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Virtual and augmented Reality for Cultural Computing and Heritage:

a case study of Virtual Exploration of Underwater Archaeological Sites (preprint)

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Abstract The paper presents different issues dealing with both the preservation of cultural heritage using Virtual Reality (VR) and Augmented Reality (AR) technologies in a cultural context. While the VR/AR technologies are mentioned, the attention is paid to the 3D visualization and 3D interaction modalities illustrated through three different demonstrators: the VR demonstrators (Immersive and semi immersive) and the AR demonstrator including tangible user interfaces. To show the benefits of the VR and AR technologies for studying and preserving cultural heritage, we investigated the visualisation and interaction with reconstructed underwater archaeological sites. The base idea behind using VR and AR techniques is to offer archaeologists and general public new insights on the reconstructed archaeological sites allowing archaeologists to study directly from within the virtual site and allowing the general public to immersively explore a realistic reconstruction of the sites. Both activities are based on the same VR engine but drastically differ in the way they present information and exploit interaction modalities. The visualisation and interaction techniques developed through these demonstrators are the results of the on-going dialogue between the archaeological requirements and the technological solutions developed.

Keywords Underwater Archaeology · Mixed Reality · Virtual Reality · Augmented Reality · Cultural Heritage · Cultural Computing

1 Introduction

Cultural Computing (CC) implies the application of computer technology in the field of culture, arts, humanities, or social sciences. It is an emerging field and the answer to the computability of culture is not clear as mentioned by Fei-Yue Wang in [41]. For Tosa N et al. [38] the CC is a method for cultural translation that uses scientific

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methods to represent the essential aspects of culture. An other definition of CC can be given as a computer technology which can enhance, extend, and transform human creative products and processes [11]. Virtual and Augmented Reality Technologies will provide new means to create and transform culture. On one hand, VR technology provides us with the possibility of immersion within multimodal interactions (audio, video and haptics) to enhance user presence in digitalised culture (digital theatre; digital dance; digital music; digital heritage, etc.). On the other hand, AR or mixed reality technology provides us with the possibility to extend, transform and combine different cultures in the same mixed environment (for example combine object from digital dance with others from digital music over space and time). However, we need to develop new interfaces and new interaction metaphors to allow 3D visualisation of culture and 3D interaction with different objects of such culture. In this paper we focus our contribution on the domain of Archaeology by developing interfaces and new interactions for both presentation of existing archaeological underwater sites including interactions with artefacts in a cultural context as well as developing tools for preserving cultural heritage.

Most of the work mentioned in this paper is related to Research & Development performed within the VENUS project (Virtual ExploratioN of Underwater Sites), sponsored by the European Community. The main goal of the VENUS project is to provide scientific methodologies and technological tools for the virtual exploration of deep underwater archaeological sites. Such sites are generally out of reach for divers and requires new technologies and tools in order to be surveyed by archaeologists. The first step of the proposed methodology consists in performing a bathymetric and photogrammetric survey of the site with remote operated or autonomous underwater Vehicle. Bathymetric and photogrammetric data are then used to reconstruct the seabed while photogrammetric data are processed in the "Arpenteur" photogrammetric tool[1] which measure points on artefacts (in our case Amphorae) from several geolocalised points of view in order to reconstruct artefacts shapes, dimensions and location which are then stored in an archaeological database for further examination by archaeologists. Our role in the project consists in gathering the reconstructed elements in an Immersive Virtual Environment (VE) providing tools for archaeologists to survey such virtual sites in the most natural and easy way as possible. We have developed several "demonstrators" in order to assess the benefits of Virtual and Augmented Reality (VR & AR) in the field of underwater archeology. All the demonstrators are based on the same VR engine described in section 3.2.1 but drastically differ in the input and output modalities: The most simple demonstrator is called the "low-end" demonstrator and offers all the functionalities on a simple laptop. The Virtual Reality demonstrators (respectively the semi-immersive and immersive demonstrators) uses large screen or head mounted stereo display to enhance immersion and allow interaction with 3D joysticks. Finally, the Augmented reality demonstrator features a real map of the site augmented with virtual elements where interaction is provided through the use of various tangible tools related to the corresponding tools of the VE.

[1] "Arpenteur" photogrammetric tool is developed by Pierre Drap's Team at LSIS, in Marseille, France [14]

2 Related work

Drap and Long mentioned in [15] that for many years Geographic Information Systems have become common tools for archaeologists who see in this technology the alliance between the huge amounts of information collected in the field and graphical representation which supports the analysis. The GIS graphical representations most often originate from cartography, that is to say merging vectors, images, and symbology in 2D visualization tools. The old culture of chart reading is very useful in the use of GIS and probably one of the obstacles in the way of a truly 3D GIS. As a matter of fact, even without the realistic representation, the strength of the GIS is linked to the symbolic cartographic representation of the data offering a synthetic expression of the data analysis. If the 2D representation is sufficient to demonstrate the archaeological work concerning an urban scale or larger, applied to a period for which traces of the elevations do not exist, it is far from being the same when one is studying a building, or in this present case, a ship. The need for a 3D representation is then of first importance and the global understanding of the study revolved around that kind of representation. For instance, Karma VI was an interface for ESRI's spatial Database Engine (which produced the arcGIS more recently) that supports powerful visualization, manipulation, and editing of standard GIS data in a VR environment [18], However, as mentioned by Eileen Vote in [40]: "these Immersive Virtual Reality applications weren't developed for archaeological inquiry and therefore don't consider the specific research tasks archaeologists need to perform". Although efforts have been provided to turn underwater photogrammetric surveys into interactive virtual environments as mentioned in [15] which used VRML output for 3D visualisation purposes, one the goals of the archaeological demonstrator within VENUS project is to transport archaeologists within such a reconstructed archaeological site but most of all allow them to interact with the gathered data by connecting tools in the VE to an underlying archaeological database.

2.1 Immersive Virtual Reality

First of all, we need to establish a definition of Immersive Virtual Reality. A commonly accepted definition of Virtual Reality have been provided by Rheingold in 1991 as an experience in which a person is "surrounded by a three dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it". [33]. Cruz-Neira et al. have proposed in [12] a definition more confined to the visual domain: "a VR system is one which provides real-time viewer-centered head tracking perspective with a large angle of view, interactive control, and binocular display". However all definitions of VR agree on three distinctive features: (1) immersion, (2) interaction and (3) real time. Billinghurst defined in [5] three kinds of information presentation paradigms requiring increasingly complex head tracking technologies:

- In "Head-stabilised" information is fixed to the user's viewpoint and doesn't change as the user changes viewpoint orientation or position. Any VR system which doesn't provide tracking is then considered as "Head-stabilised". In the

Venus project, the low-end demonstrator running on a laptop with no tracking devices could be considered as a "Head-stabilised" system.

