

# Design Methodology for Image-based Virtual Reality Application

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**Abstract**—Image-based Virtual Reality (IBVR) consist of stitched scenic photographs to display realistic panoramic virtual environments. This view has been suggested as one of the important factors to elicit users' spatial presence. Past studies has found that higher spatial presence experience is often correlated to better users' performance, hence effective application. Currently, a design methodology for creating an IBVR application with the goal to enhancing spatial presence is not available. This paper describes a methodology to develop an IBVR application that could elicit high spatial presence experience among users. We structured the design methodology based on our practical experience creating IBVR applications and also based on the result of our comprehensive study on IBVR characteristics. Two related theoretical framework on spatial presence were referred to guide and inform the design of our study. As a result a four-phased design methodology is derived and proposed based the study result: Project Planning and Refinement, User Requirement Specification, IBVR Development and Implementation, IBVR Verification and Validation

**Index Terms**—Virtual Reality, Image-based Virtual Reality, Presence, Mental Model, Human-Computer Interaction

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## 1 INTRODUCTION

APPLICATIONS that allow user to interact with simulated 3D objects and environments in real-time is referred to as virtual reality (VR) [1]. VR applications can be categorized into two types: Geometry-based Virtual Reality (GBVR) and Image-based Virtual Reality (IBVR). GBVR is known as high interactive application [2], [3] whilst IBVR is known as low interactive application [4].

Presence has been accepted as a crucial factor in determining the effectiveness of VR applications. [1]–[8]. Previous research classified presence in many terms such as telepresence, social presence, spatial presence, physical presence, virtual presence and sense of presence. Presence experience is the feel of being located in mediated environment. One of the factors suggested that can help user to experience presence is the characteristics or functions of the mediated environment [2], [5]. However, how the user's mind [2], [4], [5], [8] and the user's feeling [3] have been also considered as important factors in influencing spatial presence. As such, in this work, spatial presence which considers user's cognitive aspect to experience presence [1] is adopted.

Spatial presence can be described as the binary presence experience among users [2]–[5]. Binary presence is the on and off of feeling of being located in the virtual environment.

One of the important features of spatial presence

theories is that they can be applied towards a variety of mediated environments [3]. The mediated environments can be non-interactive (such as movie, song), low-interactive or high-interactive application (such as Virtual Reality (VR) application) [7]. The focus of our study is focus on low-interactive VR application. This is due mainly to its low cost in development and it be run on any standard desktop computer.

The internet offers a good source of guidelines on developing an IBVR application. However, most of the design recommendation is related to image capture techniques and image stitching techniques or software. None so far has put forward a design methodology with a specific focus on enhancing user's presence and based on theoretically sound framework. As such, in this paper, we intend to address this gap by proposing a systematic design for IBVR application based our experience conducting studies on IBVR application which were guided by two spatial presence theories.

The rest of the paper is organized as follows: Background (GBVR and IBVR and Spatial Presence Theory), Related Work, Design Methodology, Discussion and Conclusion. In the Problem Outline section, we describe the differences between GBVR and IBVR and highlight the research gap. Then, we discuss spatial presence theories used in our design methodology. Next, we highlight a number of related studies on design methodology for presence and GBVR. In the Design Methodology section, we describe our design methodology. We then compare our methodology with previous design methodologies in the Discussion section.

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The last section provides the conclusion of our contribution.

## 2 BACKGROUND

In this section, we discuss about the different between GBVR and IBVR. Furthermore, we describe about spatial presence theory that is used for this study.

### 2.1 GBVR and IBVR

GBVR has various interaction functions, including manipulating the object, manipulating the environment, and navigating the environment. These functions provide high impact on spatial presence. Besides the various interaction functions, GBVR could also provide realistic panoramic virtual environment (VE) to enhance spatial presence [9]. Thus, most previous research on spatial presence focused on GBVR.

However, GBVR requires a long time to develop realistic panoramic VEs because the building process requires complex modeling and programming. Moreover, high-performance processors are required to run GBVR applications in real-time.

To overcome this problem, IBVR was introduced by [10]. IBVR is easy to develop because no geometry programming is involved [10]. IBVR applications are suitable for simple walkthroughs that require several realistic panoramic views. Moreover, IBVR applications can be run using low-performance processors.

