Tuning of the Level of Presence (LOP)

Wooyoung Shim and Gerard Jounghyun Kim

Virtual Reality Laboratory
Department of Computer Science and Engineering
Pohang University of Science and Technology (POSTECH)
Pohang, Korea
82-54-279-2260 / 2299 (fax)
{ totoro, gkim }@postech.ac.kr

ABSTRACT

One of the goals and defining characteristics of virtual reality systems is to create "presence", that is, to leave the user with the feeling of having been (or having done something) "in" the virtual environment as much as possible. While there has been much research work focused on identifying different factors that affect presence, it is still not clear how to effectively combine these results to create a content with high presence with respect to a given hardware setup, limited computing resource, and content dynamics. Along this line of thinking, this paper proposes for the concept of "Level of Presence (LOP)", analogous to the "Level of Detail", in which we attempt to select a set of "computational" presence elements and their levels to maximize their "contribution" toward the overall presence subject to system resources and possibly other constraints. Such an optimization scheme would require a reasonable characterization of the computational costs and a sufficient knowledge of the relative merits of various presence elements. While much research still remain to find a general model of presence, we made an attempt to apply the LOP concept to the VR system design for a particular application, a virtual fish tank. We selected two possibly important presence elements, the FOV and the simulation level of detail, and quantified their costs in terms of the required computation time. Then, we ran a simple experiment to quantify the relative benefits (or contribution toward the overall presence) of those two presence factors. For this particular application, it was found that providing more lifelike fish movements, for instance, incurred needlessly expensive computations compared to the amount of increased benefit. Based on the result, the virtual fish tank was configured for maximum presence while meeting various conditions including the required frame rate and content requirement (e.g. fixed number of fishes).

Keywords

Virtual environment, Presence, Level of Detail, Optimization, Cost Modeling, Structured Approach

1. Introduction: LOP

One of the goals and defining characteristics of virtual reality systems is to create "presence" and fool the user into believing that one is or is doing something "in" the synthetic environment. Most researches and papers on presence to date have been directed toward coming up with the definitions of presence, and based on them, identifying key elements that affect presence. Despite a number of different definitions of presence, it is generally accepted that the three following aspects are important in promoting it: (1) sensory fidelity and richness, (2) degrees of interactivity, and (3) other psychological cues [1][5][10][12][14][17]. Sensory fidelity and richness basically refer to providing a user with an environment that is as realistic as possible, for instance, with a wide field of view or immersive display, pictorial realism, multimodal feedback, and first-person viewpoint. Even though it is quite obvious that display "realism" would be important for presence, considering the problem of bringing presence to a "fake" virtual world, it is natural to look for other factors. In this regard, the interactivity and psychological cues can equally play important roles in increasing presence. Interactivity refers to the amount of involvement or capability of the user with respect to experiencing the virtual world. An appropriate design of interaction can increase presence by strengthening the bond between the user and the virtual world. Other psychological cues associated with the design of the virtual world, such as predictability and consistency, use of auxiliary/background objects, exaggeration and focus, situational awareness, etc. have been reported to affect presence in varying ways [7][9][15].

While prior research has identified many of these presence elements, it is not clear how to effectively combine them to create a VR content with high presence, especially with respect to a given hardware setup, limited computing resource, and content dynamics. Therefore, along this line of thinking, this paper proposes for the concept of "Level of Presence (LOP)", analogous to the "Level of Detail", in which we attempt to select a set of computational presence elements and their levels to maximize their contribution toward the overall presence subject to system resources and possibly other constraints. Ideally, the dynamic nature of VR systems should allow applications of different presence elements, ideally at different times. Such an optimization scheme would require a reasonable characterization of the computational costs and a sufficient knowledge of the relative merits of various presence elements.

While much research are still needed to find a general model of presence, we have made a simple attempt to apply the LOP concept to the VR system design for a particular application, a virtual fish tank. We selected two possibly important presence elements, the FOV and the simulation level of detail, and quantified their cost in terms of the required computation time. In this study, we excluded the hardware cost and considered only the computational cost. We also did not consider the geometric details to separate the computational cost from rendering cost.

Then, we ran a simple experiment to quantify the relative benefits (or contribution toward the overall presence) of those two presence factors. A similar approach has been taken in implementing the geometric LOD system in which the cost is defined by the number of polygons to be processed by the graphics system, and the benefit by the object's screen space size, distance from user, and other visual attributes [4]. Based on the result, the virtual fish tank can be configured for the maximum level of presence while meeting various conditions including the required frame rate and content requirement (e.g. fixed number of fishes). The work presented here is not sufficient yet to provide general criteria for manipulation of various presence elements, and should be taken as only an illustration of a possible method for integrating the concept of presence into early VR system design.