- In "Body-stabilised" information is fixed relative to the user's body position and varies as the user changes viewpoint orientation, but not as they change position. The semi-immersive and immersive demonstrators are "Body-stabilised" systems since head's orientation changes viewpoint but motion within the virtual environment is controlled with 3D joysticks rather than head's position.
- And finally in "World-stabilised" information is fixed to real world locations and varies as the user changes viewpoint orientation and position. The Augmented Reality demonstrator is typically a "world stabilised" system as position and orientation of the viewpoints needs to be computed in order to register the virtual environment over the real map. However, the immersive demonstrator could also use body motion in a "World-stabilised" way for small motion within the tracking space and whereas "Body-stabilised" is considered when travelling through the environment with the 3D joysticks.

The ARCHAVE system created by Vote and Acevedo [40] and dedicated to the archaeological analysis in VR of the excavated finds from the Great Temple site at Petra, Jordan, provided some interesting outcomes on the use of immersive VR for archaeology: The system used a CAVE for display and was interfaced with an artefact database containing over $250,000$ catalogued finds. Concerning visualisation, using an immersive CAVE allowed to examine the data in the context of a "life-size" representation; the immersive VR visualization gave the archaeologists the opportunity to explore a site in a new and dynamic way and, in several cases enabled them to make discoveries that opened new lines of investigation about the excavation. However (as mentioned by [2]) Archaeologists "consistently needed an easily accessible overview of the model, much like the experience they obtain by flying high up over the virtual model, so they could study how the different artefacts were distributed over the entire site". This problem has been addressed by accessing a "Miniature model for a site-wide analysis" at any time during exploration. In [39] van Dam, Laidlaw and Simpson propose a review of experiments in immersive VR for scientific visualisation including the above mentioned ARCHAVE system. Clearly, visualisation by itself will not solve the problem of understanding truly large datasets that would overwhelm both display and human vision system. They advocate a human-computer partnership that uses algorithmic culling and feature-detection used to identify small fraction of the data that should be visually examined in detail by the human. Immersive VR could then be a potent tool to let humans "see" patterns, trends and anomalies in their data well beyond what they can do with conventional 3D desktop displays. The immersive surrounding context provides a kinesthetic depth perception that lets users better apprehend 3D structures and spatial relationships. It makes size, distance, and angle judgments easier since it is more like in being in the real world than looking through the screen of a desktop monitor to the world behind it; the advantages arise from the difference between "looking at" a 2D image of a 3D environment on a conventional display screen and "being in" that 3D environment and basing spatial judgments relative to one's own moving body. Concerning 3D interactions, Hinckley et al. [21] presented a formal user study of interactive 3D Virtual sphere with multidimensional input devices and found out that multidimensional input tasks presented a clear advantage over conventional devices. The study provides clear evidence that test users were able to take advantage of the integrated control of 3D to perform a task more quickly than with 2D input techniques.

2.1.1 Immersion with Head Mounted Displays

The main difference between the semi-immersive and the immersive demonstrator is the use of an Head Mounted Display (HMD) as the display device in the immersive demonstrator. We call it "fully" immersive as the HMD is tracked by an optical A.R.T. [1] system so that the user can look around. Ruddle found in [35] that the ability to look around with HMD allowed users to be less static in the environment as they don't have to stop travelling, take a look around and choose a new travel direction since looking around is allowed during travel: On average, participants who were immersed in the virtual environment using the HMD navigated the environment twelve percent faster. The decreased time was attributed to the participants utilizing the ability to "look around" while they were moving when immersed, as the participants spent eight percent more time stationary when using a desktop workstation. Bowman also studied human behaviour and performance between an HMD and a four-sided spatially immersive display (SID or CAVE) in [8]. In particular, he studied users' preferences for real versus virtual turns in the virtual environment. The results indicated that participants have a significant preference for real turns in the HMD and for virtual turns in the SID. This suggests that HMDs are an appropriate choice when users perform frequent turns and require spatial orientation. Even though HMD's field of view and resolution have drastically increased lately, one can not consider HMD's field of view as larger than standing in front of large screen or several screens (in the case of a CAVE), however this drawback is easily compensated by the "look around" features provided by tracked HMDs: By tracking head orientation the user experiences a hemispherical information surround - in effect a "hundred million pixel display" and nowadays even more as Reichlen coined this term in [32].

2.2 Augmented Reality and Tangible Interfaces

Azuma et al. [3] define an AR system as a system which "supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world". Moreover, the system should feature characteristics quite similar to VR features mentioned above such as:

- combines real and virtual objects in a real environment;
- runs interactively (2), and in real time(3); and
- registers (aligns) real and virtual objects with each other.

On one hand, Virtual reality technologies immerse the user in a synthetic environment in which, he cannot see the real-world around him. On the other hand, augmented reality allows the user to see the real environment with superimposed virtual objects. Rather than replacing the real world, the user is immersed in an environment where the virtual and real objects coexist in the same space. Interaction with the augmented environment is performed with Tangible User Interfaces (TUIs) which use physical objects as tools to establish an interface with the virtual environment. The TUI provides a natural and intuitive interface, a user can manipulate virtual 3D objects by simply handling physical objects. A considerable amount of research has been done in the domain of TUIs and new Human-Computer Interaction approaches were proposed to improve the physical interaction with computational media. Kato et al. [24] implemented table-top AR environments with conventional markers and paddles for object manipulation. They advocate designing the form of physical objects in the interface using established Tangible User Interface design methods. Some of the tangible design principles include:

- Object affordances should match the physical constraints of the object to the requirements of the task.
- The ability to support parallel activity where multiple objects or interface elements are being manipulated at once.
- Support for physically based interaction techniques (such as using object proximity or spatial relations).
- The form of objects should encourage and support spatial manipulation
- Support for multi-handed interaction.

So that in an AR interface the physical objects can further be enhanced in ways not normally possible such as providing dynamic information overlay, context sensitive visual appearance, and physically based interactions.

One of the most obvious benefits of Tangible User Interface pointed out by Kato et al. in [24] is that users do not need to learn any complicated computer interface or command set to use tangible interfaces.

3 Virtual and Augmented Reality for underwater archeology

Before starting to build virtual environments reflecting the surveys performed on wreck sites, a case study has been performed on a typical underwater archaeological survey and archaeologists were interviewed concerning the requirements of such virtual environments. Archaeologists are mainly interested in the cargo which leads to determine the period of the wreck but also in the environment which could explain the artefacts' layout. A Full list of requirements was build concerning visualisation (full view and close range), navigation (free navigation, artefact's based navigation or diver's navigation) and interaction (Artefact's individual data facts, inventory and artefacts statistics in terms of types, dimensions, locations and fragment status for broken artefacts). These requirements were later transposed into a list of features implemented in various ways within the different demonstrators.