Based on a review of the related literature, most design methodologies are intended for GBVR applications. Design methodology to develop IBVR applications that can enhance spatial presence is still very much lacking. Dissimilarity in characteristics, particularly in terms of interaction function, makes existing design methodology for GBVR may not be directly applicable.

Interaction functions of IBVR applications consist only of zooming in/out, panning and hotspot hopping for navigating the VEs. By contrast, GBVR has various interaction functions that can enhance presence including navigating and manipulating VEs. Hence, in this study, we propose a design methodology to develop IBVR applications.

### 2.2 Spatial Presence Theory

For guiding the design our studies on IBVR characteristics, we combine two spatial presence theories from [2] and [3]. These theories, which are used to develop the design methodology are described in this section.

The first spatial presence theory is from [2]. The authors of this theory specified two phases: spatial situation experience and spatial presence. The mind of the user should experience spatial situation before experiencing spatial presence. Each phase involves three

main factors: media factors, individual factors, and process components.

A spatial situation experience can be described as how the mental model of the user accepts the situation, interface, and VE shown to him/her such that he/she feels situated in that particular VE. Thus, before developing IBVR applications, we have to identify first the criteria for successful user experience of the spatial situation.

The first type of factor in spatial situation experience is media factor. According to [2], the two main variables involved in media factor are the factors that support the spatial situation experience and the factors that attract the attention of the user. The second type of factor is individual factor. Two variables influence individual factor: spatial visual imagery and domain-specific interest [4]. If media and individual factors provide a positive result for the process components (the third factor), then the user can have automatic and controlled attention in the IBVR application [2]. Thus, the user experiences the spatial situation presented in the IBVR application.

The second phase in spatial presence theory is spatial presence, which is defined as the feeling of being situated in a realistic panoramic VE and realizing which type of VE you are in [2], [11].

In media factors, the characteristics of the application that could enhance spatial presence experience are in accordance with the objective of the development of the application. Process components are related to the interaction between individual and media[2]. The effects of this process determine whether user can experience or fail to experience spatial presence. Individual factors are characterized by high levels of involvement [2], suspension of disbelief [2], [11], and feelings [3]. The first two variables are taken from [2] and the third variable is from [3]. If an individual factor has a positive effect on the process components, the user will experiences spatial presence.

Furthermore In this study, we applied Schubert's theory [3] on spatial presence as a cognitive feeling. Based on this perspective, spatial presence is a form of feedback from unconscious cognitive processes that informs the conscious thought of the state of the spatial cognitive system.

Feeling present is inherently positive, considering its proposed source in successfully locating the body in a mediated environment and in determining possible actions[3]. However, identifying a comparison standard is necessary. If feeling present in a real environment is the alternative to feeling present in a virtual environment, then both should be equal with regard to feeling alone. However, if not feeling present in any environment is the alternative to feeling present in a virtual environment, then, the affective consequences of feeling present are

clear. Not feeling present is similar to disorientation, which is an inherently negative state.

Users of virtual environments can distinguish between affective consequences and spatial presence [3]. Positive affective consequences of spatial presence are independent from and add to the affective consequences of the content of an environment. Hence, we applied calmness as feeling of respondents when they experience presence in IBVR application.

### 3 RELATED WORK

Designing virtual environment that enhance spatial presence experience is not easy. Moreover, users' opinion on what features in a virtual environment that can enhance presence is really subjective.

[12]highlighted that there are two important components of a design methodology: "The aesthetic notion of designing something to create the desired perceptual responses and engineering notion of design as the creation of plans and models from which to test and build the desired artifact."

Ten steps in design methodology to design virtual environment (VE) was proposed by [13]. This guideline stated that developer should always stay alert with the technology developments and always plans the advantages of using the system on a continuous basis. Developers should also identify and understand the real characteristics of VR, end users, equipment, hardware, software, development platforms and the features of the VR application to be developed. The development of VR application should be initiated with a simple framework followed by detailed development. Pilot study should also be done repeatedly to obtain the construction of VR applications that exactly meet the needs of the users. Documentation about the developed VR application must be in itemized form. [7] stressed that each the results obtained from the application development should be shared with the other researchers.

