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Scuola Superiore
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A Flexible Framework for Mobile Based Haptic Rendering

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Premises

support cognitive and sensorimotor rehabilitation of impaired subjects

In 2011 we proposed the MOTORE device. MOTORE was conceived as a tool to ease domestic, robot aided, neuro-rehabilitation;

First of his kind, the device is a desktop-mobile vehicle which integrated force feedback through the direct control of the spin in its wheels;

MOTORE is an autonomous system which includes a local microcontroller and a wireless system to communicated with a remote PC;

The initial release of the MOTORE system included 1 exercise allowing to experiment 8 different trajectories. The exercise was fully programmed onboard.

First analysis results (Requested improvements)

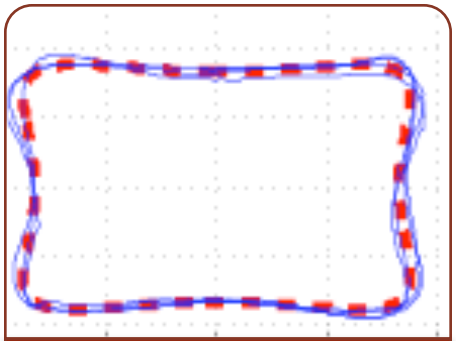
Required Feature

- Allow therapists to manipulate guidance behaviors (stiffness, viscosity);
- Adapt workspace size and trajectory location to patient;
- Introduce, Vary and design different rehabilitation tasks;
- Monitor and score all data relevant to patient performances;
- Introduce guards and active effects to assist the subject in terminating job.

Required Tasks

- Trajectory follow;
- Free point reach;
- Complex gestures (e.g. washing-dishes)
- New and flexible geometries;
- Dynamic path and velocities

Exemplary Tasks



Path Following

Motion Racing

Sequencing Task

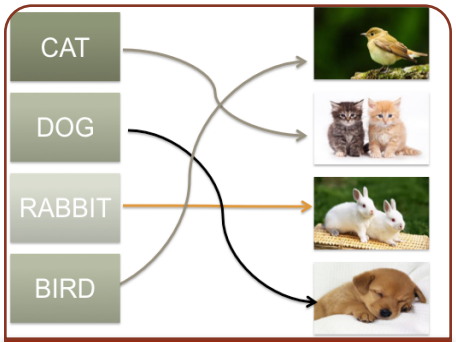
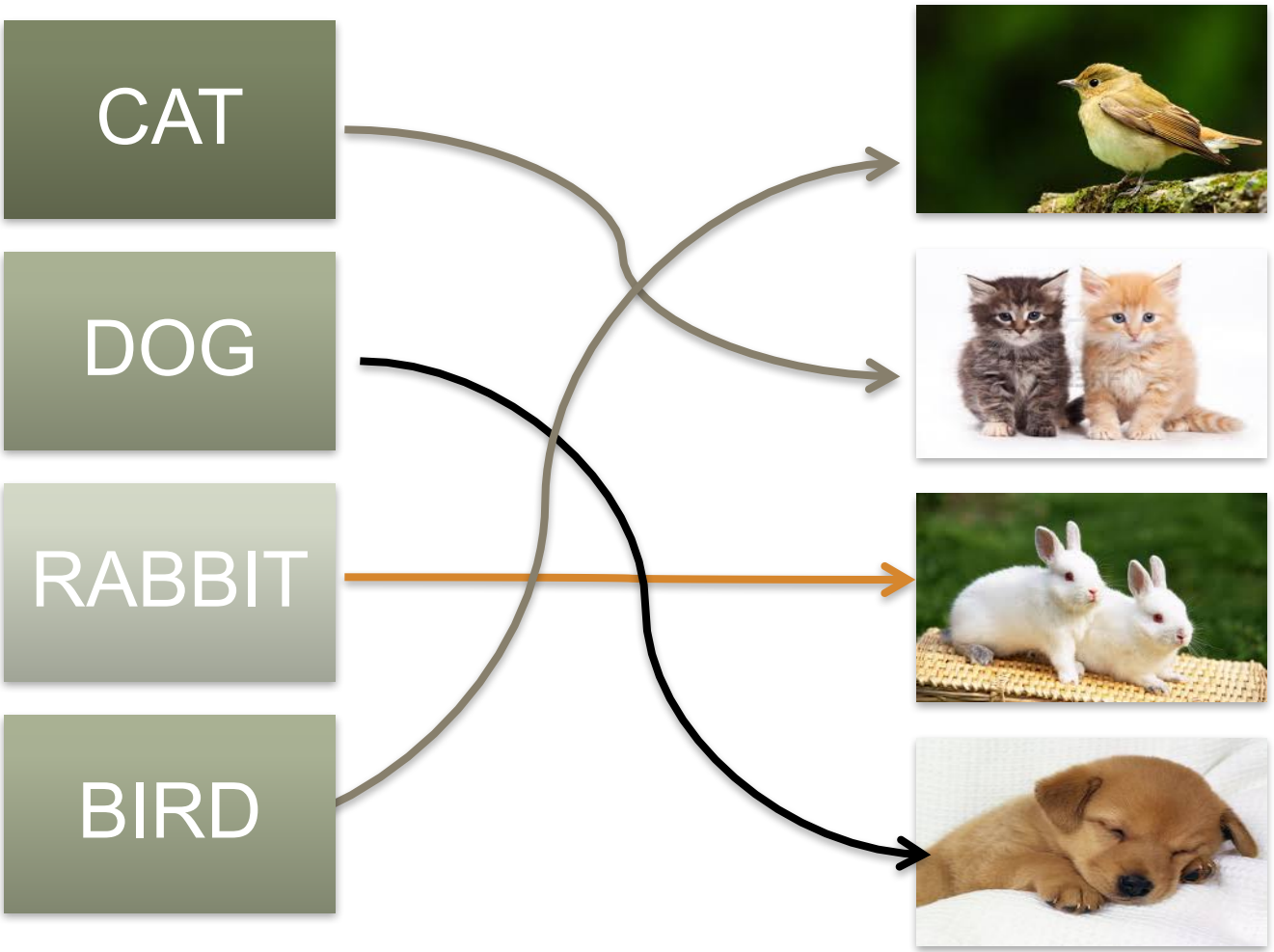