Although all proposed technologies have been already used in other fields, and even though computer graphics is a common tool to represent cultural heritage findings and results. Our goal is to introduce VR and AR technology as a working tool for archaeologists allowing them to perform actual archaeological tasks rather than just a presentation tool as there is no previous such systems in underwater archaeology.

Within the framework of the VENUS project we propose two distinct forms for the archaeological demonstrator featuring both VR-semi-immersive and VR-immersive technologies. The immersive surrounding context of VR provides a kinesthetic depth perception that lets users better apprehend 3D structures and spatial relationships. It makes size, distance, and angle judgments easier since it is more like being in the real world than looking through the screen of a desktop monitor to the world behind it; the advantages arise from the difference between "looking at" a 2D image of a 3D environment on a conventional display screen and "being in" that 3D environment and basing spatial judgments relative to one's own moving body. On the other hand, by combining Augmented Reality techniques with Tangible User Interface elements, we can create interfaces in which users can interact with spatial data as easy as real objects. Tangible AR interfaces remove the separation between the real and virtual worlds and so enhance natural interactions. The semi-immersive demonstrator is based on a large stereo display and 3D navigation and interaction are based on 3D wireless joysticks (also called "flysticks"). The immersive demonstrator is based on the same navigation and interaction devices but uses a tracked HMD to provide complete surroundings to the user. And finally the Augmented Reality demonstrator is based on a camera tracking system associated with a see through HMD registering the users viewpoint and allowing interaction with tangible interfaces over a map of the site.

3.1 Tracking technologies

The tracking technology is an optical tracking from A.R.T. [1] using 2 infrared cameras (see Figure 6) for tracking unique patterns composed of retroreflective balls which could be used as input devices such as flysticks and handles or head tracked devices such as LCD glasses, or HMD. Optical tracking allow users to wear or handle any wireless devices as long as they can be equipped with unique retroreflective balls pattern (as shown in Figure 1).

(a) A.R.T Tracking camera (b) Flystick (c) Tracked LCD glasses (d) Tracked HMD

Fig. 1 Tracking devices

The A.R.T. system is capable of measuring position and orientation of several patterns at the same time (up to 64 balls) at a 60 Hz measure rate (54 Hz if LCD shutter glasses synchronisation is required). The achievable accuracy of the tracking system is 0.4 mm for position and 0.12° for orientation within a $3 \times 3 \times 3$ m volume. However the average measured accuracy precision of the system is actually between 0.5 and 2 mm for position and 0.3° for orientation due to slow decalibration of the system over several months, which could be easily corrected by a system recalibration from time to time.

3.2 Virtual Reality demonstrators

We developed 2 versions of the VR application which uses different devices technology. The first version works with simple input/output devices (mouse, keyboard, and monitor) in order to easily run the demonstrator without needing any specific devices that can be difficult to transport.

In the second version we employed more advanced visualisation and tracking devices to offer a semi or complete immersive navigation and more natural interaction with the environment.

3.2.1 Virtual Reality system description

This section presents the structure and the construction of virtual environment and the corresponding virtual reality system.

3.2.1.1 Virtual Environment structure: All virtual environments for the VENUS project are developed around the "OpenScenegraph" (OSG) open source high performance 3D graphics toolkit for VE modelling and visualization [10]. The choice of OSG was motivated by the need of a high level API abstracting rendering features for the 3D objects, scene control and cameras views management, which is also flexible enough to develop specially tailored visualisations and interactions techniques wherever they are necessary. The main structure of the VE developed for archaeologists contains the various seabeds (large bathymetric seabed, and photogrammetric seabed with textures) and the various artefacts (in our case amphorae) lying on the seabed and recorded in the database.

The construction of the VE is divided into 3 principal steps:

- *Seabed:* Seabed meshes are loaded from an XML file containing 3D vertices and texture information.
- *Artefacts:* An initial request to the database is performed to retrieve artefacts parameters such as location, orientation, status and artefacts models. Then registered artefacts and markers 3D models are loaded.
- *Virtual Environment:* These elements are placed in the virtual environment and navigation and interaction managers are started. When 3D interaction devices are available a connection to input devices is opened by using a VRPN server [37]. The interaction manager handles inputs and eventually sends queries to the database.

3.2.1.2 Virtual Reality System Architecture: The architecture of the VR system is composed of a database containing all required data such as: photos, artefacts parameters, 2D/3D objects location, etc (see Figure 2). The archaeological database contains the pictures taken during the survey and the 2D and 3D points of artefacts lying on the seabed measured during the photogrammetry process. When these points are labelled to belong to a recognized artefact type, an actual artefact could then be reconstructed in terms of location, orientation and size and all these artefacts' parameters are stored in the database. Therefore, such a database could be shared between the photogrammetric reconstruction process and the virtual environments designed to immersively explore the site. In order for VE users to extract and study properties of the cargo (registered artefacts), users interaction with artefacts are translated into SQL queries sent to the database and results are displayed through selections or numeric data display depending on the nature of the results. Queries to the database can concern partial or complete inventory, metrology statistics (average size, similar sets,...) or spatial relationships between artefacts.

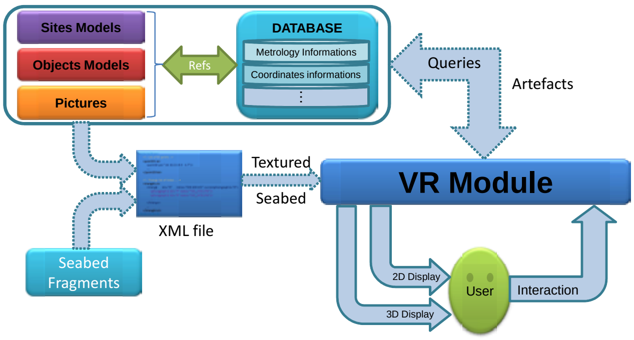


Fig. 2 VR system architecture

3.2.1.3 Virtual Reality Interface and Interactions: The VE interface is composed of many classical tools: menu bar, information panel and popup message. The menu bar contains multiple submenus, the first menu is a selection menu which proposes visualization/selection of any type of artefacts registered in the site, the second menu allows to switch between analysis and exploring navigation mode, the third one allows to hide some parts (terrain) of the VE to highlight others parts (artefacts). Otherwise, several classical menus are provided by the interface, like, font and colour manager, help and exit menu. The information panel displayed on the bottom of the VE (Figure 3) shows information about objects loading progress, user location or interaction result (e.g. amphora Id 21 was selected). A 3D popup message is displayed when the mouse passes over an object (or when the flystick selection ray casts an objects) showing the type of the objects or other information on selected objects.