Comparatively, IBVR is much easier to develop. However, no established development guidelines related to IBVR applications exist. Due to the increasing usage of IBVR type of application particularly in health and medicine, a systematic design methodology for IBVR application development that can enhance spatial presence experience among users should be available. Moreover, the construction of the application with such impact is not easy. Existing design methodologies are meant for GBVR application. As highlighted in the preceding section the characteristics between IBVR and GBVR are totally different, thus support the need for a separate design methodology for IBVR applications. The following section describes our proposed design methodology.

## 4 PROPOSE DESIGN METHODOLOGY

The proposed design methodology is according to our experience in developing and conducting studies IBVR application that could enhance spatial presence experience. Hence, we highlight four phases in our design methodology that cover from planning phase until validation phase as shown figure 1. We applied these phases based on software engineering design methodology. However, we improvised the steps in each phases based on our experience.

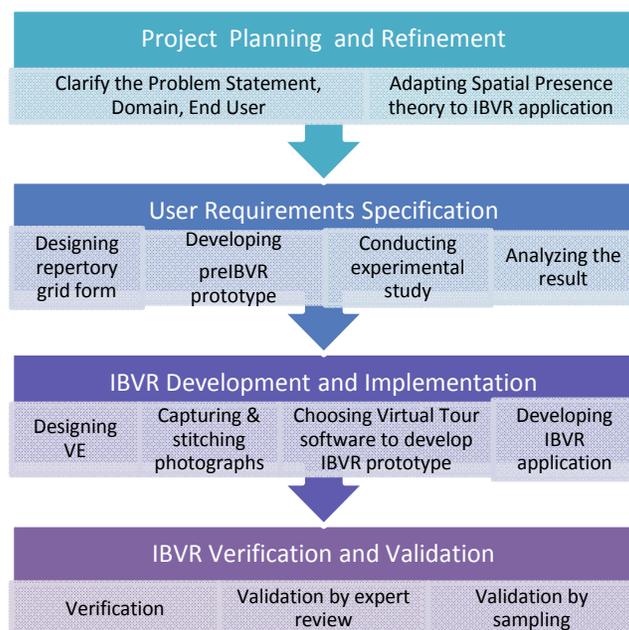


Fig.1 Design Methodology for IBVR application

### 4.1 Project Planning and Refinement

Sufficient time spent early in stages of development of an application can lead to greater economical time at later stages. Thus, it is important to clarify the problem statement, domain and end users before considering other phases[13].

#### 4.1.1 Clarify the Problem Statement and Objective

Before developing an application, the development team should identify the reason why they wanted to develop an application. The same applies to IBVR application. Thus, the development team should do is to clarified the problem statement. After that, the development team can identify the objectives of the IBVR development. This step is important because at the end of the project, a commercial product can be produced

#### 4.1.2 Clarify the Domain

The development team also should clarify the domain. This is because there are various domains that can apply IBVR application. Each domain has specific criteria that enable a successful application. Indeed most IBVR applications are used for 'a simple VR walkthrough '.

Therefore, most of these systems are used for the tourism, architecture, agriculture, planning and management, and education domain.

For travel applications, the important thing for the IBVR application is a location of scenic beauty. These views will visually attract tourists to visit that location.

For agriculture areas, a level degree of a visual must be given priority. Thus the 'zoom in' and visual clarity so important in this IBVR applications [14].

However, there are domains that require a user's presence to achieve the objective of the IBVR application; for example, in the rehabilitation and entertainment. The literature has suggested there are many features that could help create user's presence. Examples of relevant features are clear panoramic views, natural sound, panning etc..[15].

#### 4.1.3 Clarify the End User

Another important part of the development is to identify the right end user. It is not easy to identify the needs of all users. Hence, it is crucial to get the right type and number of sample that represents the majority of the end user.

Based on our study, we did a preliminary study to identify the age of respondents that suitable and prefer IBVR application. We used Presence Questionnaires (PQ) during this study. The result shows that the teenagers dislike IBVR application because they are keen to game application and old respondents (above 50 years old) dislike the application because they prefer to see the real scenery. Hence, the respondents that like IBVR application is in the range of 23 until 49 years old.

