UNIVERSIDADE DE LISBOA
Faculdade de Ciências
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360º HYPERVIDEO

Luís António da Rosa Neng

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DISSERTAÇÃO

Trabalho orientado pela Prof. Doutora Maria Teresa Caeiro Chambel

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Resumo

Nesta dissertação descrevemos uma abordagem para o design e desenvolvimento de uma interface imersiva e interactiva para a visualização e navegação de hipervídeos em 360º através da internet. Estes tipos de hipervídeos permite aos utilizadores movimentarem-se em torno de um eixo para visualizar os conteúdos dos vídeos em diferentes ângulos e acedê-los de forma eficiente através de hiperligações.

Desafios para a apresentação deste tipo de hipervídeos incluem: proporcionar aos utilizadores uma interface adequada que seja capaz de explorar conteúdos em 360º num ecrã normal, onde o vídeo deve mudar de perspectiva para que os utilizadores sintam que estão a olhar ao redor, e formas de navegação adequadas para compreenderem facilmente a estrutura do hipervídeo, mesmo quando as hiperligações estejam fora do alcance do campo de visão.

Os dispositivos para a captura de vídeo em 360º, bem como as formas de os disponibilizar na Web, são cada vez mais comuns e acessíveis ao público em geral. Neste contexto, é pertinente explorar formas e técnicas de navegação para visualizar e interagir com hipervídeos em 360º. Tradicionalmente, para visualizar o conteúdo de um vídeo, o utilizador fica limitado à região para onde a câmara estava apontada durante a sua captura, o que significa que o vídeo resultante terá limites laterais. Com a gravação de vídeo em 360º, já não há estes limites: abrindo novas direcções a explorar. Um *player* de hipervídeo em 360º vai permitir aos utilizadores movimentarem-se à volta para visualizar o resto do conteúdo e aceder de forma fácil às informações fornecidas pelas hiperligações. O vídeo é um tipo de informação muito rico que apresenta uma enorme quantidade de informação que muda ao longo do tempo. Um vídeo em 360º apresenta ainda mais informações ao mesmo tempo e acrescenta desafios, pois nem tudo está dentro do nosso campo de visão. No entanto, proporciona ao utilizador uma nova experiência de visualização potencialmente imersiva.

Exploramos técnicas de navegação para ajudar os utilizadores a compreenderem e navegarem facilmente um espaço de hipervídeo a 360º e proporcionar uma experiência de visualização a outro nível, através dum espaço hipermédia imersivo. As hiperligações levam o utilizador para outros conteúdos hipermédia relacionados, tais como textos, imagens e vídeos ou outras páginas na Web. Depois de terminar a reprodução ou visualização dos conteúdos relacionados, o utilizador poderá retornar à

posição anterior no vídeo. Através da utilização de técnicas de sumarização, podemos ainda fornecer aos utilizadores um sumário de todo o conteúdo do vídeo para que possam visualizá-lo e compreendê-lo duma forma mais eficiente e flexível, sem necessitar de visualizar o vídeo todo em sequência.

O vídeo tem provado ser uma das formas mais eficientes de comunicação, permitindo a apresentação de um leque enorme e variado de informação num curto período de tempo. Os vídeos em 360º podem fornecer ainda mais informação, podendo ser mapeados sobre projecções cilíndricas ou esféricas. A projecção cilíndrica foi inventada em 1796 pelo pintor Robert Barker de Edimburgo que obteve a sua patente.

A utilização de vídeo na Web tem consistido essencialmente na sua inclusão nas páginas, onde são visualizados de forma linear, e com interacções em geral limitadas às acções de *play* e *pause, fast forward* e *reverse*. Nos últimos anos, os avanços mais promissores no sentido do vídeo interactivo parecem ser através de hipervídeo, proporcionando uma verdadeira integração do vídeo em espaços hipermédia, onde o conteúdo pode ser estruturado e navegado através de hiperligações definidas no espaço e no tempo e de mecanismos de navegação interactivos flexíveis. Ao estender o conceito de hipervídeo para 360º, surgem novos desafios, principalmente porque grande parte do conteúdo está fora do campo de visão. O *player* de hipervídeo a 360º tem que fornecer aos utilizadores mecanismos apropriados para facilitar a percepção da estrutura do hipervídeo, para navegar de forma eficiente no espaço hipervídeo a 360º e idealmente proporcionar uma experiência imersiva. Para poder navegar num espaço hipervídeo a 360º, necessitamos de novos mecanismos de navegação. Apresentamos os principais mecanismos concebidos para visualização deste tipo de hipervídeo e soluções para os principais desafios em hipermédia: desorientação e sobrecarga cognitiva, agora no contexto de 360º. Focamos, essencialmente, os mecanismos de navegação que ajudam o utilizador a orientar-se no espaço de 360º.

Desenvolvemos uma interface que funciona por arrastamento para a navegação no vídeo em 360º. Esta interface permite que o utilizador movimente o vídeo para visualizar o conteúdo em diferentes ângulos. O utilizador só precisa de arrastar o cursor para a esquerda ou para a direita para movimentar o campo de visão. Pode no entanto movimentar-se apenas para um dos lados para dar a volta sem qualquer tipo de limitação.

A percepção da localização e do ângulo de visualização actual tornou-se um problema devido à falta de limites laterais. Durante os nossos testes, muitos utilizadores sentiram-se perdidos no espaço de 360º, sem saber que ângulos é que estavam a visualizar. Em hipervídeo, a percepção de hiperligações é mais desafiante do que em hipermédia tradicional porque as hiperligações podem ter duração, podem coexistir no tempo e no espaço e o vídeo muda ao longo do tempo. Assim, são precisos mecanismos especiais, para torná-las perceptíveis aos utilizadores. Em hipervídeo em 360º, grande parte do conteúdo é invisível ao utilizador por não estar no campo de visão, logo será necessário estudar novas abordagens e mecanismos para indicar a existência de hiperligações.

Criámos os *Hotspots Availability* e *Location Indicators* para permitir aos utilizadores saberem a existência e a localização de cada uma das hiperligações. O posicionamento dos indicadores de *hotspots availabity* no eixo da ordenada, nas margens laterais do vídeo, serve para indicar em que posição vertical está cada uma das hiperligações. O tamanho do indicador serve para indicar a distância do *hotspot* em relação ao ângulo de visualização. Quanto mais perto fica o *hotspot*, maior é o indicador. Os indicadores são semi-transparentes e estão posicionados nas margens laterais para minimizar o impacto que têm sobre o conteúdo do vídeo.

O *Mini Map* também fornece informações acerca da existência e localização de *hotspots*, que deverão conter alguma informação do conteúdo de destino, para que o utilizador possa ter alguma expectativa acerca do que vai visualizar depois de seguir a hiperligação. Uma caixa de texto com aspecto de balão de banda desenhada permite acomodar várias informações relevantes.

Quando os utilizadores seleccionam o *hotspot*, poderão ser redireccionados para um tempo pré-definido do vídeo ou uma página com informação adicional ou a selecção pode ser memorizada pelo sistema e o seu conteúdo ser mostrado apenas quando o utilizador desejar, dependendo do tipo de aplicação. Por exemplo, se a finalidade do vídeo for o apoio à aprendizagem (*e-learning*), pode fazer mais sentido abrir logo o conteúdo da hiperligação, pois os utilizadores estão habituados a ver aquele tipo de informação passo a passo. Se o vídeo for de entretenimento, os utilizadores provavelmente não gostam de ser interrompidos pela abertura do novo conteúdo, podendo optar pela memorização da hiperligação, e pelo seu acesso posterior, quando quiserem.

Para além do título e da descrição do vídeo, o modo *Image Map* fornece uma visualização global do conteúdo do vídeo. As pré-visualizações *(thumbnails)* referem-se às cenas do vídeo e são representadas através duma projecção cilíndrica, para que todo o conteúdo ao longo do tempo possa ser visualizado. Permite também, de forma sincronizada, saber a cena actual e oferece ao utilizador a possibilidade de navegar para outras cenas. Toda a área de pré-visualização é sensível ao clique e determina as coordenadas da pré-visualização que o utilizador seleccionou. Uma versão mais condensada disponibiliza apenas a pré-visualização da parte central de cada uma das cenas. Permite a apresentação simultânea de um maior número de cenas, mas limita a visualização e a flexibilidade para navegar para o ângulo desejado de forma mais directa.

Algumas funcionalidades também foram adicionadas à linha de tempo *(timeline)*, ou *Barra de Progresso*. Para além dos tradicionais botões de *Play*, *Pause* e Tempo de Vídeo, estendemos a barra para adaptar a algumas características de uma página Web. Como é um *Player* desenvolvido para funcionar na internet, precisamos de ter em conta que é preciso tempo para carregar o vídeo. A barra de *bytes loaded* indica ao utilizador o progresso do carregamento do vídeo e não permite que o utilizador aceda às informações que ainda não foram carregadas.

O hiperespaço é navegado em contextos espácio-temporais que a história recorda. A barra de memória, *Memory Bar*, fornece informação ao utilizador acerca das partes do vídeo que já foram visualizadas. O botão *Toogle Full Screen* alterna o modo de visualização do vídeo entre *full* e *standard screen* . O modo *full screen* leva o utilizador para fora das limitações do browser e maximiza o conteúdo do vídeo para o tamanho do ecrã. É mais um passo para um modo de visualização imersiva, por exemplo numa projecção 360º dentro duma Cave, como estamos a considerar explorar em trabalho futuro.

Nesta dissertação, apresentamos uma abordagem para a visualização e interacção de vídeos em 360º. A navegação num espaço de vídeo em 360º apresenta uma nova experiência para grande parte das pessoas e não existem ainda intuições consistentes sobre o comportamento deste tipo de navegação. Os utilizadores, muito provavelmente, vão sentir o problema que inicialmente houve com o hipertexto, em que o utilizador se sentia perdido no hiperespaço. Por isso, o Player de Hipervídeo a 360º tem que ser o mais claro e eficaz possível para que os utilizadores possam interagir facilmente.

O teste de usabilidade foi feito com base no questionário USE e entrevistas aos utilizadores de modo a determinar a usabilidade e experiência de acordo com os seus comentários, sugestões e preocupações sobre as funcionalidades, mecanismos de acesso ou de representação de informação fornecidos. Os resultados dos testes e comentários obtidos, permitiu-nos obter mais informação sobre a usabilidade do *player* e identificar as possíveis melhorias.

Em resumo, os comentários dos utilizadores foram muito positivos e úteis que nos ajudará a continuar a trabalhar na investigação do Hipervídeo 360º.

O trabalho futuro consiste na realização de mais testes de usabilidade e desenvolvimento de diferentes versões do Player de Hipervídeo em 360º, com mecanismos de navegação revistos e estendidos, com base nos resultados das avaliações. O Player de Hipervídeo em 360º não deverá ser apenas uma aplicação para

Web, deverá poder integrar com quiosques multimédia ou outras instalações imersivas. Provavelmente serão necessárias novas funcionalidades e tipos de navegação para adaptar a diferentes contextos. O exemplo do Player de Hipervídeo em 360º apresentado neste artigo utiliza um Web browser e um rato como meio de apresentação e interacção. Com o crescimento das tecnologias de vídeo 3D, multi-toque e *eye-tracking*, podem surgir novas formas de visualização e de interacção com o espaço 360º. Estas novas formas trazem novos desafios mas também um potencial acrescido de novas experiências a explorar.

Palavras-chave: Hipervídeo; Navegação 360º; Factor Humano; Interface pessoa-máquina; Interfaces Imersivas;

Abstract

In traditional video, the user is locked to the angle where the camera was pointing to during the capture of the video. With 360º video recording, there are no longer these boundaries, and 360º video capturing devices are becoming more common and affordable to the general public.

Hypervideo stretches boundaries even further, allowing to explore the video and to navigate to related information. By extending the hypervideo concept into the 360º video, which we call 360º hypervideo, new challenges arise.

Challenges for presenting this type of hypervideo include: providing users with an appropriate interface capable to explore 360º contents, where the video should change perspective so that the users actually get the feeling of looking around; and providing the appropriate affordances to understand the hypervideo structure and to navigate it effectively in a 360º hypervideo space, even when link opportunities arise in places outside the current viewport.

In this thesis, we describe an approach to the design and development of an immersive and interactive interface for the visualization and navigation of 360º hypervideos. Such interface allow users to pan around to view the contents in different angles and effectively access related information through the hyperlinks.

Then a user study was conducted to evaluate the 360º Hypervideo Player's user interface and functionalities. By collecting specific and global comments, concerns and suggestions for functionalities and access mechanisms that would allow us to gain more awareness about the player usability and identify directions for improvements and finally we draw some conclusions and opens perspectives for future work.

Keywords: Hypervideo; 360º Navigation; Human Factors; User-Interfaces; Immersive Interfaces;

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Chapter 1

Introduction

This chapter presents the motivation for this thesis after a brief introduction on the video, hypervideo, 360º hypervideo and some of its applications. Then we present the objectives, context and contributions, project plan and development methodology and the structure of this thesis.

1.1 Motivation

Video is a widely used medium today and has proven to be one of the most effective ways to communicate, able to present in a rich cultural context a large quantity and diversity of information in a brief period of time.