3D interactions with a Virtual environment can be divided into three principal tasks: Navigation, Selection and Manipulation. The Navigation or the control of the user's viewpoint is the most important task and most used when using the virtual

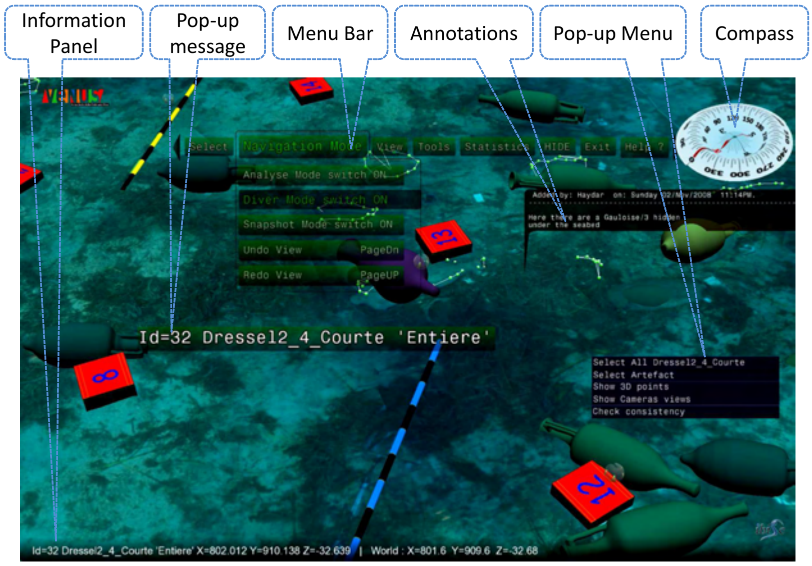


Fig. 3 Tools in the Virtual Environment

environment. Bowman et al. [7] recognized this task as the most common to all virtual environments. It allows users to explore, investigate and/or operate in a virtual space. They identified two main components for navigation: travel and way finding [9], where they classified the different navigation techniques into three basic motion tasks: the choice of direction or target, the choice of motion speed/acceleration, and choice of entry conditions [7]. For 3D interaction we used 2 flysticks tracked by an A.R.T. cameras system that allows motion control and hence navigation, each flystick have 8 buttons and offers important number of choice to accomplish multiple tasks simultaneously. Display can be performed by a large screen with active stereo visualization or by a tracked Head Mounted Display (HMD) to increase immersion (see Figure 4 for tracked devices details).

A new navigation technique has been developed [20] using both hands to determine motion direction and control speed. A similar technique have been proposed by Mine et al. [28], and is based on the knowledge of both hands position where speed is computed according to the distance between the two hands. Such a technique is cognitively difficult because the user may have difficulty in controlling the motion speed through the gap between his two hands. We used the angle between the hands rather than the distance which is easier to control. The motion direction is then given by the orthogonal axis to the segment joining hands positions. The viewpoint of the user is defined by two 3D points, the *eye* point and the *at* point. Changing user's viewpoint can be a translation of the viewpoint, or a rotation, or both translation and rotation. A viewpoint translation can be done by translating both *eye* and *at* points while a rotation is done by a rotation of the *at* point around the *eye* point. The motion speed is defined by the value of the translation step and the value of the rotation angle in each frame update. Motion speed is computed according to angle α between the

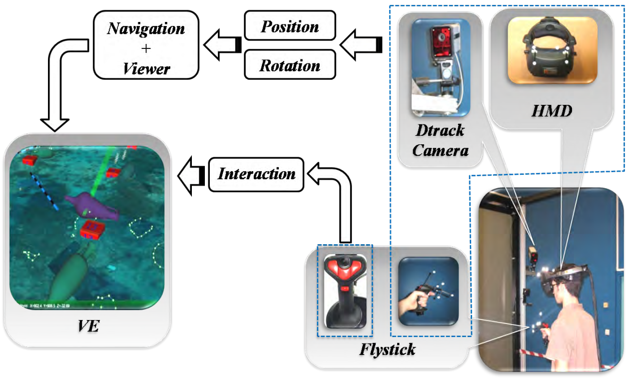


Fig. 4 VE devices technology

hands. The rotation direction and speed is given by the angle β between the segment joining hands positions and the horizontal axis (Figure 5).

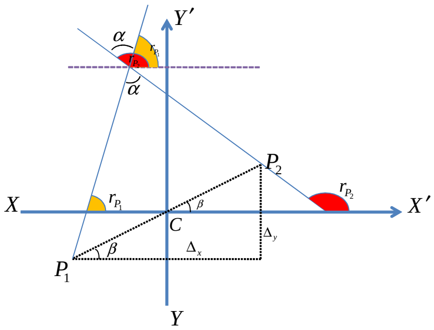


Fig. 5 Speed and new position computing

Considering $C(x_c, y_c, z_c)$ the center of $[\overrightarrow{P_1P_2}]$ as the origin of the coordinate system. All coordinates can be computed in the new coordinate system by a simple translation $T(x_c, y_c, z_c)$. Having the position of the two points $eye(x_{eye}, y_{eye}, z_{eye})$ and $at(x_{at}, y_{at}, z_{at})$ of the current frame view f (Camera position), and having the positions $P_1(x_{p_1}, y_{p_1}, z_{p_1})$ and $P_2(x_{p_2}, y_{p_2}, z_{p_2})$ of the hands (flysticks' positions) and the angles r_{p_1} and r_{p_2} between the hands and the $\overrightarrow{XX'}$ axis, we need to compute the two new positions $eye'(x_{eye'}, y_{eye'}, z_{eye'})$ and $at'(x_{at'}, y_{at'}, z_{at'})$ of the new frame view f'. We define the coefficients, S_t,S_r,$S_{t.max}$,$S_{r.max}$ as the translation speed, rotation speed, max motion speed and max rotation speed respectively. $S_{t.max}$,$S_{r.max}$ are predefined according to application needs. The values of α and β are given by the equations:

$$\begin{cases} \alpha = r_{p_2} - r_{p_1} \\ \beta = \arcsin\left(\frac{\Delta_y}{|P_1P_2|}\right) \; where \; \Delta_y = y_{p_2} - y_{p_1} \end{cases} \tag{1}$$

Then S_t and S_r are defined as follows:

$$
\begin{array}{lll}
if & |\alpha| \leq 10^\circ & \Rightarrow S_t = S_{t.max} \\
if & |\alpha| \geq 140^\circ & \Rightarrow S_t = 0 \\
if & |\beta| \leq 10^\circ & \Rightarrow S_r = 0 \\
if & |\beta| \geq 60^\circ & \Rightarrow S_t = 0
\end{array}
$$

