A reconfigurable Immersive Workbench and Wall-System for Designing and Training in 3D Environments♠

Jesús Gimeno[1], Marcos Fernández[1], Pedro Morillo[2], Inmaculada Coma[1], and Manuel Pérez[1]

[1]Instituto de Robótica
Universidad de Valencia
Polígono de la Coma, s/n
46980 Paterna, (Valencia), Spain
jgimeno@robotica.uv.es

[2]Louisiana Immersive Techonologies Entreprise (LITE)
University of Louisiana at Lafayette
537 Cajundome Boulevard
70506 Lafayette, (LA), USA
pedro@lousiana.edu

Abstract. Virtual and Augmented Reality have been widely used in many scientific fields for the last two decades in order to visualize complex data and information. Although both techniques are oriented to show users complex 3D environments by means of an intuitive and easy mechanism, they use to become useless to manipulate the information in an intuitive and realistic way. In this paper, we present SOROLLA, a new concept of workbench designed for virtual and augmented reality purposes and specially oriented to the fields of tele-education and engineering. Unlike other proposals, SOROLLA not only allows an easy utilization and configuration, but also shows a cost-effective immersive visualization system based on off-the-shelf elements. The initial results using our workbench and wall-system show that both efficiency and user satisfaction are higher than the ones obtained using conventional devices.

Keywords: Virtual Workbench, VWB, Virtual Reality, Augmented Reality, Virtual Prototyping, Immersive Visualization Systems.

1 Introduction

Nowadays, new visualization technologies and multimodal user interaction offer users a new way to easily fulfill their tasks. In this sense, both Virtual Reality (VR) and Augmented Reality (AR) techniques have been extensively employed in the last two decades in order to visualize complex data and information in many scientific fields [15]. The use of these techniques has become especially relevant when inherently

♠ This paper is supported by both the Spanish MEC under grant DPI2006-14928-C02-02 and the European Commission Network of Excellence INTUITION IST-NMP-1-507248-2

complex information (usually composed of a huge amount of data) is represented using classic visualization devices: the entire plan of a skyscraper, the design of a route for a road traversing hundreds of miles, a high quality representation of the human body for anatomy and surgery instruction, etc.

One of the most affordable VR devices oriented to this type of applications is the Virtual Workbench. The term Virtual Workbench (VWB) refers to a small semi-immersive visualization device consisting of a projection screen under which virtual environments are backprojected stereoscopically [17,23]. A VWB uses to join cutting-edge input devices, advance visual mechanisms and even audio capabilities and creates a new “front-end” interface for the VR applications. The manipulation of the new and complex information elements using a Virtual Workbench has led to evolve the classic metaphors in the human-computer interaction process towards new interaction styles. Even though these new styles are oriented to show users complex 3D environments by means of an intuitive and easy mechanism, they have three main important problems. Firstly, they do not offer optimal capabilities to manipulate information in an intuitive and realistic way. For instance, it is not very realistic to manipulate the 3D visualization of a virtual terrain using a classic device (2D mouse or a spaceball) that limits the motion control in a plane. Second, they impose a qualitative variation in the way of working when a WBS is used as work tool in professional activities as CAD/CAM design, graphic design, etc. By their nature, these professional activities have require workers to perform well-established actions using the computer for their working life, and therefore the transition to the new environment becomes a hard adaptation or even the rejection of the new working environment. Finally, the investment in new adapted devices (to be presented as general purposes devices for virtual reality applications) is not only resulting in high costs, but also is releasing products that lack easy usability.

In this paper, we present SOROLLA, a new concept of workbench designed for virtual and augmented reality purposes and specially oriented to the fields of tele-education and engineering. SOROLLA is a new system consisting of a 3D visualization and manipulation software and a special hardware. This hardware is composed of a virtual reality workbench and a wall projection system, both of them including stereo viewing and tracking capabilities. The main premises in the design of SOROLLA are an easy utilization and configuration and also a framework based on inexpensive off-the-shelf elements. Taking into account the increase in importance achieved by the new paradigms of visualization and interaction, our system offers the next features: a suitable visualization more according to the handled information, an interaction mechanisms for properly modifying the real data in the virtual environment and a software that takes advantages of these visualization and interaction features. This paper also presents a set of preliminary experiments oriented to evaluate the initial performance of SOROLLA. Our results suggest that SOROLLA performs slightly better that some classical immersive visualization devices in terms of easiness of adaptation to the new device, and also to the new interaction styles.