This paper is organized as follows. In the next section, we review previous research results on various concepts of presence, several proposed models, and factors known to affect presence. Then, we introduce the idea of LOP, namely, using the cost-benefit management model for presence elements in VR system design. We illustrate how the concept could be applied to a particular application, in this case, a virtual fish tank, and step through the optimized system design process. Then, we conclude the paper with a discussion, a summary of results, and directions for future work.

2. Presence and Its Characteristics

2.1 Concept of Presence

Presence, or the sense of presence is defined as the degree to which participants feel that they are somewhere other than where they physically are when they experience the effects of a computer-generated simulation [3]. It is often dubbed as the "sense of being there" [5][10]. It means that the human processes the external stimuli provided to the visual, auditory, haptic, or proprioceptive sensory system and transform them into information, which gives him/her an illusion that he/she is immersed in another space. While it would practically be impossible (at least with the current technologies) to fool any VR user to think the VEs they are experiencing are real or perfect (they certainly know), with sufficient and clever integration of the sensory stimuli, VR users can still generate the sense of presence and obtain the virtual experience through one's ability to conform to the environment, or through the "suspension of disbelief" [11].

2.2 Model of Presence

To create a VE with the sense of presence, a conceptual model of the sense of presence will be necessary. The model would provide a theoretical framework that would help researchers investigate the relationships among immersion, presence, and performance in VEs, and also help designers of virtual worlds select and manipulate appropriate display/system features. Slater and Wilbur suggested a presence model as closely related to the degree of immersion, and attempted to quantify immersion (an thereby presence) by measuring how displays were inclusive, extensive, surrounding and vivid [13]. Barfield and his colleagues have proposed a "spatial fidelity" model that thinks presence in terms of the similarity of spatial, auditory, and haptic transformations of objects in a VE to those in the real world [2]. Bystrom et al have put these two major axes; immersion and spatial fidelity, together into one coherent model, and added the role of specific tasks in the VE [3]. According to them, presence occurs when immersion and sensory fidelity are provided and a specific task is given: "*the requirements of the tasks that the user must perform will influence the amount of attentional resources that are allocated to the virtual environment. If the participant allocates sufficient attentional resources to the virtual environment, and if there is a sufficient degree of sensory fidelity, the participant may suspend one's disbelief, and view the virtual environment as an actual place, thereby developing a sense of presence*" [3]. While we agree to the proposed importance of the attentional resource in its contribution toward creating presence, we do not believe that a specific task is absolutely necessary for that purpose.

2.3 Presence Factors

Despite a number of different definitions and models of presence, it is generally accepted that the three following aspects are important in promoting it: (1) sensory fidelity and richness, (2) degrees of interactivity, and (3) other psychological cues such as content consistency, situation awareness, and predictability [1][5][7][9][10][12][14][15][17]. Witmer and Singer also have provided a comprehensive categorization and list of factors that affect presence [16]. Their list is similar to our above compilation, but also adds distraction factors. They also made a distinction between immersion and involvement (latter being regarded closer to the concept of presence) [16]. In Witmer and Singer's work, involvement is a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events, whereas immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences. In any case, it is quite accepted that (physical) immersion or the psychological state achieved by physical immersion contributes positively to the creation of presence. In our work, regardless of their categorization, among the important factors that affect presence, we, in the context of LOP, look for those that might incur some computational cost such as, for instance, the field of view (view frustum), frame rate, geometric details, simulation details, use of texture, sound spatialization, lighting and shadow calculation, device handling, etc.

3. Cost and Benefit Estimation of Presence Factors in VR Systems

Any computer-based VR system uses various "resources" to make an illusion of "place" - it may use a head-mounted display (HMD) with stereoscopy implemented by drawing to two graphics channels for each eye, provide 3D sound effect by a complex and heavy computation, give haptic display for an active response after physics-based simulation. Any algorithm takes CPU time and memory space to process input and output a result, and any device causes a sampling and response delay (latency). What we get at the expense of these "cost" is the "benefit" possibly toward enhancing the sense of presence. Since a VR system has limited computational resources and other requirements, a successful VR system must provide its users with the sense of presence efficiently, that is, the benefit (presence) should be achieved at as low cost (resources) as possible. Such an optimization scheme would require a reasonable characterization of the computational costs and a sufficient knowledge of the relative merits of various presence elements.