Otherwise,

$$
\begin{cases} S_t &= \left(1 - \frac{\alpha}{140}\right) * S_{t.max} \\ S_r &= \frac{\beta}{90} * S_{r.max} \end{cases} \tag{2}
$$

The β value is limited between -90° and 90°, the rotation direction is defined by the sign of β. The rotation is clockwise when β is negative and anticlockwise when β is positive. To avoid the motion noise, due to user hands shaking, we define a noise angle value for rotation and translation. When β is between -10° and 10° we consider that motion is a pure translation and the rotation speed is null, whenever α is between -10° and 10° the translation speed is considered as maximal. The values of the new two points positions $eye'(x_{eye'}, y_{eye'}, z_{eye'})$ and $at'(x_{at'}, y_{at'}, z_{at'})$ are given by the equations:

first we apply the rotation S_r around the point eye :

$$
\begin{cases} x_{at'} &= x_{eye} + ((x_{at} - x_{eye}) * \cos S_r \; + \; (y_{at} - y_{eye}) * \sin S_r) \\ y_{at'} &= y_{eye} + ((y_{at} - y_{eye}) * \cos S_r \; - \; (x_{at} - x_{eye}) * \sin S_r) \\ z_{at'} &= z_{at} \end{cases} \tag{3}
$$

Then we apply the translation:

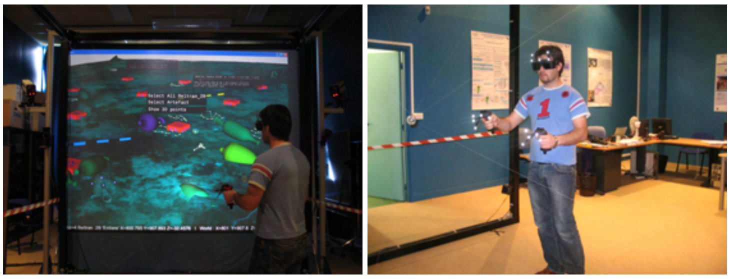
$$
\begin{cases} x_{eye'} &= x_{eye} \; + \; S_t * \sin\theta \\ y_{eye'} &= y_{eye} \; + \; S_t * \cos\theta \\ z_{eye'} &= z_{eye} \\ & \\ x_{at'} &= x_{at_1} \; + \; S_t * \sin\theta \\ y_{at'} &= y_{at_1} \; + \; S_t * \cos\theta \\ z_{at'} &= z_{at_1} \end{cases} \tag{4}
$$

Where θ is the camera rotation around the $\overrightarrow{ZZ'}$ axis of the viewer's coordinate system. We multiply by θ to overlay the camera and the viewer coordinate system.

3.2.2 Virtual Reality demonstrators setup

3.2.2.1 Semi - immersive demonstrator setup: The semi-immersive demonstrator (see figure 6) allows a human-scale representation of the virtual environment with a simultaneous navigation and interaction. It mimics the divers' paradigm and hence recreates but also enhance the diving process by allowing user interaction with the data collected on the cargo. Several archaeologists can easily share the same immersion level to collaborate in front of the large screen and benefit from the stereo view. However, only one stereo viewpoint could be modified on the display according to a tracked head position.

The semi-immersive demonstrator uses the Evr@ platform at UEVE featuring a large screen (3.2×2.4 m) allowing a user standing 1.5 m away from the screen to experience a 94° horizontal field of view and a 77° vertical field of view. Navigation and interaction through the Virtual Environment are controlled by one or two flysticks.



(a) (b)

Fig. 6 Semi-immersive demonstrator setup

3.2.2.2 Immersive demonstrator setup: The immersive demonstrator takes up most of the semi-immersive demonstrator's features such as life-size stereo viewing, simultaneous navigation and interaction but adds the look around capability which has proved to enhance users' orientation and mobility within the virtual environment (see [35] and [8]).

The same tracking technologies as in the semi-immersive demonstrator is used but a Head Mounted Display (HMD) is used for viewing the Virtual Environment. The chosen NVisor helmet offers a 50° Field of view with a 100% overlap between each eye display, hence ensuring a complete stereo display with a double 1280×1024 resolution (see figure 7).

From a larger point of view, such a HMD with "see-through" capabilities could also be used in outdoor environments such as terrestrial archaeological site as the one

Fig. 7 Immersive demonstrator setup

reported by Drap et al. in [16]. However, in this case, another kind of localisation sensors are required, such as the ones developed for the RAXENV[2] Project [42].

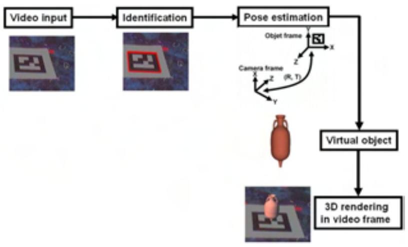
3.3 Augmented Reality demonstrator

Since archaeologists interest is mainly focused on the nature of the cargo one of the first feedbacks from archaeologists concerning VR demonstrators was that immersive navigation didn't provide much help to archaeological tasks in opposition to general public concerns where immersive navigation provides a deeper experience of a site. This observation lead us to propose an augmented map based navigation paradigm such as the "World in Miniature" proposed by (Stoakley et al., [36]) and later applied to Augmented Reality (Bell et al. [4]) which provides a much more familiar interface to archaeologists. Indeed, archaeologists have more ease working with maps where they can see the real world rather than a totally immersive environment in which it is difficult to be localized. Moreover, the Augmented Reality paradigm offer the opportunity to introduce a tangible interface (Ishii and Ullmer [22]; Poupyrev et al. [30]) to the tools developed in the VR demonstrator for archaeologists. These elements lead to the definition of a new demonstrator for archaeologists: AR Venus.

In AR Venus, archaeologists use a real map representing the deep underwater site. AR Venus proposes to enrich this environment and complete the real-world perception by adding synthetic elements to it rather than to immerse the archaeologist in a completely simulated artificial world. AR Venus provides an easy tool to interact with the real-world using tangible interface (in our case physical objects equipped with visual targets) to select and manipulate virtual objects by using a pose estimation algorithms to display artefacts models at the right location on the 2D map. Users need to wear special equipment, such as "see through" head mounted display, to see the map, augmented in real time with computer-generated features (see Figure 8(a)).

[2] http://raxenv.brgm.fr/

(a) The AR VENUS system



(b) Pose estimation and overlay process

Fig. 8 The AR VENUS system and Pose estimation.