#### 4.1.4 Adapting Spatial Presence theory to IBVR application

It is important to identify the right spatial presence theory that suit with the criteria as discussed in the previous section. For an example, the objective of our study is to produce IBVR application that can provide high spatial presence experience. Besides the display equipment, users' cognitive effect is the plays an important in eliciting spatial presence experience. For example, the objective of our study is to investigate if provision of positive feeling of calm could produce spatial presence experience. Thus, spatial presence theories from [2] and [3] are more relevant to our studies and design of the application.

### 4.2 User Requirement Specification

User requirement specification also forms a crucial part in design methodology. Researches use questionnaires, interviews and etc. in this phase. However, in our study, we used systematic mental model technique. This is because mental model technique can help users to give their opinion without bounding to specific guidelines. Hence, they can freely give their opinion based on their experience.

We chose Repertory Grid technique in our study. The advantage of this technique is that users develop their own Personal Construct to list the IBVR characteristics that can enhance spatial presence experience and they also have to evaluate the application based on the list. The steps are illustrated in figure 2.

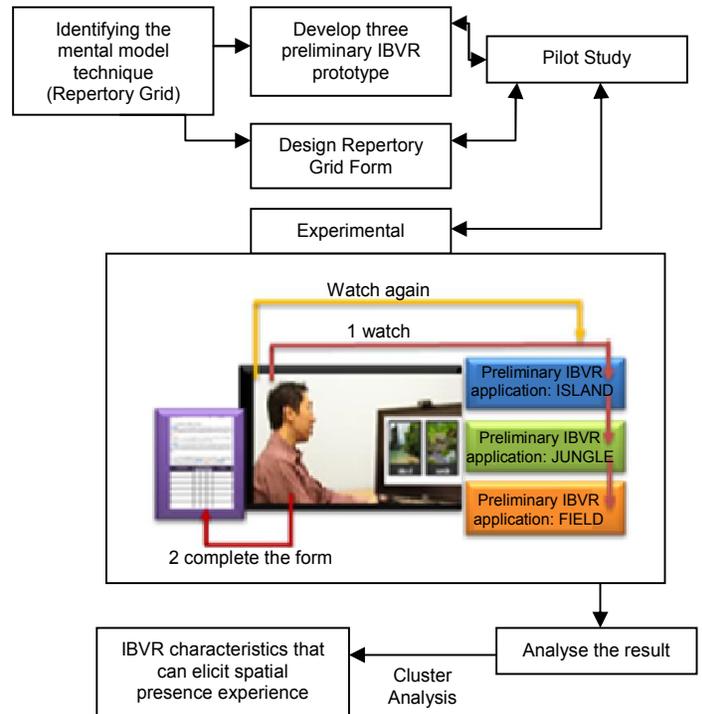


Fig.2 The steps in User Requirement Specification

Hence, in this section, we will discuss how the Repertory Grid form and three preliminary IBVR applications are designed as required by the repertory grid technique.

#### 4.2.1 Designing the Repertory Grid Form

We design the form based on [16]. The challenge in designing the form lies in the questions and scenario from preliminary IBVR applications. The questions should clearly describe the objective of the survey, and make it easy for the respondents to understand what they should answer in the form. A pilot study is conducted to ensure that the respondents understand the form.

#### 4.2.2 Developing the Preliminary IBVR Prototype

In Repertory Grid technique, more applications are displayed to respondents, more results can be obtain. According to [16], minimum six applications can be used in the repertory grid technique to identify the criteria of a VE. These applications were exhibited to users for a short period during the first pilot study. However, the results shows that, users were unsatisfied with the short duration, particularly in terms of presence experience.

Thus, according to our study, the quality of the application is more important than the quantity of the application. This statement is based on our first pilot study. Even though we provide six applications, four out of six users only do not seriously see all the preliminary IBVR application.

