Visualizing Learners' Navigation Behaviour using 360 Degrees Interactive Videos

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Abstract: The use of 360-degrees interactive videos for educational purposes in the medical field has increased in recent years, as well as the use of virtual reality in general. Learner's navigation behavior in 360-degrees interactive video learning environments has not been thoroughly explored yet. In this paper, a dataset of interactions generated by 80 students working in 16 groups while learning about patient trauma treatment using 360-degrees interactive videos is used to visualize learners' navigation behavior. Three visualization approaches were designed and implemented for exploring users' navigation paths and patterns of interaction with the learning materials are presented and discussed. The visualization tool was developed to explore the issues above and it provides a comprehensive overview of the navigation paths and patterns. A user study with four experts in the information visualization field has revealed the advantages and drawbacks of our solution. The paper concludes by providing some suggestions for improvements of the proposed visualizations.

1 INTRODUCTION

In recent years, there has been an increasing interest in the use of 360-degrees interactive videos in such application domains as eHealth and eLearning, (Taylor, 2018; O'Sullivan et al., 2018; Feurstein, 2018). This technology offers engaging experiences for learners due to the use of interactive content (e.g., tasks, questions) and the presentation of authentic environments using moving images. Unlike traditional videos and cinema, in 360-degrees videos, the viewers have control over what they see and where they want the focus of the video to be. In 360-degrees videos, only a portion of the entire scene is watched at a time and is called "*viewpoint*". Unlike just traditional 360-degrees video, in 360-degrees interactive videos, the viewers using the computer pointing device can navigate to the viewpoint of interest and explore the environment according to the interactive contents (e.g., learning task, information, question). Viewers interacting with the 360-degrees video generate a "*navigation path*" as a sequence of visited viewpoints with a specific timestamp. Understanding learners´ navigation paths in 360-degrees interactive videos can be beneficial for teachers. Examples of such benefits can be the following: improving the learning scenario, interactive content design (information, question, task), adapting the interactive content according to learners' navigation behavior (add/remove questions/tasks in specific place and time in the video) in order to increase the learning engagement. However, the issue of understanding learner's navigation behavior in 360-degrees interactive video has not been thoroughly addressed yet.

Visualization techniques can help to analyze the user's navigation behavior in order to understand the different navigation paths and patterns. The "*navigation pattern*" refers to the similar/common users´ navigation behavior and it represents the average path between two or more group's/user's navigation paths. Understanding the navigation behavior and patterns is very important in an emergency response application domain. For instance, visualizations could help to reflect on decisions taken based on the interactions with the learning scenario presented in 360-degrees videos, to identify the lack of skills, knowledge, experience of medical student or personal, and identifying the weak parts in learning scenarios. However, the visualization of 360-degrees

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datasets including temporal features is a very challenging task. For example, visualizing three-dimensional datasets (pitch, yaw and timestamp) may give us a better understanding about the video scene/viewpoint and interaction content (e.g., a question, information tag, task). Thus, this paper aims at visualizing the collected 360-degrees datasets from students in order to explore their navigation path while using the 360-degrees videos and to find out their patterns of interaction with the learning materials as well as issues related to learners´ experience/content.

In order to achieve this aim, together with health care teachers and computer science experts, we have designed a visualization tool, called Xcalpel. By using the tool, we can visualize datasets collected from 16 groups of nursing students (80 students) that watched 360-degrees interactive video containing realistic cases about patient trauma treatment at the emergency department at a Central Hospital in southern Sweden. The main contribution of this paper is to present and discuss an innovative approach to automatically identify and to visualize similar navigation patterns.

The paper is organized as followed: Section 2 describes previous work in this field; Section 3 presents a short background about 360-degrees interactive videos used in this research; Section 4 describes the 360-degrees datasets used in this study; Section 5 presents the Xcalpel visualization tool and the visualization approaches designed and implemented; Section 6 describes the evaluation approach we have used together with the discussions about the results. Finally, section 7 presents the initial conclusions and outlines our future work.