3.3.1 3D map overlay

The first step in AR Venus is to project the 3D models of the seabed on the real 2D map using a system of visual markers identification and a pose estimation algorithm. For this visual tracking module, we used a simple webcam for tracking visual markers made up with printed 60×60 *mm* black and white fiducials. The tracking algorithm computes the real camera position and orientation relative to the physical markers in real time and also identify the content of the fiducial as a unique identifier (see Figure 8(b)). Some fiducials are stuck on the real map in order to compute the pose of the virtual environment over the real map whereas others are used to interact.

We used OSGART library to identify targets and overlay the 3D models on the real scene. OSGART has been designed to provide an easy bi-directional transition from VR to AR [26] by integrating ARToolkit [23] within OpenSceneGraph. The tracking library finds all squares in the binary image. For each square, the pattern inside the square is captured and matched to some pre-trained pattern templates. The square size and pattern orientation are used to compute the position of the camera relative to the physical marker, hence, the pose accuracy mostly depends on the marker size. Figure 8(b) shows the different steps of pose estimation algorithm (also called registration).

3.3.2 Virtual objects registration

We used single and multiple targets with different scale to improve the tracking stability and accuracy. We started our tests using a single marker. The obtained results with a single marker were not accurate and we noticed a large shift between the virtual model and the real one represented on the 2D map. The size ratio between the small target and the large map didn't provide a correct registration, which led us after trying a larger target to consider a multitarget tracking approach since these targets are lying on the same map plane.

3.3.3 Tangible interface

We saw in the previous section that static fiducials are used to register the virtual environment and artefacts, however, other targets can also be moved around the map and associated with virtual tools allowing the users to interact with the augmented environment using Tangible User Interfaces (TUI). Many research work have been done in this field over the last years [24], several interfaces have been developed for manipulation and exploration of digital information [19] using physical objects as interaction tools in virtual environments [22]. Several moving targets have been associated with virtual tools. These tools are activated whenever the camera identifies their corresponding patterns and discarded when they aren't visible anymore. such as:

- *selection tool:* The selection tool represents two sides of the same tangible "pallet" or "tile" as denoted by Billinghurst & Kato in [6]. The first side is used to trigger nearby object search and when an object is selected we can then flip to the other side for a closer inspection of the selected object (Figure 9(a)). Tracking of the selection tile is important in this case since objects are selected when the tile's target is close the object of interest. The selection of amphorae is performed using a probe target and the selected object stays attached to the selection probe for closer investigation. The developed technique consists in computing distance between the marker centre attached to the selection tool and the centre of amphorae got from the archaeological database. For unselecting, another marker is attached in the other side of the selection probe, when this marker is visible, the amphorae is deselected and placed into its original position on the map.

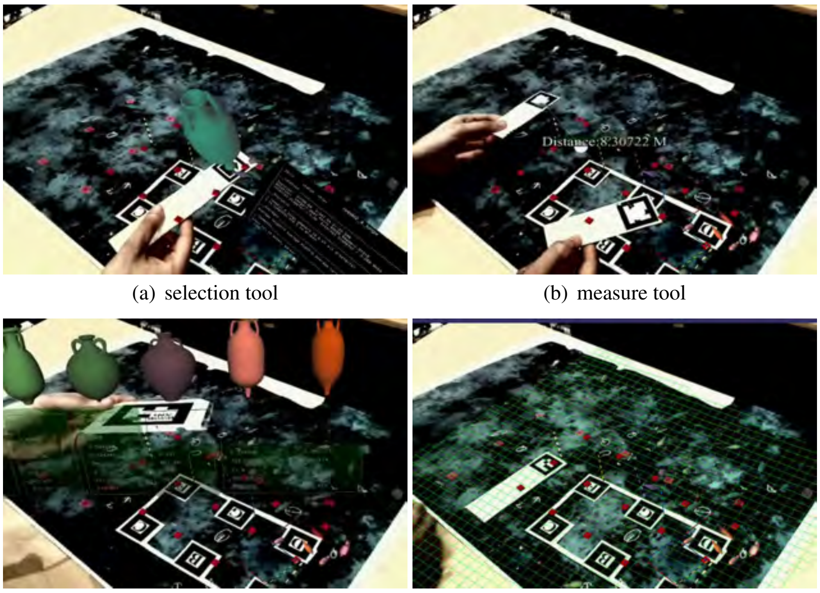
- *measuring tool:* the measuring tool allows to measure distances (expressed in the VE dimensions) between two specific targets moved around on the real map (see Figure 9(b)).

- *inventory tool:* Whenever the inventory tool target appears to the tracking camera, a virtual site inventory (in terms of artefacts' type and occurences) is attached above the target and can be placed on the map or handled for a closer inspection (see Figure 9(c)).

- *grid tool:* The grid tool allows to display a north-south oriented regular grid on the site (see Figure 9(d)). The grid target uses the same principle of a two sided tile used for selection tool in order to provide two different grid steps. Tracking the targets on the tile is not important in this case as only target recognition is used to trigger the two possible grids.

4 Evaluation

Some recent work [17] [13] addressing the evaluation problems in VR and AR systems confirm the domination of Objective and Subjective Measurement. Objective



(a) selection tool (b) measure tool

(c) inventory tool (d) grid tool

Fig. 9 AR Venus tools

and Subjective measurements are measurements methods used in empirical evaluations. Usually we found these measurements in many evaluations [27], [25], [8]. Objective measurements are studies that include objective measurements such as: completion times, accuracy/error rates and generally, statistical analyses are made on the measured variables. Subjective measurement studies users using questionnaires. They also employ statistical analysis of the results or a descriptive analysis.

4.1 Subjective evaluation

The functionalities offered by the various demonstrators have been evaluated by archaeologists during a workshop. The goal of the workshop was to present the already developed features to archaeologists but also to trigger feedbacks by having the archaeologists actually experiment the demonstrator by themselves. After a short presentation of the goals and means of the archaeologists demonstrators and a quick demo of the main features each of the archaeologists were asked to perform the following tasks:

- Artefacts group selection.
- Individual artefact selection.
- Circular area selection.
- Distance measuring between two artefacts.
- Add an annotation on the site, modify it then remove the annotation.
- Switch between seabed display mode (regular → grid → topographic)

- Display snapshot locations and images related to an artefact.

The survey was conducted individually with 11 archaeologists on two laptops running the low-end demonstrator. By the end of the test they were asked to fill in a questionnaire dedicated to help us pointing what's good and bad in the VR demonstrator for archaeologists.

