Designing Real-time, Continuous Emotion Annotation Techniques for 360° VR Videos

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Abstract
With the increasing availability of head-mounted displays (HMDs) that show immersive 360° VR content, it is important to understand to what extent these immersive experiences can evoke emotions. Typically to collect emotion ground truth labels, users rate videos through post-experience self-reports that are discrete in nature. However, post-stimuli self-reports are temporally imprecise, especially after watching 360° videos. In this work, we design six continuous emotion annotation techniques for the Oculus Rift HMD aimed at minimizing workload and distraction. Based on a co-design session with six experts, we contribute HaloLight and DotSize, two continuous annotation methods deemed unobtrusive and easy to understand. We discuss the next challenges for evaluating the usability of these techniques, and reliability of continuous annotations.

Author Keywords
360° video; emotion annotation; continuous; visualization

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);** *Virtual Reality;*

Introduction
Immersive Virtual Reality (VR) experiences, such as watching 360° videos using head-mounted displays (HMDs), al-

low users to interact with content and feel immersed in the experience. An important aspect of this immersion is the capacity of content to evoke a wide range of emotions in individuals as they interact through head movements in this virtual space [25]. Whether the end goal is to evoke emotional responses and positive associations for educational purposes [1], for news engagement [36, 37], or improve tourism experiences through immersive previews [3], it is important to collect accurate and precise ground truth labels throughout the user's immersive experience.

As stated by Toet et al. [35], most methods for the subjective evaluation of emotional responses to 360° VR videos are either time consuming, demand considerable cognitive effort and interpretation, or are carried out outside the VR experience (cf., [25, 5]). Typically for emotion assessment, these are provided via post-interaction or post-stimuli self-reports, that are discrete in nature (e.g., Self-Assessment Manikin (SAM) [4]). However, post-stimuli self-reports are temporally imprecise, especially for watching 360° videos, since one can experience multiple emotions throughout [23, 33] (e.g., experiencing >1 emotion when entire video is labeled 'happy'). While recent work enables emotion assessments during VR experiences (cf., EmojiGrid [35]), these are still discrete self-reports. This requires new tools for *continuous annotation* of affective reactions of users while they are immersed in VR and watching 360° videos, whereby such annotations can only be generated in such a setting, so must be provided in real-time.

Research Objectives

In this early work, we investigate how to design an unobtrusive real-time, continuous emotion annotation technique for annotating 360° videos. We scope our work to a commonly used HMD, Oculus Rift, and develop an input technique based on the Rift controller, given that physical joysticks have been shown to be effective for inputting continuous valence and arousal ratings in desktop settings [31]. For output, we draw on peripheral information visualization research, and follow a user-centric approach to design several alternatives for how to display user state feedback continuously while users are watching a 360° video. We use stimuli drawn from a validated public database of immersive VR videos [18]. In this work, we ask: How can we design an annotation method that is suitable for collecting continuous valence and arousal self-reports while users are wearing an HMD and watching 360° VR content? Based on our design session and prototypes, we contribute two suitable peripheral visualization techniques (HaloLight and DotSize), for real-time, continuous emotion annotation of 360° video content. Below we start with a survey of related work.

Related Work

We first review emotion models, then existing emotion annotation software and tools, and lastly, we review research on how to design for peripheral attention.

Emotion Models

Theories of emotion are generally represented in two main ways: as categories or as dimensions. Categorical emotion models represent emotions with discrete labels. Ekman [8] summarized six basic emotions based on various experiments, and Plutchik [27] further proposed a wheel model with eight basic emotions: joy, trust, fear, surprise, sadness, disgust, anger and anticipation. While categorical models are typically employed in research since they are easy to understand and less complex [26], however they are not suitable for precisely specifying degrees of emotion. Dimensional models by contrast operate in an n-dimensional space (n>=2). Much work is based on Russell's Circumplex model [28], characterized often by the two dimensions of arousal and valence. The combination of these two di-