Hence, we want the user to experience the spatial presence by using all IBVR characteristics that is applied in preliminary IBVR application. So that, it is easier for them to list IBVR characteristics that could enhance spatial presence experience in Repertory Grid Form. As such, we consider only three applications. This is because, the respondents of our study is among staff. They do not have enough time to navigate more than 15 minutes. Thus, one IBVR application can take approximately 3 minutes to 5 minutes. In our study, most respondents are willing to participate in the survey for not more than 15 minutes.

We apply psychological theory in the first application. The theories used are destination theory and picture theory because according to [6], psychological theory can cause the mind of the user to believe that he/she is in the mediated environment. The second preliminary IBVR application consists of a first panoramic view with animation and a second panoramic view without animation. The third IBVR application consists of a panoramic view without sound. These applications are entirely different from one another. The results do not exhibit a connection with spatial presence theory.

Thus, we redesign our preliminary IBVR application. Most criteria for these preliminary IBVR application applications are similar. For example, we apply psychological theory to the first two applications. Hence, a story line is included in these two applications. For the third application, we use the same panoramic view as in the first two applications, but we do not include a story line. A second pilot study is then conducted. The result shows that theory of spatial presence is elicited among the respondents.

#### 4.2.3 Conducting the Experimental Study

In the experimental study, users view the first preliminary IBVR application and list the features that enable them to experience presence. Next, the users view the second application and list the different features that create presence. This activity is repeated until the users can no longer list different features. Upon completing the listing, a short unstructured interview is conducted. The purpose of this interview is to understand the true meaning of each feature listed by the users. During this session, users provide additional ideas regarding the IBVR application.

#### 4.2.4 Analyzing the Results

The data obtained from the respondents are evaluated using WebGrid II software through hierarchical cluster analysis. This software uses FOCUS algorithms that employ distance measures to reorder the grid. The grid is sorted based on the rating scale on the three preliminary IBVR application applications. The related dendrogram produced by the clustering is a overall correlation between items that could elicit spatial presence experience. Various IBVR characteristics are then obtained using this technique.

TABLE 1: AN EXAMPLE OF IBVR CHARACTERISTICS BASED ON USER REQUIREMENTS

IBVR characteristics
<b>Field of View</b>
<ul style="list-style-type: none"> <li>• Best fit view for full screen</li> <li>• Clarity</li> </ul>
<b>Hotspot</b>
<ul style="list-style-type: none"> <li>• Consistent hotspot icon</li> <li>• Meaningful hotspot icon</li> <li>• Go back to the same place</li> <li>• Shuttle to next scene</li> </ul>
<b>Auto-panning</b>
<ul style="list-style-type: none"> <li>• Adjustable rate of rotation</li> <li>• The view is not jerky</li> </ul>
<b>Manual panning by clicking the mouse</b>
<ul style="list-style-type: none"> <li>• Can begin at any starting point</li> <li>• Can be started at any point</li> </ul>

#### 4.3 Developing IBVR application

IBVR characteristics that can elicit spatial presence must be applied in the IBVR prototype. The steps are illustrated in figure 3.

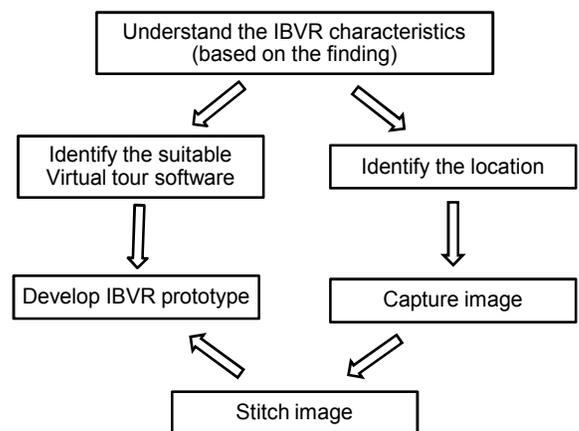


Fig.3 Steps in Developing IBVR Application phase

Each of the steps is describe in detail in the following sub-section.

##### 4.3.1 Designing the virtual environment

After understanding the criteria given by the respondents as Table 1, a suitable VE is designed. The location of the VE is also determined because the real

location can be identified in this step, thus making capturing and stitching the image easier.