With the boom of broadband connections, nowadays is easier to access video through the Internet via the video sharing websites such as YouTube (url-YouTube), Dailymotion (url-Dailymotion) and Vimeo (url-Vimeo).

A recent study (url-Wired) indicates that YouTube is now responsible for 10% of the total traffic of the Internet.

The YouTube system allows the user to upload their own video for free and share them to the world. This is a great incentive to the user to capture they own video and publish it online and in consequence it helps spreading the usage of this kind of medium. YouTube is not just a simple website for sharing video content. It actually allows the user to add links/anchors and annotations that transforms the common video content into hypervideo content.

Hypervideo, or hyperlinked video, is a displayed video stream that contains embedded, user-clickable anchors (Smith & Stott, 2002), allowing navigation between video and other hypermedia elements. Hypervideo is thus analogous to hypertext, which allows a reader to click on a word in one document and retrieve information from another document, or from another place in the same document. That is, hypervideo combines video with a nonlinear information structure, allowing a user to make choices based on the content of the video and the user's interests.

A crucial difference between hypervideo and hypertext is the element of time. Text is normally static, while a video is necessarily dynamic; the content of the video changes with time. Consequently, hypervideo has different technical, aesthetic, and rhetorical requirements than a static hypertext page. For example, hypervideo might involve the creation of a link from an object in a video that is visible for only certain duration. It is therefore necessary to segment the video appropriately and add the metadata required to link from frames or even objects in a video to the pertinent information in other media forms.

Hypervideo is a very rich media type, presenting huge amounts of information that change along time.

360º hypervideos extends even further the hypervideo. Traditionally, to view the content of a video or hypervideo, the user is locked to the angle where the camera was pointing to during the capture, and the resulting video content has boundaries. But with 360º video recording, there are no longer boundaries. A 360º hypervideo player will let the users pan around to view the rest of the content and quickly access related information provided by the navigational links.

360º hypervideo features even more information in the same time, and adds extra challenges when we cannot watch all around at the same time. But it provides the whole picture all around the viewer, holding the potential to provide full immersive user experiences.

Challenges for presenting this type of hypervideo include: providing users with an appropriate interface capable to explore 360º contents, where the video should change perspective so that the users actually get the feeling of looking around; and providing the appropriate affordances to understand the hypervideo structure and to navigate it effectively in a 360º hypervideo space, even when link opportunities arise in places outside the current viewport.

1.2 Objectives

We are exploring navigation techniques to support users to get around a 360º hypervideo space, taking the 360º video watching experience into a new level, through an immersive hypermedia space. The users can get around the current video and get around the hypermedia space, following navigational links available during the hypervideo playback to extra or related information. The links take the user to other hypermedia contents such as text and video. For example, when playing a video that contains the Liberty Statue, the users see an icon over the statue when a link may be followed, taking them to other hypermedia content, such as another video about the statue, some extra information on a text based page in this hyper document, or external information like a Wikipedia (url-Wikipedia) page on a related topic. After the users finish watching the related information, they may return to the original video where they left off. In addition, by using summarization techniques (Shipman et al., 2003) an overview or outline of the content of the video can be provided to help the users get aware of the video content without watching it through, and navigate it in a more effective and flexible ways.

1.3 Research Context

This thesis was done in the context of the Dissertation for the Master Degree in Computer Science at the Faculty of Science of University of Lisbon, Portugal, in one of the research group, HCIM – Human Computer Interface and Multimedia Group (url-HCIM) – which is part of LaSIGE – Laboratório de Sistemas Informáticos de Grande Escala (url-LaSIGE).

The advisor of this thesis is Prof. Maria Teresa Caeiro Chambel of the Computer Science Department of the Faculty of Science of University of Lisbon and member of the LaSIGE/HCIM research group.

The initial draft of this thesis was done in Lisbon, Portugal and then completed in Macau SAR, China. This thesis is also part of the research project: ImTV - "On-Demand Immersive-TV for Communities of Media Producers and Consumers", FCT UTAustin | Portugal project, with participation of research teams from FCT/UNL, Inesc Porto, FCUL/LaSIGE/HCIM, UTAustin/USA, RTP, Zon, FCCN, Duvideo and MOG, 2010-2013.

1.4 Contributions

A 360º hypervideo player was developed in order to study an approach to the design and development of an immersive and interactive interface for the visualization and navigation of 360º hypervideos. With the objective of demonstrating 360º hypervideo player as well as contact members of the scientific community which are working in areas related to this work some papers were submitted and published in the following conferences:

- Neng, L. and Chambel, T., 2010, "Get Around 360º Hypervideo", ACM MindTrek 2010 – International Academic Conference, Envisioning Future Media Environments, 6-8, October, 2010, Tampere, Finland.
- Neng, L. and Chambel, T., 2010, "Interfaces para Hipervídeo em 360º" Interacção 2010, 14-15, October, 2010, Aveiro, Portugal.

- Chambel, T., Narendra, M. and Neng, L., 2011, “Towards Immersive Interactive Video Through 360º Hypervideo”, Late Breaking Results, ACE 2011 – International Conference on Advances in Computer Entertainment Technology, from 8-11, November, 2011, Lisbon, Portugal.
- Neng, L., and Chambel, T., “Get Around 360º Hypervideo: Its Design and Evaluation”. In Lugmayr, A., Sotamaa, O., Safran, C., Franssila, H., Hannu Kärkkäinen, and Timo Aaltonen (Eds) “Ambient and Social Media Business and Applications”, Special issue for International Journal of Ambient Computing and Intelligence (IJACI), 2011, to appear.

1.5 Document Structure

In the first chapter an introduction of the thesis was made which includes the motivation, contribution, objectives, project plan, development methodologies and the structure of this thesis.

In the next chapter 2, it contains a brief description of the history of hypervideo, a description on how a 360º video is being captured, differences between hypervideo and 360º hypervideo and also a review of the most relevant related work. Next, in chapter 3, we present the Get Around 360º Hypervideo Player, focusing on the design and implementation process, methodology used and design options for navigation support, followed by user tests and evaluation described in chapter 4. In chapter 5, the thesis draws some conclusions and opens perspectives for future work. Finally in chapter 6, it contains the references used.

Chapter 2

State of the Art

This chapter presents the results of the study on the state of the art in the area of hypervideo and 360º hypervideo. This chapter also describes the main concepts, the systems and current applications available which will serve as the basis for the development of the system proposed in this thesis. The chapter begins with a presentation of the systems currently available that give ideas and solutions to the problems addressed in the hypervideo context.

2.1 Context

This section gives a brief historical perspective and evolution of the hypervideo, following by a description of 360º videos and the possibility and challenges of extending the hypervideo concept into the 360º video space.

2.1.1 Hypervideo

Hypervideo refers to the true integration of video in hypermedia spaces, where it is not regarded as a mere illustration, but can also be structured through links defined by spatial and temporal dimensions (Chambel & Guimarães, 2002).

Although the concept exists since the early days of hypertext, when Ted Nelson extended his hypermedia model to include “branching movies” or “hyperfilms” (Nelson, 1974), hypervideo has not yet been as widely adopted as it might have been expected, partially due to technological constraints in hardware and supporting tools. As video is becoming easier to process and transmit with good quality, and faster through streaming over high bandwidth net-works, and we witness a growing popularity of public access to video on the Internet, it is becoming more relevant to adopt hypervideo and provide tools that support its authoring and access.

Video in hypermedia was discussed in the early nineties by (Kahn & Haan, 1991) and (Buchanan & Zellweger, 1992) and also demonstrated in the hypermedia journal

Elastic Charles (BrØndmo & Davenport, 1991) developed in the late eighties. Both (LiestØl, 1994) and (Sawhney et al., 1996) addressed aesthetical and rhetorical aspects of hyperlinking in video, following earlier work of Landow in hypermedia (Landow, 1989), with a special focus in the new dimension brought into the picture: time. The former presents Kon-Tiki, a video based hypermedia environment for public access in a museum, later redesigned for the Web. The latter, HyperCafe, adopts a filmic metaphor to simulate the visit to a real cafe. Adopting a particular form of hypervideo, Hyper-Hitchcock (Shipman et al., 2003) is an editor enabling the authoring of "detail-on-demand video", focusing on summarization and building on the concepts of spatial hypertext.

The basis for the definition of dynamic links from content objects in video was done by Hirata in 1993 (Hirata et al., 1993), in the Miyabi system, defining a new concept of media-based navigation. Through the automatic identification of elements with certain features, like shape, color, image structure, scenes and sound, link opportunities were found, and objects could be tracked along time. HotVideo developed by IBM developed this kind of hypervideo in 1996. The next year, Hypersoap (Dakss et al, 1998) was developed at MIT Media Lab (url-MITMediaLab), a soap opera where the user can inquire and get external information about purchasing clothing and furnishings used in the show. In 1997, V-Active was the first commercial object based authoring system for hypervideo, changing its name to Veon in 1999, while shifting its focus away from hypervideo. In 2001, VideoClix was released as a hypervideo authoring tool able to dynamically track and link objects along the whole video, and has proven to be reasonably successful. Another company that provides online services for hypervideo authoring is Asterpix, but still with limited features.

In another perspective, the Amsterdam Hypermedia Model (AHM) (Hardman et al., 1995), in the mid-nineties, added mechanisms for hyper-linking dynamic media, as an extension to the Dexter model (Halasz & Schwartz, 1990). SMIL (url-SMIL) is an XML-based language based on the AHM model, as a W3C recommendation since 1998, addressing multimedia object synchronization, positioning and hyperlinking, and control of content, based on network and preferences conditions, allowing for adaptive hypermedia. Although it has been developed through a couple of versions, with new and interesting features added along time, hypervideo support has not received much attention. For example, it is not yet addressing some of the important aspects concerning link awareness and high level structuring constructs for richer and more contextualized integration of dynamic media, an important aspect in hypervideo addressed for e.g. in our previous approaches (Chambel & Guimarães, 2002); and players are not yet widely available or integrated with most common web browsers.

2.1.2 360º Videos

Video has proven to be one of the most effective ways to communicate, able to present in a rich cultural context a large quantity and diversity of information in a brief period of time (Chambel & Guimarães, 2002). With 360º videos, we are able to deliver an even richer and larger quantity of information than before, that can span all over the viewer.

360º videos, also known as panoramic videos, are sequences of still panoramic images representing scenes in motion. The term "panoramic" e derived from the term "panorama", formed from Greek "all" + "sight" is any wide-angle view or representation of a physical space, whether in painting, drawing, photography, film/video, or a three-dimensional model. The word was originally coined by the Irish painter Robert Barker (Yelick, 1980) to describe his panoramic paintings of Edinburgh. In panoramic imaging, the cylindrical projection is most often used for prints of wide panoramas.

A cylindrical projection is a type of projection for mapping a portion of the surface of a sphere to a flat image. It can be envisioned by imagining wrapping a flat piece of paper around the circumference of a sphere, such that it is tangent to the sphere at its equator. Shining a light from the center of the sphere then projects the spherical surface onto the flat paper. The cylindrical projection was actually invented in 1796, also by the painter Robert Barker who even took a patent on it (Yelick, 1980).

The 360º video used on this thesis is captured with a digital camcorder with hyperbolic or parabolic mirror (with an optical path folded by a flat mirror, as it turns out) known as a catadioptric system (Nayar & Peri, 2001; url-CatadioptricSystem).

A catadioptric optical system is one where refraction and reflection are combined in an optical system, usually via lenses (dioptrics) and curved mirrors (catoptrics). Catadioptric combinations are used in focusing systems such as search lights, headlamps, and early lighthouse focusing systems, optical telescopes, microscopes, and telephoto lenses. Others optical systems that use lenses and mirrors are also referred to as "catadioptric".

Figure 1 is a sample of a video frame captured by a Sony Bloggie MHS-PM5K Camcorder (url-SonyBloggie) during a driving tour in Macau SAR, China. The "donut vision" (annular) video captured needs to be transformed into something more useful, such as a long panoramic strip — a process variously called unwarping, dewarping, inverse warping, remapping, reprojection, rectilinearization, or simply distortion correction.

In Figure 2, the same footage is projected onto a long panoramic strip of video showing all 360º angles. We are able to see both buildings in the projection.