The rest of the paper is organized as follows: Section 2 describes the related previous work in the area of semi-immersive visualization systems and virtual workbenches. Section 3 describes the software and hardware architecture of SOROLLA. Next, Section 4 establishes a realistic environment for the preliminary performance evaluation of SOROLLA and discuses the first obtained results. Finally, Section 5 presents some concluding remarks.

2 Related Work

Traditionally, the Virtual Workbenches have been used for Virtual Reality purposes because users not only can visualize three-dimensional objects and spaces, but also they can interact and travel through the scenes [17,23].

The development and commercialization of products based on Virtual Workbenches have been led by both public organizations [9,11,13,14,16,18,27] and privates companies [2,3,4,22]. Although most of the proposed designs follow the same pattern using a single mode of visualization, the main important structural differences among the different proposals are related to the position and location of the screen. In this sense, [9, 14, 16] take advantage of the initial design [17,23] where a fixed screen is set as a regular element of the framework. Some products offer more versatility allowing the user to modify the initial orientation screen [4], or even the height of the single projection surface [5]. Another system includes an additional screen in order to create an L-shaped projection table [3]. Concerning to the stereo-projection techniques, most of Virtual Workbenches incorporate passive stereo and only few products incorporate active stereo projection to allow a group of users to share the same workbench (using infrared glasses) [1,11,18].

Since this type of devices was initially presented for medical purposes [17] where 3D virtual widgets interact with real surgical tools, some areas of the advance medicine such as neurosurgery [23,9] or bronchial surgery [14] incorporated prematurely the use of virtual workbenches as a part of their surgery procedures. Nowadays, Virtual Workbenches are used in many different fields such as collaborative design [1,18], industrial maintenance training [27], hydraulics [13], physics [16] and applied social psychology [11].

The cost of immersive VR devices is the major barrier to its wider use and application. Therefore, some universities and commercial initiatives have oriented the research towards to launch low-cost immersive visualization devices. However, from our knowledge, only a initial prototype has been proposed to reduce the costs of manufacturing Virtual Workbenches [1]. In this proposal, the reduction of the final cost is based on using some low-cost interaction devices involved in the architecture of the system, and without redesigning any other additional aspect.

3 System Description

The system architecture of SOROLLA consists of two major elements. On the one hand, a projection and visualization subsystem allows projecting stereoscopic images to the user for any of the two feasible configurations. On the other hand, an interaction subsystem makes an abstraction of all the different input data (using a shared data structure) that the system can offer to the VR application running on SOROLLA. In this sense, this data structure includes information about the user's point of view obtained from the capture of the head position and also about the current position and type of gesture obtained from the virtual reality glove.

Framework and Projection System. The hardware architecture of SOROLLA consists of a visualization subsystem together with a projection subsystem and has been designed to join the comfort of a regular virtual workbench and the group work capacity of a projection-wall system. In this sense, our system includes two visualization modes associated with the two different included screens called *work mode* and *presentation mode*. The first 50-inch screen is linked to the surface of the workbench forming an angle which value can be configured manually to reduce the reflection of external lights. However, the second 100-inch screen is placed perpendicular to the surface of the workbench acting as a presentation screen. Both visualization modes include stereo visualization based on active projection. This feature, achieved by means of passive stereo glasses offers a more realistic and comprehensive visualization of the virtual scene. The projection subsystems is composed of two standard projectors including circular filters. These filters polarize the left and right eye images from the projectors while the user wear low cost, lightweight polarized glasses to direct the left/right images into the correct eye. Figure 1 shows a detailed schematic of SOROLLA when it is configured using the work or presentation mode. As shown in this figure, in order to make the system more compact, the optical path was folded 90-degrees using a mirror and, therefore, the images are obtained by back-projecting from both projectors (left/right images) onto any of the screens.