Image Association

Association Exercise



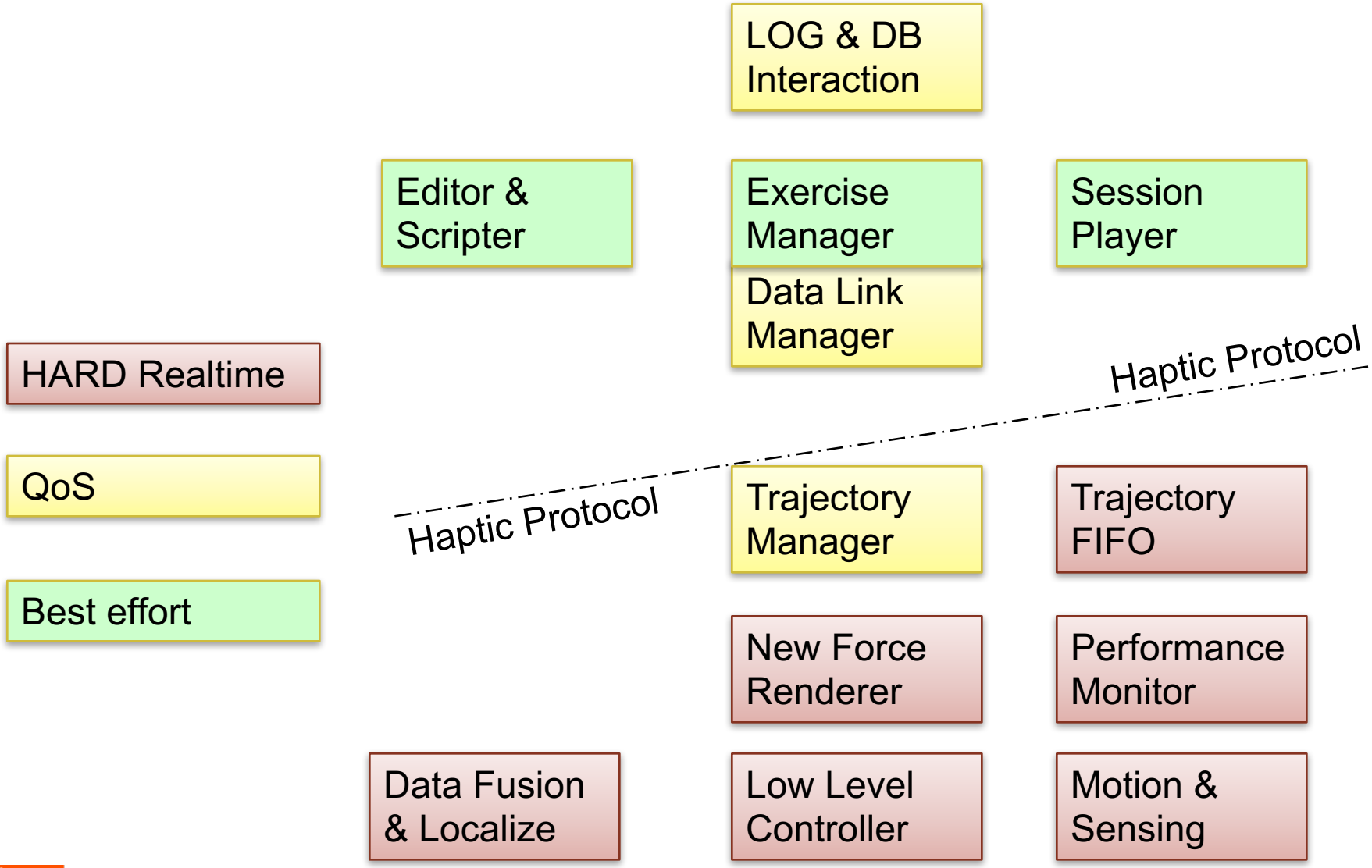
The Challenge

Pre-Defined control algorithms have not enough flexibility	Opening control schemes jeopardizes stability and safety of the subject

The requested features required a switch from a pre-defined (and close) architecture, to a unknown, variable and dynamic environment.

How to allow all the requested flexibility by preventing that an improper Use of the design tools jeopardize user safety or creates instability?

The Proposed Approach



Haptic Rendering Scheme

A new Haptic Rendering Scheme is at the core of the framework.