Figure 1 – Annular video frame (before projection)

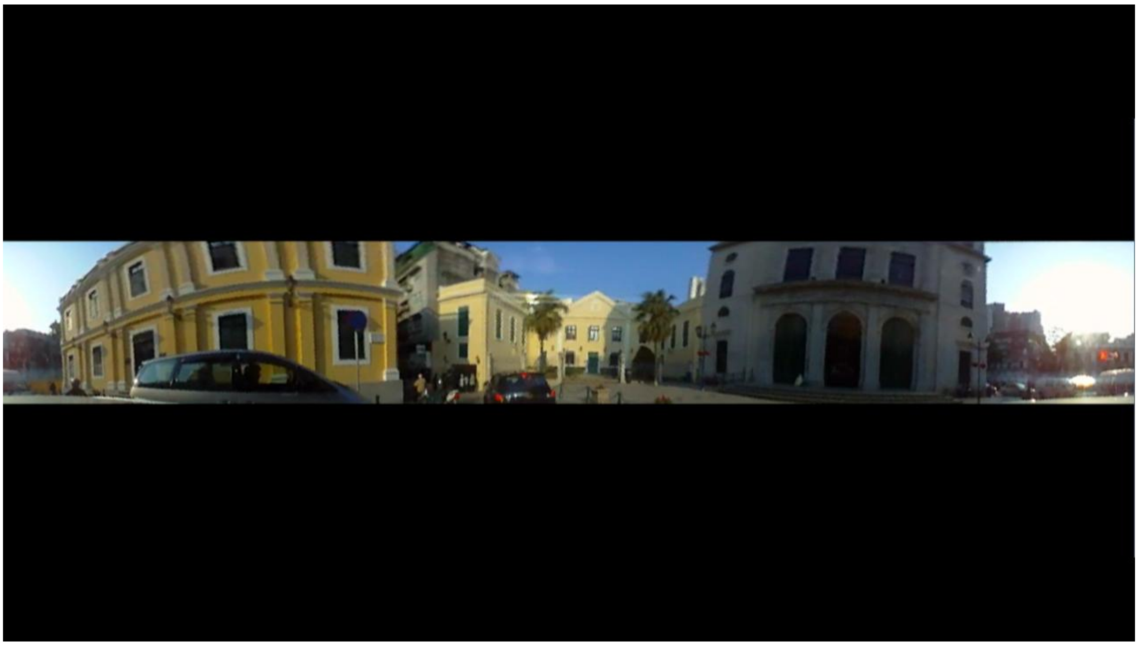

Figure 2 – Long panoramic strip video frame (after projection)

Figure 3 – Sony Catadioptric Reflector and Bloggie MHS-PM5K Camcorder

The camera and catadioptric reflector in the figure 3 were the ones used to capture the "Macau Tour" 360º video.

2.1.3 360º Videos Capturing Devices

Immersive Media (url-ImmersiveMedia) is a provider of 360º, full motion, and interactive videos. Their high-resolution camera is being used for entertainment and advertising, street views, mapping and location-based services, situational awareness and surveillance.

Figure 4 – Immersive Media Dodeca® 2360 Camera System

The Dodeca® differs from the common 360º capturing devices, instead of using a catadioptric system; it has 11 lenses that capture high resolution 360° video from every direction simultaneously, at more than 100 million pixels per second or 30 frames per second. The camera system is configured according to the dodecahedron, a 12-sided sphere. The Dodeca maximizes the images produced by each lens, blending the images and providing a seamless and accurate capture of the entire environment.

For viewing the video captured by the Dodeca® 2360 Camera, Immersive Media developed a cross platform 360º Video Player but it currently does not support link navigations or annotations.

The GoPano Plus from EyeSee360 (url-EyeSee360) is a 360º lens for digital cameras and camcorders. It enhances all digital cameras camcorders that support changeable lens. GoPano Plus comes with PhotoWarp and VideoWarp software that converts the captured photos and videos into cylindrical projections, but it does not support link navigations or annotations. GoPano Micro, also from EyeSee360 and Kogeto Dot (url-Kogeto) are two consumer and commercial products that bring 360º video recording to the Apple iPhone 4 (url-Apple). There are other manufacturers of 360º video capturing devices such as the Palnon parabolic C-mount panoramic lenses from JBC (url-JBC), OmniAlert360 from RemoteReality (url-RemoteReality), P360 from PentaOne (url-PentaOne) and Panoramic Optic from 0-360 (url-0-360).

2.1.4 360º Hypervideo

The use of video inside web pages consists mostly in the simple inclusion of this type of content, and the users are expected to watch it linearly. The interaction between the user and the video, in general, is limited to the actions like play and pause, fast forward and reverse. In the last years, more and more researchers and companies are concerned with improving video functionalities and implementing higher interactivity over the video stream.

The most promising one is likely to be the possibility of implementing hypervideo - providing true integration of video in hypermedia spaces, where it is not regarded as a mere illustration, but can also be structured through links defined by spatial and temporal dimensions (Chambel & Guimarães, 2002). It provides form of interactive video that greatly increases the video capabilities by providing flexible interactive mechanisms that allow to navigate video and to integrate it with different types of media.

The structure and interaction introduced by hypervideo allows the users to have greater control over the contents they want to see. By extending the hypervideo concept to 360º videos or panoramic videos, new challenges arise, especially because parts of the video may be out of sight. The 360º hypervideo player must provide to the users with the appropriate affordances to understand the hypervideo structure and to navigate it effectively in a 360º hypervideo space, while allowing them to have an immersive experience.

2.2 Related Work

This section presents some related works which are more relevant to the context of this thesis, separated in different categories which are deemed that its contribution is greater: Hypervideo, 360º Photos and Map Navigation, and 360º Augmented and Virtual Reality.

2.2.1 Hypervideo

Hypersoap (url-HyperSoap) addressed hypervideo in the context of entertainment in interactive TV, for example, delaying link following till the end of the programs.

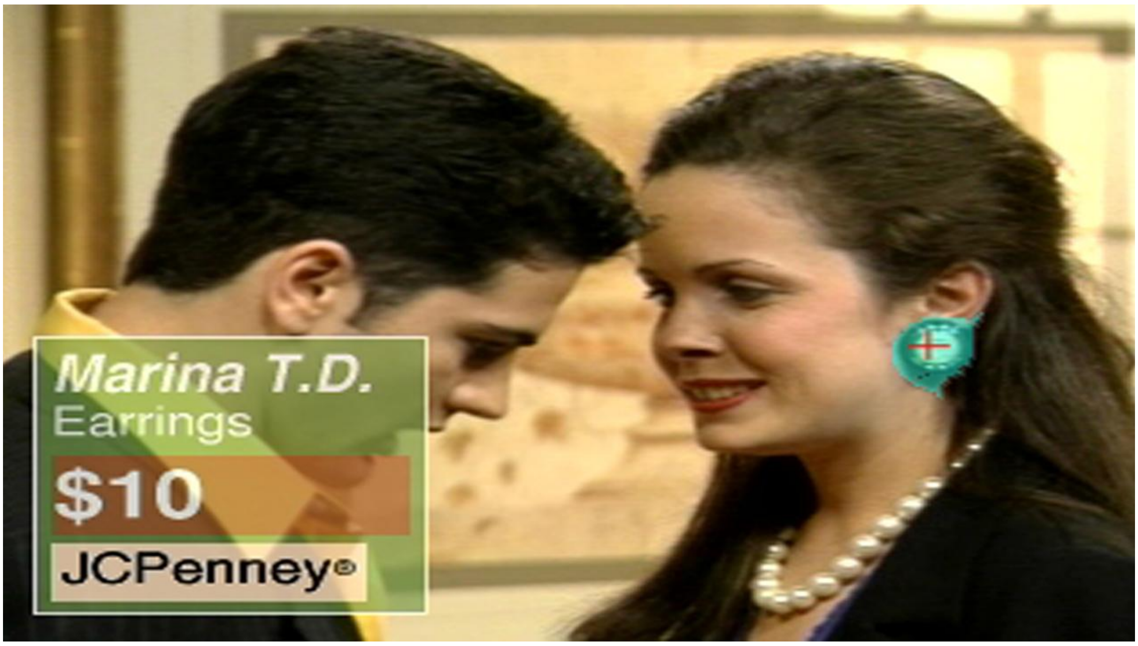

Figure 5 – Example of a HyperSoap Video Frame

In HyperSoap a viewer can "click" (Figure 5) with an enhanced remote control on clothing, furniture, and other items to see information about how they can be purchased. It is an example of hyperlinked video, or video in which specific objects are made selectable by some form of user interface, and the user's interactions with these objects modify the presentation of the video. The *hotspots* featured in the 360º Hypervideo are based on the same concept.

W3C SMIL language (url-SMIL), based on the Amsterdam Hypermedia Model (Hardman et al., 1995), took an important step towards multimedia integration and synchronization on the web, but actual hypervideo support has been limited. Since late nineties, some commercial initiatives have also taken place in the area of hypervideo, but with mild success.

HyperCafe, a popular experimental prototype of hypervideo, made use of this tool to create "narrative video spaces". HyperCafe was developed as an early model of a hypervideo system, placing users in a virtual cafe where the user dynamically interacts with the video to follow different conversations.

Figure 6 – HyperCafe

HyperCafe has been envisioned primarily as a cinematic experience of hyper-linked video scenes. The video is shown in black and white to produce a film-like grainy quality. In HyperCafe, the video sequences play out continuously, and at no point can they be stopped by actions of the user. The user simply navigates through the flow of the video and links presented. This aesthetic constraint simulates the feeling of an actual visit to a cafe where the "real-time video" of the world also plays out continuously. A minimalist interface is employed by utilizing few explicit visual artifacts on the screen. All the navigation and interaction is permitted via mouse movement and selection. For instance, changes in the shape of the cursor depict different link opportunities and the dynamic status of the video. By minimizing the traditional computer-based artifacts in the interface and retaining a filmic metaphor, we hope to provide the user with a greater immersion in the experience of conversations in the cafe. The 360º Hypervideo Player followed the same direction by minimizing the traditional computer-based artifacts in order to provide greater immersion experience to the user.

The YouTube website could be one of the best web hypermedia systems around when it started to support video annotations (url-YouTubeVideoAnnotations) that work like navigational links. It also allows the users to query databases for specific topics and to obtain a list of video relevant to their search.

Figure 7 – YouTube Video Annotations

The figure above is a screenshot of an example of YouTube Video Annotations. The user can click on each sub-video shown on the bottom and will be linked to the corresponding video. YouTube Video Annotations enables a new way for the user to add interactive commentary to the videos such as adding background information, create stories with multiple possibilities (viewers can click to choose the next scene, just like the HyperCafe concept), and link to related YouTube videos, channels, or search results within a video. However it does not provide support yet for 360º videos.

In the context of learning support, web lectures, more recent works on computer supported collaborative video analysis, and our own previous work (Chambel & Guimarães, 2002) in the design and support of individual and collaborative learning with hypervideo, since late nineties, have made some contribution to the field.

The Story of Pi (Chambel et al., 2005) structures and integrates the video with other materials such as images and texts, augmenting their individual affordances to support learning. Video can be navigated from different types of indexes that are presented in synchrony with the video.

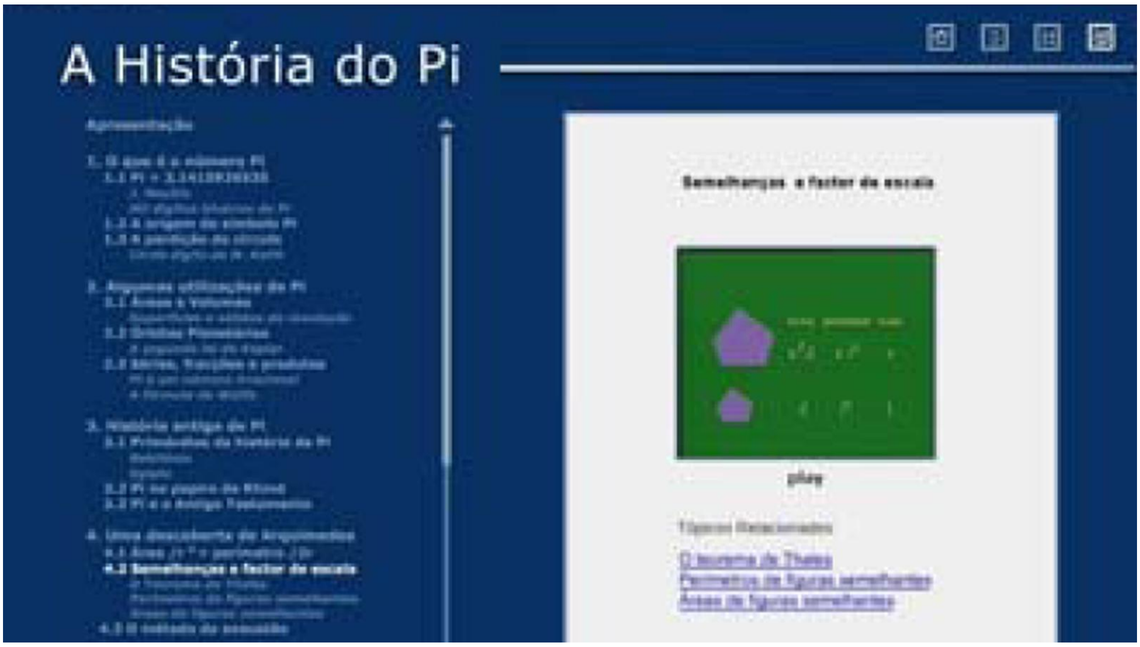

Figure 8 – The Story of PI: Video segment embedded in the textbook

The textbook was converted into hypertext, respecting its underlying hierarchical structure, and further enriched with links involving text, images, video, and applications, allowing to capture relations among them and to illustrate or complement the information conveyed by each one.