However, this is quite difficult as the cost of the resources encompasses many things ranging from the hardware and maintenance cost to software computation and memory usage, and secondly, as the relative benefits of presence factors are difficulty to quantify due to its cognitive nature, let alone for the general case, but even for a particular application. In our work, we simplify the problem and define the cost as the computation time required to create a particular presence factor. The benefit is also defined simply as the "presence score" obtained from a subjective test/questionnaire assessing the overall presence of the chosen application when configured with different presence factors. While such simple cost and benefit models are admittedly insufficient to be used in any general context, however, our purpose is to rather give VR researchers and designers an insight or a clue to understand the problem of creating a VR system which provides presence to its users at the limited cost economically. The total computational cost to render various presence factors is simply the summation of the individual cost. The individual cost may be tied to an instance of a virtual object (e.g. simulation code of a fish) or as to the entire system feature (e.g. shading).

4. Example: A Virtual Fish Tank

In this section, we apply our cost and benefit model to select an appropriate content configuration for a particular application, a virtual fish tank.

4.1 Application Analysis and Cost Estimation

The objective of the virtual fish tank is simply to have users observe and experience what it is like to be under the sea (See Figure 2). Given a particular amount of computational power and hardware setup, we would like to "tune" the content so that we get the best effect out of the given resources. The content of the virtual fish tank consists of a few species of fishes and seaweeds distributed uniformly throughout the scene, swimming freely in the water. For the sake of simplicity and less complication with the presence experiments (to be explained later), we have set the following system requirements: (1) no interaction, (2) use of a wide, but adjustable, FOV display system (See Figure 1), (3) no head tracking.

Figure 1: The wide display system with an adjustable FOV

Figure 2: Snapshot of the virtual fishtank

The system was programmed using the Sense8's WorldToolKit release 9 (OpenGL version) and ran on Microsoft Windows 2000 Operating Systems installed on three (one for each display) Intel-Pentium III PC's with NVIDIA Quadro chipset based graphic accelerator cards. Among many presence elements that one can apply to this application, we decided to tune the followings.

> **Number/density of fishes** - We hypothesized that the more fishes there are in the VE, the higher the content reality, and thus the presence would be. However, we can also assume that there probably will be a limit at which the presence no longer increases (appropriate fish density) or even start to decrease (too many fishes) as well.
>
> **The motion of the fishes swimming within it will affect movement of the fish – Users' feelings about the VE**. Complex and realistic motion will enhance realism, and the involvement factor of presence.
>
> **Horizontal Field of view (FOV)** - FOV is known to affect the sense of presence significantly (e.g. immersion factor).

Among some of the obvious presence elements, for instance, geometric detail was excluded as our study is focused more on the computational capacity of the processor rather than the graphics subsystem. We chose to experiment with tuning the simulation level of detail (i.e. movement of the fish, an involvement factor) and the FOV (an immersion factor). In fact, the FOV is directly related to the number/density of fishes rendered in the scene (for a fixed density), the wider the FOV, the more fishes are simulated and rendered. Note that unlike previous studies of the effect of narrow FOV, we only adjust the FOV at the periphery of the human visual system (120 ~ 180 degrees) [6].

The costs for these two factors were formulated as follows.

Cost of FOV - FOV determines viewing (culling) frustum that traverses scene graph and removes culled geometry. Therefore, a smaller FOV means more geometry are culled (removed) during the scene traversal and saved time. The number of objects (mainly fishes) seen and simulated is determined by the FOV, and is directly related to the fish simulation cost. The costs among different FOV's turned out to be rather negligible because only relatively small number of fishes would be added or removed from the scene by varying between 120 and 180 degrees (if the fish density was to be kept constant). Moreover, if the total number of fish were to be kept constant instead, the cost of just widening the FOV would be even more negligible.

Cost of (fish movement) simulation – The cost of simulation was estimated in two ways. First, we analyzed the corresponding simulation source code and tabulated the integer/floating point arithmetic operations. Memory operations were ignored. Such estimation would reflect neither the cost associated with the memory transfer nor the unpredictable operation system and other graphics related overheads. We, therefore, also measured and collected the average run times of the simulation code. We still had a problem of getting a precise cost estimates due to the complex structure of the Pentium III processors, and various features of the Window 2000 such as the process and thread management protocols, constant system call interrupts, the virtual memory (caching) and unpredictable I/O operations.

