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Evaluation of the FOLLOW-ME technique for grabbing virtual objects in semi-immersive virtual environment

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Abstract

The implementation of an interaction between a user and a Virtual Environment (VE) in Virtual Reality (VR) may use various techniques. However, in some cases, the interaction must be very precise and comfortable for the user. In this paper, we evaluate the FOLLOW-ME technique which is a selection and manipulation technique. The model associated to this technique splits the Virtual Environment into three zones in which a specific interaction model is used: a free manipulation zone, a scaled manipulation zone and a precise manipulation zone. Each one of the three zones is characterized by a specific interaction granularity which defines the properties of the interaction in the concerned zone. This splitting is created in order to have both precision near the object to reach or to manipulate (scaled and precise manipulation zone) and to maintain a realistic and free interaction in the VE (free manipulation zone). In the precise manipulation zone, we use the concept of virtual guides in order to assist the user to achieve his task. The aim of this paper is both to compare the FOLLOW-ME technique with classical interaction techniques in the case of selection task in semi-immersive VR and to give some insights about the conditions of usefulness of virtual guides in a selection task. The preliminary results show that FOLLOW-ME technique is more efficient to select remote and dynamical objects compared to other techniques such as Go-Go and Ray-casting techniques. In all the situations, we have tested, the FOLLOW-ME technique makes the selection process easier.

Keywords: 3D interaction technique, virtual guide, granularity of interaction.

1 Introduction

As the technology of display and graphics systems has developed, VEs applications have come into common use outside the research laboratory [5]. The technology of VEs offers to the user new interfaces which enable him to interact easily and naturally with the VE. Currently, interaction is one of the main problems of the majority of applications in this field. There are a lot of varieties of existing human-computer interaction techniques, which attempt to solve the problem of grabbing and manipulating objects in VEs[4][7][11][12][14].

In today's life, if one wants to grab an object, his arm is firstly moving fast to the target and, when approaching, it slows down and then the hand uses a grabbing strategy to take the object. The different steps of the task may be characterized by different needs of precision (lower precision far from the target and higher precision near to the target). This induces the idea of *granularity of interaction* that is used in our model.

What precisely interests us in the splitting of VE is the possibility to have both a wide zone in which the user interacts freely and realistically with the virtual world and also limited zones near the objects to select or manipulate where there exists a strong assistance to the user that offers him precision and easiness to accomplish his task. The assistance may be materialized by visual cues (like Ray Casting [7]) in the VE or an active assistance to reach and grab an object. For example, in this article, we use virtual guides [8][13] for this active assistance.

In general, the study of the interaction involves the specification of both:

- A technique and a formal model that specifies the

relation between a user (or a group of users) and a virtual world;

- The devices needed to implement the model;
- A suitable evaluation method which validates or invalidates the proposed model.

In this paper, we evaluate performances of the FOLLOW-ME technique [10] with other various interaction techniques. We use a formal measurement method inspired from the testbed evaluation method [2][3] in order to evaluate a selection task. We keep some criteria utilized in [3] like the comparison of task completion time (speed). Besides, we want to find a compromise between the necessity of having free and realistic interaction (which may not be precise) and the necessity to manipulate an object with high precision (which uses virtual guides that induce quite unrealistic interactions). This compromise may be found in our model by finding an appropriate splitting of VE. In this paper, we show that the evolution of the distance to the target over time may be used as a new criterium to achieve a correct splitting of VE.

In section 2, we present a short review of related 3D interaction techniques which are commonly utilized in the context of VR. Section 3 describes the formal model of the FOLLOW-ME technique which incorporates the notion of granularity of interaction and virtual guides. Section 4 gives experimental results in a simple VE in which we measure the effectiveness of the assistance of the FOLLOW-ME technique to the classical Go-Go and Ray-casting techniques. We use a formal measurement method inspired from the testbed evaluation method [3] in order to evaluate the performance of interaction of the classical and assisted techniques. The first results show that FOLLOW-ME technique brings useful assistance to achieve a selection task.

