Digital Management and Representation of Perceptual Motor Skills

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ABSTRACT

In this chapter we address the issue of combining the design of interactive virtual environments with complex human data analysis schemas. A guideline of such a design in order to improve usability, efficacy and intuitiveness of the data content is also being addressed.
The work presents a new system to manage and analyze the experimental data which are collected over time across experimental trials which involve different subjects and may span across years. A complete data workflow has been setup within the system.
The system supports data acquisition and organization which is based on a self organizing, graphically edited digital format. The system architecture is interoperable by multimodal virtual environment and provides facilities to interact in real-time with complex data formats such as haptic, audio and video streams.
The architecture is portable across most operating system and makes use of a standard database format allowing simple data sharing.

Keywords: Multi Modal Interaction, Digital Representation of SKILLS, Digital Repository

INTRODUCTION

The growing complexity of systems is increasing the complexity of experimental data management. In some research disciplines new tools for automatically handling of data are appearing such as biological data (Pacific, 2008), statistical data (Reading, 2003), chemical data (IDBS, 2010). Usually, dedicated programs, commonly known as Laboratory Information Management Systems (LIMS), handle data management from the early design up to publishing results. Among these the BioArray Software Environment – BASE – (Saal et Al., 2002) demonstrated the management of microarray data in genetic research.
Experiments within Virtual Environment (VE) commonly provide user with a huge amount of data. The adoption of database systems in handling data for Haptic Interfaces was pioneered by Yokokoji and Henmi (Yokokoji, 1996; Henmi 1998). Their system stored human motion as a reference for later haptic guidance. In such a system the sensori-motor actions were collected from experts to a database. Yokokoji's database simply recorded force and position data to be forwarded to a specialized impedance controller. By following the Yokokoji approach several authors have later tried to integrate the basic database representation with more advanced systems which included elements of artificial intelligence: Sano (Sano, 1999) proposed to integrate these system with a set of Neural Networks which can model and generalize over task variability; Calinon (Calinon, 2006) employed a structured approach to cope also with non stationary properties of human actions. In this case, PCA was used to extract the relevant component of motions while mixture of probability density functions described the correlation among inputs/outputs.
However, the application of LIMS architecture to virtual environment is not suitable. LIMS systems consider the storage and analysis process as a component independent from the experiment itself, while VEs involve a deeply interaction between collected data and human behavior. This is even truer when considering recent developments on VE systems that include high level artificial intelligence to modify the response of the VE itself.

The system introduced by this chapter deals with a digital representation system that enables the capture, storage analysis and real-time interaction of human motion data. The system supports complex data structures, long term management and manipulation of the real-time feedback required by the interaction in the environment.

SYSTEM ARCHITECTURE

The proposed Data Management System is designed along two orthogonal issues:

- The data content: data content relates the formats that will be employed and ensure that whoever is storing/retrieving information from the system feed it (or is feed) with a minimum requirement of information. To this purpose a specific (extensible) standard has been developed in order to make coherent the data organization: Multi Modal Data Format (Ruffaldi E., 2009);

- The data management: a set of portable tools that supports the storage and retrieval of data: the Digital Repository (Avizzano, 2009).

The storage engine, SQLite, was preferred with respect to other standard formats like HDF-5 (Chilan, 2006) for its implicit capability and flexibility of structuring data by tagging, linking, and attributes, and the additional features offered by relational features.

The Multi Modal Data Formats (MMDF) considers that information can be grouped in classes accordingly to an efficient R-Tree hierarchy (Guttman 1984). Six levels of hierarchy have been predefined in order to facilitate the organization of the data gathered from any interactive session.