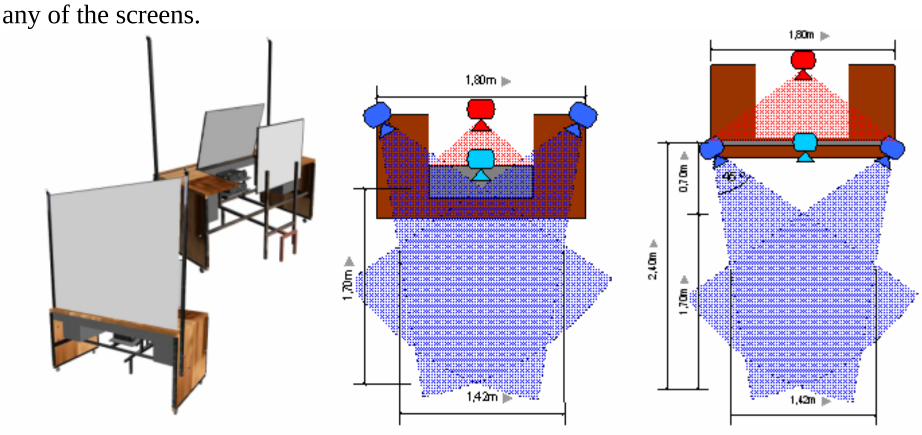

Fig. 1. A schematic views of the projection and visualization subsystems included in the design of SOROLLA: (left) A perspective view of the workbench showing both configuration modes, (center) A schematic plan view of the field-of-view (FOV) of the capture system when the work mode or the presentation mode (right) have been selected.

One of the key aspects in the design of SOROLLA was to develop a compact (and therefore a portable) immersive visualization system. Since the compactness has an effect on the storage and transport costs, our device can be packed and shipped in a hard-shell flight case with dimensions of about 185x80x95 cm.

The Multimodal Interaction System. SOROLLA extends the classic style of interaction based on the desktop metaphor with new styles of interaction from three-dimensional virtual environments such as direct manipulation of 3D objects and multi-user interaction. These features have been implemented into the interaction subsystem. This subsystem is composed of a optical capture system based on webcams and two tracked pinch gloves. The capture system employs four standard webcams (C1,C2,C3 and C4)and a custom software to obtain the final 2D/3D coordinates associated to optical tracking devices. The trackers have been designed as a multiple color light-emitting diodes (LED) covered with an spreading spherical screen in order to avoid the extreme directionality of the regular LEDs. By using the stereoscopic principle and performing an initial camera calibration, two of the cameras (C1 and C2 are installed on the upper corner of the workbench) obtain the 3D position of the trackers differentiated by their colors. This low cost capture system can detect the position of several trackers simultaneously inside a visual field of three meters with an approximate error radius of 1cm. Although high-cost solutions based on infrared capture systems (such as ART[2], ViCom [20] or IR-PRO) could offer a lower positioning error, our approach not only provides a sufficient precision for our purposes, but also is more robust and reliable to the common and unintentional movements in the framework of the workbench. Unlike infrared capture systems, our approach avoids recalibrations when variations of the camera position greater than one degree occurs, since it includes color information about the existing trackers.

The classic interaction style based on the desktop metaphor is implemented using the camera C3 (located behind the screen to remove occlusions), which objective is to capture the movements of the users on the screen and move the cursor to the specified positions. In order to deal with different lighting conditions, an adaptive algorithm detects the contact of the user’s fingers by means of placing infrared LEDs fixed on the end of the index finger of each glove. The camera C4 is placed in the central part of the workbench focusing ahead on the users. The purpose of this camera is to offer compatibility with existing and well-known software libraries for AR applications (such as ARToolkit [6], osgART [19] or ARTag [12]) where a single camera can recognize square marker patterns located in real environments.

SOROLLA includes two tracked pinch gloves (named as Thimble-Glove) which offer an accurate and low-cost mechanism of recognizing natural gestures such as grabbing an object or initiating an action. Unlike other similar products [25], the Thimble-Glove is a wireless device made from cloth and incorporates electrical sensors in each fingertip. This device provides not only information about pinching gestures of the user's hand, but also tracking information since (like a virtual stick) it incorporates infrared LEDs fixed on the fingertip of the index finger. Since Thimble-Glove does not includes external measurement devices such as a goniometers or flexometers it does not require any type of recalibration. The wireless communication of data included in Thimble-Glove is based on a commercially-available device known as “mote” which is a generic sensor node platform that integrates sensing, computation, and communication.

Figure 2 shows an example of different views of the Thimble-Glove in use. This figure emphasizes the compactness and lightweightness of the device which consists of wired connections from the covered fingertips to the wrist where the “mote” is adjusted by Velcro strips.

Fig. 2. Different views of the same Thimble-Glove. The wireless device consists of a mote motherboard, five contact switches and infrared LEDs fixed on the fingertip of the index finger.

Since in the design of this device we have avoided the idea of assembling a totally covered virtual glove, Thimble-Glove fits easily into any hand, regardless of size or hand preference. Moreover, it overrides the hygienic problems related to sweating problems (hyperhidrosis) when the device is used for exhibition or demonstration purposes.