2 PREVIOUS WORK

A search of the literature revealed few studies that explore the user's navigation patterns, paths, and their behaviour while watching 360-degrees videos (Corbillon, 2017; Duanmu, 2018, Wu et al., 2017). These studies provide the data collection, datasets of head and eye movements for 360-degrees videos, and statistical analysis to find similarities in users´ navigation patterns as well as video quality evaluation aspects. One similar study conducted by Duanmu (2018) investigated the navigation patterns of visualizations and it explored the similarities and differences between head-movement datasets and computer-based navigations. They have identified the viewpoints distribution visualization over 360-degrees video content and trajectory analysis with the calculated angular movements over different video segments. According to their study, the users´ navigation patterns were driven by the content of the video. Another study focuses on analysing the navigation behaviour in a virtual reality spherical video streaming application (Wu et al., 2017). The authors also provide the viewpoint distribution over the video content and angular velocity of the head motion. The literature review revealed the lack of visualizations for 360-degrees videos navigation behaviour datasets in to better understand the relationship between the video content and the users´ interactions. To the best of our knowledge, no work has been conducted towards analysing learner's behaviour in educational 360-degrees interactive videos. In addition to enhance existing solutions, our approach aims to explore learners´ navigation patterns within 360-degrees interactive video containing educational content in order to help teachers to better understand learning performance as well as how to improve content creation in these environments.

3 360-DEGREES INTERACTIVE VIDEO

In our previous study (Herault, et al., 2018) we designed and developed a HTML5 based prototype for creating and viewing interactive 360-degrees videos in a web browser. Various types of interactions are integrated into the videos to which learners can act and response. Examples of interactions are (a) "*hotspots*" that pop-up in a certain location in the video, in a specific time and contain some learning information, task, or question; (b) dynamic changing scenes according to the actions performed by the learners in the different hotspots. The learner's navigation in the video and the hotspots interactions are collected by the prototype each time a user interacts with the 360-degrees videos by using the computer mouse/pointing device. The 360-degrees videos were recorded using a GoPro Omni camera located at the emergency room in a hospital. The videos contain the learning scenario about patient trauma treatment. For detailed information about this study please refer to (Herault, et al., 2018(a), Herault et al., 2018(b)).

4 DATASET

The collected dataset contains camera movements' interactions (e.g., pitch, yaw, timeline, timestamp, and group name) collected from 16 groups of specialist nursing students (five students in each group, only one user at the time could interact with the 360-degrees video) using the prototype. The students come all from the Department of Health and Caring science and their ages range from 25-45 years old with a great majority of females who never had experience with immersive videos. In addition to the computer screen the projector was used in order to get better 360 degrees interactive video overview among all students in the group (in each group around 5-7 students). Only one student from the group was using computer mouse to interact with the video. Each group was interacting with the 360 degrees interactive video around 18 minutes. The learner´s viewpoint is described from *pitch* and *yaw* values, while the navigation path is described by a sequence of *pitch*, *yaw* and *timestamp* values. The "*navigation pattern*" is calculated as the average value of *pitch* and *yaw* between two or more navigation paths. The dataset is stored in a database and used for the visualization of learner´s navigation behavior that is described in the following section.

5 VISUALIZATION TOOL

We have developed a web-based application called Xcalpel that relies on the open-source JavaScript based framework NodeJS[1]. Additionally, the Dimple library[2] was used for producing the visualization graphs while the Panellum.js[3] library for getting and displaying the 360-degrees video content. The main requirements were gathered from nursing teachers in order to develop the visualization tool to address the following aspects: (a) *the tool should visualize the data for a single group of students as well as for all groups of students*; (b) *it should be possible to compare the data (e.g., navigation path, visited viewpoints) between different groups of students*; (c) *the tool should provide the visualization of visited viewpoints and how much time spent in it*; (d) *The visualization should be interactive and provide some information that helps analysing the navigation behaviour of users in 360-degrees interactive videos.* Based on these requirements, an initial mock-up of visualization was designed and presented several times to the nursing teachers in order to get their feedback before the development process. After receiving feedback from teachers, the visualization tools were improved, re-designed and implemented in Xcalpel as described in the coming sub-section.

5.1 Visualization Approaches

Based on the requirements described above and the goals of this work, the following visualizations are proposed: (a) t*he viewpoint distribution graph for the entire 360-degrees video;* (b) *the distribution of viewpoints for a single group over the 360-degrees video content*; and (c) *navigation paths visualization graph in order to find similar/common patterns*.

5.1.1 Viewpoints Distribution Visualization

Similar to the other studies described in previous work, we have chosen to visualize the distribution of the visited viewpoints. This provide an overview of which part of the video content students were interested in most and spent most of their time.