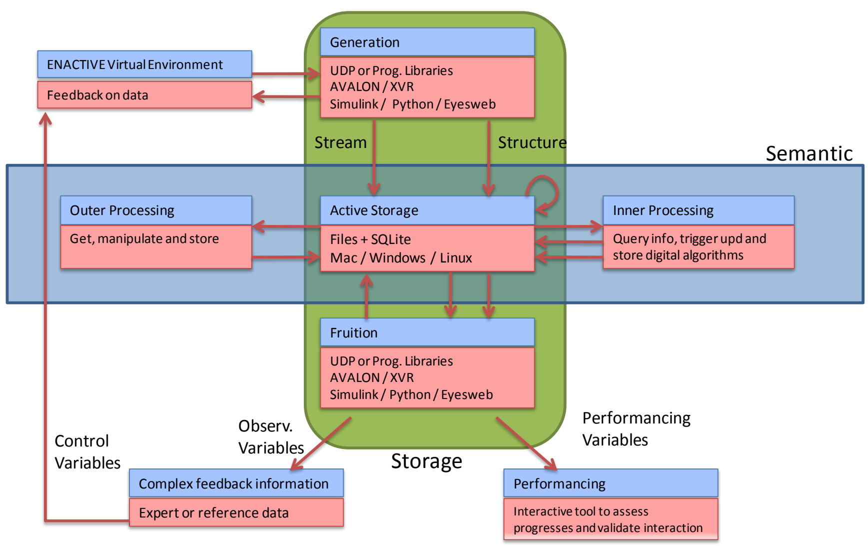


Figure 1 Digital Repository functionalities

All the available tools are built on the Datakit, and engine which embeds the data storage and offers a unique level of C-functionalities available to different development languages. The choice of using a Datakit ensures that portability and maintenance of repository functionalities in much faster. The Datakit is available as a library on Linux, Mac and Windows operating systems, and its calls have been exported to C, Python, Matlab Simulink and 3D interaction toolkits such as XVR (Carrozzino, 2005) and AVALON (Behr, 1998).

Digital Repository tools is complemented with three development interfaces: a Python Library, which is intended to implement by Python code higher level processing on data and complex GUI interactions; A Simulink ® library that combines the storage process with a unique graphical interface that simplifies the process of creating data structure in the database in the process of interconnecting three of graphical blocks in its interface; A Matlab extension class library that links the Digital Repository tools with those numerical functionalities available from the Matlab community.

USING THE DIGITAL REPOSITORY

Most of the Digital Representation functionalities have been implemented as a Simulink extension (a 'toolbox'). The toolbox makes use of Python calls to map digital representation concepts into intuitive graphical interactions. The root of the integration is a basic block that masks the access to specific locations of MMDF structure. Additional nodes (the Data Entities) can be cascaded to the database root by creating a graphical tree. The toolbox provides to map such a tree into a respective relational hierarchy in the database. This is possible because each Data Entity can simultaneously act as a child (using its input ports) and as an ancestor (using the specific output port). The toolkit deeply interacts with the Simulink initialization and simulation procedures in order that this graphical interconnection can be mapped into a proper structural tree before any simulation begins, and with a consequent zero-overhead in runtime (Avizzano, 2009b).

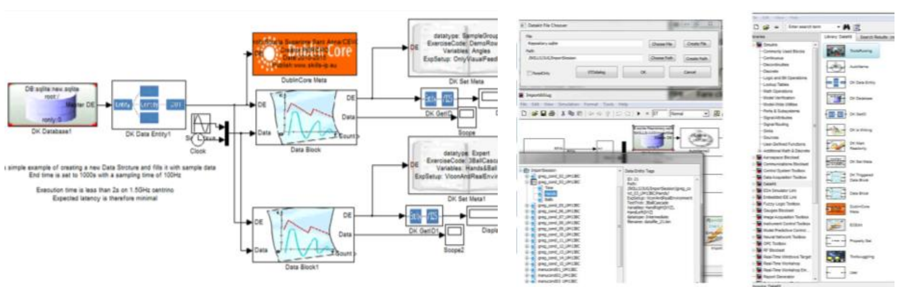


Figure 2. Tree structure (left) and GUI (right) examples

In order to implement the data tagging, several additional types of storing blocks are available: Meta data blocks add informational properties to the stored data; Parameters Data Blocks store information related to parameters required for the experiment and/or the virtual environment; Triggered data Blocks store information related to event related interactions. Additional tools complements the basic Simulink toolkit, among the most relevant ones: A code editor, An experiment name generator.
In the development of the Digital Representation toolbox, we focused on specific

research contexts as defined in the SKILLS demonstrators (Bergamasco, 2006; Bardy et al. 2008): a set of multimodal virtual environments (Ruffaldi, 2009; Tripicchio, 2009) dedicated to the acquisition of expertise and to the transfer of to novel and intermediate users.

Such project has several research phases which can be considered to be in common with most experiments that require data processing phases of knowledge management: Real time data acquisition and storage; Pre-processing, filtering and segmentation of data streams; Data clustering, labeling and performance indicators; Model creation and data regression/calibration to fit on models; Realtime delivery of protocols and historical view of performance.

THE JUGGLING ANALYSIS

In order to facilitate the understanding of concepts introduced by the Digital Repository, we will consider a case study based on the capture and analysis of data related to “three ball cascade” in juggling. A set of data has been captured from a group of experts in one development center using a high precision optical tracker. Data captured from experts need to be imported in the digital repository and analyzed to indentify information to be used in later training analyses.