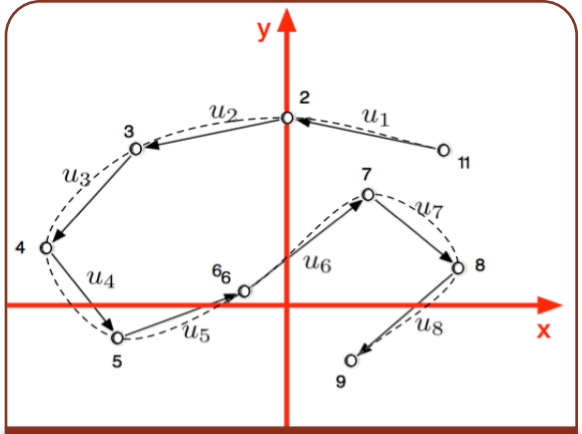
It has been designed to decompose:

- safety issues (which are managed at low level by the controller),
- And, interaction issues (which are implemented at higher level from the remote player);

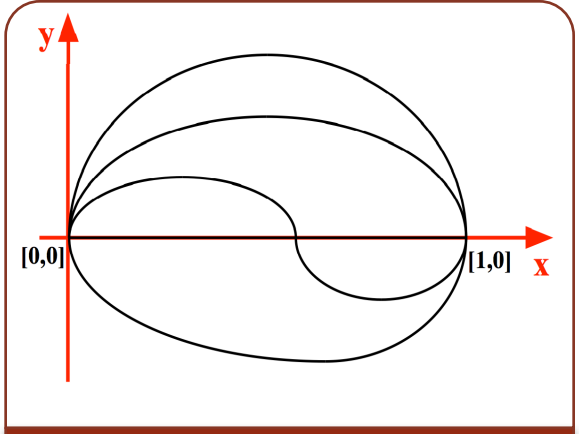
The scheme has been enriched with a set of dynamic property to allow self triggering of effects at low level.

- Motion are programmed to a predefined set of spline models (geometries);
- Each spline carries an end destination point and the effective geometry is determined at low level;
- Splines may be rejected from the low level controller is they jeopardize stability;
- The behavior of the device in the starting and ending points of a spline can be changed to allow spline streaming;
- Admittance/Impedance behavior can be changes

Spline definition and tools



Trajectories are defined through spline sequences in the editor;

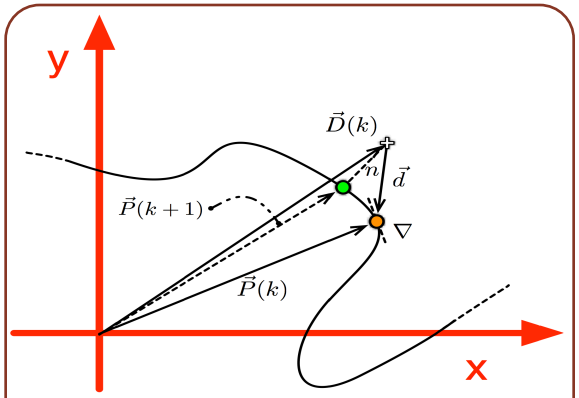


Each spline is converted by the editor into an appropriate set of 3rd order multipoint model;

$$\begin{cases} x = a_{x_i} + b_{x_i} u_i + c_{x_i} u_i^2 + d_{x_i} u_i^3 \\ y = a_{y_i} + b_{y_i} u_i + c_{y_i} u_i^2 + d_{y_i} u_i^3 \end{cases}$$

$$l(k+1) = l(k) + \alpha \left(\left[\frac{\vec{d}(k)}{|\vec{d}(k)|} \right]^T \frac{\vec{\nabla}(k)}{|\vec{\nabla}(k)|} \right)$$

These model have been chosen as a compromise between smoothness and computational load;