Hvet (Tiellet et al., 2010) is a hypervideo environment to support learning of veterinary surgery. The design was based on cognitive and media theories, and evaluation was based on the use of Hvet by veterinary students, in order to test its efficacy in substitution of learning and training with live animals. Results support the hypothesis, showing the potential of hypervideo as a valuable and effective tool to support learning of surgery techniques and revealing the most appreciated design options.

2.2.2 360º Photos and Map Navigation

The computer game Freeciv (url-Freeciv) uses a *Mini Map*, it is the bottom left corner. On this *Mini Map* a white rectangle represents the area of the map currently visible on the main screen (Figure 12). The different colors represent land and ocean and the territories of the different players. The white dots are the position of cities and the blackness is the unexplored areas. It shares the same concept our Mini Map but in the 360º Hypervideo Player the *Mini Map* image is actually an exact copy of the 360º video projected into long strip and the "rectangle" used is for navigation instead of only representing the area of the video currently visible.

Figure 9 – Freeciv with the Mini Map on the bottom left corner

In most games, the *Mini Map* begins as a solid field of black, and the map is automatically drawn as the player discovers new areas of the game world.

Google Maps features a *Mini Map* in the right corner, it is disabled by default. The *Mini Map* used by Google let the user to pan on the invisible area of the map in all directions. The *Mini Map* in the 360º Hypervideo Player shares the same concept.

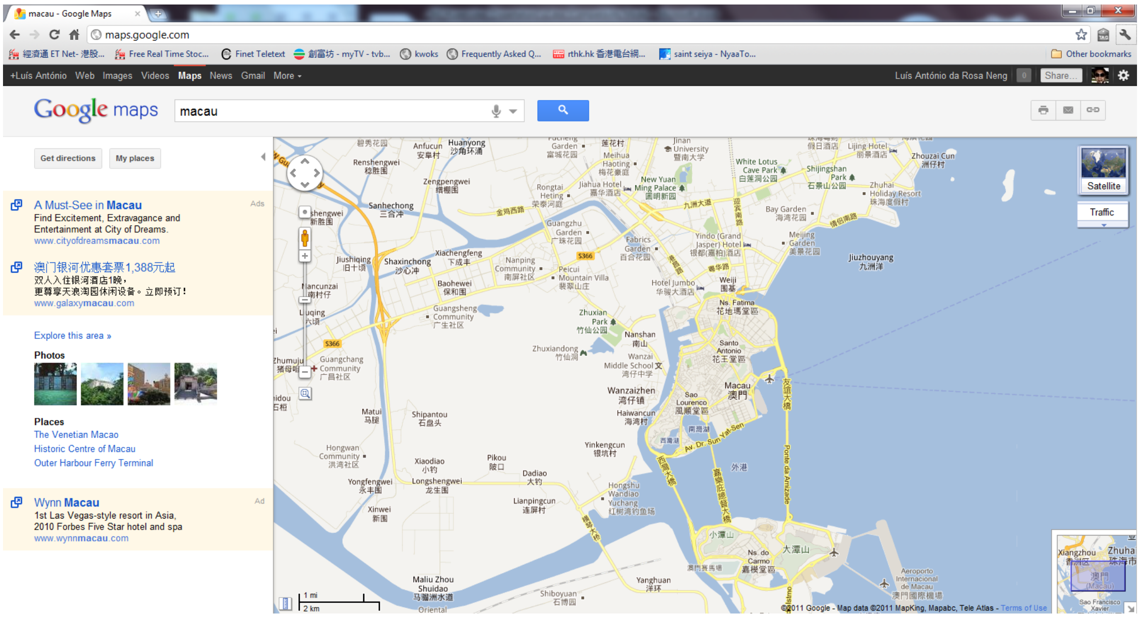

Figure 10 – Google Maps with Mini Map on the bottom right corner

Google Maps with Street View (url-GoogleMaps) could be one of the widely known free 360º spherical panorama viewer available on the market. It uses equirectangular projection (Snyder, 2003) to give the users an immersive feeling but it does not provide any kind of video. There is some very special navigation implemented due to its nature. The user can pan around to see the contents in a 360º environment and "dive" into the scene to follow the streets available. Its hyperlinks are mapped over the streets where contents (e.g.: photos) are available to view.

Figure 11 – Google Maps with Street View

DIY-Streetview (url-DIYStreetview) is a do it yourself open-source alternative for the Google Street View. With the DIY street view camera you can shoot your own panoramic images, and then display them on your own website, using either the official Google Street View player or the DIY-Streetview player. DIY-Streetview aims to unleash a more creative approach to the Street View technology. Its goal is to work towards a network of Streetview websites that are connected behind the scene to provide a seamless surfing experience to the visitor.

In the context of link awareness of off-screen contents which usually happens in maps applications, arrow-based techniques such as City Lights (Zellweger et al., 2003) convey only direction. Halo (Baudish & Rosenholtz, 2003) conveys direction and distance. Halo is a technique that provides a solution for visualizing off-screen information. Its objective is similar to our *Hotspots Indicator* but it uses an arc to display off-screen information of map based applications on mobile devices. Based on our tests, Halo works well on static content such as map where the off-screen information exists in all directions but in a long panoramic strip where the links only exists on the left and right side and in time-based, the design of our *Hotspots Indicator* is more appropriate because the Halo arcs tends to overlaps themselves too many times and susceptible to clutter, resulting noises to the users and hard to interpret.

Figure 12 – Halo Arcs

The map from the figure above (a) with Halo shows where in off-screen space the five point of interest are located. Each off-screen location (b) is located in the center of a ring that reaches into the display window.

Wedge (Gustafson et al., 2008) is a visualization technique that conveys direction and distance, yet avoids overlap and clutter. Wedge represents each off-screen location using an acute isosceles triangle: the tip coincides with the off-screen locations, and the two corners are located on- screen. A wedge conveys location awareness primarily by means of its two legs pointing towards the target. Wedges avoid overlap programmatically by repelling each other, causing them to rotate until overlap is resolved. As a result, wedges can be applied to numbers and configurations of targets that would lead to clutter if visualized using halos. However, Wedges calculations are CPU intensive and it is not suitable to be used in conjunction with real-time rendering and time-based application which is the case of 360º Hypervideo.

2.2.3 360º Augmented and Virtual Reality

Layar Reality Browser is the world first mobile Augmented Reality (Wagner, 2009) browser available for users of most smartphones, including iPhone and Android devices, which displays real time digital information on top of reality (of) in the camera screen of the mobile phone. While looking through the phone’s camera lens, a user can see houses for sale, popular bars and shops, jobs, healthcare providers and ATMs (url-Layar). The information presented on the Layar Reality Browser works like navigational links.

Figure 13 – Layar Reality Browser

The Layar Reality Browser also features a *View Area and Orientation* that displays the links available around the user’s mobile device instead of the viewing angle.

Quake III Arena 360 Panoramic Virtual Reality Installation with PanoramaScreen (url-QuakeIIIArena360Demo) is a cylindrical projection environment for 360º panoramic projections, which has been developed at the ZKM | Institute for Visual Media (url-ZKMInstitute) in collaboration with the iCinema Research Centre (url-iCinema), Sydney, since 2005.

Figure 14 – Quake III Arena 360 Panoramic Virtual Reality Game Play

It shares some features and challenges with 360º hypervideo but it focuses essentially in virtual reality and game interaction instead. The PanoramaScreen has been implemented to display panoramic movies via 4 or 6 projectors, such as 3D animations or video footage. For the recording of 360°-moving imagery, the Institute specially developed a high resolution 360°-PanoramaCamera. The screen can also be used for stereoscopic VR-applications. Furthermore, the environment is equipped with an 8-channel audio system and offers by means of the Panorama Display Software, a software system developed at the Institute, a wide range of applications for interactive real-time applications, which are being further developed in the context of international artistic and research projects and co-operations.

Chapter 3

Get Around 360º Hypervideo

In order to be able to navigate in a 360º hypervideo space, we need new navigation mechanisms. This section presents our main design options so far in the Get Around 360º Hypervideo Player, addressing the main challenges in hypermedia: disorientation and cognitive load, in this richer and more challenging 360º context.

This section presents the methodology used for designing the functionalities of the Get Around 360º Hypervideo Player to take advantage of the 360º context and focus in navigation mechanisms that help orientation with reduced cognitive load.

3.1 Cognitive Load and Disorientation

The Cognitive Load Theory (Sweller, 1994) aims to provide guidelines to help the presentation of information in ways that optimize intellectual performance, especially in learning materials that involve audiovisual information. Based on previous work from Miller, it employs aspects of information processing theory focusing the relation between short and long term memories, and emphasizing limitations of concurrent working (short term) memory load, with latencies of a few seconds (Baddeley, 1992). Long term memory extends its capacities with information schemes and structuring. In interactive multimedia and hypermedia environments, users must cope with and integrate at least three cognitive loads or demands: the content; its structure; and the response options available (Reeves & Harmon, 1994).

Hypervideo shares with traditional hypermedia the potential of increased cognitive load that might also lead to disorientation (Chambel et al., 2006) such as with early hypertext users becoming lost in hyperspace. This problem might be even more pronounced in the 360º context, carrying the risk of overstraining the cognitive capacities of the user, and the dynamic nature of nodes and links that may put time pressure on the users in navigation. Having video as a dynamic and central medium integrated with other media, such as text and images, also raises important rhetorical and aesthetic challenges, since they induce different attitudes in the user (Chambel & Guimarães, 2002; Sawhney et al., 1996).

3.2 Design

For designing and implementing the 360º Hypervideo Player, the methodology used is based on extended-UML.

The extended-UML (Knoch et al., 2000) is an extension of the UML (url-UML). This methodology differs from the UML; it is designed for the modeling of hypermedia applications with a user-centered design. The user-centered design is a design philosophy and a process in which the needs, wants, and limitations of end users of a product are given extensive attention at each stage of the design process. User-centered design can be characterized as a multi-stage problem solving process that not only requires designers to analyze and foresee how users are likely to use a product, but also to test the validity of their assumptions with regards to user behavior in real world tests with actual users. The main difference from other product design philosophies is that user-centered design tries to optimize the product around how users can, want, or need to use the product, rather than forcing the users to change their behavior to accommodate the product.

The methodology consists of five distinct steps: use cases, conceptual model, navigation space model, navigation structure model and presentation model. The usage of the methodology is primarily the execution of three steps in an iterative fashion: the transformation of the conceptual model to the navigation space model, and then to the navigation structure model and finally to the presentation model.

3.2.1 Use cases

A use case in software engineering and systems engineering, is a description of steps or actions between a user (or "actor") and a software system which leads the user towards something useful (Bittner & Spence, 2003). The user or actor might be a person or something more abstract, such as an external software system or manual process.

Use cases are a software modeling technique that helps developers determine which features to implement and how to gracefully resolve errors (Adolph et al., 2002).

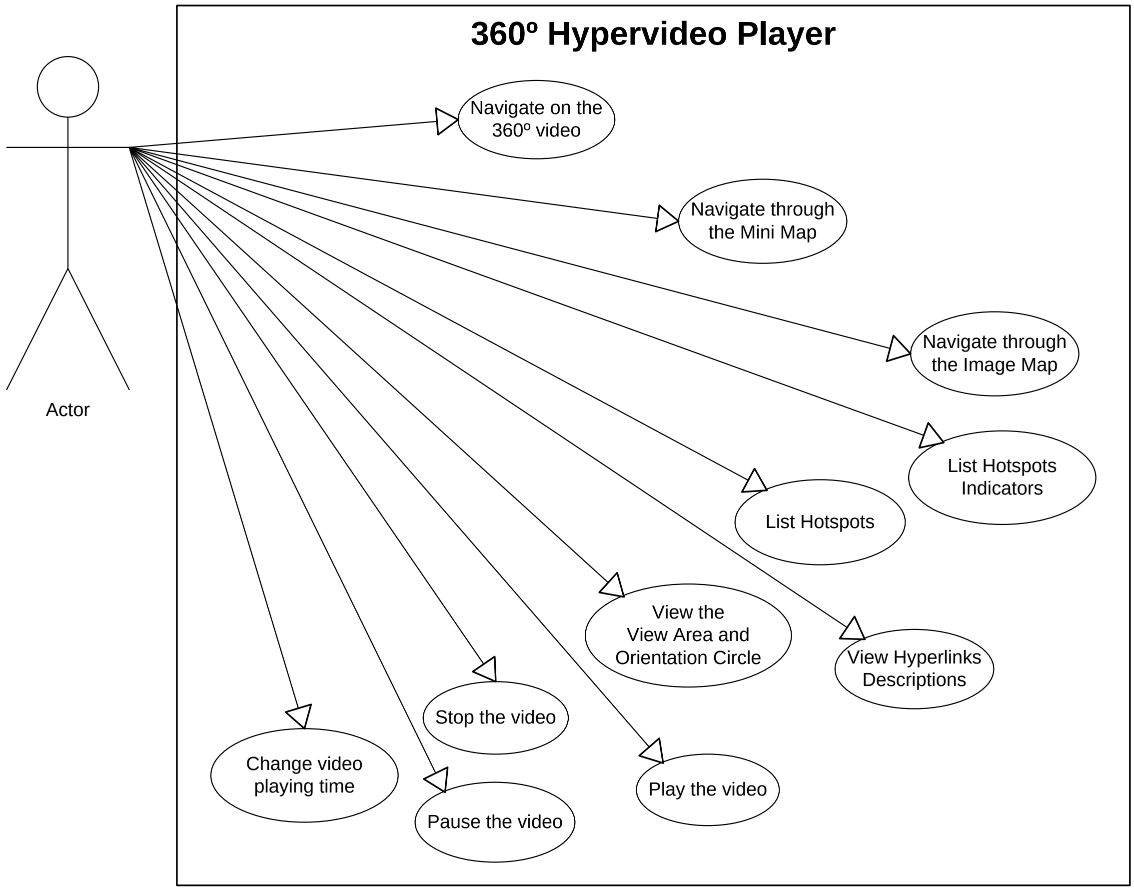

Figure 15 – 360º Hypervideo Player Use Cases

3.2.2 Conceptual Model

The conceptual model is modeled based on the functional requirements obtained from the previous stage, thus creating a class diagram with attributes, operations and associations. The conceptual model denotes a set of objects used in the system. The objective of the conceptual model diagram is to find classes, specify their attributes and determine their relationships and hierarchy between classes and set the restrictions.