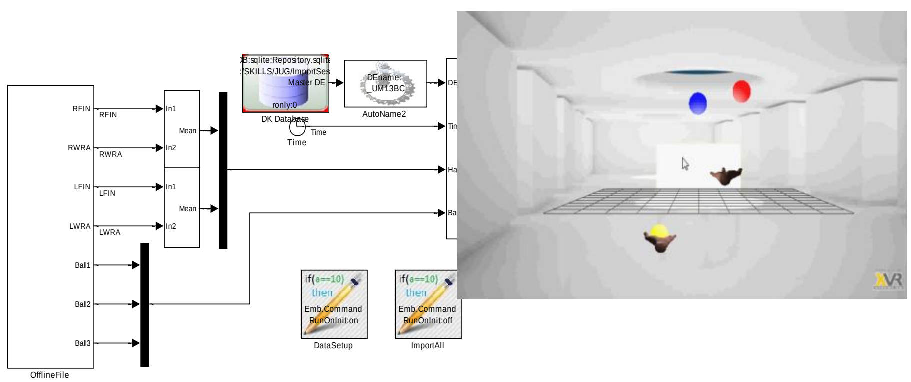


Figure 3. Schema for data acquisition and VR rendering

Acquisition of data was achieved through the scheme represented in figure 3 (left), where two major scripts controlled the data acquisition process. The script named Data Setup provides to setup the simulation process and to decode in real-time the information stored in the storage files of the Optical Tracker. The script named Import All provides to run between all files coming from the experts and run the simulation interactively in order to store all trajectories in the database. The rest of the Schema provides to reorganize data information into information relevant for the Juggling, and encode it in variables which need to be observed for simulation and performance estimation. The tree-architecture is implemented in the

StorageRoot block which is organized accordingly to the data format set for the Juggling experiments. On the right part of the same structure, the stored data have been read back from the digital repository in order to play-back and analyze in a virtual environment the sequence of motion. We consider the possibility to reply, analyze and change the point of view of any previous experiment a relevant tool to understand the causalities of data and actions.

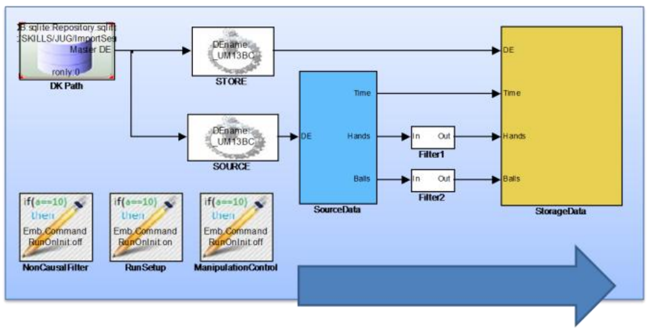


Figure 4. Schema for data filtering and segmentation

Once all data have been stored a specific filtering and segmentation policy is be applied to data. Filtering in this case has been performed using an ad-hoc Piece-Wise-Polynomial (PWP) approximation which allows a reduced set discontinuities on acceleration data and removes outliers by considering the effect of data removal on the statistical properties of the whole regression. The use of PWP has been demonstrated to be effective when using data coming from camera capture, for instance in basketball segmentation. The choice of this policy for Juggling was highly motivated by the following factors: a) PWP do not introduce delay on filtering; b) the introduction of discontinuity points allows to remove the high frequency cut introduced by linear filters; c) an implicit segmentation rule automatically outcome from best fitting optimization and can be verified onto the dynamic of the process; d) Polynomial expressions optimally describe the balls flying phases and allows to reduce the complexity of data description.

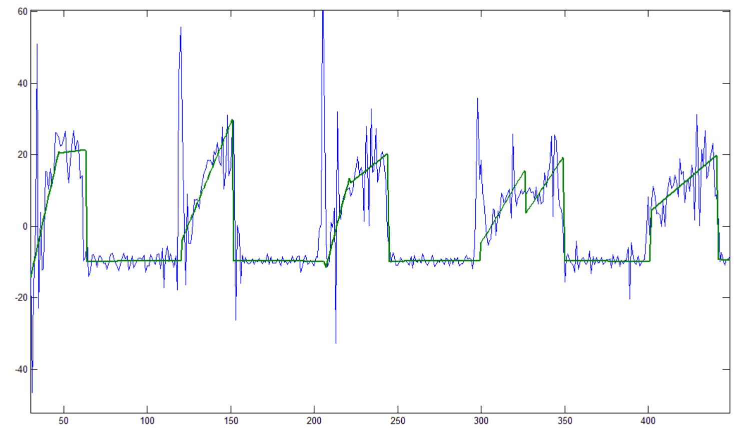


Figure 5. The 2nd derivative of balls acceleration computed on original data and with the implemented PWP regression.

