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# Software to prototype 3D Interaction Technique Empirical Evaluation

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## Abstract

*Designing usable and effective 3D Interaction Technique (3D IT) is very challenging for system developers and human factors specialists. Indeed, time consuming empirical evaluation is necessary to have an idea about the goodness of 3D IT at the end of its development lifecycle. This may induce a huge loss of time if the result appears to be not satisfying at the end.*

*We have designed and implemented an Empirical Evaluation Assistant to rapidly gather significant feedbacks about the usability of 3D IT during its development lifecycle. Thus, it may be possible to enhance iteratively the 3D IT before it would be classically evaluated by ergonomics experts at the end of its development lifecycle.*

*EEA has been used to gather results about a 3D IT developed in our research laboratory which is still under study. Results show that EEA has permitted to redesign some characteristics of this 3D IT.*

**Keyword:** Human Computer Interaction; 3D Interaction Evaluation; Empirical evaluation; Evaluation tool; Database; Virtual Reality.

## 1. Introduction

In our laboratory we have been creating interaction models and techniques for our semi-immersive Virtual Reality/Augmented Reality platform, especially dedicated to robot teleoperation and collaborative telework. The most important constraint we are facing is the usability of our techniques. In the teleoperation case, IT must be user-friendly and usable to prevent from damages and to easily manipulate the remote robot.

However, seeking the best 3D Interaction Technique (3D IT) and Interaction Method (IT) requires a long period of time of usability testing.

Moreover, rapid changes in hardware capabilities, devices, and lack of mature methodology in interaction design (Rizzo et al. [1]) involve problems to design user-friendly and usable interfaces. No true guidelines exist to remove these constraints when building and implementing an interface on a VR/AR platform. Thus,

the only choice we had was to validate our IT by ergonomics experts at the end of their development lifecycle. But this validating phase takes a long time and if it appears at the end that the result is poor, the validation feedback comes too late.

Our idea is to build an Empirical Evaluation Assistant (EEA) in order to perform light evaluations of 3D IT during its development lifecycle without the need of being an ergonomics expert.

We want this tool to:

- Bring assistance to fasten the design of the validating experiments by using information collected in a dedicated database;
- Bring fast feedbacks about a tested 3D IT during the validation experiments;
- Collect data and enrich the database to increase the knowledge about 3D IT behaviors.

We hope the EEA system may improve the quality of our 3D IT, leading in most cases to positive final evaluation by ergonomics experts.

This paper is structured as follows. Section 2 will briefly review the classical techniques of ergonomic evaluations. The EEA system is described in section 3. Section 4 briefly reviews practical questions about the use of EEA system. And finally, section 5 gives some insights about the feedback given by EEA.

## 2. Related work

Seeking the best 3D Interaction Technique for a given application requires numerous and long ergonomic evaluations. Indeed a lot of ITs for Virtual Environment (VE) have been developed without specifying requirements for specific applications, although it is a necessary step in order to create intuitive and transparent interaction for final users (Bowman et al. [2]).

ITs for VE are totally different from 2D IT that are typically used with a keyboard and a mouse to manipulate a graphical interface (WIMP paradigm). In this case, there are a lot of guidelines, principles or predictive models (e.g. Fitt's law or KLM model) to build an effective 2D IT. However, it is not the case for 3D IT. The main reasons are rapid changes in hardware capabilities, devices, fewer experts and the lack of mature methodology in interaction design (no strong

models) ([1] and [3]). Nevertheless, methodologies, 2D laws extension, guidelines or principles are emerging for VE such as:

- Usability engineering methodology (Gabbard et al. [4]) that focuses only on VR application but not on 3D IT;
- Principles and guidelines for VE (Kaur et al. [5]). However they are taken from experimenter experience rather than from empirical results ([3]);
- Fitt's law extension (Mackenzie et al. [6]) for VE.

Moreover, there are evaluation tools using guidelines and principles such as MAUVE system (Stanney et al. [7]) which provides a structured approach for achieving usability in VE system design and evaluation. Those evaluations methods are based on analytical approaches. They compare the behavior of the interaction to a reference model which describes the necessary conditions to obtain an efficient interaction.

Unfortunately, the VR domain is not as mature as the 2D desktop domain. Due to a lack of norms and ergonomics experience, analytical approaches cannot be used to evaluate 3DUI ([3]). Consequently, empirical approach must be utilized instead to measure the skill of different subjects using the IT in the VE [3].

However empirical evaluations are complex to perform due to many difficulties: large list of parameters such as subjects' profile, subjects' questionnaires or the design of tasks scenarios. In particular, the huge list of performance metrics and outside factors pointed out in [2] and [3] where they are gathered in 4 categories. In [8] (Poupyrev et al.) and [9] (Wingrave et al.), they are classified especially for selection/manipulation tasks.