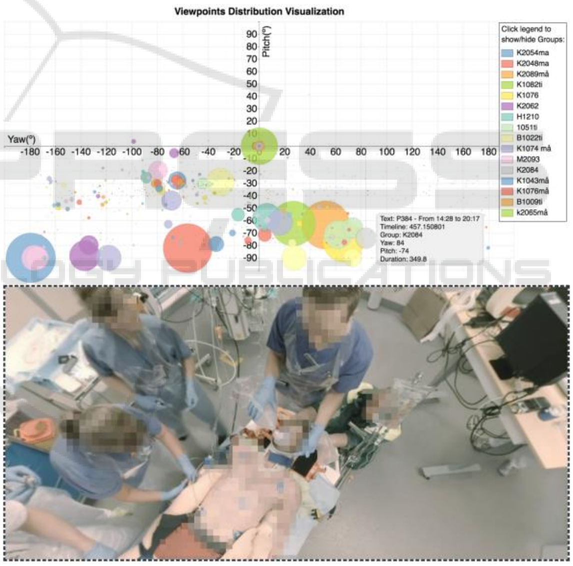

Figure 1: Xcalpel viewpoint distribution visualization for all groups.

Figure 1 presents the interactive visualization of viewpoints distribution using scatterplot for all groups: a circle represents the visited viewpoint (with pitch and yaw value on the axis), colours represents students' group/user, and a size of the circle is how much time (in second) a user spent in this viewpoint.

Additional information about the students' group name, when, and how long a learner has visited this viewpoint are displayed as pop-up tags when the viewer places the mouse cursor over the circle. Moreover, when the viewer clicks on the viewpoint

[1] https://nodejs.org/en/
[2] http://dimplejs.org/
[3] https://pannellum.org/

(circle) the application takes a snapshot from the 360-degrees video containing the viewpoint's pitch and yaw and displays it below the graph. This enables a better overview of the viewpoints than proposed in previous approaches. It provides not just numerical values of pitch and yaw but also the visual representation of most visited video scenes (snapshot from the video).

5.1.2 Viewpoints Distribution Visualization for a Single Group

Another viewpoint distribution visualization we are proposing is to visualize the viewpoints for a single user over the 360-degrees video content (as shown on Figure 2). The main purpose is to explore the navigation of a single user in the 360-degrees space. Similar to the previous graph, the circle represents a centre of visited viewpoint (with pitch and yaw coordinates) and the size of the circle differ depending on the amount of time that the user spent on this viewpoint.

Figure 2: Xcalpel viewpoint visualization for a single user over 360-degrees panorama image.

When hovering over a circle, the viewer can see when in the video the specific area was looked at, and if a question/task was asked during the time spent in this location. By clicking on the circle, the image will change to the specific timestamp is associated to in order to give a better learning context. The viewer can navigate inside the 360-degrees panorama image by dragging the mouse in order to explore the user's viewpoints. This approach provides the visualization of pitch/yaw and time with better overview of video scenes/viewpoints visited by a single user than just by using standard graph/line charts.

5.1.3 Navigation Path Visualization

In order to visualize the navigation path, a line graph is used for pitch and yaw values. Figure 3 shows the navigation path for all student groups, where *Axis X* is the video timeline in seconds, and *Axis Y* is the yaw/pitch in degrees, and a colour represents the student group/user. Additional information about students' group name, timeline and yaw value is displayed when hovering over a navigation path line in the graph.

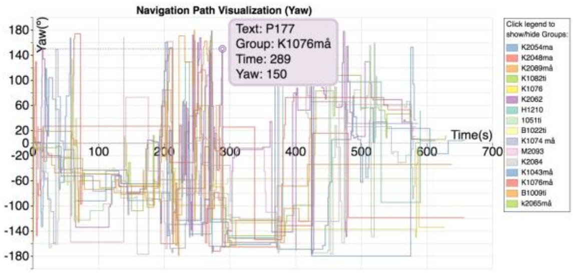

Figure 3: Xcalpel visualization navigation path in 360 degrees video.

As it can be seen in Figure 3, all interactions performed by students are in the first 11 minutes of the video and no interactions at the end of it (the total video duration is 18 minutes). The pattern identification performance is measured by selecting the distance threshold (in percentage) between 0 – completely similar, and 100 – no similarities. For example, distance threshold 13%, the system found seven patterns and visualize the student groups that have no more than 13% difference in their navigation paths (Figure 4). The distance between two yaw and pitch of navigation paths *X* and *Y* is calculated with absolute deviation between X_i and Y_i (where, *i* is a timestamp in second) divided by maximum value 360° and multiply by 100 in order to obtain the percentage (Formula 1).

$$D_{XY} = \left\lfloor \frac{\sum_{i=1}^{N} |X_i - Y_i|}{360} * 100 \right\rfloor \qquad (1)$$

In order to visualize the common pattern, the user should click on "Draw Average" button that will calculate the average navigation path between student groups as shown on Figure 4.