2 RELATED WORK

Obtaining realistic interactions between user and a virtual world is the main issue of the majority of applications in Virtual Reality. Several common techniques for basic 3D tasks have mostly been developed in the context of Virtual Environment nowadays, but many of them are not useful in other types of 3D systems such as Mixed Environment (ME). There is little chance to find many experiments, formal models and roles which can control interaction in the ME. There are four basic 3D interaction tasks that are found

in most complex 3D applications: the Navigation task, the Selection task, the Manipulation task and the System Control task. In this paper, we'll be discussing 3D interaction technique for Selection tasks.

Selection is the specification of an object or a set of objects for some purpose. Manipulation refers to the specification of object properties (in general position and orientation). Selection and manipulation are often used together, but selection may be a stand-alone task [1]. Several techniques can be used for selection and manipulation tasks.

Currently, there are three basic metaphors for the 3D interaction [1]: virtual hand, virtual pointer and World-In-Miniature (WIM).

The most common interaction technique which uses the metaphor of virtual hand is the simple virtual hand [1]. This technique is used for selection or manipulation tasks. It uses a one-to-one mapping between the virtual hand and the physical hand. Selection is made via direct "touching" of virtual objects. In general, this is done by intersecting the virtual hand with a virtual object. The Go-Go technique[12] also called arm-extension technique is based on the Simple Virtual Hand, but it introduces a non one-to-one linear mapping between the virtual hand and the physical hand. The selection of remote or small objects is very difficult with the simple virtual hand and the Go-Go techniques.

Another common technique is the Ray-casting [7]. This technique uses the metaphor of a laser pointer - an infinite ray extending from the virtual hand. The first object intersected along the ray is eligible for selection. This technique is very efficient to achieve selection tasks. The flash light technique [6] is based on the same principle that the Ray-casting technique, but it replaces the laser pointer by an infinite cone. It allows the selection of remote or small objects, but it presents ambiguities in the selection of close objects. As an example of technique which based on the metaphor of WIM, we may refer to the World-In-Miniature technique [14][11], which uses a small representation of the environment to allow the user to do indirect manipulation of the objects in the world. Each of the objects in the WIM is selectable using the simple virtual hand technique, and moving these objects causes the full-scale objects in the world to move in a corresponding way. The selection of the close or remote objects is possible with WIM technique, but the selection of small objects is very difficult.

There exists other type of interaction technique like the PRISM technique [4], which can be used as

an addition to other existing techniques to increase precision.

3 DESCRIPTION OF THE FOLLOW-ME TECHNIQUE

3.1 Main Properties

When one grabs an object with his hand, his arm has a fast and quite unprecise movement far from the target, a precise and slower movement when approaching the target and a grabbing strategy associated to the geometry of the object. Each of the three steps has its own interaction strategy and may have what we will call a specific *granularity of interaction*. This specifies the consequences of the movements of the user (in the real world) on the virtual world. The consequences may be expressed as a difference of movements amplitude between the two worlds or a loss of degree of freedom of the movement in the virtual world compared to the real world.

The FOLLOW-ME technique [10] takes inspiration from this simple grabbing example. It has two main characteristics:

- the VE is divided into three zones in which the interaction has its own granularity, whether one wants to navigate freely and realistically in the VE (free manipulation zone), approach more securely to a target but without losing any degree of freedom (scaled manipulation zone) and then finally approach to the target and manipulate it easily with high security (precise manipulation zone);
- In the precise manipulation zone, virtual guides are used to handle both precision and security of manipulation, which induces a loss of freedom for the user (for a review, one may refer to [8][9][13]). The aim of a virtual guide is firstly to anticipate the most probable action of the user into the VE and then to make him perform his action as simply as possible with high precision. In order to achieve this goal, the virtual guide puts limitations to user's possible actions in the virtual world so that he has to *follow* the virtual guide with a specific direction and orientation. This characteristic of the interaction has led us to call our technique the *FOLLOW-ME technique*.