**In consequence, we propose to include all the knowledge of interaction experiments in a database and build a tool that allows creating empirical evaluation quickly and easily in order to iteratively test and improve the design of 3D IT.**

### 3. The Empirical Evaluation Assistant

#### 3.1. Motivations and objectives

Excluding problems pointed out in the related work we have encountered many problems (e.g. long period of time for testing experiments, software implementation and VE specification) during the development and tests of our 3D IT. So, we propose a tool that permits to:

- **Save evaluation time:**
  - By adjusting 3D IT outside problems such as Virtual Environment design or VR devices

integration in order to get ideal conditions. This stage permits to eliminate factors in the system and only studies the 3D IT;

- By extracting a limited list of outside factors that may influence selected performance metrics in order to find a compromise between the total duration of an experiment and its soundness.
- **Share experimental results:**
  - By permitting replicability of experiments;
  - By permitting collaborative work with 3DUI developers and evaluation experts.
- **Centralize 3D IT knowledge in a database.**

EEA is intended to be used during the development lifecycle of 3D IT by non experts of ergonomics. Typically, it is dedicated to 3D IT developers. **It has no aim to bypass a complete evaluation process made by ergonomics experts.**

We propose to divide the evaluation process timeline in three stages (see figure 1 for an illustration) where stages part correspond to specific objectives.

Stage 1 is an iterative debug stage where the experimenter, may configure the hardware parameters, adjust the 3D IT software (e.g. technique internal parameters) and improve the VE specification (e.g. adjusting obstacles for a navigation task).

In stage 2, we are iteratively testing/improving the design of the 3D IT with voluntary subjects. This stage is split in three parts (before, during and after the experiment) and corresponds to different objectives.

**Before the experiment**, the system must provide assistance for the preparation of the experiment:

- Auto generation of qualitative questionnaires;
- Help to select useful metrics and factors to be used during the experiment;
- Help to design task scenarios.

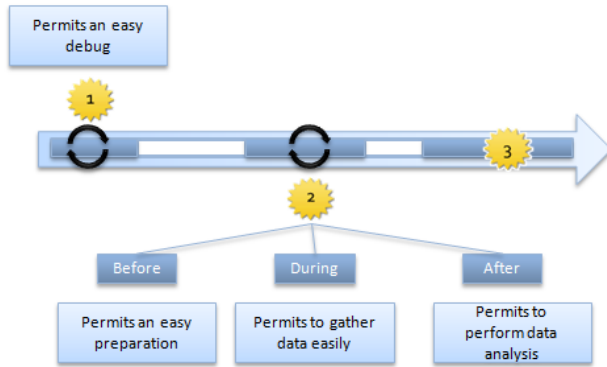
**During the experiment**, the system must permit to build a trace of selected quantitative metrics during the whole experiment.

**After the experiment**, the experimenter can perform statistical analysis over qualitative and quantitative data.

Finally, the stage 3 is a complete evaluation done by ergonomics experts.

During all stages, the system must permit collaborative work:

- To enrich the Knowledge Database;
- To share results with experts and 3D IT developers;
- To annotate and compare experiments.

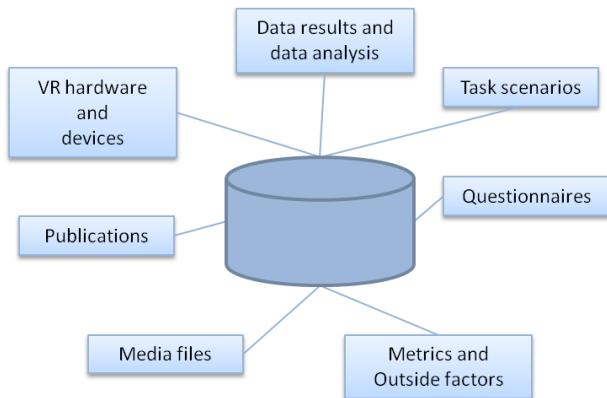


**Fig.1. The three stages to obtain a finalized and usable 3D IT using EEA system. Stage 1 is an iterative debug stage. Stage 2 is an iterative testing/improving stage.**

### 3.2. System Features

#### 3.2.1 The Experimental Protocol Conception (EPC) Tool

In order to achieve the specifications of the EEA system, we have built two distinct tools. The first tool is dedicated to Experimental Protocol Conception, which we call EPC tool. EPC is composed of four main modules and a Knowledge Database (see figure 2 for the KD components).