The first questionnaire was about participant skills and habits concerning computer usage and more specifically the use of 3D and VR software as well as their current state by the end of the test. The second questionnaire was about the usability of the archaeological demonstrator in terms of navigation, interaction, accessing the tools and displayed data. The third questionnaire referred to users' satisfaction and allowed users to suggest improvements. The exploitation of these evaluation results is part of the validation of developed software as well as part of an iterative cycle methodology. This workshop was a unique opportunity to get feedback from a large panel of (well known) archaeologists.

The survey has been performed by 7 women and 4 men, aged between 31 and 60 with an average of 43 ± 10 years old, hence providing a rather senior researchers panel. Most of them are using computers on a daily basis. More than half of the users have already used 3D software and a bit less than a half of them already used virtual reality software.

4.1.1 **Usability**

Users were asked to rank the difficulty (on a 1 to 5 scale) of various aspects of the demonstrator such as navigation, interaction, accessing tools and also rank whether data display associated to various selection methods were satisfying. Individual data facts refers to the data sheet associated with a single selected object (as shown on Figure 11), type data facts refers to the information displayed by selecting all instances of a specific type of artefact (see also Figure 12) and Area data facts refers to the information displayed during area based selection (see also Figure 13). Figure 10 presents the assessments of these various topics.

The following analysis is based on the results of the questionnaires as well as archaeologists' comments during the test written down by the two experimenters.

4.1.1.1 Navigation: Navigation (whether free or guided by the artefacts) was considered as easy (or very easy) by 64% of the users, however 36% gave marks between 2 and 3 which tends to indicate they encountered some difficulty in navigating. This might explain the suggestions for new navigation modes (such as diver's mode) we have found in the possible improvements.

4.1.1.2 Interaction: Interaction marks features the same repartition as navigation, 64% found it easy and 36% encountered some difficulties. Once again, this might explain the number of improvements requests concerning the "Interaction with artefacts" feature (14 improvements requests out of 27).

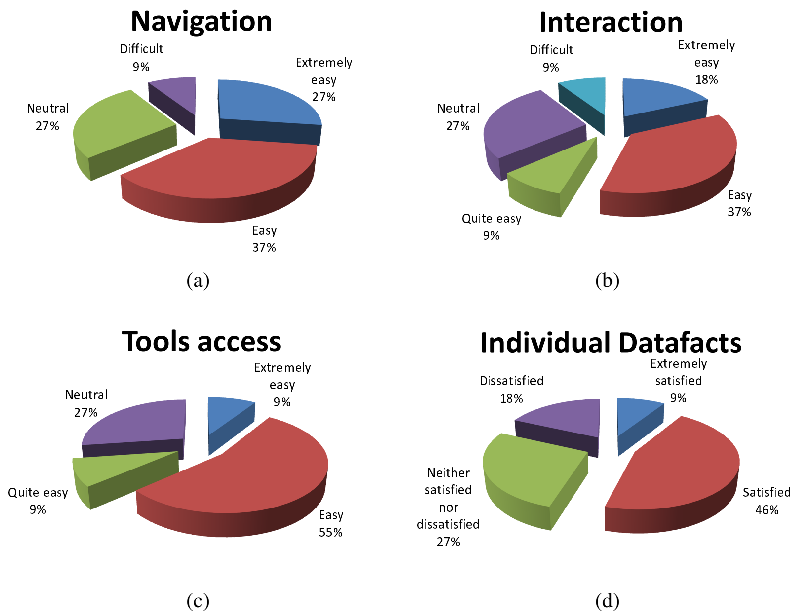


Fig. 10 Usability summary

4.1.1.3 Tools access: Tools are mainly situated in the menu and were considered as easy by a majority of 73% of the users; however 27% of them gave a mark of 3 and would have appreciated a clear separation of tools and various options in the menu.

4.1.1.4 Individual data facts: Individual data facts presenting the data sheet of a selected artefact were considered as satisfactory by 55% of the users, however, this also means that 45% of them were not satisfied or at least had not a good opinion of it. This also shows through the improvements request as 5 of them directly concerned "Individual data facts". The comments made on this point focused on the numerical aspect of the information presented to the user (Location and statistics) whereas they would have appreciated pieces of information like orientation and tilt or object visual reference (as displayed in classical artefacts catalogs such as the Dressel catalogue) which has been partially fulfilled by a new information panel (see Figure 11).

4.1.1.5 Type data facts: Type data facts presents the exact opposite repartition as 45% of the users only were satisfied by the information displayed by selecting types. Once again the numerical nature of the information panel (see Figure 12) could have been enhanced by showing an instance (the 3D model) of the selected type in the information panel. Besides, selecting types leads to a viewpoint change encompassing all instances of the selected type as well as a highlight of the selected artefacts. As a matter of fact, this highlighting could have easily been confused with fracture lines on artefacts (see also Figure 12) representing broken artefacts at the moment and this

Fig. 11 Individual Data facts

might also explain why the improvement request concerning a "better enhancement of selected artefacts" occurred 4 times in the survey.

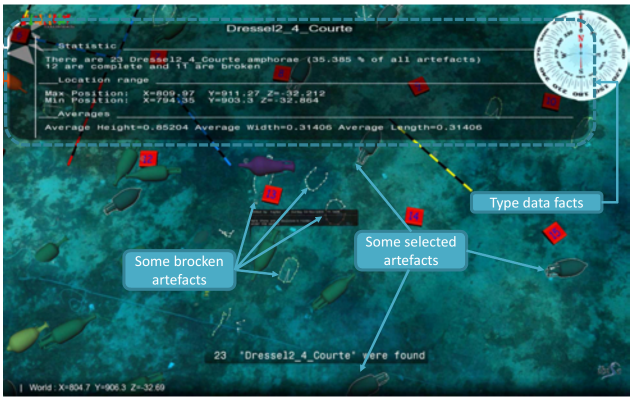


Fig. 12 Type data facts, selected artefacts and fracture lines

4.1.1.6 Area data facts: 55% of the users were satisfied by information panel displayed during circular area selection featuring the population of selected artefacts showing artefacts' type and occurrences (see Figure 13). But 45% had no opinion of were dissatisfied once again by the numerical nature of the information panel which could have been enhanced with artefacts type silhouettes.

This subjective evaluation performed with archaeologists allowed us to improve the core functionalities of the demonstrators and also add some new features to the virtual environment such as "diver's navigation" mode which allow archaeologists to review the site and measured artefacts just like divers would during the photogrammetric survey.