Each object of VE which may be selected or manipulated has its own scaled manipulation zone and precise manipulation zone which are volumes surrounding the object (see Fig. 1 (a)). The objects may

be selected by using a virtual tools (virtual pointer or virtual hand). We associate a set of states to the virtual tool whether it is in the free manipulation zone (*Free_Manip_Stat*), the scaled manipulation zone (*Scaled_Manip_Stat*) or the precise manipulation zone (*Precise_Manip_Stat*) of an object (see Fig. 1 (b)). Each state is linked with a specific granularity of interaction (depending on where the virtual tool is in VE):

- the *Free_Manip_Stat* is linked with a high granularity of interaction. This means that a movement in the real world is translated as is for the virtual tool in VE (gain equal or greater than 1);
- the *Scaled_Manip_Stat* is linked with a medium granularity of interaction. This means that a huge movement in the real world is translated into a smaller movement of the virtual tool in VE (gain comprised between 0 and 1);
- the *Precise_Manip_Stat* is linked with a low granularity of interaction. We use virtual guides in order to assist user. In this case, the degree of freedom for the virtual tool in VE is reduced to 1 so that the movements of the user are interpreted as *go forward to the target* decision or *go backward* decision. This means that the virtual tool may move along a 1D curve in VE.

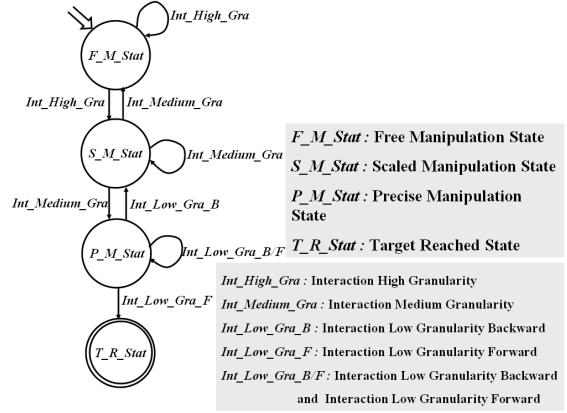
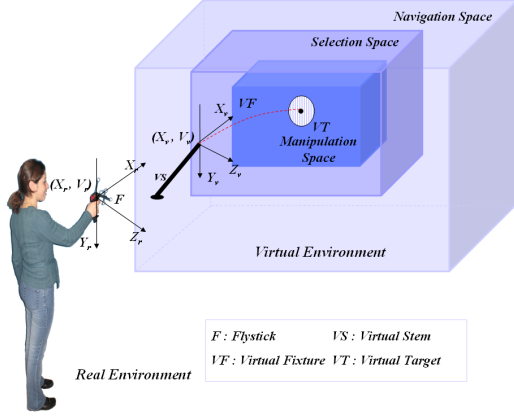
A transition between one state to another corresponds to a modification of the granularity of interaction. We will see in par. 3.3 that it corresponds to a modification of the equation that handles the evolution of the virtual position and orientation of the virtual tool.

3.2 Notation

The 3D position of the user's hand is noted \vec{P}_r and its orientation is $\vec{\theta}_r$ at each time t . The resulting virtual position in VE is \vec{P}_v and the resulting orientation in VE is $\vec{\theta}_v$. The linear velocity of the hand is noted \vec{P}_r and its angular velocity is noted $\vec{\theta}_r$. The linear velocity of the virtual tool is noted \vec{P}_v and its angular velocity is noted $\vec{\theta}_v$.

We depict \vec{C}_* and $\vec{\theta}_*$ as the position and the orientation of the normal of the target to be reached.

The time at which a transition between two states happen is noted t_0 .



(a) Interaction of a user with the VE including three different zones (b) State graph associated with the evolution of the virtual tool in the three zones of VE

Figure 1. The Follow-Me Model

3.3 Formalisation of the FOLLOW-ME model

For each state of the virtual tool, there exists a unique set of equations that gives its position $\vec{P}_v(t)$ and orientation $\vec{\theta}_v(t)$ in VE at time t . In the following, we will have a look at these equations.

These equations may have *a priori* free parameters. However, when the virtual tool quits at time t_0 a zone of VE to enter another one which has a different granularity of interaction, a state transition happens in the graph (see Fig. 1 (b)) and the set of equations that compute $\vec{P}_v(t)$ and $\vec{\theta}_v(t)$ change. It is necessary that there exists a continuity constraint at time t_0 over $\vec{P}_v(t)$ and $\vec{\theta}_v(t)$. Hence, this continuity constraint permits to fix some parameters because it is possible to know the values of $\vec{P}_v(t_0)$, $\vec{P}_r(t_0)$, $\vec{\theta}_r(t_0)$ and $\vec{\theta}_r(t_0)$ at time t_0 .