This diagram will be used in the next stage (navigation space) where the classes and associations defined here are used to generate nodes and links.

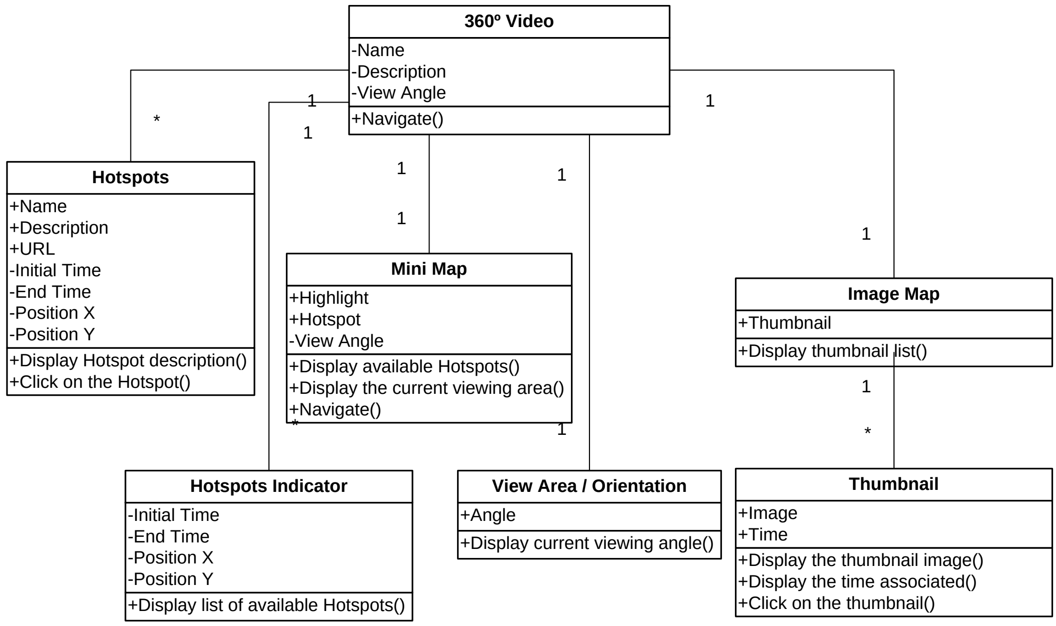

Figure 16 – 360º Hypervideo Player Conceptual Model

3.2.3 Navigation Space Model

As mentioned above, this model is based on the previous stage with additional nodes and links added to the specification that will define the navigation. This stage the not visited classes and irrelevant attributes were omitted. Specific attributes for the navigation are also added in the corresponding association.

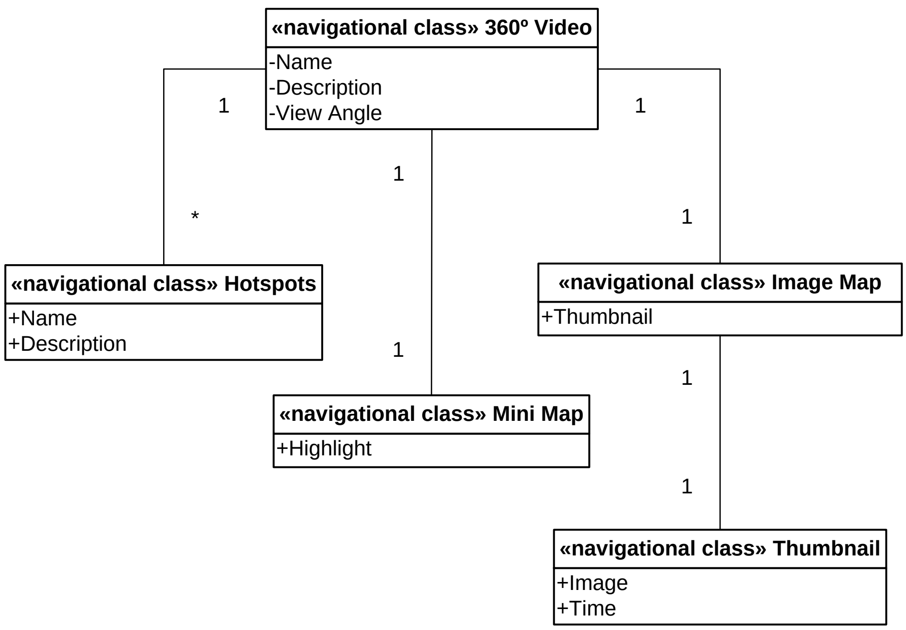

Figure 17 – 360º Hypervideo Player Navigation Space

3.2.4 Navigation Structure Model

By defining the structure of nodes and links created in previous stage, the navigation model could be enriched by accessing to the structures, e.g.: Implementation of indexes, guided tours, queries and menus in order to facilitate access to different classes of the system thus enabling the choice of the direction of navigation.

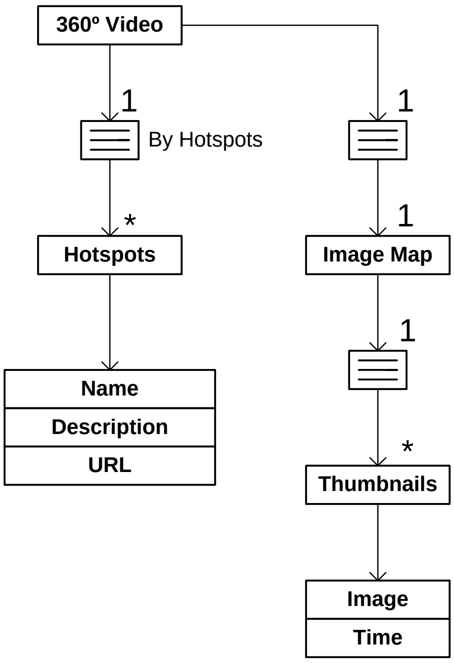

Figure 18 – 360º Hypervideo Player Navigation Structure

3.2.5 Presentation Model

This stage describes how the information of the navigation structure model is presented to the user in terms of organizational structure and not in appearance. At this stage various elements are introduced for the construction, including framesets that may contain other elements such as text boxes, images, anchors, and even other framesets. The visual part is left out for the implementation phase of the model then leaving room for creativity by the designer.

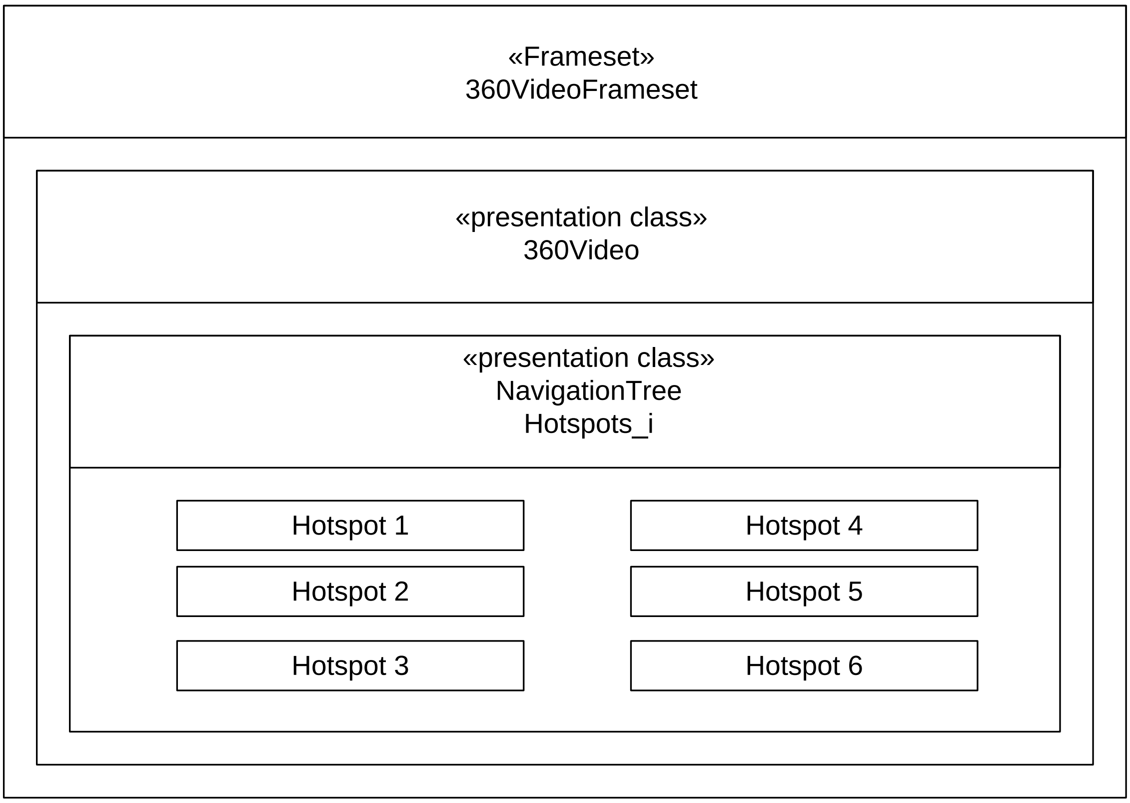

Figure 19 – 360º Hypervideo Player Presentation Model, Hotspots

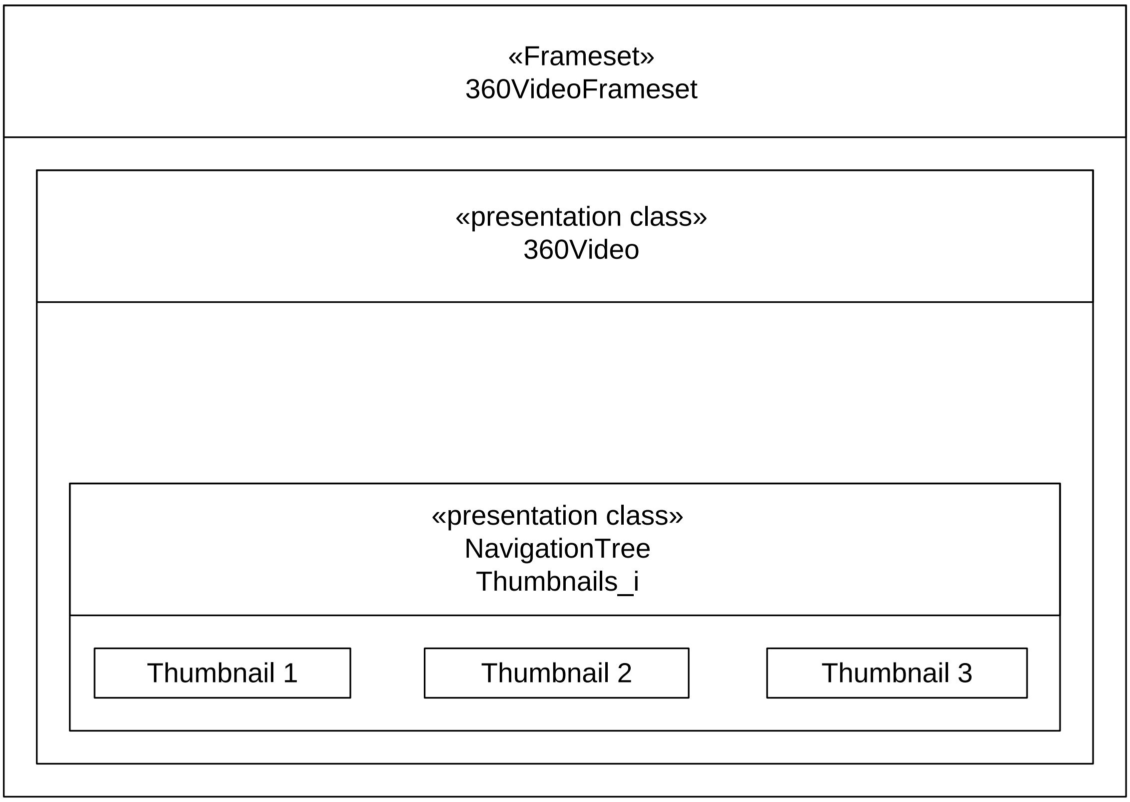

Figure 20 – 360º Hypervideo Player Presentation Model, Image Map

3.3 360º Hypervideo Player Navigation Mechanisms

This section we describe various navigation mechanisms and functionalities developed to aid the users to navigate and get the most out of a 360º hypervideo.