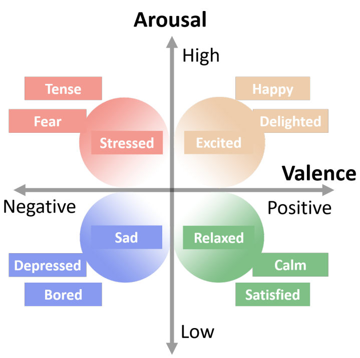


Figure 1: Arousal-Valence model space based on Russell's Circumplex model [28]. In our annotation prototype, four distinct colors are selected across quadrants (HEX values = #eecdac, #7fc087, #879af0, #f4978e for quadrants one to four clock-wise, respectively) [13].

mensions allows specifying a wide range of emotions. In our work, we draw on two-dimensional models for continuous emotion annotation, given our task of simultaneously watching 360° videos and annotating in real-time.

Annotating Emotions Continuously
Primarily, users' emotional experience is obtained through Likert-scale based post-stimuli questionnaires [4]. While there is recent work on enabling emotion assessments during the VR experience (e.g., EmojiGrid [35]), such techniques are still discrete in nature, and self-reports occur after the experience. Considering the dynamic nature of human emotion, there has been a wave of research aimed at developing real-time, continuous emotion annotation techniques to collect valence and arousal labels at each time step of an experience. Examples include FEELTrace [6], EMuJoy [23] and DARMA [10]. For these systems, it is important to specify a controller as input device that can provide continuous ratings, as well as feedback relayed back to the user to indicate where in the valence-arousal space they are specifying. For inputting annotations continuously, prior research use either joystick-based controllers (e.g., DARMA [10] or *CASE* [32]), or a physical radial controller if specifying a single, continuous dimension such as emotional intensity (e.g., RankTrace [20]). Recently, Zhang et al. [38] proposed RCEA, which is suitable for mobile touchscreens and mobile video watching scenarios. Given that in our case users will be wearing an HMD, we need to enable easy controller-based input that can be used while users' visual attention is occupied by the 360° video content.

Peripheral Information Visualization
Lastly, since users will be simultaneously watching 360° videos and annotating their emotional state, it is important to ensure annotating does not incur high mental workload and distract users from the watching experience. Prior work on peripheral visual interaction found that information presented to the periphery of users' visual attention (peripheral displays) can help participants quickly and effectively understand information while performing other primary tasks [2, 22]. Previous work on leveraging such peripheral cues in VR has focused on using such cues to guide visual attention (cf., HaloVR and WedgeVR techniques [11]). Mairena et al. [21] and Gutwin et al. [12] used visual variables like color, shape and motion to provide peripheral notifications in desktop environments. In our context, we draw on these works and design several types of peripheral visualizations to aid users in receiving non-distracting feedback on their continuous annotations while watching 360° videos.

Designing 360° VR Emotion Annotation Prototypes
Below we discuss the design principles and development of our continuous 360° VR video emotion annotation prototype based on the Circumplex model of emotion (Figure 1).

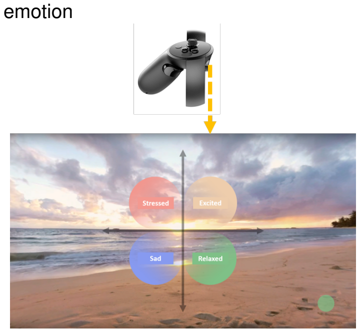
Design Principles
We consider three design principles, while developing the continuous 360° VR video annotation prototypes. These served as heuristics to narrow down the design space, and are based on considerations for designing VR HMD-based interactions [15]:

P1 - Design for HMD-based 360° VR video. It is well known by now that wearing an HMD while watching video content can result in motion sickness [17]. Factors that lead to this include latency, display flicker, calibration, and ergonomics [7]. Thus, our design needs to consider and minimize these problems.