In the following, when we will type $\vec{P}_r(t_0)$ or $\vec{\theta}_r(t_0)$, it will mean: $\vec{P}_r(t_0)$ or $\vec{\theta}_r(t_0)$ computed with the former set of equations valid just before t_0 (former granularity of interaction)

Let us describe the equations giving $\vec{P}_v(t)$ and $\vec{\theta}_v(t)$ for the three states of the virtual tool.

Free_Manip_Stat state

For the *Free_Manip_Stat* state, we have chosen the equations associated to the Go-Go technique (see [12]) and the Ray-casting technique (see [7]).

Scaled_Manip_Stat state

For the *Scaled_Manip_Stat* state, we consider a gain k_S between the real and virtual velocities. k_S is a positive real value. As we want to be more precise in the scaled manipulation zone, k_S must be less than 1. We have the following set of equations:

$$\begin{cases} \vec{P}_v(t) &= k_S \vec{P}_r(t) + \vec{P}_v(t_0) - k_S \vec{P}_r(t_0) \\ \vec{\theta}_v(t) &= \vec{\theta}_r(t) + \vec{\theta}_v(t_0) - \vec{\theta}_r(t_0) \end{cases} \quad (1)$$

Precise_Manip_Stat state

For the *Precise_Manip_Stat* state, the idea we have is to diminish the linear velocity of the virtual tool when approaching to the target so that the virtual tool position converges to \vec{C}_* . It may be written as follows:

$$\vec{P}_v(t) = k_M \cdot (\vec{C}_* - \vec{P}_v(t)) \quad (2)$$

Where k_M is a real parameter. In the following, we will first consider that k_M is constant over time.

The equation 2 is a first order linear differential equation over $\vec{P}_v(t)$. Using the continuity constraint, the solution of this equation is:

$$\vec{P}_v(t) = (\vec{P}_v(t_0) - \vec{C}_*) \cdot e^{(-k_M \cdot (t-t_0))} + \vec{C}_* \quad (3)$$

If $k_M > 0$, $\vec{P}_v(t)$ converges to \vec{C}_* as t grows, whereas if $k_M < 0$, $\vec{P}_v(t)$ diverges from \vec{C}_* as t

grows. Besides, if $k_M = 0$, the virtual tool keeps still ($\vec{P}_v(t) = \vec{P}_v(t_0)$).

In the same way, the orientation of the virtual tool evolves as its position over time. The orientation will be given by the following equation:

$$\vec{\theta}_v(t) = \left(\vec{\theta}_v(t_0) - \vec{\theta}_* \right) \cdot e^{(-k_\theta \cdot (t-t_0))} + \vec{\theta}_* \quad (4)$$

Where k_θ is a positive real.

The value of k_M and k_θ are fixed given the information of P_r (if a forward movement of the user's arm is detected, k_M and k_θ will be fixed as positive values).

4 EXPERIMENTS

4.1 Aim of the experiments

The goal of the experiment is to evaluate the FOLLOW-ME technique. To show the contribution of this technique for the assistance to other classical techniques, we have implemented and compared several techniques in the same experimental settings. On the one hand, we have compared the classical Go-Go technique with the Go-Go technique assisted by the FOLLOW-ME technique, and on the other hand, we have compared the classical Ray-casting technique with the Ray-casting technique assisted by the FOLLOW-ME technique.

The different techniques are implemented in the same Virtual Environment which is composed of different targets placed at different depths. The targets can be static or dynamic. We think that the FOLLOW-ME technique might be particularly useful in two kinds of situations: first, when targets are far, second when targets are moving.

4.2 Experimental setting

Figure 2 shows the experimental setting. The user is situated in front of a workbench (3,20x2,40 m). He interacts with the virtual world by using a Flystick which position $\vec{P}_r = [X_r, Y_r, Z_r]$ and orientation $\vec{\theta}_r = [\theta_r^X, \theta_r^Y, \theta_r^Z]$ are computed in real time by an ART tracking system using two infrared cameras placed on the left and the right opposite sides of the workbench.

