitoring of chosen measurements
- Our solution: Fuzzy systems + Feedback
- Knowledge of the therapist encoded in the monitor through (fuzzy) rules

![Diagram showing head and upper body tilt angles with fuzzy sets: ok, risky, bad, wrong.](image-url)
Fuzzy reasoning inspired by therapists

If ..... or ..... then Max Tnorms

If (trunk largely_tilted) then high_level alarm
If (head small_tilted) or (several alrms before) then low_level_alarm

The output is an alarm level and the cause
Virtual therapist

- Smiles 😊
- Virtual therapist (puppetry)
- Virtual therapist (Hannah)
- Real therapist
Monitoring implementation

Video: monitoring3.wmv
Interaction between monitoring and adaptation

Blocks or mitigates adaptation.

When an alarm is raised because of maladaptation or wrong execution, adaptation has to be mitigated and modified only in a facilitating direction.

Secondary monitoring level.

More information in:
M. Pirovano, R. Mainetti, G. Baud-Bovy, P. L. Lanzi, N.A. Borghese (2012), Self-Adaptive Games for Rehabilitation at Home, Proc. IEEE Conference on Computational Intelligence and Games
http://www.rewire-project.eu
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Scene Flow

- PS Menu
- Schedule
- Game Menu
- Instructions
- Introduction
- Game
- Summary
• Paradigm of choice: make the interface natural to use
• This is an important point when dealing with impaired patients and the elderly
• Usability concerns are stricter than with other users!
The controls of the menus are abstracted through a **Command System**.

Using any device, the end interaction will be the same: through the buttons on the screen.
Gesture Control

- Control of the menu using one’s hand gestures
- Implemented using the Kinect SDK skeleton tracking
- Supports gestures and position checks

Video: gesture.mp4
Speech Control

- Control of the menu using one’s voice
- Implemented using Microsoft Speech SDK
- Supports many languages

Video: Speech.mp4
Thank you for your attention!

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  - Renato Mainetti
  - Isabella Cattinelli
  - Max Goldwurm

- [www.rewire-project.eu](http://www.rewire-project.eu)
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