An internal NR minimum distance algorithm allows to define traditional Proxy

New Force Renderer

Combines feature from Impedance and Admittance controllers

Impedance Controller

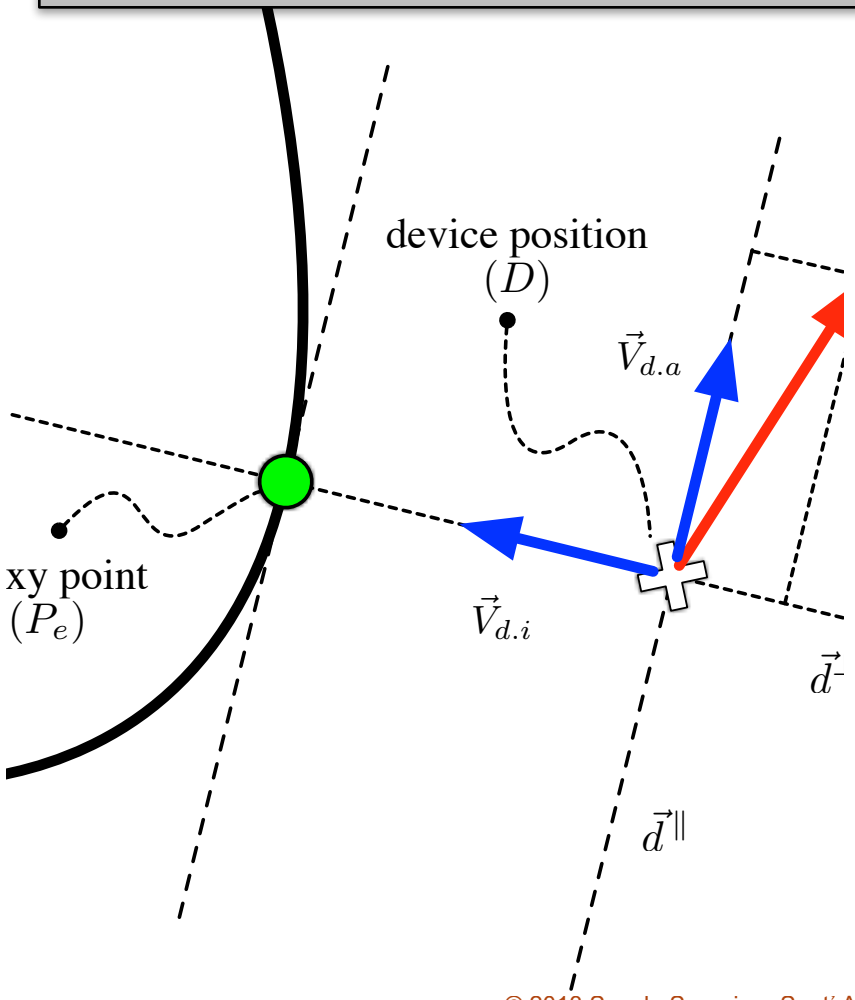
$$\vec{F}_r = -Z(\vec{D} - \vec{P}_e)$$

+

Admittance Controller

$$\vec{V}_r = \vec{F}_S/(Ms+b)$$

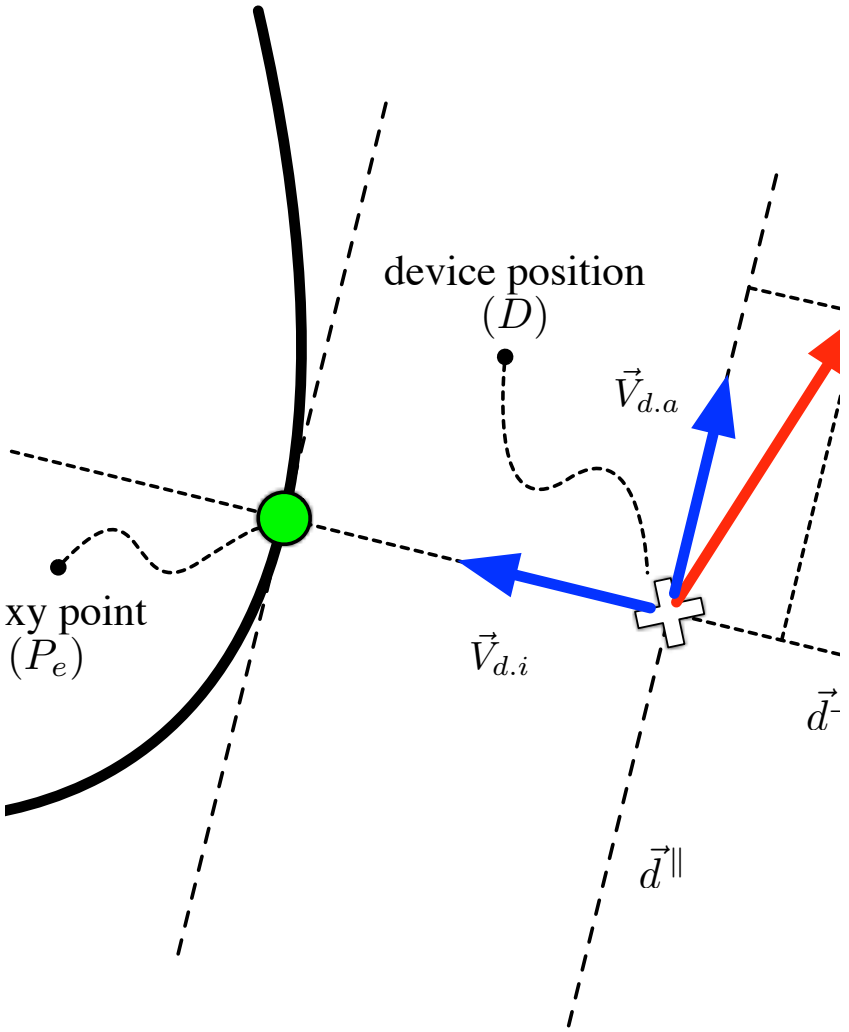
The Force Renderer is based on the current position, the proxy information and the spline geometry



The Force Renderer Benefits

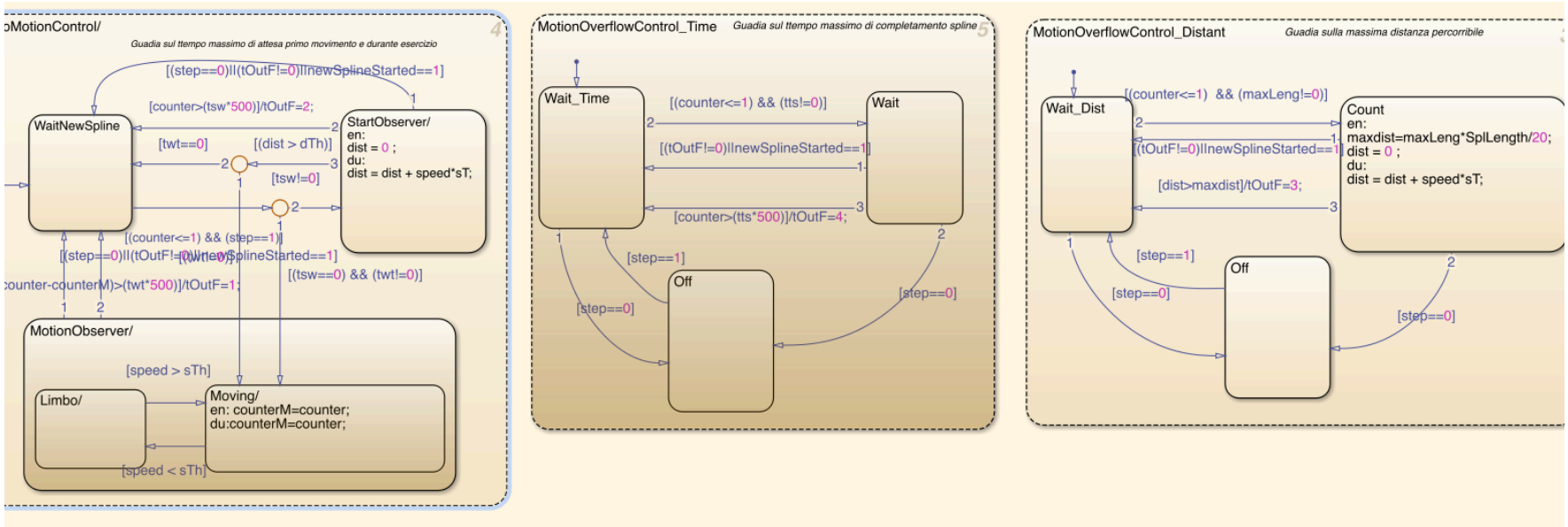
- Works with analytic trajectories
- Free motion, contour following, trajectory following, and constrained velocities
- In steady state collapses to impedance (k1/k2);
- Allow decoupling motion direction from constraint
- Sensitive to very low user forces and Intrinsically stable