**Fig.2. Components of the Knowledge Database**

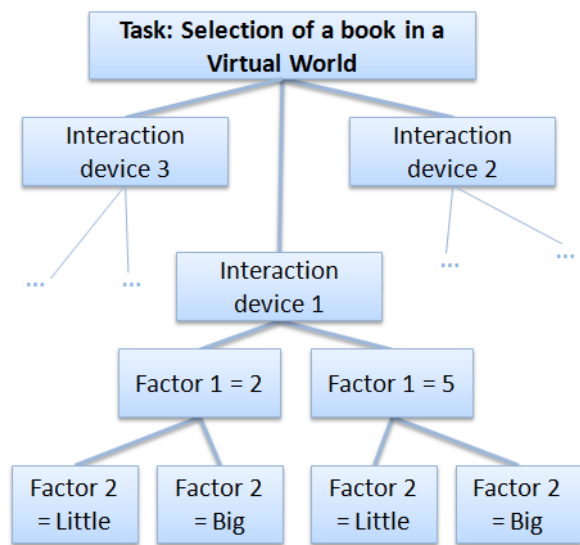
To design task scenarios, the experimenter uses the Scenario Conception Module (SCM) that allows:

- An assistance to minimize meaningful outside factors that may influence selected performance metrics. The system automatically excludes factors and metrics according to the VR hardware selected by the experimenter (e.g. no selection of stereo glasses excludes Stereo/Mono vision outside factor). To do that, we have linked hardware to many metrics and factors according to Bowman or Wingrave work ([2] [3] and [9]);

- Next, we try to link factors and metrics together to get an auto-selection of factors according to selected metrics. For the moment, this step remains semi-automated.

Moreover the system gives the experimenter information about metrics or factors grouped by categories. This is possible due to links with KD (e.g. using publications or former experiments).

- Auto-setting of software resources in order to run the experiment. Questionnaires for qualitative results and MD tool configuration file are created according to selected elements;
- The task scenario is automatically created, stored and will be attached at the future results (see figure 3 for an illustration).



**Fig.3. A task scenario where 3 factors are tested: Book size (factor 2), book-avatar distance (Factor 1) and three interaction devices.**

Statistical analysis is done by the Data Analysis Module (DAM). It allows the experimenter to perform different kinds of statistical analysis. During step 1 (stage 1), the experimenter may perform a quantitative analysis or linear regression in real time. Consequently, he may perform quick tests to adjust VE and 3D IT internal parameters.

During stage 2, the experimenter may perform analysis on the data traced during the experiment relatively to selected metrics and factors (e.g. inferential analysis as ANOVA, Student's t-test) and the evaluation with pre-selected people. An EPC module which is called Collaborative Module (CM) permits to enrich the KD. It allows two main possibilities: share KD between different 3D IT developers to Consult/Add/Modify/data (e.g. to add metrics) and utilize SCM with other experimenters to design efficient task scenarios.

#### 3.2.2 The Measurement and Debugging Tool

The second tool is dedicated to Measurements and Debugging, which we call MD tool. MD tool includes a debug module that allows experimenter to view in real time all quantitative metrics available on EPC tool (during stage 1).

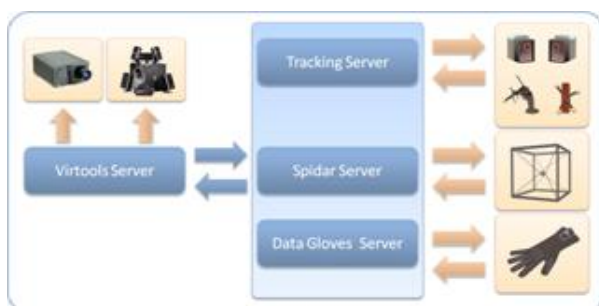
However, all available statistical tools cannot be used (e.g. inferential or qualitative analysis) and results are not stored in KD. During stage 2, all the statistical analysis tools are available due to the pre-selected metrics and results are stored in the KD. This stage permits to evaluate 3D IT with voluntary subjects. Storing the results permits to get evaluation traces and share results with others 3DUI developers.

### 3.3 Implementation of EEA system

#### 3.3.1 Hardware Context

In our laboratory, we own a **semi-immersive** VR/AR platform which enables stereoscopic display, wireless hand/head/fingers tracking and force feedback (see figure 4). Each device is associated to a specific server which is accessed by clients via the VRPN library. The interactivity between the user and the VE is done by using Virtools as a front-end. We have chosen Virtools and VRPN library for two main reasons. First, our aim is to provide a tool that permits to share experimental results over the community. These tools are considered as standards and the experiments have a better reproducibility. Using these tools permits to create a standardized collection of interaction experiments to search for replicability.

Second, Virtools is suitable software for prototyping and testing our 3D IT because it offers a fast and graphical way to compute and link them with devices and VEs by connecting specific building blocks to each other.