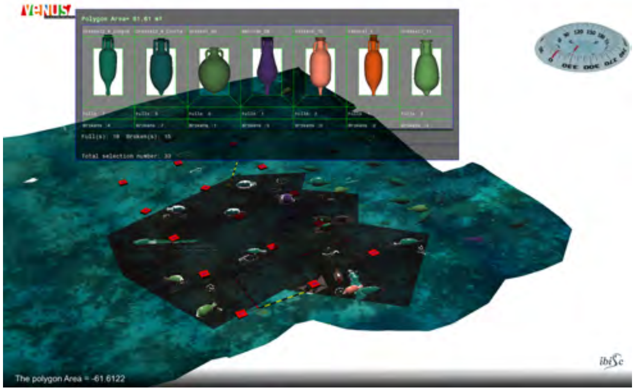


Fig. 13 Area data facts

4.2 Objective evaluation

In addition to the subjective evaluation mentioned above, we also evaluated the benefits of immersive VR versus non immersive by comparing users performances with three distinct forms of the VR demonstrators: in our case the low-end demonstrator, the semi-immersive demonstrator and the immersive demonstrator.

4.2.1 Evaluation setup

The evaluated platforms are:

- D1: The low-end demonstrator (non-immersive), featuring only standard input/output devices such as keyboard, mouse and 19” monitor.
- D2: The Semi-immersive demonstrator, featuring large stereo screen display and two flysticks for navigation and selection tasks. Snowplough is used as a navigation metaphor with the flysticks (as exposed in 3.2.1.3)
- D3: The immersive demonstrator, featuring a tracked VR helmet allowing to look around and the same two flysticks.

Navigation on demonstrators (D2) and (D3) uses the same technique and same interface.

4.2.2 Evaluation protocol and experiment

In this experiment a navigation task was carried out on all three platforms. Fifteen volunteers (six women and nine men) performed this experiment. All of them were right handed. Each subject was given pre-test along with a short briefing. The subjects were divided into 3 groups. Each group performed the experiment using demonstrators in the following order: D1, D2 and D3 for group 1, D2, D3 and D1 for group 2 and finally D3, D1 and D2 for group 3. Each group carried out four tests of each task and for each demonstrator. The evaluation is based on task completion time for the navigation.

4.2.2.1 Task completion time: Navigation task consisted in reaching a sequence of hotspots within the virtual site (progressively appearing and disappearing once they have been reached).

The average completion time for this task was 99 ± 26 seconds with the immersive demonstrator, 120 ± 43 seconds with the semi-immersive demonstrator and 187 ± 81 seconds with the non-imersive demonstrator with a significant ANOVA (P= 0.000185 $<< 0.01$). These results (presented in figure 14) show that immersive conditions have an influence on navigation task performance and the immersive demonstrator provided the best navigation task performances.

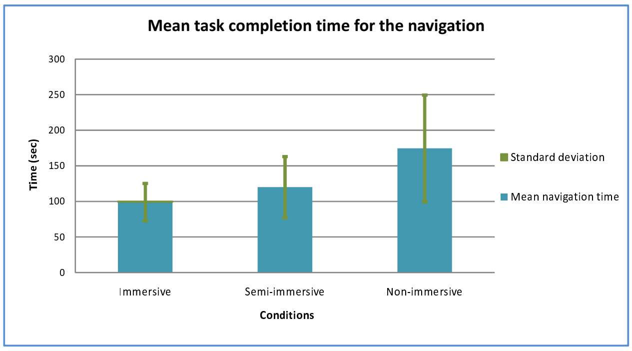


Fig. 14 Navigation task completion time under various conditions

4.2.2.2 User learning: Learning is defined here by the improvement of group performance during task repetitions. Figure 15 shows user learning during the navigation task for various conditions (immersive, semi-immersive and non-immersive demonstrators). The results show that using immersive condition, the average completion time was 123 ± 35 seconds during the first test and 81 ± 20 seconds during the fourth test. The average completion time under semi-immersive condition was 147 ± 71 seconds during the first test, and 101 ± 32 seconds during the fourth test. Similarly, the average completion time under non-immersive condition was 242 ± 115 seconds for the first test and 125 ± 54 seconds for the last test. These results show a navigation performance improvement of 34.22%, 31.09% and 48.24% for immersive, semi-immersive and non-immersive conditions respectively.

In this section we introduced the first results of evaluation of the three demonstrators (Immersive, semi-immersive and non-immersive). Two types of evaluation have been accomplished: objective and subjective evaluations. We compared principally the influence of the immersion type with the navigation and selection tasks performances. Results show that the performances for the navigation task are clearly better with the immersive demonstrator. However, the performances for the selection task are better with the non-immersive. It is necessary to note that the preliminary objective evaluation introduced here is based on task completion time performance measurements. Other measurements (selection and/or navigation errors) can be considered in the future. In the same way, the use of the virtual guides [34], [29] and [31]

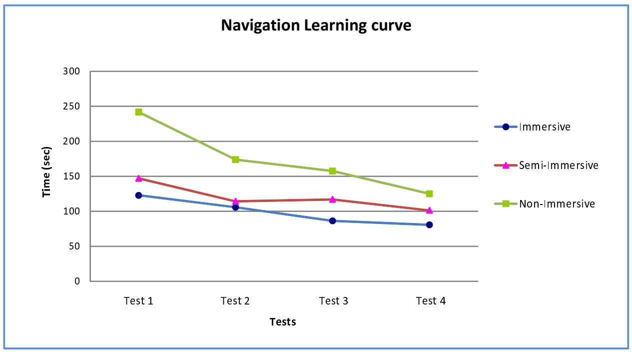


Fig. 15 Illustration of user learning for various conditions in navigation task

as assistance tools for navigation and in selection could also contribute to improve 3D interaction tasks performances. Some other evaluations concerning the Augmented Reality (AR) demonstrator still need to be performed. We will attempt to study the influence of this type of immersion on navigation and selection task performances and to compare it with the three previous demonstrators.

5 Conclusion and perspectives

We have described an attempt to introduce VR and AR technologies in the field of underwater archaeology as a working tool rather than the usual presentation tool. Pursuing this goal we tried to apply various levels of immersion and interaction facilities to a virtual environment designed to allow archaeologists to review and study underwater wreck sites possibly unreachable to divers reconstructed in terms of environment (seabed) and content (cargo) only through bathymetric and photogrammetric surveys. Several demonstrators using VR and AR technologies were build around this environment allowing us to start evaluating the benefits of these technologies with archaeologists.

A first subjective evaluation with archaeologists allowed us to review and amend the features of the virtual environment and also introduce new features resulting from this first “handover” and enter the iterative cycle of refining the features. In a similar way, preliminary evaluations have been performed to compare immersive and non-immersive VR demonstrator in terms of performance gain in order to assess the benefits of immersive VR. However deeper evaluation needs to be performed as well as an evaluation of the AR demonstrator against the other ones.

Using these innovative methods of research and dissemination can capture the imagination of the general public and generate interest not only in the historical aspect of archaeology but also in the work and expertise that goes into supporting these archaeological surveys.

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