### 4.3.2 Capturing and Stitching Photographs

If the panoramic view in the preliminary IBVR application receives a positive response from the respondents, the developers may reuse this panoramic view. However, the users are not always satisfied with a panoramic view from a preliminary application. Therefore, the developers need to take pictures of areas favored by the majority of the respondents. Techniques for capturing and stitching images are described below.

To build a panoramic view, a regular 35 mm camera with the capability to take clear pictures at different exposure settings is required. In addition, a tripod is also used to ensure that the captured image stay within the same margins.. For a normal stitching session, the best result for virtual environment approximately 12 images of panoramic view.

Figure 4 shows how the captured images are merged to form a cylindrical image. Each captured image should overlap by 50%. To produce a clear cylindrical image, the developers should ensure that the pictures free of "dust" before these pictures are stitched. The pictures should also have the same colors to prevent the cylindrical image from appearing like a merged image. In general, developers use Adobe® Photoshop® (Adobe Systems, Inc., USA) to remove "dust" digitally and to even out the colors of the pictures.

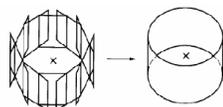


Fig.4. A collection of images transformed into one cylindrical image

In the field of photography, cameramen need to merge captured images themselves. However, for VR applications, developers should choose suitable stitching software. Selecting such software depends on the type of IBVR image. For example, most stitching software packages only combine pictures into a cylindrical image, and only a few produce cubic and spherical images by themselves.

### 4.3.3 Choosing a Virtual Tour Software to Develop the IBVR Prototype

Based on the analysis conducted, the developer can determine the features in the IBVR application that are capable of creating user presence. The next step is identifying IBVR software capable of producing features required by the users.

Several programs are capable of building IBVR applications. Table 2 serves as a brief guide for developers to analyze which software is most suitable for building applications. Based on this table, IBVR characteristics are re-listed to serve as a guide in selecting appropriate

software. The software that best suits the requirements of consumers is used to develop the applications.

One important criterion for selecting software that enables IBVR application is the final product. In this study, "final product" refers to the IBVR prototype that is converted into a Web or desktop application in ".exe file". Developers are encouraged to choose 'exe file' because these products are convenient for users as they do not need to download or install software to open the application.

TABLE 2: EXAMPLE OF IBVR CHARACTERISTICS AND VIRTUAL TOUR SOFTWARE

Virtual-Tour Software	PTGUI	Tourweaver	Pixmaker Pro
<b>IBVR Characteristics</b>			
<b>Hotspot</b>			
Consistent Hotspot Icon	√	√	√
Meaningful Hotspot Icon		√	
<b>Auto-Panning</b>			
Adjustable Rate of Rotation		√	
The rotation moves smoothly without stuck	√	√	√
<b>Panning</b>			
Can begin at any starting point	√	√	√

### 4.3.4 Developing IBVR application

The IBVR application is then developed based on user requirement. Upon completion, the developers should check the application on user requirement if it has fulfill all the user requirements. The example of IBVR application is illustrated in figure 5.



Fig.5 Example of IBVR application

In case, developer is suggested to develop many different locations in IBVR application. This is because user's preferable locations are unique and different. The

examples of the locations are Island, mountain, jungle, flower field and lake. Besides that, the locations must be separated into two sections. One section has locations that include people and other section must have people the virtual environment. However, these sections are suggested according to our result of the experimental study. Again, developer has to understand the requirement from the respondents. Thus, the section is design accordingly.

In each location, should have first - middle - end virtual environment. The example of the virtual environment is described as in PART 2 in Figure 5.

#### 4.4 Validating the IBVR Application

The validation phase consists of three steps: system verification, validation by expert review, and validation by sampling.

##### 4.4.1 Verification

Before we start the validation process, we have tested the functionalities of the IBVR application. For an example, to test the button function for IBVR application is function accordingly or not. Another important test is on display capabilities of the display computer that is to see if the images can be displayed smoothly without much lagging.

##### 4.4.2 Validation by Expert Review

Based on our research, expert opinion is important because such experts possess years of experience in their field of study. In addition, a developer may not have the right experience in the selected domain. For example, we have built an IBVR application, which we call 'VReST', for use in therapy. Given that we do not have any experience in this field, we have employed therapists to validate the application. The validation technique used is a semi-structured interview. This technique has been selected because we want to ensure that the questions posed to the experts do not stray from the objectives of the study. This technique also allows experts to share their opinions easily. Experts may also provide new inputs suitable for developing the IBVR application.