In order to facilitate compatibility to any type of applications, SOROLLA provides two different types of connectivity based on sockets and VRPN [26]. When a third party (VR or AR) application selects a connection type based on sockets, a server is listening for a network connection on a predefined port, and once a connection is established it starts sending a XML message describing all the devices included in the interaction subsystem (Thimble-Gloves and capture system). Moreover, a VRPN server defines three determined devices (called tracker2d, tracker3d and th-glove). When third party applications are launched on SORLLA, they only have to register and include (using the proper function defined in the VRPN protocol) these three devices as regular elements in their software architecture.

4 Applications and Experiments

We have designed a set of preliminary experiments oriented to evaluate the initial performance of our virtual workbench [8,21]. These experiments consist in testing and evaluating the behavior of a benchmark applications on SOROLLA compared to a regular desktop monitor fitted with a hand-tracked interaction device (usually called Desktop VR [24]) and a four-sided CAVE [10]. In our case, the human performance and behavior have been tested in terms of navigation (or exploration) and interaction (or manipulation) in the 3D virtual world. The reason of this type of evaluation lies in the fact of SOROLLA has been defined as a generalist device designed to VR and AR purposes. Our benchmark includes two different multiplatform Virtual Reality applications called VALLE [7] and VISUALG. VALLE is a roadway design system based on Virtual Reality technologies where users design roads and skid trails to follow the natural topography and contour, minimizing alteration of natural features. The navigation mechanisms permit users to navigate through 3D landscapes and city models to evaluate the impact of the designed roads. On the other side, VISUALG is a training software program based on Augmented Reality to provide a method for disseminating expertise on ocular surgery procedures and other complex processes related to ocular physiology. VISUALG merges a full 3D model of the ocular anatomy and images from real users in real time and provides an excellent training interface where all the element belonging to the ocular anatomy can be manipulated. This application was chosen as an example of AR software where the interaction and manipulation of the elements in the 3D virtual environment are extensively exploited.

In order to obtain these results we organized a evaluation session at our laboratories in early June 2006. In this experiment, a selected set of 40 students and staff of our university were invited to test SOROLLA in a session of two hours of duration. All the participants performed the same sequence of six exercises (three executed on VALLE and the rest executed on VISUALG) using the three different immersive visualization devices. The evaluation test (see Figure 3) lasted roughly one hour and a half including a brief training, the exercises, and the time to fill out the final evaluation forms. The participants ranged in the age from 19 to 55 years and 22 (55%) were men. The educational levels among the participants ranged from grade school through doctoral level.

Fig. 3. Some snapshots of VALLE and VISUALG running on SOROLLA during the evaluation session

The evaluation session was divided in different phases. First, a brief training video showed the participants the objective of the experiment, the relevant points and what they should do in each one of the six exercises in the three immersive visualization devices. The basic personal information such as sex, age and academic level was also gathered in this phase. Next, an instructor showed the participants the basic operations and commands of both hardware (SOROLLA, Desktop VR and CAVE) and software (VALLE and VISUALG) for short periods of time before the real experiments. Once all the experiments were completed, the participants answered verbally several questions targeting some relevant aspects (interactivity, presence, etc) concerning the exercise. Finally, they scored the three devices in a scale from 0 (worst) to 10 (best) following the next aspects: visual realism of the simulated 3D environment (VR3D), easiness of adaptation to the new device (EAND), easiness of adaptation to the new interaction style (EAIS), degree of immersion (DI) and degree of usability (DU). Table 1 shows the results of this evaluation session. This table shows the average and the standard deviation of the obtained results for the different immersive visualization devices.

Table 1. Comparative results of Desktop-VR, CAVE and SOROLLA obtained in the evaluation session.

	Desktop-VR		4-sided CAVE		SOROLLA	
	Average	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
VR3D	5.70	1.45	8.50	1.17	8.10	1.05
EAND	8.90	0.76	6.60	1.30	8.30	0.95
EAIS	9.10	0.80	6.40	1.10	8.50	1.07
DI	5.50	1.28	9.00	0.90	8.40	0.89
DU	6.50	1.62	5.70	1.60	7.70	1.65

The results presented in Table 1 seem to indicate that the perception of visual realism (VR3D) is significantly related to the projection mechanism included in the system. In this sense, although the CAVE system obtained the best results due to the screen size, it is possible to appreciate that SOROLLA has a similar performance. The reason of this similitude could be caused because both SOROLLA and the 4-sided CAVE used in our experiments offer a similar final quality of the projected images.