We implemented two levels of fish behaviors and the low level behavior changes its orientation and moving velocity randomly, and checks its position and orientation periodically not to get out of its pre-established base position. For the high level behavior, skin deformation was added, that is, every vertex in the fish geometry (~ 100 vertices) was transformed by rotation and translations. Table 1 shows the average number of arithmetic instructions called in the execution path of the low and high-level fish simulation codes, and Table 2 shows the estimates from actual measurements. For fishes with about 100 polygons, one can see the higher level simulation is approximately 100 times costlier, and there is approximately three times of difference in terms of the total cost.

	Integer		Floating point	
	+, -	×, ÷	+, -	×, ÷
Low Level	1	0	27	36
High Level	$6 + 7*n$	0	$72 + 33*n$	$84 + 33*n$

Table 1: Integer / floating-point arithmetic operations in the low/high level simulation details (average) (*n* = no. of vertices in the fish geometry)

	Low level simulation	High level simulation
Loop time	9.91	28.22
Simulation time	0.14	15.02
Rendering time	9.77	13.20

Table 2: The average loop time and estimated simulation time and rendering time (unit: milliseconds)

4.2 The Presence Experiment

To assess the benefit part of the presence factors, we ran a subjective presence experiment for six different combinations as shown below in Table 3.

SLOD \ FOV	120 degrees	150 degrees	180 degrees
Low	E1	E2	E3
High	E4	E5	E6

Table 3: Six different configurations of the virtual fish tank by FOV's and simulation level of details

A modified version of the Witmer & Singer's Presence Questionnaire (PQ) [16] was used to ask 23 subjects (20 males, 3 females, age 19 ~ 27) to rate one's sense of presence. The questionnaire was comprised of 8 questions with 7 level scoring: questions 1 ~ 2 were about the FOV, 3 ~ 4 about simulation detail, 5 ~ 7 about the overall involvement/sickness, and the last question (Q8) about the overall presence score for the respective test configuration. Each subject experienced all six combinations in a random order, answering the same questionnaire after each session (combination). During the session, the subject did nothing but watch the display screen and the subject's head was placed on a fixture and made to look at the center of the screen (to neutralize the effect of head movement for the FOV tests).

4.3 Results

The two factor ANOVA with repetition have revealed significant effects of both FOV ($F(2, 135) = 6.85$, p-value = 0.0025) and simulation detail ($F(1, 136)=25.58$, p-value=0.0001) upon the presence score, but no interaction ($F(2, 135)=1.68$, p-value=0.1978) was found. It was contrary to our expectation that no interaction was found, because we had conjectured that a larger FOV would help the subjects better recognize the difference between different simulations levels, resulting into a more significant rise in the presence score than with a smaller FOV.

Var	ANOVA SS	F value	P value
FOV	16.22	6.89	0.0025

SIM	28.76	25.58	0.0001
FOV*SIM	2.13	1.68	0.1978

Table 4: The ANOVA result of Q8 by two factors

Mean values and standard deviations of the presence scores according to each level of each factor are tabulated in Table 5. While the overall scores were rather low (most probably due to many VR features that were deliberately disabled for the experimental purpose), statistically significant differences were found between FOV of 120 and 180 degrees, and between high and low levels of fish behavior.

FOV	Mean	SD
120	3.70	1.43
150	4.24	1.66
180	4.52	1.35

SLOD	Mean	SD
LOW	3.70	1.51
HIGH	4.61	1.38

Table 5: Means and standard deviations of Q8 by two factors

Mean presence score values for each of the six combinations are likewise shown in Table 6. While it is quite obvious that the combination of the lowest SLOD and the narrowest FOV, the highest SLOD and the widest FOV resulted in the lowest and the highest scores respectively, interesting results were obtained in between.

FOV	SLOD	Mean	Std
180	HIGH	**4.91**	1.04
150	HIGH	**4.87**	1.52
180	LOW	**4.13**	1.52
120	HIGH	**4.04**	1.43
150	LOW	**3.61**	1.59
120	LOW	**3.35**	1.37

Table 6: Presence scores for each test combination

Then, we have applied the cost model explained in the previous section and obtained a blueprint for the effectiveness of the presence factors (or combinations of them). The results are shown in Table 7. At a glance, we observe that the cost of providing the fish skin deformation has incurred relatively too much cost compared to its increased effect.