Surprisingly, there are quite big variations in navigation paths between groups even though the interactive video scenario is relatively simple (one emergency room with one patient). This might be explained by the screen choice for interaction (e.g., all participants have the same size for computer screen to view the video and in addition to it the projector with the bigger screen). It might be that one student watched the projector while navigating with computer mouse in the 360-degrees video, and another one watched the computer screen, or both. The most common pattern identified was that students first actively explore the 360-degrees environment in the beginning of the video (first 11 minutes) and less active in the end of the video. This could be explained by the learning scenario (video content): an emergency room with all attention on the patient view, no other movements/viewpoints of interested was detected.

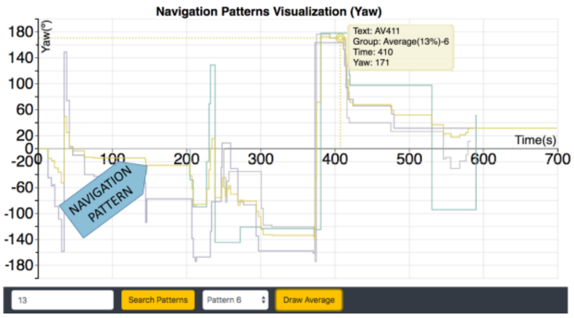

Figure 4: Xcalpel identification of navigation patterns.

6 EVALUATION

A control experiment was performed in order to investigate whether the different visualization approaches proposed in this work may help teachers to understand students' navigation behaviour and patterns in 360-degrees interactive video (described in Section 3). In order to do this, we designed a user tasks for each visualization graph (Table 1) and used a questionnaire (Stasko, 2014) (Table 2) for assessing the visualization.

Table 1: User tasks.

Task N	Visualization graph	Task description
T1	Viewpoint distribution graph all groups (see Figure 1)	How many "clusters" of viewpoints you can see on the graph?
T2		Can you identify and provide the names for 3 most visited viewpoints?
T3		Can you identify and provide the names of groups that spent most of the time in a singular viewpoint?
T4	Viewpoint distribution graph for a single group (see Figure 2)	Which part of the video (quarter) the group A focused most in a single viewpoint?
T5		What is group A viewing?
T6		Can you compare the interaction level for group B and group C? Which group is more interact with 360-degree video?
T7	Navigation Path Visualization (see Figure 3,4)	Can you provide the pitch and yaw values for Group D on the timeline 338 seconds?
T8		How easy was to complete the previous task?
T9		Could you identify two groups with similar navigation path by manually filtering the group names?
T10		How difficult was to do the previous task (T9)?
T11		Could you find two groups with that have big difference in navigation path?
T12		Could you find two groups with most similar navigation path?
T13		Can you identify the least interactive group?
T14		Can you identify the most interactive group?
T15		Can you draw some conclusion by looking on the graph (Figure 3) about their navigation patterns?
T16		How many patterns system identified with threshold 13%?
T17		Select patter 3 and visualize the average path
T18		Compare the task (T16) with the task (T9) automatic search against manual search by rate from 1 to 7 (1-is very difficult, 7 –is very easy).

Table 2: Questionnaire.

QN	Statement/Question
Q1	The visualization helps identify unusual or unexpected, yet valid, data characteristics or values
Q2	The visualization provides useful interactive capabilities to help investigate the data in multiple ways
Q3	The visualization shows multiple perspectives about the data
Q4	The visualization uses an effective representation of the data that shows related and partially related data cases
Q5	The visualization provides a comprehensive and accessible overview of the data
Q6	The visualization facilitates generalizations and extrapolations of patterns and conclusions
Q7	The visualization avoids using misleading representations
Q8	Which visualization graph was easy to understand and why?
Q9	Which visualization graph was most hard to understand and why?

The questions were selected according to our study goal and taken from Stasko (2014), we also added two open questions (Q8 and Q9) for getting advantages, disadvantages and general feedback about the proposed visualization approaches.

6.1 Participants

Participants of the study were four experts (researchers and PhD students within a range of 28-35 years of age) in the information visualization domain at the Computer Science and Media Technology Department at Linnaeus University, in order to test whether the visualization approaches help in analysing users' navigation path and patterns. Additionally, we wanted to receive valuable feedback from experts in information visualization in order to improve the visualization approaches before showing it to the nursing teachers.

6.2 Results

For each task in Table 1, we have measured the time spend to accomplish it (Figure 6) and the corresponding answer.