Concerning to the easiness of adaptation to the new device (EAND), it is noticeable how the Desktop-VR has obtained the best scores. This apparently surprisingly result is not strange because this type of environments is currently used by the subjects with only a few extra additions mainly related to the 3D render quality. In the case of the two actually new immersive environments, it is possible to emphasize that our virtual workbench performs better than the tested 4-sided CAVE. In absolute terms, the reason of this behaviour may be because SOROLLA has been provided with some interaction devices oriented to offer to the users similar elements of interaction to the ones they are used to for the most usual tasks (menus, buttons, etc.). However, elements like FlySticks, 3D mouses, wands or data gloves are completely new to the CAD/CAM users when they are participating in a CAVE experience. The aspect of the easiness of adaptation to the new style of interaction (EAIS) has very similar results than the EAND, the reason is that SOROLLA has been designed taking into account the use of 2D interaction techniques for common tasks meanwhile in the CAVE system the interaction style is more revolutionary and involves new ways of working to perform the most common tasks. Concerning to the aspect of the feeling of immersion (DI), and as we expected, the CAVE environment has obtained the best scores. However, SOROLLA obtained proper results (in terms of feeling of immersion when specially the projection mode is selected) because the use of a large-screen graphics display surface, a high quality stereo projection and the head tracking.

Finally, SOROLLA received the top score when the users evaluated the general usability of the system (DU). The reason of this high-unexpected acceptance could be our virtual workbench not only offers a new interaction mechanism (oriented to improve the classical 3D object manipulation and navigation in virtual environments), but also it still keeps some of the familiar desktop mechanisms which allow the users feel more comfortable performing regular task like file system administration, etc.

5 Conclusions

In this paper, we have proposed SOROLLA a new virtual workbench designed for virtual and augmented reality purposes. We have compared the performance and user satisfaction of our system with some devices specifically designed for the same purposes and the obtained results have been very encouraging.

The reason for these results could be caused by the "*evolutionary*" approach suggested by SORROLLA. The system proposes to introduce new 3D interaction styles to traditional 2D/3D desktop-like applications, but centering the interaction on actual 3D aspects of the object manipulation and scene navigation. Moreover, it maintains the classic management of the 2D elements included in most of applications (menus, buttons, scroll-bars, etc) by using a touch screen interface. The fact of maintaining this interaction style makes people more comfortable and self-confident within the new environment because they perform their regular tasks in the same manner in which they did in their usual workspaces. This transition probably will not be needed in the future when desktop metaphors are not so assumed by people that have worked for long periods of time using this paradigm. Meanwhile, the use of smooth transitions between interaction styles, maybe a good way to gain acceptance for the new generation of multimodal interfaces.

References:

1. Andujar, C., Fairen, M., Brunet, P.: Affordable Inmersive Projection System for 3D Interaction. 1st Ibero-American Symposium on Computer Graphics, Proceedings of Ibero-American Symposium on Computer Graphics (SIACG'02), Guimeraes, Portugal, (2002) 1-9
2. Advanced Realtime Tracking GmbH, A.R.T. Infrared Tracking System. Information brochure, April (2001).
3. Barco CONSUL, http://www.barco.com/VirtualReality/products/product.asp?element=313
4. Barco TAN, http://www.barco.com/VirtualReality/products/product.asp?GenNr=968
5. Barco BARON, http://www.barco.com/corporate/products/product.asp?GenNr=324
6. Billinghurst, M, Kato, H, Poupyrev, I.: Artoolkit: A computer vision based augmented reality toolkit, In Proceeding of IEEE Virtual Reality 2000, New Jersey, USA, IEEE Press, (2000)
7. Bosch, C, Ballester, F, Otero, C., Fernández, M., Coma, I., Togores, R., Pérez, M.A.: VALLE®: A highway design system in a virtual reality environment Proceedings of the 11th International Conference on Computing and Decisión Making in Civil and Building Engineering (ICCBE-06), Montreal, Canada (2006)
8. Bowman, D.A, Johnson, D.B., Hodges, L.F.: Testbed Evaluation of Virtual Environment Interaction Techniques, Proceedings of the ACM symposium on Virtual Reality Software and Technology (VRST-99), London, United Kingdom, (1999) 26 - 33
9. Chua, G.G., Serra, L., Kockro, R.A., Ng, H., Nowinski, W.L., Chan, C., Pillay, P.K.: Volume-based tumor neurosurgery planning in the Virtual Workbench. Proceedings of IEEE VRAIS'98, IEEE CS Press, Atlanta, USA, (1998) 167-173
10. Cruz-Neira, C., Sandin, D., DeFanti, T.: Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE. In Proceedings of the ACM SIGGRAPH Computer Graphics Conference, ACM Press, September (1993), 135-142
11. Di Fiore, F., Vandoren, P., Van Reeth, F.: Multimodal Interaction in a Collaborative Virtual Brainstorming Environment. First International Conference on Cooperative Design,