The position and orientation of the Flystick determine the position $P_v = [X_v, Y_v, Z_v]$ and the orientation $\theta_v = [\theta_v^X, \theta_v^Y, \theta_v^Z]$ of the virtual tool used in the virtual world to reach the targets. The model associated with the implemented techniques gives the for-

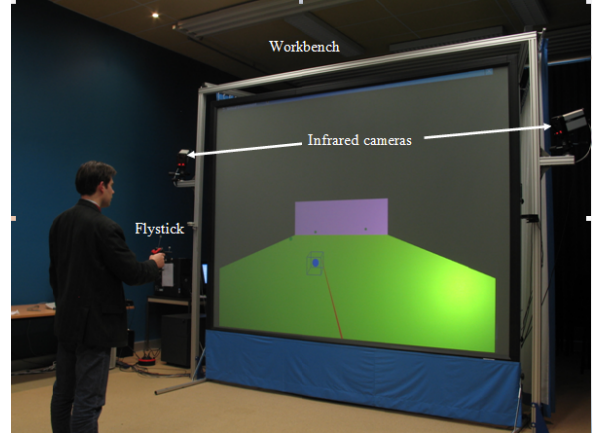


Figure 2. Experimental setting

mal relation between the couple (P_r, θ_r) and the couple (P_v, θ_v) .

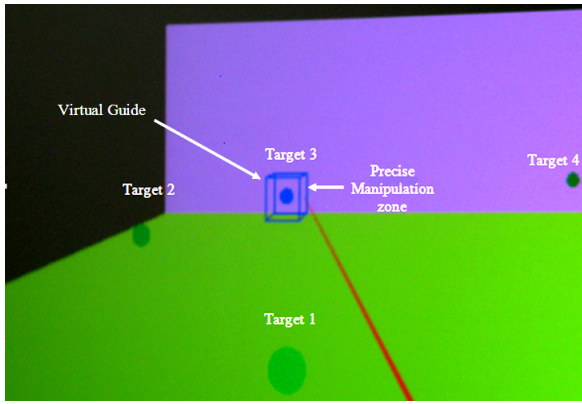
4.3 Experimental protocol

Four targets T_i , which are disks with the same diameter D_i , are placed at N different depths in VE. The targets are green colored (see Fig.3(a)). Each target T_i is centered on $C_{Ti} = [X_{Ti}, Y_{Ti}, Z_{Pi}]$ and situated at depth $Z = Z_{Pi}$. The user may control a virtual tool which position is $[X_S, Y_S, Z_S]$ and orientation $[\theta_S^X, \theta_S^Y, \theta_S^Z]$. The virtual tool is represented by a virtual pointer when we apply the Ray-casting technique or by a virtual hand when we apply the Go-Go technique.

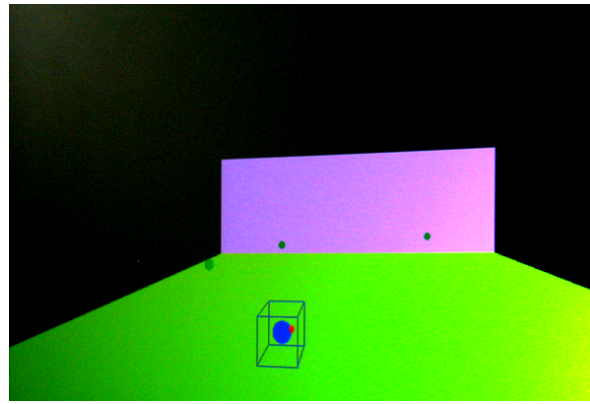
An object can be selected by intersecting it with a virtual pointer (or the virtual hand) which is activated by holding down the Flystick button. When an object is intersected, its color changes and it can be picked up by releasing the button. In the case of the Go-Go technique, the user selects an object by intersecting it with the virtual hand.

The experiment is composed of two principal phases. In the first phase, the different techniques are tested on static objects. In the second case, the same techniques are tested on moving objects. In the two phases of the experiment, we implemented the two techniques (Go-Go and Ray-casting) with different types of assistance:

- without assistance (classical Go-Go and classical Ray-casting techniques);
- visual assistance (see the box around the target in Fig. 3);



(a) The Ray-casting technique



(b) The Go-Go technique

Figure 3. Go-Go and Ray-casting techniques with the FOLLOW-ME assistance

- FOLLOW-ME assistance (visual and command assistance).