$$\begin{cases} V_{\vec{d},i} = (k_1(\vec{P}_e - \vec{D}) + k_2\vec{F}_S) \cdot \vec{d} \\ V_{\vec{d},a} = (\vec{F}_S \cdot \vec{d})/(Ms + b) \\ V_{\vec{d}} = \gamma V_{\vec{d},i} + (1-\gamma)V_{\vec{d},a} \end{cases}$$



Performance Monitor & Guards

- The Performance Monitor monitors the state of the currently running spline (in percentage and length);
- During run if collects all the motion and force related information (length, active and passive work, energy);
- Through the use of Guards it also monitors the active and resting timings of the trajectory to solicit automatic completion features.



Four Types of Guards: Total duration, Total Length, Max Start wait, Max running wait

Trajectory FIFO Manager

Each spline change is managed automatically at low level when the previous spline is completed;

A number of preconditions should be met to allow spline switching (see code)

If a trajectory is rejected the ending condition of previous trajectory apply (stay on spline, lock to endpoint, free)

```
 * Here We check that the candidate spline curvature is not
 * compromising the safety condition.
 */

int EvaluateSpline(real32_T *CurrentPos, real32_T *Dest, int16_T
SplineType)
{
    int Fail = 0 ;
    /**
     * We use the current position, the spline orientation
     * and the new spline information to determine the candidate
     * spline geometry.
     */
    GenerateSpline();

    /**
     * First we check continuity on the normals (a maximum
     * direction chancge is allowed between splines)
     */
    Fail = CheckDirection();

    /**
     * Here We check that the candidate spline curvature is not
     * compromising the stability condition.
     */
    Fail = CheckCurvature();

    /**
     * Then we check that the whole spline is within the allowed
     * workspace.
     */
    Fail += CheckWorkspace();

    /**
     * Finally we avoid higher switching rates which can cause
     * stability issues at lower level (compromise pole
separation).
     */
    Fail += CheckSwitchRate();

    if (Fail) RejectSpline();
    else SetNewSpline();
}
```

Exercise and Data-Link Manager

GUI interface

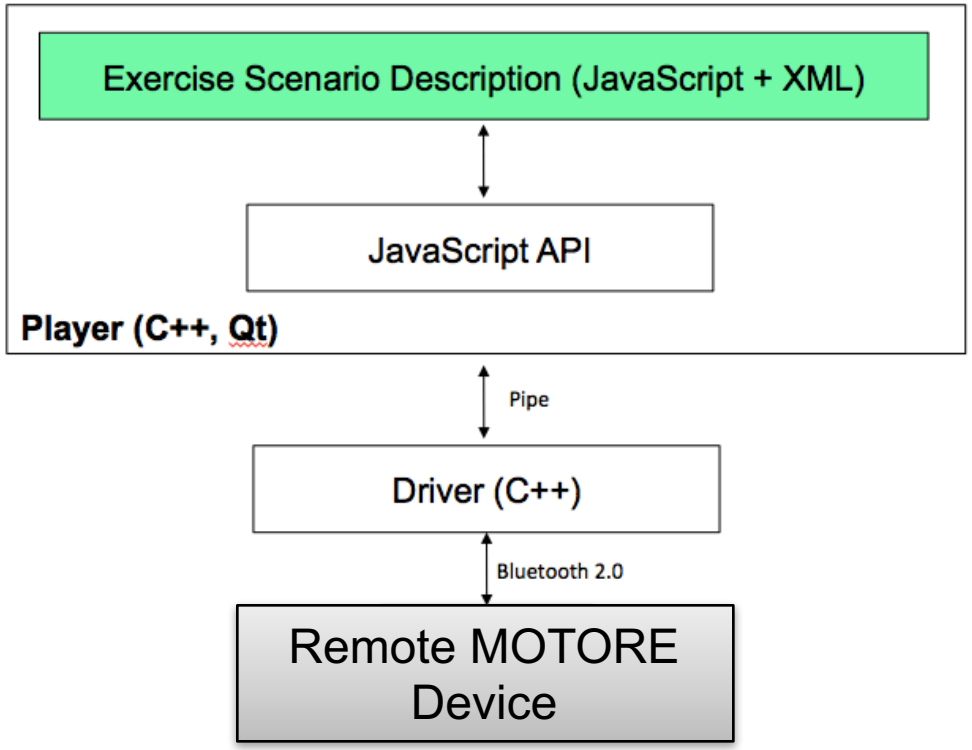
- Developed in a portable environment through Qt;
- Versatile operation as editor or player.