**Fig.4. Software architecture supporting our semi-immersive VR/AR platform**

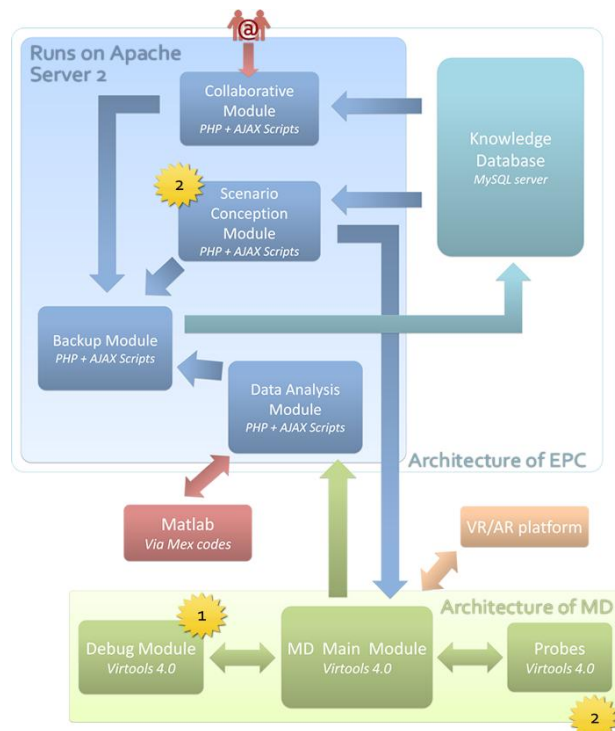
#### 3.3.2 Software architecture

The **MD tool** has been implemented by making specific Virtools blocks that we have called **Probes** and a master block called MD main module. Probes **objectives** are to retrieve quantitative data from VR devices, VE and subjects' tasks (e.g. navigation time,

selection errors or system frame rate). Probes may be connected to building blocks where the output has to be measured, traced or displayed in real time.

**MD main module** permits to initialize the measurement schema of all pre-selected quantitative metrics by using a configuration file (a XML document) created by the EPC. It sends synchronization signals to the probes (e.g. start/stop/pause signals) in order to gather data. This is done by the "Synchronization" and "Wait" modules. When a probe is enabled and the synchronization done, the appropriate module (e.g. Distance Module) is started/stopped/paused. At the end of evaluation, MD main module transfers data to DAM of EPC to perform statistical analysis and store results into KD.

Moreover, the debug module (used on the debug stage) allows the experimenter to view metrics in real time (e.g. position, speed or time to reach a position in the 3D space) by using the probes. This stage is generally done before the empirical evaluation (stage 2). In the debug tool case, MD main module does not require a configuration file, all probes are enabled. However, results are actually not stored in KD. There are two links between EPC (XML document) and MD (Transfer data) as we can see on the global architecture and software implementation (figure 5).



**Fig.5. Software architecture of the EEA system. Debug tool is only used during stage 1. During stage 2, the experimenter uses SCM (EPC) and MD tools.**

The EPC tool permits the access to the KD. We have chosen a WEB based architecture centered on an Apache 2 server. The database is implemented with a

MySQL server which is accessed via SQL queries from the EPC tool written in PHP and AJAX. EPC creates the configuration file (XML document) that permits to MD main module to initialize the measurement schema. We have chosen these tools because:

- They do not require plug-in like Java or Macromedia Flash and work with all internet browsers. Moreover using PHP/MySQL permit an easy access over internet;
- They are open source and used by a lot of web site.

### 3.3.3 The Knowledge Database

The Knowledge Database contains eight tables. Each table is composed of different attributes (e.g. name or type). The main table is called “Experimental Protocols” and is linked with the others table. The figure 6 shows the relational model of our database. Tables are represented in blue. Relations between tables are symbolized in green and black arrows (two relations colors have been used to get a more readable graphic). Each relation is linked by one key.

#### Composition of tables:

- **Metrics/Factors table:** This table contains information about metrics and factors. This table is linked with “Questionnaire” because some metrics need questions to gather them, with publications to get the information of metric and with “VR

devices” because some metrics are specific to VR devices. For example, if the experimenter selects “Age” as a metric (with EPC tool), the system will auto-selects the appropriate questions.

New metrics/factors are added manually by experimenters.

- **Experimental protocols table:** This table contains the task scenarios created with EPC tool. A task scenario incorporates different elements used for the evaluation (e.g. metrics, factors or devices used). This table is linked with all the other tables. A new task scenario is only added by the system during its creation with EPC tool.
- **Data Results:** This table is composed of two categories of data: the evaluation results and statistical analysis perform on the results. Results and analysis are linked with a unique protocol. Moreover, access permissions to results and data are stored in this table. The experimenter assigns access to selected users and groups to make his data public or private.
- **VR Devices:** This table is composed of information about VR devices and hardware in order to permit replicability of experiments and have comparison with others experiments. Moreover, it permits to prevent from impossible combinations due to its link with metrics table. When adding devices, the experimenter must create links between new device and metrics which are already in the database.