The interest of implementing the two techniques with the visual assistance only (second case) is to measure the influence of the command assistance comparing to the visual cue assistance. Thus, it may be possible to show the benefits of the FOLLOW-ME technique comparing to a simple visual cue assistance. Ten volunteers, all are men (their age varied between 25 and 35 years), participated to the experiments. Although they all had basic knowledge about computer technology, they had never experienced human-computer interaction tasks such as selection in VEs.

For each phase (static or dynamic objects), each kind of assistance (classical, visual or FOLLOW-ME assistance) and each interaction technique (Go-Go or Ray-casting techniques), the user executes a series of fifteen trials (150 trials for all the users). A trial consists on selecting a predefined target (color blue) in the VE with the virtual tool with a minimum laps of time. At the beginning of each trial, the target which must be selected by the user is given randomly by the system. If a user could not select a given target after 45 seconds, the trial is considered to be a failure.

We ask the participants which one of the different kinds of assistance is the most convenient, inconvenient or without interest for each interaction technique (Go-Go and Ray-casting) and write down reason. Each user must quantify the quality of each type of assistance between 1 and 5 such as 1 accounts for a poor assistance and 5 for a good assistance. The answers to these questions become the basic data for qualitative analysis.

4.4 Performance cues

Three performance cues are considered:

- (K_1) laps of time to reach the targets;
- (K_2) evolution of the distance between the virtual tool (virtual pointer or virtual hand) and the target during time (utilized for the Go-Go technique);
- (K_3) evolution of the angular distance between the virtual tool (virtual pointer or virtual hand) and the target during time (utilized for the Ray-casting technique).

Whereas the first cue is classically used, we think that the other ones are particularly relevant. Indeed, when far from the target, the user will probably make the virtual pointer (virtual hand) nearer to the target very easily without any assistance (visual or other). But, when approaching to the target, errors in piloting the virtual tool may occur if the target is small enough. The direct consequence of an error is the growth of K_2 or K_3 during the trial. The zone around the target in which K_2 or K_3 may grow corresponds precisely to zone in which the user needs assistance to reach the target. So, the K_2 or K_3 cues may be used to determine the minimum volume of the zone surrounding the target in which assistance has to be utilized. This may determine the appropriate volume of the scaled and precise manipulation zones for the FOLLOW-ME technique.

5 Results and discussion

5.1 Quantitative evaluation

First, let's analyze the results for the Go-Go technique. In general, we have found that the assistance of the FOLLOW-ME technique gives better results than the assistance of visual cue, that itself gives better results than the classical Go-Go technique (see Fig. 4 (a),(b) and Fig. 5 (a),(b)). In particular, if we take the example of target 3, which is far from the user, the FOLLOW-ME technique permits to drastically diminish the number of failures (timeouts). In the case of a static target 3, the percent of timeout decreases from 16% (classical case) to 10% (visual cue only) and to less than 5% (FOLLOW-ME) (see Fig. 5 (a)). Moreover, if the target 3 is moving, the results show a more important difference between the three kind of assistance: 27% (classical), 17% (visual cue) and less than 5% (FOLLOW-ME) (see Fig. 5 (b)).

We may also notice that the results for the FOLLOW-ME technique for static and dynamic targets do not vary very much, whereas it is not the case for the classical and visual cue assistances. Besides, the results do not vary a lot from one target to another for the FOLLOW-ME technique. So, the first results we have tend to show that the duration of a trial is little dependent to the position of the target or the fact it is moving or not.

Second, let's analyze the results for the Ray-Casting technique. In general; we have found that the mean time to reach a target (static or dynamic) is not lessen significantly by the assistance of the FOLLOW-ME technique (see Fig. 4 (c),(d) and Fig. 5 (c),(d)). We may explain those results with two arguments:

- First, the selection task may seem to be very easy. Even when the target is moving, the percent of timeouts is very low in for all the three kinds of assistance;
- Second, the time to automatically reach the target when entering the precise manipulation zone was non neglectable (about one second). And, looking at the duration of a trial (from four to six seconds), this delay is important.