Scenario-Exercises manager;

- Scenario DOM from DB
- Session Management
- Client side scripting also allow complex animation effects.
- Spline generation from scenario.

Device driver (C++):

- Custom Storage
- Device Management
- Spline Management



Storage and retrieval of realtime data

Scenario's data (XML);

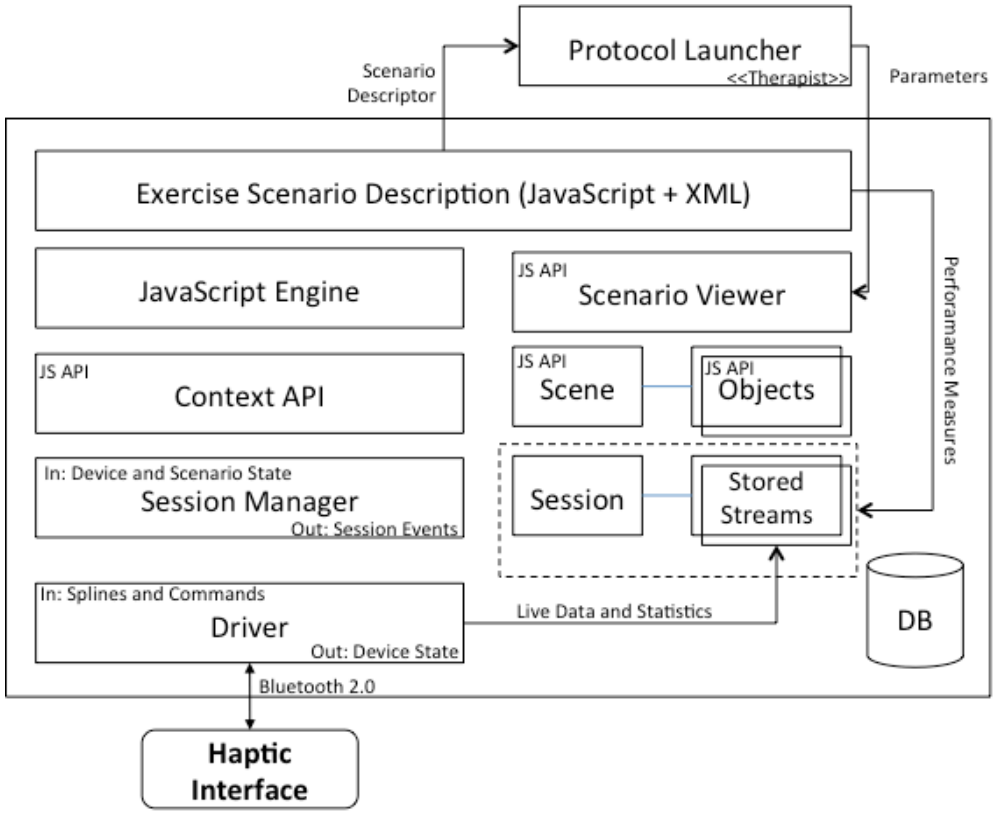
- Elements of the Scenario DOM
- Image Sprite
- Audio Elements
- Spline Template
- Trigger Region

Patient data

- Personal Info
- Experiment Info & Record
- Collected statistics
- Runtime device log
- Runtime session log

Visualizer

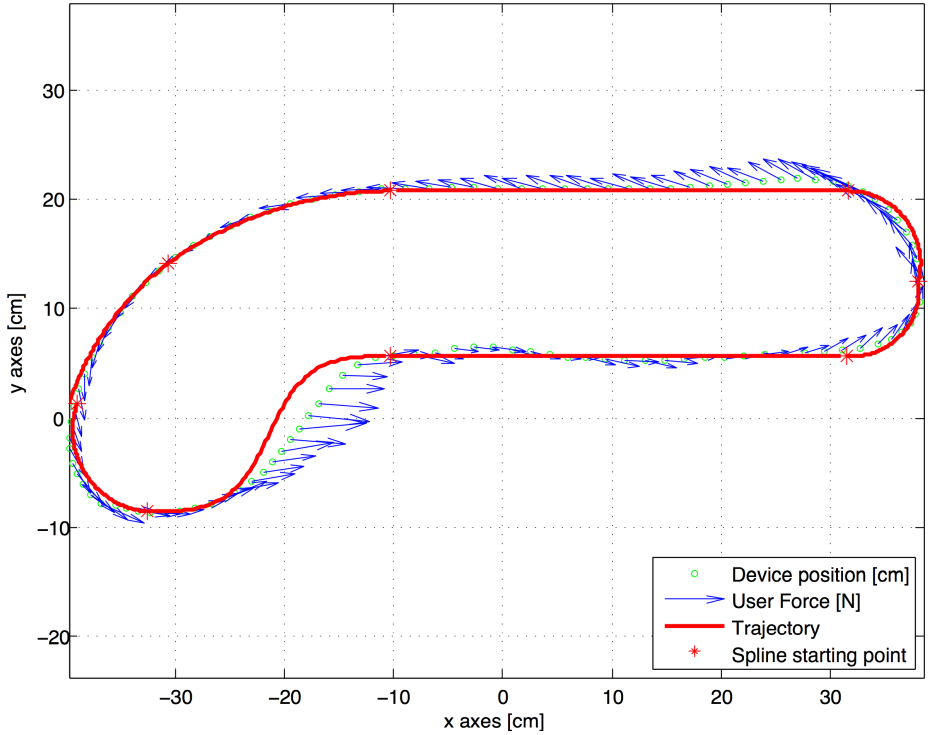
- Data retrieval
- Visualization filters