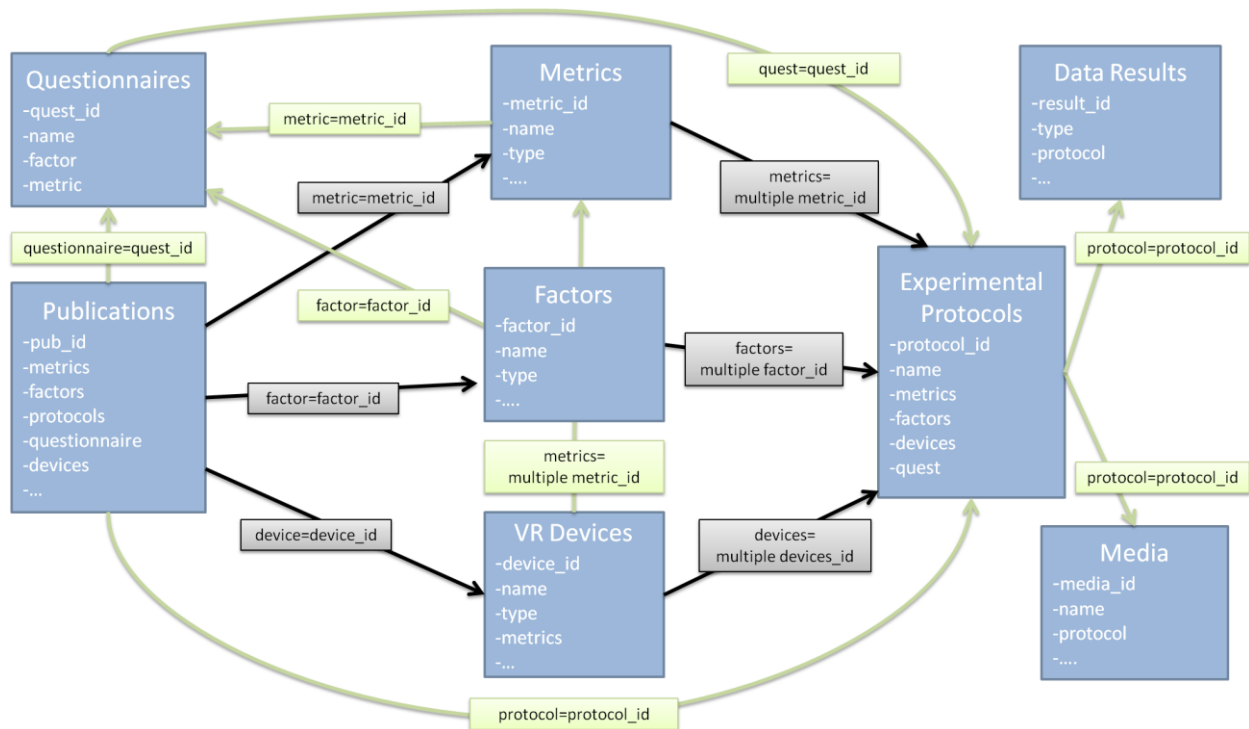


Fig.6. The relational model of the Knowledge Database.

## 4. EEA: How to?

Along this paper, some questions concerning the mechanism of our system have appeared. They point out practical issues of EEA and we will try to answer to them in the following:

### **A: What happens if a new device must be taken into account in the EEA system?**

The Flystick is natively supported by Virtools thanks to the use of VRPN [10]. VRPN supports a huge list of VR devices. However all devices are not compatible as the force feedback SPIDAR. In this case, we have added a VRPN extension in the VRPN server program. As Virtools reads data sent by VRPN, nothing else has to be done in the MD tool. To enrich the EPC module with a new device, a procedure exists that links this device to metrics and outside factors already existing in the KD.

### **B: What happens if there are new metrics or factors?**

*EPC tool procedure:* New metrics, factors or any kinds of elements may be added just as the devices. The experimenter gives to the system information about metrics (e.g. metrics category type). However it is not possible yet, to link metrics with others KD elements (outside factors and metrics). This link might permit to have a semi-automated stage during the design of task scenarios. *MD tool procedure:* In this case there is a problem that has not been solved yet. If new quantitative performance metrics are added, the system cannot create automatically a new probe for the metrics and so it's not possible to get data directly from our software. The only solution is to create a Probe building block for this metric. However, we are working on a system which might work without the use of probes.