Figure 6 shows the average time in seconds spent for each one of the tasks. The most time-consuming task is T6 (2 min and 30 seconds) and is related to the viewpoint visualization over 360-degrees video for a single group (Figure 2). In this task, participants first selected the group and then viewed four 360-degrees images (one image represents five minutes of video). This task requires user interactions in 360-degrees space in order to see all visited viewpoints. Thus, participants spent different time on interacting with 360-degrees visualization graph.

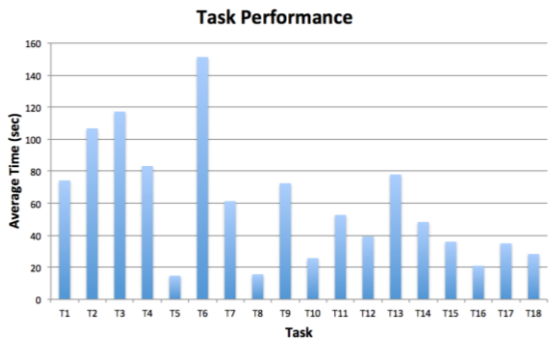

Figure 6: Task Performance Results.

Overall, dealing with viewpoint visualization graphs (Figure 1 and Figure 2) were the most demanding tasks (T1-T6) in terms of performance in comparison with navigation paths visualization graphs. This could be explained also by the comments received from the participants (Q8 and Q9 in Table 2): for some persons the navigation path graph was easy to understand because it is a simple line chart and viewpoint visualization with scatterplot (Figure 1) is not easy to understand, due to a lot of information presented at the same place.

Most of the tasks were performed correctly. The ones that were not the same among participants are T9-T15 and about using navigation path visualization graph in order to analyse navigation patterns manually. Surprisingly, participants who performed on T10 with 7 (most difficult) answered mostly correctly on T9-T15, and participants that answered on task (T10) with 2 (easy) performed mostly incorrectly on tasks T9-T15. However, they all agreed (T18 with answer 7 –very easy) that automatic pattern identification by the system can be useful and helpful in analysing the navigation patterns. After interacting with the Xcalpel application while performing the tasks described in Table 1 the questionnaire (in Table 2) were given to participants. Table 3 summarizes the average answers on each question where 1 - Strongly Disagree and 7- Strongly Agree.

Table 3: Questionnaire Answers.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Avg	5,25	6	6,25	5,25	6	5,25	4

Overall, the answers in Table 3 indicate the positive feedback about the different visualization approaches used in the Xcalpel application. Q3 received most points (*avg = 6,25*) and shows that the suggested visualization approaches help to explore and analyse the patterns and make some conclusions. The Q7 received the lowest point (*avg=4*) and can be explained by receiving comments and feedback from participants about not proper colour choice, small fonts size and sometime mismatch of text and visualization elements. However, the Q2 and Q5 (*avg=6*) show that the proposed visualization approaches provide useful interactive visualization and a comprehensive and accessible overview of the 360-degrees dataset. Answers on Q8 and Q9 were very different, for some participants viewpoint visualization graph over 360-degrees video and navigation path was easier to understand, while for others, these two types of graphs were harder to understand. Additionally, the comments about advantages and disadvantages for the different visualization approaches were given by participants and also observed during the study (described in Table 4).

Table 4: Advantages and Disadvantages for Visualization Approaches.

Approach	Advantages	Disadvantages
Viewpoint distribution visualization (Figure 1)	Most useful for overview of points of interests	Too much information at the same place
Viewpoint visualization over 360 video content (Figure 2)	Semantically important information Visualizes regions of interests	No temporal overview Difficult to compare with other groups
Navigation Path Visualization (Figure 3-5)	Better overview Allows to compare all groups	Cluttered view when several paths displayed

In summary, the results in this study provide some evidence about the usefulness of the proposed visualization approaches in analysing user navigation behaviours and navigation patterns. Additionally, suggestions for improvements (disadvantages) are identified and left for future work.

7 CONCLUSIONS

This paper suggests three visualization approaches (*viewpoint distribution graph*, *viewpoint visualization over 360-degrees video content*, and *navigation path visualization*) for analysing learners´ navigation behaviour and patterns in 360-degrees video dataset. Additionally, the system provides automatic identification of similar patterns and interactive visualizations in order to make some decisions/conclusions about the users' navigation behaviour. The user study shows some advantages and disadvantages for each one of the visualizations approaches we proposed. Further work needs to be carried out to address the disadvantages and improve some features of the visualization and evaluate it with the nursing teachers. Additionally, we plan to conduct a similar study with police, ambulance, and firefighters related learning scenarios and to explore students´ navigation paths in these learning environments containing 360 degrees interactive videos.

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