The objective of this phase is to determine whether the IBVR desktop application can be used inguided imagery therapy. Three therapists are involved in this validation phase. Examples of the questions asked during the interview are as follows:

- Do you think this application can be used to reduce stress? Why?
- The purpose of this application is to prevent patients fromimagining a negative path. In your opinion, can this application replace "location imagination" in guided imagery therapy?
- Do you think a therapist's voice is needed in this application? Why?

- Can this application provide a positive effect on the patient? Why?
- What other factors, applications, or techniques should be added in this application so that it can give a better impression to the user?

Additional questionswere asked based on the answers of the therapist. The purpose of the follow-up questions was to gain in-depth understanding ofthe therapist's answers.

##### 4.4.3 Validation by Sampling

Validation by the user is also required. The reactions of the users after using the application are important in determining whether the application is appropriate for the respective domain. Moreover, feedbacks and comments could be used to further improve the system.

## 6 DISCUSSION

The process model for a VE design methodology appears to be reasonably well populated with appropriate techniques but is not suitable for IBVR application. In this section, we discussed about our work with respect to previous work on design methodology.

In VE design methodology, most authors proposed the first phase is to identify the problem statement, objective, end user and other requirement that related to the research. So, it is important to make a thorough review on previous literature. Reviewing previous literature is important to determine the research gap and the problem statement. A similar point is made in [13].

Based on the spatial presence theory, it is important to set the user's mental model to accept the VE before the users experience spatial presence[2]. Based on these statements, a systematic mental model technique is selected; Repertory Grid technique. However, a few IBVR applications have to be developed with similar characteristics.

We have conducted two pilot studies. For the first pilot study, the IBVR characteristics for these applications are different from each other. Contrary to the findings of [17], spatial situation experience in spatial presence theory is not achieved in this pilot study. Thus, a second pilot study was conducted with the similar IBVR characteristics for different types of panoramic VE were used. Users were found to experience spatial presence as described in Spatial Presence theory in this study. As such, similar characteristics for all the IBVR application would offer better spatial presence experience.

The result from repertory grid technique obtained extensive data on IBVR characteristics. These characteristics are accepted because the result is from user's mental model. A similar point is made in [16].

Six applications are commonly used for the repertory grid. However, we use only three in our exploratory

study. According to [16], VR applications shown for a short period do not satisfy users, particularly in terms of presence experience. Thus, we suggest using only three applications for the repertory grid. None of the users has commented that that he/she has not experienced presence. In the pilot study, we also found that the users feel presence experience from IBVR prototype.

After analyzing the user requirements, then IBVR application can be developed. Numerous guidelines exist on how to capture pictures for cylindrical panoramic view from previous literature [17]. A 50% overlapping percent between two pictures presents the best result of panoramic view. Selection of appropriate stitch software is also important. The stitch software should be able to provide clear panoramic view with no distraction such as visibility of stitched.

To develop a virtual tour of the IBVR application, selection of suitable software that can fulfill users' requirement is important. [6] and [17] proposed steps for adding hotspots to IBVR applications. We enhanced this step. The hotspot function can display a story line in IBVR application. Besides that, IBVR application should integrate recorded natural sound to elicit spatial presence experience [18].

Upon completion, the application has to be validated. Most researchers validate VR applications among respondents or samples. Such applications include virtual library environments [17], VR rehabilitation applications [19], [20], and educational VEs [21]. We also apply the concept of sampling, but we add expert review before validating the application through sampling.

## 7 CONCLUSION

This paper proposes a four phase design methodology for IBVR application whose goal is to enhance the spatial presence experience of users. The design methodology is proposed based on our experience in developing and conducting studies for IBVR application which is guided by two spatial presence theories. The proposed design methodology could be useful in designing IBVR application that require user to experience high spatial presence. In such application, presence is necessary to increase their perceptual realism of the developed virtual environment; hence could improve their performance. However, further validation need to be conducted for our proposed design methodology.

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