FOV	SLOD	Presence score (P)	Total cost (C_T) (milliseconds)	100 * P/ C_T
120	LOW	3.35	62.45	**5.36**
150	LOW	3.61	78.06	**4.62**
180	LOW	4.13	93.68	**4.41**
120	HIGH	4.04	198.013	**2.04**
150	HIGH	4.87	247.5	**1.97**
180	HIGH	4.91	297.0	**1.65**

Table 7: The estimated cost and benefit / cost ratio (no. of fish = 31)

4.4 LOP Tuning

The benefit to cost ratio simply tells us that, among the combinations we tested, the narrow FOV / low-level simulation was the most efficient presence factor. Combined with other system constraints, we can take advantage of the above results to optimize our content. For instance, if, for some reason, the system is to maintain a LOP of about 4 (out of 7), we might choose to render as many fishes with the FOV=180/SLOD=low combination, since it is the most efficient one with LOP of about 4. Inversely, we might put a constraint on the number of fishes in the scene. Like indicated before, we can safely assume that the size of the fish population would affect the sense of presence, perhaps in an almost linear fashion at first. We can also assume that at some point, the increase fish count will no longer positively affect the sense of presence (too many fishes). Thus, we might want to find the right mix of low and high level fishes that satisfy the total required number of fishes and a given computational resource. The situation can be formulated as follows.

$$\textbf{Maximize } B = \sum(n_i * b_i) + q(\sum n_i)$$
$$\textbf{subject to}$$
$$R > \sum(n_i * c_i), \text{ and } n_1 + n_2 = 100$$

n_i is no. of the fishes with SLOD level i
c_i is the cost of an instance of the SLOD level i
b_i is the benefit of an instance of the SLOD level i
R is the amount of the available resource

In the above equation, **B** represents the total benefit formulated as sum of $\sum(n_i * b_i)$, the sum of the effect of the presence factors (in this case just the SLOD), and $q(\sum n_i)$, an additional benefit obtained by the fish population size (probably some kind of nonlinear function). $\sum(n_i * c_i)$ is the expected total software cost, and $n_1$and n_2, reporesents the no. of fishes with low and high SLOD respectively (i.e. there must be total of 100 mixed fishes). Given the following figures of,

c_1 = 0.004ms, c_2 = 0.5ms,
b_1 = 3, b_2 = 4,
R = 20ms (~ 50Hz frame rate),

we compute that when n_1 = 61, n_2 = 39, B is maximized at 339 + q(100).

Since the above example considers only the SLOD factor, we can repeat the optimization process for different FOVs. Now we add another constraint that the density of the fishes must be kept constant to the existing constraint that there must be at least total of 100 fishes, formulated as,

(1) FOV = 120 degree / $n_1 + n_2$ should be at least 100
(2) FOV = 150 degree / $n_1 + n_2$ should be at least 125
(3) FOV = 180 degree / $n_1 + n_2$ should be at least 150.

For each case, the population mix is found with the maximum benefit as follows,

(1) FOV = 120, $n_1 + n_2 = 100$
$n_1 = 39$, $n_2 = 61$
$B_1 = 339 + B(120) + q(100) = 342.5 + q(100)$

(2) FOV = 150, $n_1 + n_2 = 125$
$n_1 = 39$, $n_2 = 86$
$B_2 = 414 + B(150) + q(125) = 414.2 + q(125)$

(3) FOV = 180, $n_1 + n_2 = 150$
$n_1 = 32$, $n_2 = 118$
$B_3 = 482 + B(180) + q(150) = 486.7 + q(150)$.

Assuming that $q(180) \approx q(150) \approx q(120)$ (i.e. fishes more than 100 does not contribute much to presence), we would choose the last configuration (3) for our application.

5. Discussion and Future Work

In this paper, we have proposed LOP as a concept of selecting the most economical presence factors in designing a VR content, and demonstrated it by configuring a simple virtual fish tank application. In this paper, we only showed how LOP could be used for the initial content configuration. Ideally, since the content of VR systems change dynamically to various user interactions, presence factors must be reconfigured dynamically as well (like the LOD does). This requires more theories on composing the right presence factors for a given scene and switching between different configurations without distracting the user.

While our example only used two presence factors, for most practical applications, there would be many more presence factors to consider and choose from at once. It would be quite impractical to conduct large-scale presence effect tests for each given application, however, there is not a good alternative as yet. Hopefully with the continuing research on presence in the HCI and VR community, assessing a rough measure of relative benefits of various presence factors might be possible without conducting customized experiments. The cost model needs to be refined further as well to reflect various overheads and simulation models and ultimately eliminate the need for explicit measurements. Also we make a note that the result could have been different depending on how the fish simulation algorithm was designed, that is, a more efficient skin deformation algorithm would have resulted in a different benefit to cost ratio.