Visualization and Engineering (CDVE2004), Lecture Notes in Computer Science LNCS series, LNCS 3190, Springer Verlag, (2004) 47-60
12. Fiala, M.,: Artag revision 1, a fiducial marker system using digital techniques. In National Research Council Publication 47419/ERB-1117, November (2004)
13. Fok, S.C., Xiang, W., Yap F.F: Internet-enabled Virtual Prototyping Workbench for Fluid Power Systems. Proceedings of International Conference on Fluid Power Transmission and Control (ICFP 2001) , Quan Long, China, (2001)
14. Heng, P.A., Fung, P.F., Wong, T.T, Leung K.S., Sun H.:, Virtual Bronchoscopy, International Journal of Virtual Reality, Volume 4, Number 4, IPI Press, (2000) 10-20
15. Kim, G.,:Designing Virtual Reality Systems: The Structured Approach, Springer (2005)
16. Koutek, M., van Hees, J., Post, F.H., Bakker, A.F.: Virtual Spring Manipulators for the Particle Steering in Molecular Dynamics on the Responsive Workbench. Proceedings of Eurographics on Virtual Environments ’02, (2002) 55–62
17. Kruger, W., Bohn, C.A., Frohlich, B., Schuth, H., Strauss, W., Wesche, G.: The Responsive Workbench, IEEE Computer Graphics and Applications, volume 14, issue 3, (1994) 12-15
18. Kuester, F., Duchaineau, M.A., Hamann, B., Joy, K.I., Ma, K.L.: The Designers Workbench: towards real-time immersive modeling. In Stereoscopic Displays and Virtual Reality Systems VII, volume 3957, Washington, USA. The International Society for Optical Engineering, (2000) 464–472
19. Looser, J., Grasset, R., Seichter, H., Billinghurst, M.,: OSGART - A pragmatic approach to MR, In Proceedings of the IEEE/ACM International Symposium on Mixed and Augmented Reality (ISMAR), Santa Barbara, USA, (2006)
20. MacIntyre, B., Coelho, E.M., Julier, S.J.,: Estimating and adapting to registration errors in augmented reality systems, In Proceeding of IEEE Virtual Reality 2002, Orlando, USA, IEEE Press, (2002) 73-80
21. Marsh, T.,: Evaluation of Virtual Reality Systems for Usability, Proceedings of ACM SIGCHI 99, Pittsburgh, USA, (1999) 61-62
22. Murray, N., Roberts, D.: Comparison of head gaze and head and eye gaze within an immersive environment. Proceedings of the International Symposium on Distributed Simulation and Real-Time Applications (DS-RT'06), Torremolinos, Spain (2006) 70-76
23. Poston, T., Serra, L.: The Virtual Workbench: Dextrous VR. Proceedings of Virtual Reality Software and Technology (VRST 94). IEEE CS Press, Los Alamitos, USA, (1994) 111-121
24. Robertson, G., Czerwinski, M., Dantzich., M.: Immersion in Desktop Virtual Reality. In Proceedings of Symposium on User Interface Software and Technology (UIST), Alberta, Canada, (1997), 11-19
25. Seay, A.F, Ribarsky, W., Hodges, L., and Krum, D.: Multimodal Interaction Techniques for the Virtual Workbench. Proceedings of ACM SIGCHI 99, Pittsburgh, USA, (1999) 282-283
26. Taylor, R.M., Hudson, T.C., Seeger, A., Weber, H., Juliano J., and Helser, A.T.: VRPN: a device-independent, network-transparent VR peripheral system. Proceedings of the ACM symposium on Virtual Reality Software and Technology 2001(VRST-2001), Bannf, Canada (2001) 55-61
27. Wang, Q.H., Li, J.R.,: A Desktop VR Prototype for Industrial Training Applications, Journal of Virtual Reality, Volume 7, Number 3, Springer Verlag (2004), 187-197