But, one thing that the FOLLOW-ME technique seems to bring is the reproducibility of the selection task. The reproducibility is measured with the standard deviation associated to each kind of assistance. For target 1 (dynamic case) and target 3 (static and dynamic), the standard deviation of the duration of

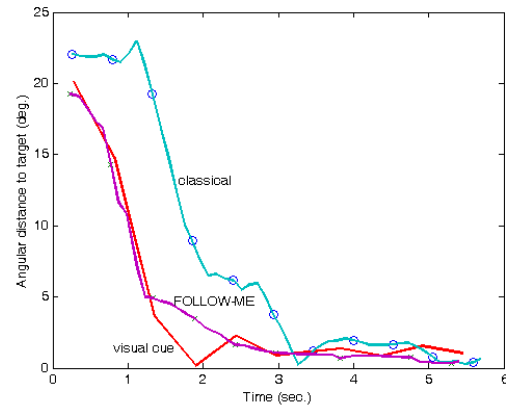


Figure 6. The evolution of angular distance over time

a trial is minimized by the FOLLOW-ME technique (see Fig. 4 (d) and Fig. 5 (c),(d)). If we look at the K_3 measure, we notice that the evolution of the angular distance to the target over time diminish more regularly for the FOLLOW-ME assistance than for the classical and visual cue assistances (see Fig. 6).

5.2 Qualitative evaluation

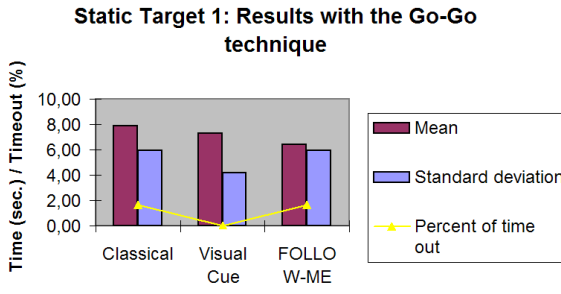
Table 1 represents the results of qualitative analysis. Subjects noted difficulties to select dynamic and remote virtual objects with classical Go-Go and Ray-casting techniques. The visual assistance has advantages for the Go-Go technique but not forcing for the ray-casting technique. The FOLLOW-ME assistance is the best in terms of convenient and easiness of learning. On the other hand, almost every user commented that grabbing static objects via classical Ray-casting is easier than when using other techniques.

Only three of our users (see table.1) commented on the inconvenience of FOLLOW-ME technique.

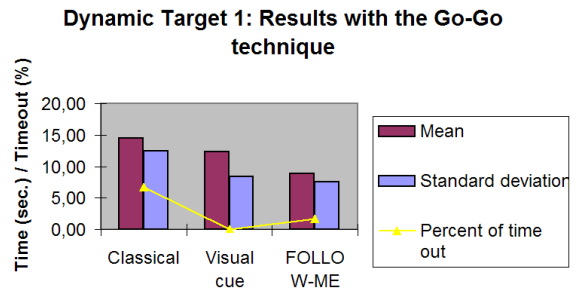
6 Conclusion and perspectives

In this article, we have evaluated the FOLLOW-ME interaction technique. The main characteristics of this technique are:

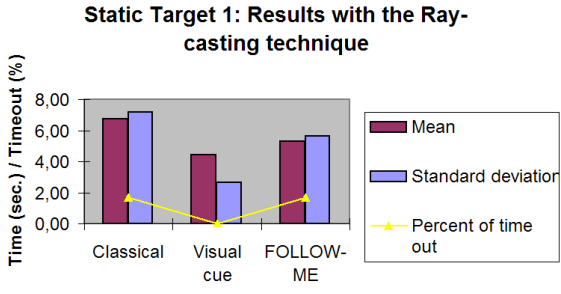
- the splitting of the virtual environment into three zones (free manipulation, scaled manipulation and precise manipulation zones) differing from each other by the *granularity of the interaction*;