In a different paper, the author has proposed to treat and model form and function/behavior (of VR objects) separately and integrate them into an object model [8]. Each modeling process can be carried out in a hierarchical fashion to produce models with different levels of detail. In fact, an LOD was defined as a pair of a selected level of "compatible" form and function/behavior models. We can extend this approach and imbue the concept of LOP by refining the form, function/behavior models further with presence elements. Now, "form" consists of a set of core and presence related form representations and likewise "function/behavior." An LOP is defined as a conglomeration of form and function/behavior as before. This separation makes the performance tuning process easier by selectively turning on/off the presence elements. There will be many presence elements for a system designer to consider and manipulate for creating a highly persuasive content, and such an activity must become structured and systematic with the deep understanding of presence for VR to become a viable media alternative.

6. Acknowledgement

This research has been supported in part by the Korea Ministry of Education BK21 project, and by the KOSEF funded Virtual Reality Research Center.

7. References

[1] Barfield, W., Hendrix, C., The Effect of Update Rate on the Sense of Presence in Virtual Environments, Virtual Reality: Research, Development, Applications, Vol. 1, pp 3-15, 1995
[2] Barfield, W., Zeltzer, D., Sheridan, T., Slater, M., Presence and Performance Within Virtual Environments, Virtual Environments and Advanced Interface Design, New York, Oxford University Press, pp 473-514, 1995
[3] Bystrom, K.E., Barfield, W. & Hendrix, C., A Conceptual Model of the Sense of Presence in Virtual Environments, Presence: Teleoperators and Virtual Environments, Vol. 8, pp 241-246, 1999
[4] Funkhouser, T.A., Sequin, C.H., Adaptive Display Algorithm for Interactive Frame Rates during Visualization of Complex Virtual Environments. In ACM SIGGRAPH Computer Graphics, pp 247-254, 1993
[5] Heeter, C., Being There: the Subjective Experience of Presence, Presence: Teleoperators and Virtual Environments, Vol. 1, pp 262-71, 1992
[6] Hendrix, C., Barfield, W., Presence within Virtual Environments as a Function of Visual Display Parameters, Presence: Teleoperators and Virtual Environments, Vol. 5, pp 274-289
[7] Kalawsky, R.S., Bee S.T., Nee S.P., Human Factors Evaluation Techniques to Aid Understanding of Virtual Interfaces, BT Technology Journal, Vol. 17, No. 1, 1999
[8] Kim, G. J., Kang, K. C., Kim, H., Lee J., Software Engineering of Virtual Worlds, Proc. of ACM VRST, pp 131-138, 1998
[9] McGreevy, M. W., The Presence of Field Geologists in Mars-like Terrain, Presence: Teleoperators and Virtual Environments, Vol. 1, pp 375-403, 1992
[10] Sheridan, T.B., Musings on Telepresence and Virtual Presence, Presence: Teleoperations and Virtual Environments, Vol. 1, pp 120-126, 1992
[11] Slater, M., Presence in Immersive Virtual Environments, Proc.. of IEEE VRAIS, pp 90-96, 1993
[12] Slater, M. et al, Immersion, Presence and Performance in Virtual Environments: An Experiment with Tri-Dimensional Chess, Proc. of ACM VRST, 1996.

[13] Slater, M., & Wilbur, S., A framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual environments, Presence: Teleoperators and Virtual Environments, Vol. 6, 603 – 616, 1997

[14] Welch, R. B., Blackman, T. T ., Liu, A., Mellers, B. A., Stark, L. W., The Effects of Pictorial Realism, Delay of Visual Feedback, and Observer Interactivity on the Subjective Sense of Presence. Presence: Teleoperators and Virtual Environments, Vol. 5, pp 263-273, 1996

[15] Wells, M. J., Virtual Reality: Technology, Experience, Assumptions, Human Factors Soc. Bull., 35, 1-3, 1992

[16] Witmer, B.G., Singer, M.J., Measuring Presence in Virtual Environments: A Presence Questionnaire, Presence: Teleoperators and Virtual Environments, Vol. 7, pp.225-240, 1998

[17] Zeltzer, D., Autonomy, Interaction and Presence, Presence: Teleoperations and Virtual Environments, Vol. 1, pp 127-132, 1992