3.3.1 Video Navigation Drag Interface

A drag interface was developed as illustrated in the sketches of Fig 4. This interface will let the users pan around to view the content in different angles. The users simply need to drag the content left or right to move the viewport. The user can move to one of the side continuously, to get around without any kind of boundaries.

Location awareness became an issue due to the lack of boundaries. During our tests, the users would often get lost in the 360º space without knowing in which angle they were looking at.

3.3.2 View Area and Orientation

View Area and Orientation is a circle similar to a pie graph where there is only one piece of pie that corresponds to the angle the user is looking at. It rotates to left or right when the user pans to the left or to the right. With this navigation mechanism, the user will be able to know the viewing angle.

3.3.3 Mini Map

Mini Map is the cylindrical projection video resized to a size where the users are able to see it all at once on the viewport. The *Mini Map* cursor (Figure 23) highlights which part of the video the users are currently watching.

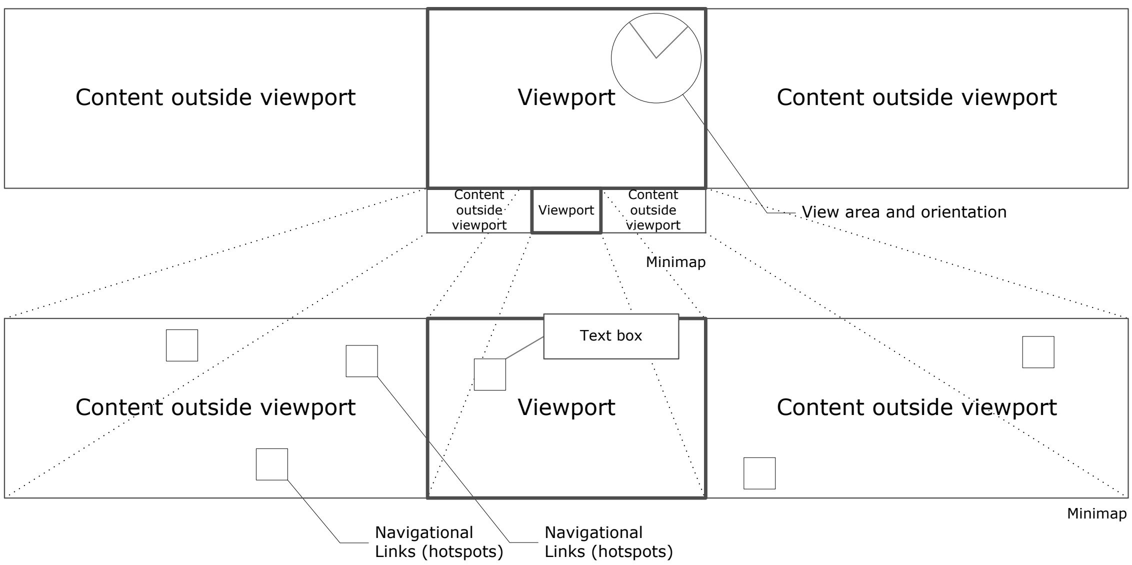

Figure 21 – 360º Hypervideo Initial Mock-Up

3.3.4 Hotspots and Hotspots indicator

Link awareness is vital for orientation. In hypervideo, link awareness is more challenging than in traditional hypermedia because links may have duration; several links can coexist in time and space and video changes in time. So, in order to be perceived by the users, more information has to be provided (Chambel & Guimarães, 2002). In 360º hypervideo, most of the content is invisible to the user because it is not in the viewport, which means more work has to be done to provide new approaches for link awareness.

We designed a *hotspots* availability and location indicators (Figure 22) to let the user know the availability and location of a *hotspot* outside the viewport. The *hotspot availability indicators* Y-axis position is used to locate them in the video, in terms of height. Their size is used to indicate how far away the *hotspots* are located. The closer the *hotspot* is located, the bigger is the *hotspot availability indicator*. The indicators are positioned at the edge of the screen and all the *hotspots* have a transparent design (not opaque) to minimize the impact over the video content.

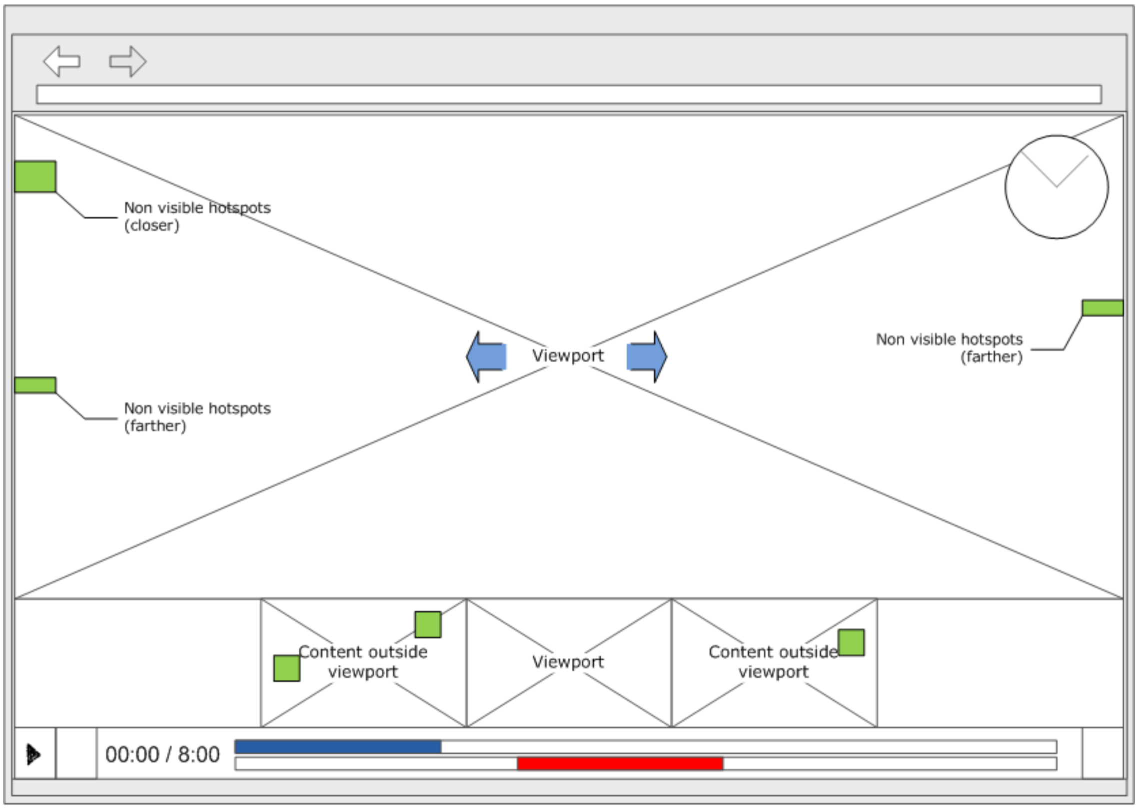

Figure 22 – Hotspots Availability and Location Indicators Mock-Up

The *Mini Map* also provides information about the *hotspot* availability and location (Figure 23). We believe that a *hotspot* is not just a single link or button to other hypermedia contents. It must contain at least some information to give the users some expectation of the contents they are about to see after clicking on the *hotspot* (where to and when to link awareness). A comic balloon look-alike text-box (Figure 23) can accommodate a lot of important information. In the example of Figure 23 we place information like the name and description on the text-box of the *hotspot* regarding the nearby shop.

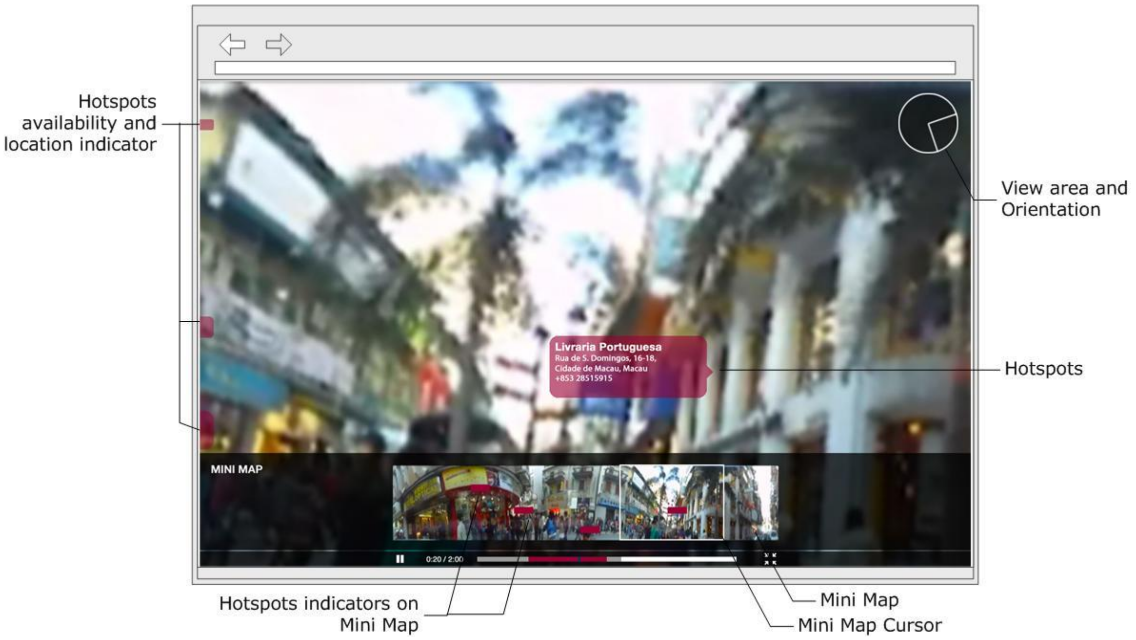

Figure 23 – 360º Hypervideo Player Mini Map Mode

When the users click on the *hotspot*, they may be redirected to the shop website or the click information will be memorized in the system and displayed to the user on demand, later on. Depending on the characteristics of the video content, we can set the 360º hypervideo player to open the link directly or memorize it in the system. For example, if the purpose is learning, opening the link directly might make more sense because the users usually watch that kind of video step by step. If the video is for entertainment, the users might not want to be interrupted by the link opening, so the link memorization system might come handy in this kind of situation. The memorized links will be available in the system and the users can access them whenever they want. e.g.: at the end of the video.

3.3.5 Image Map

The *Image Map* mode gives an overview of the content of the video (Figure 24). It is the type of summarization technique described in (Chambel & Guimarães, 2002; Shipman et al., 2003) but with some extra features for the 360º environment.

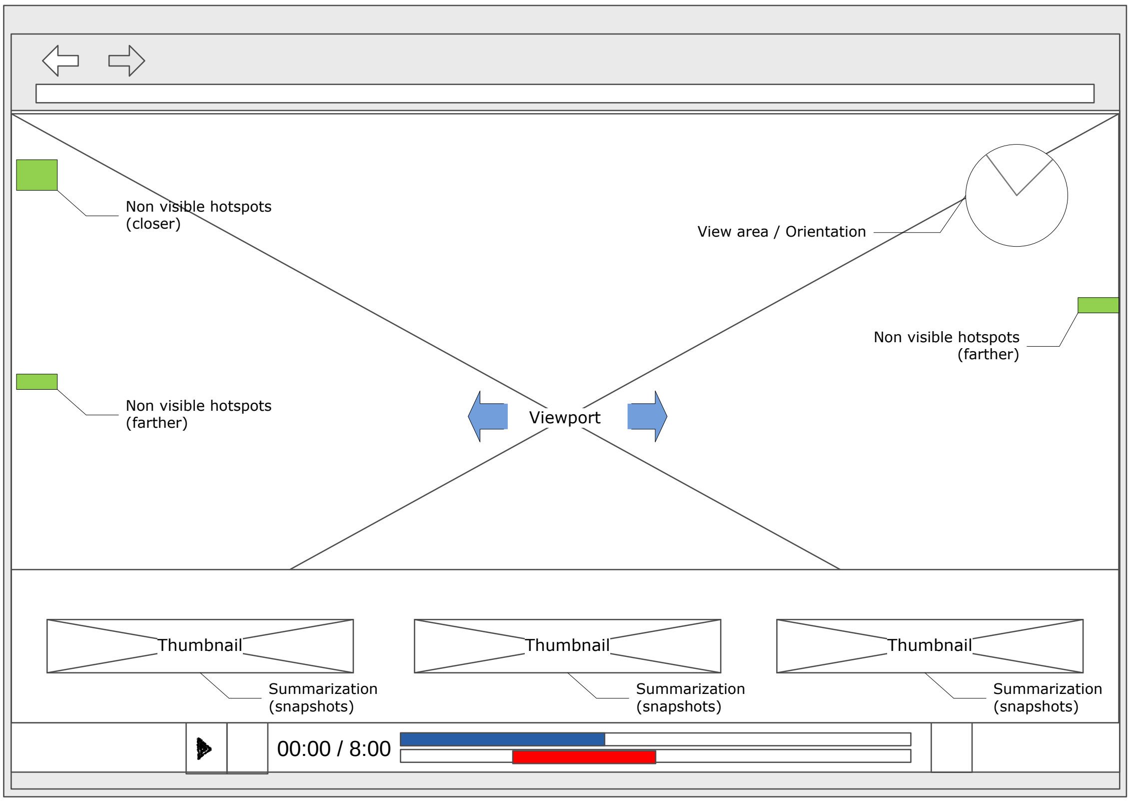

Figure 24 – Image Map Mode Mock-Up

Thumbnails refer to video scenes and are represented by cylindrical projection in order to give, all at once, a full overview of the video content over time, synchronously indicating the current scene, and offering the possibility to navigate where the user chooses to go. The whole thumbnail is an area sensible link that detects which is the coordinates of the thumbnail the user clicked at. For example if the user clicks on the left side of the third image map, it will link directly to the angle which is pointed to the left and move the video play head to 00:01:38. A more condensed version presents thumbnails of the central viewport in every scene. It allows us to present more scenes in the same space, but limits awareness of the full surround video and flexibility to navigate to the desired viewport in one click. Instead, the users select the scene and, on the scene, change the viewport as they wish.