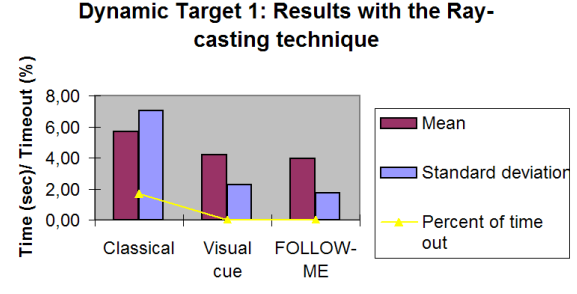
(a) Static Target 1: Go-Go technique



(b) Dynamic Target 1: Go-Go technique

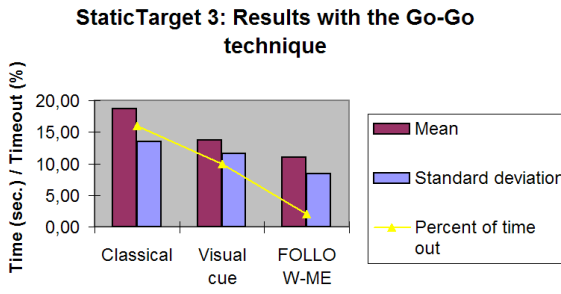


(c) Static Target 1: Ray-casting technique

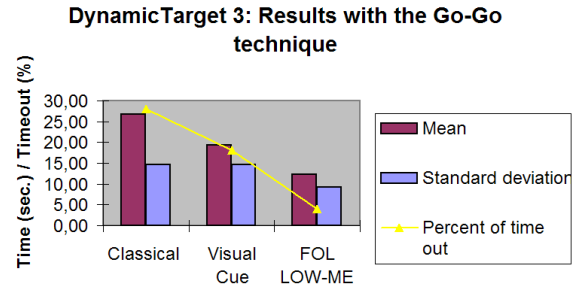


(d) Dynamic Target 1: Ray-casting technique

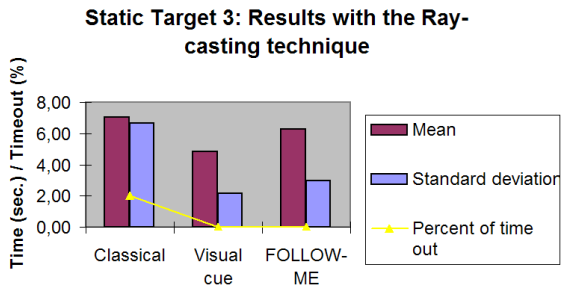
Figure 4. Quantitative evaluation : Target 1 (Results)



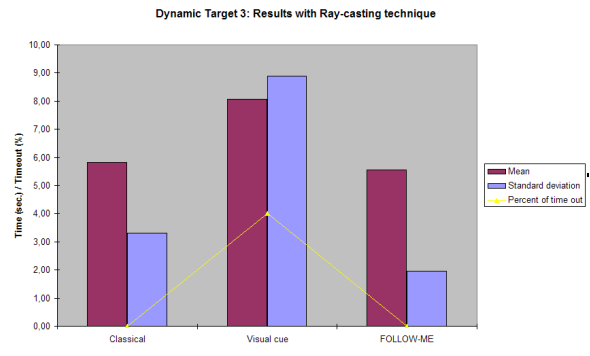
(a) Static Target 3: Go-Go technique



(b) Dynamic Target 3: Go-Go technique



(c) Static Target 3: Ray-casting technique



(d) Dynamic Target 3: Ray-casting technique

Figure 5. Quantitative evaluation : Target 3 (Results)

	Convenient	Inconvenient	Without Interest
Classical Ray-casting	0	10	0
Ray-casting with Visual Assistance	1	4	5
Ray-casting with FOLLOW-ME Assistance	8	2	0
Classical Go-Go	0	10	0
Go-Go with Visual Assistance	2	5	3
Go-Go with FOLLOW-ME Assistance	10	0	0

Table 1. Qualitative Evaluation

- the use of virtual guides in the precise manipulation zone.

This technique is dedicated to assist other techniques (in this paper, we have focused on the Go-Go and Ray-casting techniques, in the case of a selection task). First we have proposed a formal model to the FOLLOW-ME technique (see section 3). The particularity of this model relies on the automation of the target reaching process when the virtual tool used to select it is close enough to the target (precise manipulation zone).

The preliminary results described in this paper show that the FOLLOW-ME assistance permits to decrease significantly the time to reach a target for the Go-Go technique. If the target is moving, its permits to achieve the task whereas it may be very difficult without the help of FOLLOW-ME. Another important result is that the reproducibility of the selection task is facilitated by the use of the FOLLOW-ME technique, even if the mean time to reach the target is not lessen (case of the Ray-Casting technique). This may induce that the user has to concentrate less while using FOLLOW-ME to reach a target. So, this technique might be used with benefits for teleoperation tasks.

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