### **C: What happens if experimenters want to replay the experiment?**

Experiments done with EEA are stored, classified and dated in the Knowledge Database. It includes data gathered from the probes, statistical results, MD configuration files and task scenarios summary. The experimenter can retrieve the evaluation scenario and MD configuration file (actually VE is not stored) to launch the experiment with same metrics and factors and the same generated PDF questionnaires. He can also enrich an existing experiment with new results or data. The evolution of the experiment is stored and may be viewed.

### **D: What happens when experimenters want to share results?**

By default, results are stored in the KD with a restricted access and may be accessed with a WEB browser through the internet. Each element of the experiment may be retrieved. Until now, we have not

worked on a proper data format that may be used by common visualization software.

## 5. Preliminary evaluation done with the EEA

We have experienced our EEA system to refine the condition of use of 3D IT we have developed, called Follow-Me (see [11] for the model). The model had been roughly tested before without the EEA system (see [12] for the first evaluation). However, some results we had were put into questions and some questions remained unanswered.

The particularity of Follow-Me is its use of virtual guides to reduce the number of degrees of freedom in VE when approaching an object to be selected and when manipulating it. Thus, the system anticipates what the user may do to lessen his need for concentration. But this system may puzzle the user if its anticipation is wrong. Moreover, we already knew that Follow-Me behaves well for selecting far and small objects comparing to classical tested 3D ITs.

### **Our questions were:**

- Is there a real benefit of using Follow-Me if the object is near from the user in VE?
- Is there a real benefit of using Follow-Me for a user who is an expert of VEs?
- How is Follow-Me perceived by users (helpful, disturbing and neutral)? Is there any difference in this perception if the user is a novice or an expert?

These questions have implied the creation of specific qualitative questionnaires given to the users after the experiment. It has been done with the help of the EPC tool. They also implied the nature of the probes utilized in the experiments which were traced in a log file and statistically analyzed after the experiment.

For our evaluation, each user had to select a book on a shelf and put it on another shelf **as fast as possible**. The device used to interact with the VE was a wireless Flystick which position and orientation were captured by two infrared cameras situated at each side of the wide screen

### **5.1 Setting up the evaluation with the EEA**

During the debug stage, the experimenter will adjust the internal parameters of the Follow-Me technique (e.g. size of virtual guides) and the Virtual Environment (e.g. books position and size). To do that, the experimenter will only use the MD tool with connected probes (connections are done by the experimenter).

The second stage consists on creating the tasks scenarios. Here, our task is to select and manipulate books as fast as possible.

To do that an experimenter must follow three steps to set up the evaluation using the EPC tool:

- First, the experimenter selects VR devices which evaluation task scenario we have selected: Active stereo capability, Flystick 1, the SPIDAR and the Data Gloves were not used, so they are not been selected) (see figure 8 on the bottom).

This step is necessary in order to permit replicability of the experiment and to avoid impossible combinations according hardware.

- Secondly, the experimenter selects remaining metrics in the list (see figure 9 on the bottom) and desired factors according his environment and what he wants to test. All metrics and factors are given with applications of use and “help message” (view figure 10 for a global view of EPC tool).

**Metrics selected** for the evaluation are: selection and manipulation time, selection and manipulation mistakes, subjects’ age, experience, sex etc.

**Factors selected** are: books size, use of stereo vision, distance between books and avatar initial position.

**The system will creates the required automated resources and saves all in the Knowledge Database. It produces questionnaires for qualitative results and a list of tasks to give to voluntary subjects.**

- Finally, the experimenter uses the MD tool to put probes in his Virtools Script to retrieve data. This step is similar to the debug stage. But here, only given probes, specified in the configuration file are enabled. Moreover, data results will be stored. Figure 11 shows probes connected in a Virtools script use for our preliminary evaluation.

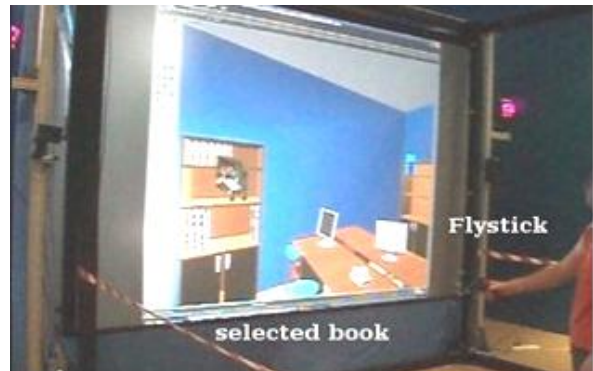
## 5.2 Feedbacks after the preliminary evaluation

The figure 7 shows our experimental setting using the semi-immersive platform. We have performed a comparative evaluation of Follow-Me and two other classical 3D IT (HOMER [2] and Go-Go [13]) over 15 voluntary subjects.