By taking advantage of the 360º video space, the thumbnails were also designed to support clicks on different areas of the thumbnail. Since the thumbnail is actually a projected long strip of a frame of the video, if the user clicks on the left side of a specific thumbnail, it will rotate to the angle which is pointed to the left and move the video play head to the time indicated in the thumbnail.

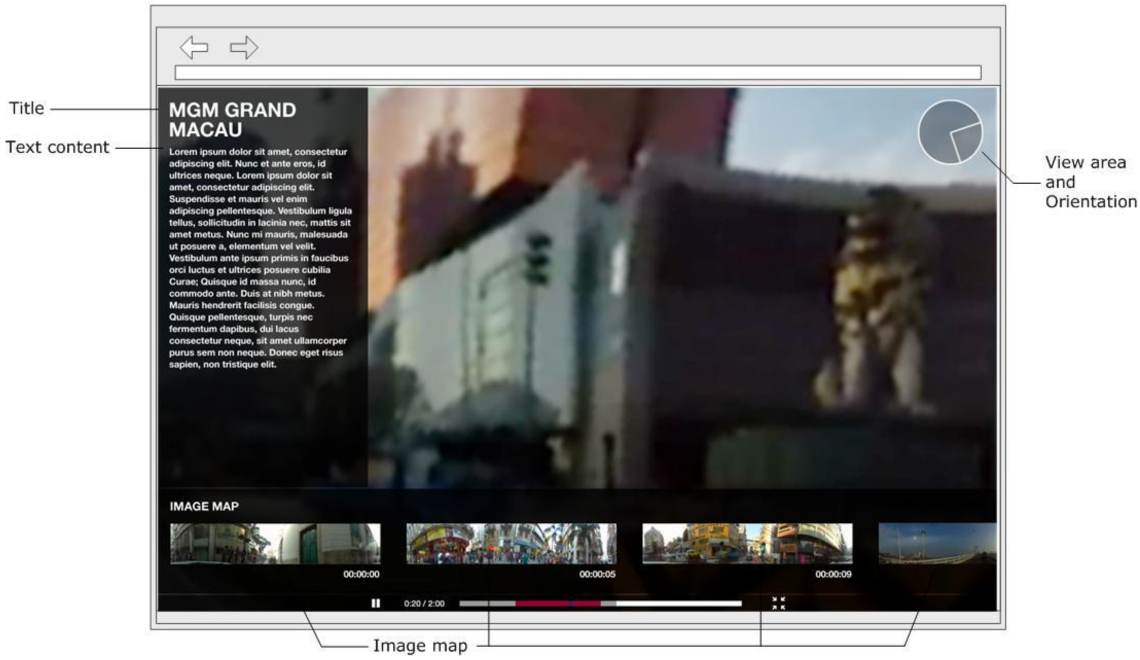

Figure 25 – Title, Description and Image Map Mode

3.3.6 Progress Bar and Bytes Loaded Bar

Some additional features are also provided in the traditional timeline, or progress bar, to aid user orientation and control (Figure 26). Besides the traditional Play, Pause and Video Time feature, we extended the timeline in response of some characteristics of a webpage. Since this is a web-based hypervideo player, we need to have in mind that the video requires time to load. A Bytes Loaded Bar gives the user the information on how much content is loaded and prevents the user to access some inaccessible area. For example, the video play head only can be moved within the Bytes Loaded Bar width.

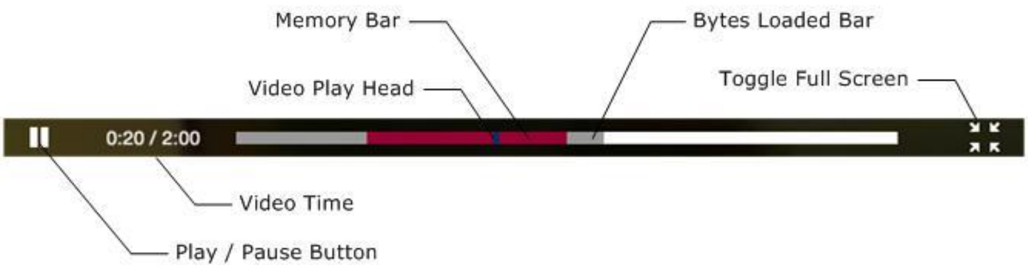

Figure 26 – 360° Hypervideo Player Progress Bar

3.3.7 Memory bar

The hyperspace is navigated across spatial-temporal contexts that history recalls (Chambel & Guimarães, 2002). The *Memory Bar* provides information to the user about the parts of the video have been viewed.

The Toggle Full Screen button switches the video between Full Screen or Standard Screen mode. The Full Screen Mode takes the user out of the frame of the browser and makes the video content fill the entire computer screen. This is a bridge to more immersive viewing modes, possible for example in 360º projection in a cave, as we intend to explore in our future work.

3.4 System Architecture

The 360º Hypervideo Player is developed with Adobe Flash Platform (url-AdobeFlashPlatform). The reason of using Adobe Flash Platform to develop the 360º Hypervideo Player because Adobe Flash Player is a cross-platform, widely distributed multimedia and application player with over 98% of penetration (url-AdobeFlashPlayerStatistics) worldwide. The version used in this thesis is the Adobe Flash Player version 9 Update 3 which supports media formats such as H.264, AAC and F4V based on the ISO Base Media File Format (MPEG-4 Part 12) (url-MPEG4). Adobe Flash Player (url-AdobeFlashPlayer) is a software for viewing animations and movies using computer programs such as a web browser. Adobe Flash is an authoring environment for producing expressive interactive content. It allows us to create immersive experiences that present consistently to audiences across desktops, smartphones, tablets, and televisions.

The IDE used for the development is the Adobe Flash CS4 which already comes with native support of ActionScript 3.0 (url-ActionScript3.0). ActionScript 3.0 is a scripting language very similar to Java. The animations and behaviors of the 360º Hypervideo Player interface is built entirely with ActionScript 3.0. The library used for the animations is the Greensock TweenLite (url-Greensock). Papervision3D (url-Papervision3D) is used for the cylindrical projection of the video. Papervision 3D is an open source 3D engine written in Action Script 3.0 and it gives the Adobe Flash the 3D capability. The cylindrical projection gives the user a perspective feeling while navigating through the interface developed. Moreover, with the Adobe Flash Media Streaming Server (url-AdobeFlashMediaStreamingServer) which is compatible with the Adobe Flash Player, we will be able to provide on-demand and live HTTP delivery.

The data / contents of the system are stored in 2 XML files and the ECMAScript (url-ECMAScript) for XML (E4X) was used for querying and accessing the XML.

The fact that XML is being used for data storage / content is for keeping the configuration and scalability in mind. E.g.: For changing a hyperlink of the system we just need to change the XML file. It is not necessary to open the application source code developed in Flash and compile it again. Besides the advantage of scalability and ease to update, by using an external file also allows lower network overhead during hypervideo streaming over the Internet (Florin et al, 2002). During the playback it is possible to calculate the positions of the different *hotspots*.

The video used in this thesis is in MPEG-4 (url-MPEG4) format. The use of this type of compression simplifies the programming work and the quality / compression ratio is good.

Chapter 4

User Evaluation

This section presents the objectives, method and results of the user study conducted to evaluate the 360º Hypervideo Player's user interface and functionalities.

4.1 Objectives

The main objective of this evaluation is to determine the usability and user experience when using the 360º Hypervideo Player according to their comments, suggestions and concerns about the functionalities, access mechanisms or information representation. By collecting specific and global comments, concerns and suggestions for functionalities and access mechanisms that would allow us to gain more awareness about the player usability and identify directions for improvements, was also among the goals we had for this user evaluation. The usability dimensions are based on the USE questionnaire (Lund, 2001), and the following properties were evaluated:

Usefulness – How useful can the exploration of a 360º video space be? Which is the best way to access the information? Were the results provided by the system perceived as useful?

Satisfaction – Do users find 360º Hypervideo Player fun to use? Do users have a good experience using it? Satisfaction is composed of comfort and acceptability of use (Bevan, 1995). Comfort refers to overall physiological or emotional responses to use of the 360º Hypervideo Player (whether the user feels good, warm, and pleased, or tense and uncomfortable). Acceptability of use may measure overall attitude towards the 360º Hypervideo Player, or the user's perception of specific aspects such as whether the user feels that the system supports the way they carry out their tasks, do they feel in command of the system, is the system helpful and easy to learn. If satisfaction is low when efficiency or ease of use is high, it is likely that the user's goals do not match the goals selected for measurement of efficiency or ease of use.

Efficiency or Ease of Use – Do users find 360º Hypervideo Player easy to use? Measures of efficiency or ease of use relate the goals or sub-goals of using the system to the accuracy and completeness with which these goals can be achieved (Bevan, 1995).

Perceptiveness of the information is provided by the system as a supplement to the satisfaction and ease of use dimensions of this USE usability analysis. Two questions were asked for this purpose: Is the information representation easy to understand? Which was the best way to understand the information?

4.2 Method

We evaluated each function individually by observation and had a semi-structured interview with the users in order to get their opinion and experience feedback.

The procedure began briefing the subjects about Hypervideo and then 360º videos. After the interviewers understood what hypervideo and 360º videos are, we explained the 360º Hypervideo concept, as the combination of both, and the system they were about to test and the evaluation purposes.

The interview session began with a set of demographic questions, to help gain insights about user's knowledge of video and previous experience, to help later in the analysis of the results. The user evaluation population included 8 people, 5 males and 3 females, aged 23 to 45 years old, all used to access the internet for more than 7 hours per week. All of them had previous experience with video recording and playback, e.g. from VHS camcorders. They also have some experience, from user's perspective, with basic hypervideo features such as the relatively new ones available in systems like YouTube.

In order to introduce the context and increase the users' awareness about 360º Hypervideo, we then asked the users to try out the 360º Hypervideo player for 15 minutes. Next, users were asked to perform a few tasks with the player to view and navigate the "Tour in Macau" hypervideo. Errors, hesitations and timings were observed and registered. In the end of each task, users were asked USE-based questions, to be answered in a five point Likert scale, and given the opportunity to provide qualitative feedback through comments and suggestions for the player features involved in that task.

The results of the evaluation are presented and discussed below.

4.3 Results

The results reflected in the mean (M) and the standard deviation (Std.) obtained from the analysis of the USE data, based on 5 five point Likert scales, on the proposed tasks (Tn) and underlying questions, are presented in the next tables, complemented with the presentation and discussion of the most relevant results and comments obtained, in addition to our own observations.

4.3.1 Drag Interface

We started by asking the users to navigate to Wynn Macau Resorts in the video (T1) and to discover what is around when they reach there and then move back to the initial angle (T2). These tasks aim to test the continuous 360º navigation and to evaluate if and how the users can navigate to a specific location in the video, by themselves, with the navigation mechanisms provided in the interface.

USE	**Usefulness**		**Satisfaction**		**Ease of Use**	
Features in task:	**M**	**Std.**	**M**	**Std.**	**M**	**Std.**
T1	4.1	0.2	4.4	0.5	4.6	0.6
T2	4.3	0.4	4.1	0.7	4.3	0.8

Table 1 – USE evaluation in the 360º continuous navigation (scale: 1-5).

We found that the users naturally chose to use the timeline with progress bar to do fast forward in order to reach the time of the video featuring the Wynn Macau Resorts. According to the users, they found the navigation through the timeline and progress bar easy, due to their previous experience with YouTube. On the other hand, the drag interface seems to be user friendly but not very obvious to the users, at first. Only the two users which were already familiar with computer games tried to drag the screen and discovered the drag interface feature. If we did not introduce the drag interface to the remaining users, they would not figure it out and would stick with the *Mini Map*, which they found very useful and fast to scroll around. Anyway, after finding out about the drag interface, they had fun by dragging the video around and commented that it is especially useful when they want a more precise panning. The users' observations and comments were very useful in this case. An overlay animation, a guide or just a couple of arrows should be introduced in the interface to increase the awareness about the dragging feature.