In figure 4 the schema to recover data imported in the previous step (DK Path), to iterate all over data (run Simulation), to apply PWP best fitting (non causal filter), and to control the writing back to the database (Manipulation, Control and Storage Data) is represented. Figure 5 shows a comparison between PWP approach and an optimal linear filtering when the Z acceleration is computed from experimental data. The PWP decomposition, not only properly fits the given data, but also matches with a-priori information such as the correct determination of gravity during the flying phases.

The filtering and segmentation process also offer a support for the reduction of problem dimensionality. In the specific example it maps arcs of trajectories into 3rd order polynomials which can be described by only four parameters each (three coefficients and the starting time).

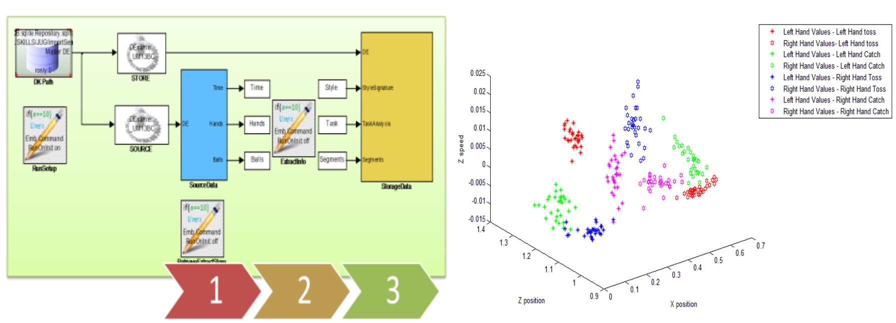


Figure 6. Data analysis.

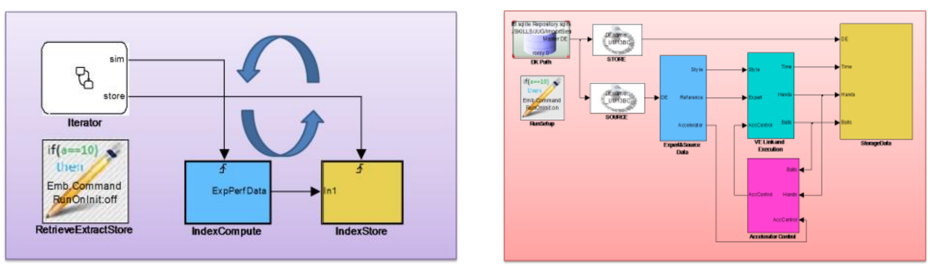
Once the relevant information has been extracted from trajectories and encoded into a small subset of parameters, data can be compared across experiments. This will allow determining if the there exists a control rule that underlies the motion control.

This is accomplished according to the computing schema shown in figure 6. The schema takes in inputs the parameters extracted from the previous step (filtering and segmentation), applies, if possible, any additional data tagging, such as the procedural decomposition deriving from task analysis, then creates nMaps one for each tasks, which summarize the parameters changes before and after each segment. The plotting includes an iteration among all the available sets of acquired examples, and whenever reasonable classification tools to identify task related properties (in figure 6 a simple classification by task analysis is shown).

A JUGGLING MODEL?

The result of classification/regression on dataset can be used for both devising dynamic relationship underlying the task control, as well as for calibrating on the same properties any external model that replicates similar behavior.

This is generally achieved into with two reference models, the first one that extracts metrics from real-time and batch experiments, the second one that employs the optimal parameters to drive a closed loop model as a digital trainer in the virtual environment.



(a) (b)

Figure 7. Model to compute performance (a) and deploy a training experiment (b)

In figure 7(a), an example of complex data analysis for the evaluation of learning curves is shown. The schema makes use of triggering events to store data extracted by complex samples. Finally figure 7(d) shows how these information can be integrated into a real-time feedback trainer.

The evaluation of these two models will be shown at the conference.

CONCLUSIONS

A new tool to handle simulation data for complex experiment analysis has been presented. The tool can manage complex experiments carried out by several researchers, at different sites. It encodes the information in a self documented and portable structure. Data management allows simultaneous organization and analysis of data trough a structured data format called multi modal data format.
The system allows real-time as well as batch data analyses, including data collection, filtering, processing and the construction of data driven models. The overhead of the system is minimal and the tools allow portability across several operating systems.

ACKNOWLEDGEMENTS

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