**Two days of work for one experimenter were necessary to:**

- Adjust the internal parameters of the three 3D Interaction Technique and parameters of the virtual environment with the use of the debug module;
- Build and implement the experimental protocol depending on the questions we were asking [the EPC tool configures the probes and deliver questionnaires];
- Perform the experiment in itself with 15 voluntary subjects (an average of 30 minutes per user was necessary) [MD tool produces a dated trace of all probes];

- Analyze the collected data to produce a feedback [dated trace and qualitative data from questionnaires are submitted to DAM to perform an ANOVA for example].



**Fig.7. Experimental settings using the semi-immersive platform to test the 3D IT Follow-Me for a book selection and manipulation task in VE.**

EEA permitted us to know that Follow Me is favorably accepted by novices in VE and permits faster selection and manipulation than other 3D IT whereas experts are puzzled by *Follow-Me* and prefers classical 3D IT (Go-Go and HOMER).

This feedback will be utilized in the future to refine the use of virtual guides in the Follow Me model. Moreover EEA will be reuse to see if the score of metrics is better.

## 6. Conclusion

The EEA system is dedicated to light evaluations of 3D Interaction Techniques during the development lifecycle. However, this tool is not limited to 3D IT and can be used for others kinds of systems. It may be used by non ergonomic experts.

**The aims of this tool are:**

- To offer design and trace facilities;
- A fast design of an evaluation by assisted selection of useful metrics and factors;
- To perform statistical analysis;
- To recursively enrich a Knowledge Database that can be used for the future experiments.

The core idea is to get fast feedbacks in order to improve the tested 3D IT. In order to accumulate knowledge about 3D ITs, the whole experiments may be stored in the Knowledge Database that may be accessed worldwide via a WEB interface, whereas the debug tool is connected to our VR/AR platform and it is implemented under Virtools. We have used EEA to test the 3D IT we have developed recently and the feedback we obtained in only two working days permitted us to upgrade the Follow-Me model.



However, the major problem of this approach is to populate the Knowledge Database (KD).

EEA system has been used to redesign conditions of use of 3D IT that we have developed, called Follow-Me [10]. The model had been roughly tested before but without the EEA system [11]. The characteristic of Follow-Me is, its use of virtual guides to reduce the number of degrees of freedom in VE when approaching an object to be selected and manipulated. Thus the system anticipates what the user may do to reduce subjects' concentration. We have performed a comparative evaluation of Follow-Me with two others 3D IT (HOMER and Go-Go) over 15 voluntary subjects.

Each user had to select a book on a shelf with a Flystick and put it on another shelf as fast as possible. EEA permitted us to know that Follow-Me is favorably accepted by novices in VE and permits faster selection and manipulation than other 3D IT whereas experts are puzzled by Follow-Me and prefer classical 3D IT. This feedback will be utilized in the future to refine the use of virtual guides in the Follow-Me model.

#### **Future work on the EEA will concentrate on:**

- Continuing the development of our system;
- Removing **the probes** to get an autonomous system with pre-configured settings using EPC;
- **Collaboration with ergonomic experts** or others 3D IT developers to improve our system;
- Enrich the Knowledge Database to create a large collection of Interaction experiments;
- **Related work on data mining techniques** to find and extract useful information to enrich automatically the Knowledge Database;
- Allow **creation and backup of VE** using Virtools supported formats in order to have a standardized collection of VEs to replicate/compare 3D IT evaluations;

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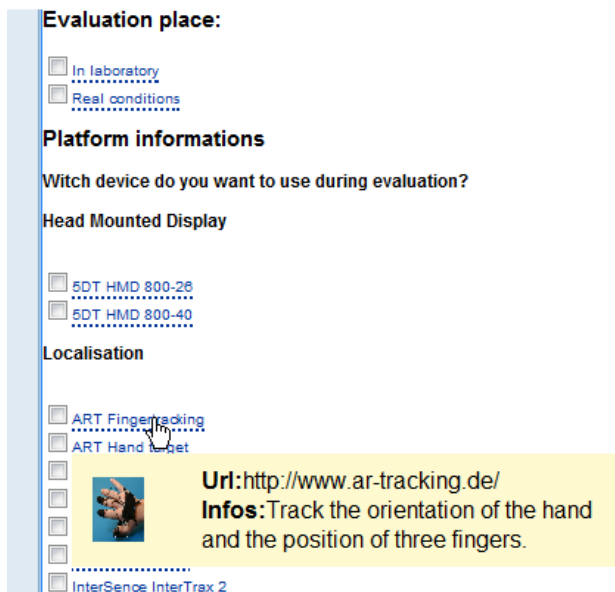


Fig.8. View of devices selection during the EPC use.