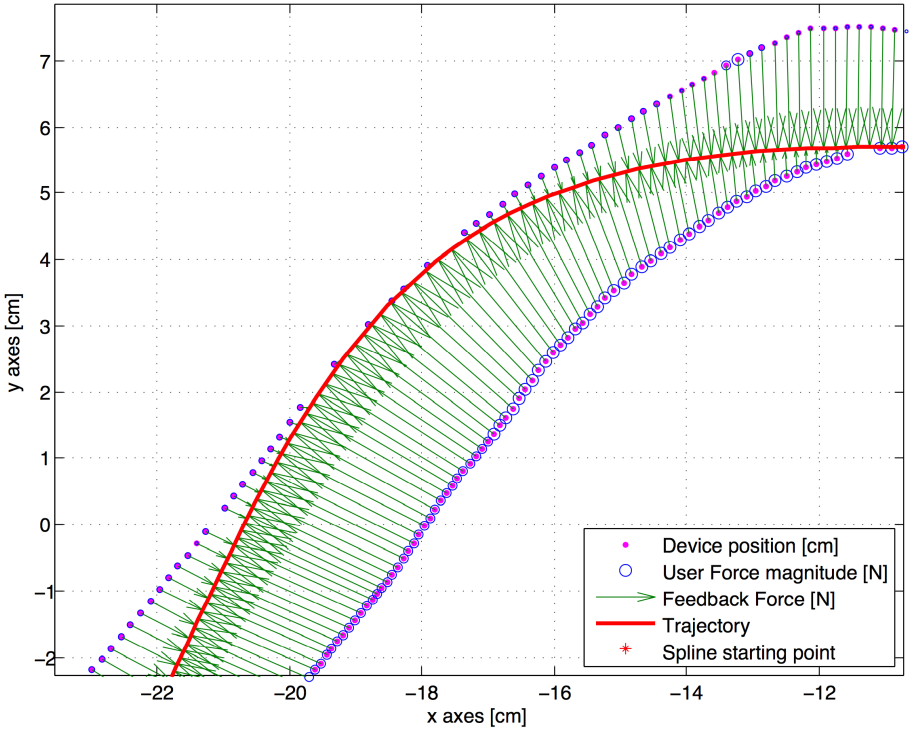
The Editor And Player

Performance analysis of spline switching

Spline Parts Switching

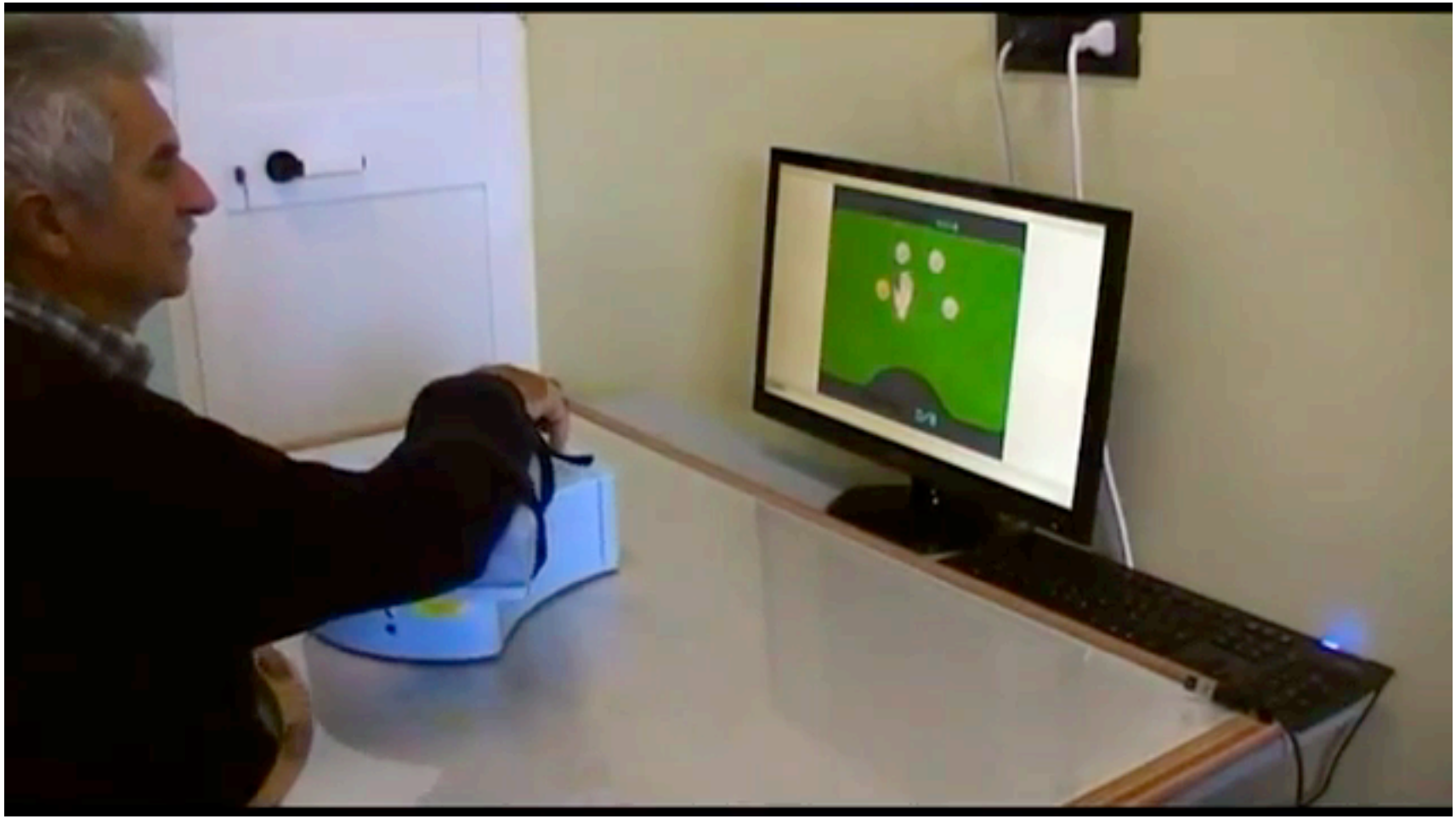


Results of Force Feedback



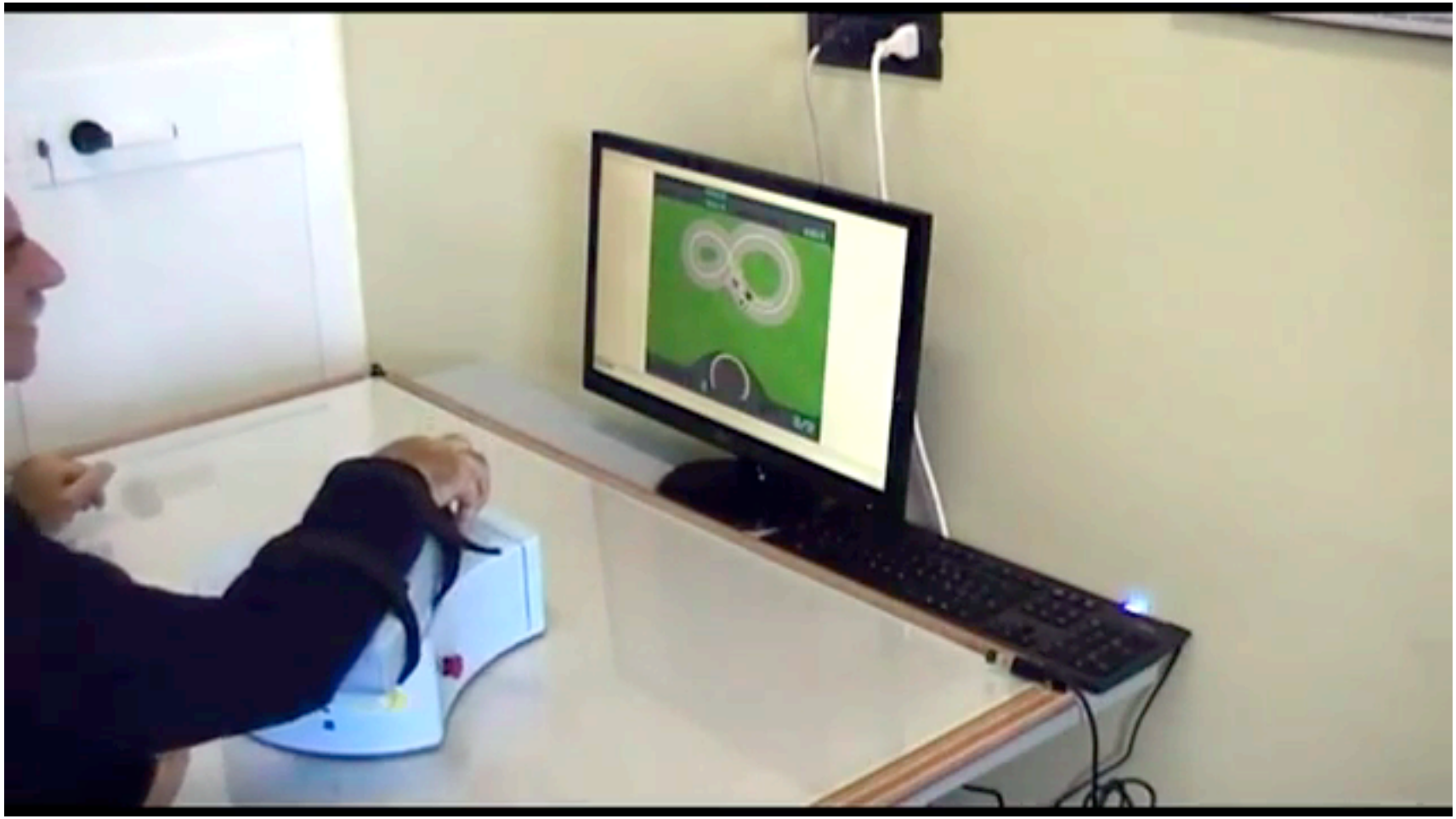
Trajectory

Reaching



Association

Cars



Scores

Conclusion

- A new framework to deliver haptic information through wireless connection was developed;
- The Haptic processing has been decomposed into a stream of properties which can be downloaded with given QoS;
- A new low level haptic renderer was required to support the needed flexibility;
- Relevant mechanisms to ensure comfort of operation as well as safety criteria were developed;
- Performance test showed proper behavior of the framework, both from the rendering PoV as well from the spline-streaming PoV;
- Three copies of the device are operating since Sept. 2012 in different Tuscany clinics;

Future Directions

- Data will be presented when consolidated and available
- Rehabilitation Results
- HTML5 based scenarios for improved flexibility and portability

THANK YOU FOR YOUR ATTENTION

QUESTIONS ?

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