4.3.2 Mini Map

The main purpose of the *Mini Map* feature of the 360º Hypervideo player is to provide a larger view area to the users and be a shortcut to navigate through the 360º video space quicker. We asked the users if they know what the *Mini Map* represents (T3) and around 90% answered correctly, most of them had already used it for task T2 as well. The remaining 10% were not sure what it was at first sight. This was a new feature for most of the users and only two of the users had previous experience with such type of functionality on computer games or video games. Still, it was easy to learn by the novices.

USE	**Usefulness**		**Satisfaction**		**Ease of Use**	
Features in task:	**M**	**Std.**	**M**	**Std.**	**M**	**Std.**
T3	4.6	0.5	4.1	0.2	4.3	0.8

Table 2 – USE evaluation in the Mini map (scale: 1-5).

The users think that the *Mini Map* is very useful and the USE evaluation reflects the test results. Even so, they were not entirely satisfied with it at the beginning, because it occupies too much space on the screen. Then we introduced them to the toggle button (hide/show) on the *Mini Map* interface, which was able to solve the space issue experienced by the users.

4.3.3 View Area and Orientation

Task T4 requested the users to use the *View Area and Orientation* and to answer in what orientation - degree - they were currently looking at. This task aims to test the perceptiveness of the feature.

USE	**Usefulness**		**Satisfaction**		**Ease of Use**	
Features in task:	**M**	**Std.**	**M**	**Std.**	**M**	**Std.**
T4	4.8	0.4	4.5	0.5	4.6	0.5

Table 3 – USE evaluation in the Orientation circle (scale: 1-5).

All the users answered the questions correctly, and this feature was considered very useful (4.8), satisfactory (4.5) and easy to use (4.6). But, during the tests, we noticed that some users tried to click on it. Since the *View Area and Orientation* is currently just for display, it did not present any kind of feedback upon click. Thus, based on these observations and the users' opinions, its function could be enhanced further: instead of being only a display of the current orientation, it could receive user input such as drag and click to control the angle of the visualization, as an alternative way to control the viewing angle, as the *Mini Map* does.

4.3.4 Links and Hotspots

With the *hotspots* functionality, we asked the users about what they would expect to see after clicking on one of them (T5) and then asked them to follow it (T6).

USE	**Usefulness**		**Satisfaction**		**Ease of Use**	
Features in task:	**M**	**Std.**	**M**	**Std.**	**M**	**Std.**
T5	4.8	0.4	4.5	0.5	4.6	0.5
T6	4.4	0.5	4.6	0.5	4.9	0.2

Table 4 – USE evaluation in the Hotspots (scale: 1-5).

T5 aims to verify if the representation of *hotspots* are an obvious feature similar to traditional *hyperlinks* awareness, and the T6 objective is to test if the result is as expected. We tried to design the *hotspots* to have features that users are used to in other hypermedia environments, such as the web, including highlight and hand icon on mouse over the *hotspot*.

All users answered correctly about what each *hotspot* represented. Since they are actually hyperlinks, the results were as expected, that the users would not find any difficulties in using them, and hence, ease of use level was very high (4.9).

Regarding the *Links Within the Video* feature, only some basic tests were performed during the user evaluation due to the footage limitation. The "Tour in Macau" 360º video only has a few crossroads which makes the test more difficult. In the few tests we did with the users, we figured out that the *hotspot* awareness and design should be different from the other *hotspots* in order to provide a clear indication that the link is inside the video instead of to external or additional information.

4.3.5 Hotspots Indicator

For the *hotspots indicator*, the users were requested to count how many *hotspots* were available on the video, at a specific time (T7) and to tell the distance of each *hotspot* (T8).

USE	Usefulness		Satisfaction		Ease of Use	
Features in task:	**M**	**Std.**	**M**	**Std.**	**M**	**Std.**
T7	4.6	0.5	4.3	0.4	4	0
T8	4.8	0.4	4.1	0.4	3.8	0.4

Table 5 – USE evaluation in the Hotspots indicator (scale: 1-5).

The T7 objective is to discover if it is easy to identify the *hotspots* and get to know if the number of *hotspots* will create a heavy cognitive load on the users. The users' answers were very close to the correct one, with scenes with around 10 links. So we believe that the design of the *hotspots* indicators met its goal of providing information about the *hotspots* available in this context, in spite of some initial user hesitations. Since links are presented at only one side of the video (the closest to the link), this design may scale to a larger number of links, a reasonable amount at any specific time, considering the cognitive load of having too many links at the same time. Nevertheless, cases where a very high number of links would need to be presented may require some redesign, for example based on grouping or zooming, providing a better support for a more thorough user navigation and exploration of the points of interest in the videos.

The T8 objective is to check if the *Hotspots Indicators* resizing feature is clear to the user. The *Hotspots Indicators* change their sizes depending on the distance. In full screen mode, and while the video is playing, the moving image of the video slightly interferes with the perception of the indicators and identification of the relative distance of the links. But their opinion was still very positive regarding to the utility of this feature (4.8), and the users recognized that full screen allows for a more immersive feeling that they appreciate, that they can pause the video if they want, and that they can access the *Mini Map* to complement this feature by showing all the links at once.

4.3.6 Image Map

We asked the users to describe the video contents through the *Image Map* (T9), to go to a specific part of the video (T10), and finally, to rate the overall usability (T11) of the *Image Map*. The users did not have any problem using it, and rated this navigation feature very high in terms of USE (Table 6).

USE	Usefulness		Satisfaction		Ease of Use	
Features in task:	**M**	**Std.**	**M**	**Std.**	**M**	**Std.**
T9	4	0	4.5	0.5	4.8	0.4
T10	4.3	0.4	4.6	0.5	4.9	0.2
T11	4.8	0.4	4.4	0.5	4.9	0.2

Table 6 – USE evaluation in the Image Map (scale: 1-5).

The *Image Map* seems to be a pretty standard feature in DVD players and Games consoles. The users commented that the *Image Map* of the 360º Hypervideo Player is similar to the DVD one but works much better and faster, especially comparing to that summarization feature that generates the thumbnails on the fly in DVDs, e.g. every 30 seconds. The way the users interact with the *Image Map* was also praised, because it is just through point and click. In the DVD player, the users said they have to use the remote control, often slow, to navigate thumbnails one by one, making the interaction clumsier.

The thumbnails on the “Tour in Macau” hypervideo, that was tested, play a big role. Actually, the quality of the *Image Map* depends a lot on its contents. If the images differ a lot from the closest ones, they are more useful as a summary and the user can identify them faster, to decide where to go. If the *Image Map* contents are divided in a short interval or for a video with a still background, e.g. a ping pong game (url-PingPong360), the *Image Map* would be almost useless because the scenes would look alike, making them harder and slower to identify.

4.3.7 Memory Bar

The *Memory Bar* was still under development while we ran these tests, so the user opinions were based on the very first version of the feature that still has a few bugs, working well in many situations, but not totally consistent or reliable. The task was to try to use the *Memory Bar* and rate the overall usability of its design to remember, or mark, portions of the video that were already visited (T12).

USE	Usefulness		Satisfaction		Ease of Use	
Features in task:	**M**	**Std.**	**M**	**Std.**	**M**	**Std.**
T12	4.6	0.5	4.8	0.4	4.9	0.2

Table 7 – USE evaluation in the Memory bar (scale: 1-5).

This feature was highly rated by the users, in terms of usefulness, satisfaction and ease of use. The users found the *Memory Bar* very useful in the 360º video space, because it actually could help them to explore the video on the timeline, knowing where they had already been.

It was perceived especially useful when there are links within the video. For example, in the case of the “Tour in Macau” 360º Hypervideo, the user can choose to enter some streets when they encounter a pre-defined crossroad during the playback of the video by clicking on the pre-defined *hotspot*. The video will automatically jump to the frame of the selected street, and the user can view the range skipped on the timeline.

Currently the *Memory Bar* provides information of the skipped timeframe in the timeline but in the 360 º hypervideo space the timeline is just a small part of a new world. For example the memorization of the angle viewed and the *hotspots* visited in a specific timeframe are yet to be explored. Challenges for this kind of memorization include the design of an entirely new user interface for this specific feature to be able to provide a huge amount of structured information to the user while reducing unnecessary cognitive load.

Chapter 5

Conclusions and Future Works

5.1 Conclusions

In this thesis, we presented an approach for visualizing and interacting with 360º hypervideos, its design rationale and a user evaluation based on user interviews and testing with the "Tour in Macau" 360º hypervideo. While there are a number of panorama photos viewers and tools available, there is hardly any work on 360º hypervideos. Navigation in a 360º video space and its navigational links presents a new experience for most people and there are no consistent intuitions as to the behavior of these links. The users will likely experience similar problems as with early hypertext users becoming lost in hyperspace. As such, a 360º Hypervideo Player needs to be as clear as possible about how a user should interact with it.

A user evaluation was done based on the USE questionnaire and user interviews to determine the usability and user experience when using the 360º Hypervideo Player according to their comments, suggestions and concerns about the functionalities, access mechanisms or information representation. The collected specific and global comments, concerns and suggestions of the functionalities and access mechanisms tested, allowed us to gain more awareness about the player usability and identified directions for improvements. During the *Drag Interface* test the users wasn't aware of that feature but when we introduced it, they had fun playing and dragging with it. The *Mini Map* is also another feature that the users found very useful. Even so, they were not entirely satisfied with it at the beginning, because it occupies too much space on the screen. Then we introduced them to the toggle button (hide/show) on the *Mini Map* interface, which was able to solve the space issue experienced by the users. The *View Area and Orientation* is currently just for display, it did not present any kind of feedback upon click. Thus, based on these observations and the users' opinions, its function could be enhanced further: instead of being only a display of the current orientation, it could receive user input such as drag and click to control the angle of the visualization, as an alternative way to control the viewing angle, as the *Mini Map* does. The *Hotspots Indicators* change their sizes depending on the distance. In full screen mode, and while the video is playing, the moving image of the video slightly interferes with the perception of the indicators and identification of the relative distance of the links. But their opinion was still very positive regarding to the utility of this feature, and the users recognized that full screen allows for a more immersive feeling that they appreciate, that they can pause the video if they want, and that they can access the *Mini Map* to complement this feature by showing all the links at once. The thumbnails on the "Tour in Macau" hypervideo, that was tested, play a big role. The quality of the *Image Map* depends a lot on its contents. If the images differ a lot from the closest ones, they are more useful as a summary and the user can identify them faster, to decide where to go. If the *Image Map* contents are divided in a short interval or for a video with a still background, the *Image Map* would be almost useless because the scenes would look alike, making them harder and slower to identify.

In summary, the overall user comments and testing results were very positive and useful which will help us to continue with the research of 360º Hypervideo.

5.2 Future Works

Future works of this project will include the refinement and development of new 360º Hypervideo Player features in response to user feedback, followed by another usability evaluation. The refinement and development includes:

Adding a short overlay animation, a guide or just a couple of arrows should be introduced when the video is loaded and ready to be viewed in the interface to increase the awareness about the dragging feature. Enhancing the *View Area and Orientation* function by receiving user input such as drag and click to control the angle of the visualization, as an alternative way to control the viewing angle, as the *Mini Map* does. Changing the *Links Within Video hotspot* awareness and look and feel to better distinguish it among other *hotspots*. Review the current summarization technique for the *Image Map* contents by displaying the relevant thumbnail of a specific angle instead of displaying the full projected long strip or only the central area to reduce the users' cognitive load. Enhancing the *Memory Bar* by memorizing too, the angle viewed and the *hotspots* visited in a specific timeframe. Challenges for this kind of memorization include the design of an entirely new user interface able to provide a huge amount of structured information to the user while reducing unnecessary cognitive load.

One of the interesting feedbacks received after conducting the usability evaluation is to explore the 360º hypervideos applied on security camera footages. For example the traditional security cameras are usually installed in a fixed location. Some of them even have an electric motor that rotates in a predefined period. But even with automatic rotation, using a traditional video footage still has boundaries and has blind spots. With a 360º videos we will be able to cover a much better range by eliminating the blind spots. Motion detection could also be included in the 360º footage and it creates a much more efficient security system by using only one 360º video capturing device. The motion detection feature could be used to trigger an automatic summarization function and any movement in the security footage could be captured into an *Image Map*.

Also the 360º Hypervideo Player should not be locked on the web and it could be integrated in kiosks or more immersive installations, for example in caves with 360º projections. In order to achieve further immersive experience, the 360º Hypervideo Player will support spherical projection. New or extended 360º hypervideo features may need to be designed for these contexts. The access medium used to present the 360º Hypervideo Player is a web browser and the viewers use the mouse to interact with it. The rise of 3D video, multi-touch and eye-tracking technologies penetration could be also very interesting, allowing to build new kinds of visualization and interaction with 360º video spaces. These new ways of visualization and interaction come with new challenges but also with potential for increased excitement to explore and experience.

Chapter 6

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