Fig.9. View of the list of metrics and factors to select according to pre-selected devices. Metrics disabled are cross out (we have used CSS).

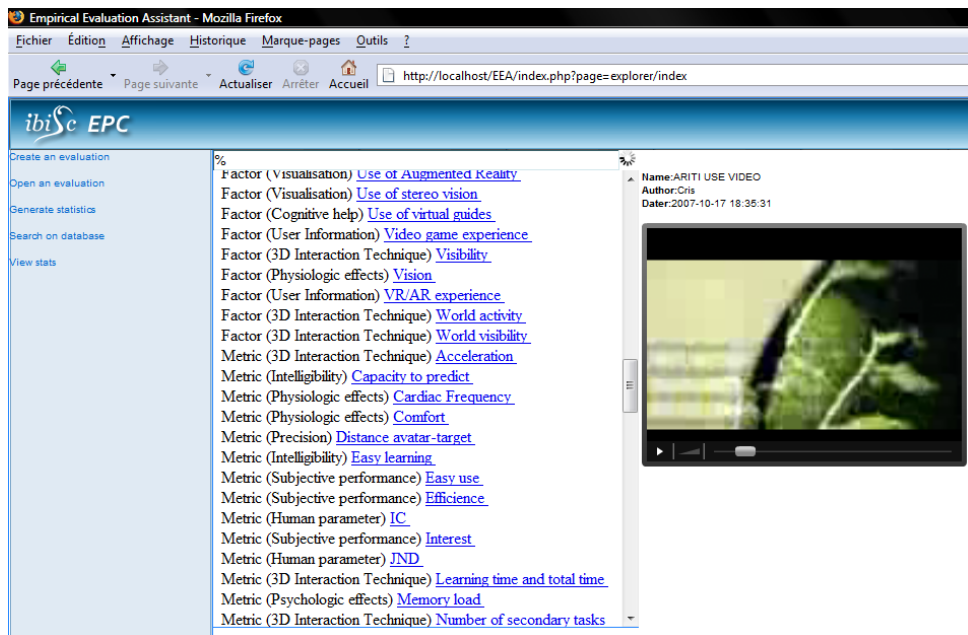
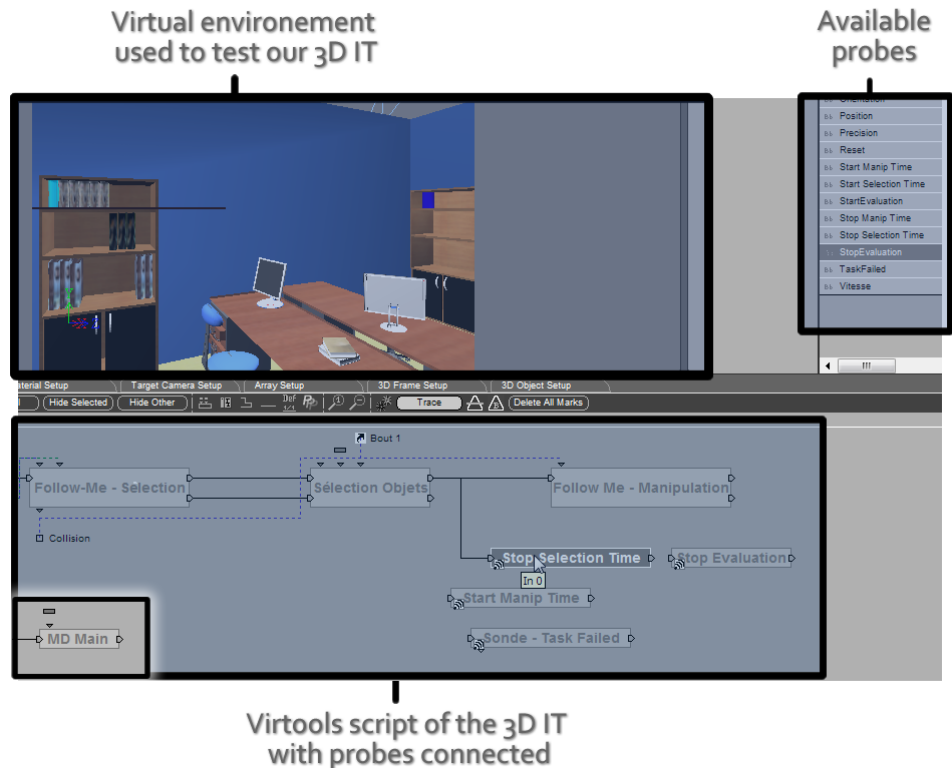


Fig.10. View of EPC Tool search engine



**Fig.11. View of MD tool in a Virtools Script. Some probes are connected.**