P2 - Design for input device ergonomics. Since users will be equipped with an HMD and cannot see the joystick, we need to ensure that annotating is comfortable, ergonomic, as well as precise. With a return spring, a phys-

(a) Oculus Rift HMD for displaying stimuli

(b) Oculus Right Touch joystick for rating emotion



(c) Oculus Right Touch button for activating help tip

Figure 2: 360° VR video emotion annotation components.

ical joystick that provides additional proprioceptive feedback could aid realigning to center position under no force [31], which makes it suitable for continuous annotation while wearing an HMD.

P3 - Design for divided attention. Since users will be watching 360° videos while annotating emotions continuously, this will lead to divided attention [16]. To this end, it is necessary to reduce the burden of annotating and conveying state feedback without interfering too much with the viewing experience. We draw on research on peripheral feedback [2], and consider GUI element transparency to lower interruptions which helps users keep awareness of the primary task [14, 19].

360° VR Annotation Prototype

Our 360° VR continuous annotation prototype is shown in Figure 2. It consists of two major components: (1) the Oculus Rift (Figure 2(a)) HMD[1] with a resolution of 2160 x 1200 pixels, a 110° field of view and a refresh rate of 90Hz (2) the input device (a joystick on the Oculus Touch right controller) for emotion annotation (Figure 2(b)). A custom scene was constructed in the Unity Engine[2] to display 360° videos online at 30 fps and show the annotation feedback based on users' continuous ratings.

A. 360° Video Stimuli

Drawing on P1, we select eight short 360° video clips with arousal and valence ratings from the database provided by Li et al [18], which contains arousal and valence ratings from 95 subjects (shown in Table 1). We selected two sample videos to represent each quadrant, ensuring the videos are largely matched by duration. In this early work, we use these videos as means to design our annotation tool.

[1] https://www.oculus.com/rift/
[2] https://unity3d.com/

Database ID	Video title	Valence (Score)	Arousal (Score)	Duration (s)
69	Walk the tight rope	High (6.46)	High (6.91)	151
52	Speed flying	High (6.75)	High (7.42)	154
21	Zombie Apocalypse Horror	Low (3.2)	High (5.6)	265
68	Jailbreak 360	Low (4.4)	High (6.7)	339
27	Mountain Stillness	High (6.13)	Low (1.8)	128
32	Malaekahana Sunrise	High (6.57)	Low (1.57)	120
14	War zone	Low (2.53)	Low (3.82)	183
19	The Nepal Earthquake	Low (2.73)	Low (3.8)	240

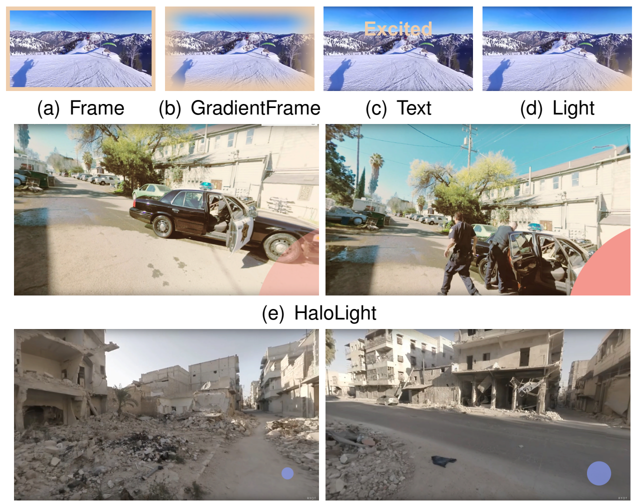
Table 1: Videos selected from the 360° VR public video database [18]. We select 8 videos such that there are 2 videos corresponding to each quadrant of the Circumplex model. Valence, arousal, and video duration (s) are shown.

B. Annotating Videos Continuously

Drawing on P2, participants can annotate videos with a physical joystick. We follow the Circumplex model of emotions [28] for annotating. Participants can move the joystick head into one of the four quadrants of the A-V model, as shown in Figure 1. To increase the emotion intensity, the participant can move the joystick head further.

C. Visual Annotation Feedback

Drawing on P3, we designed four initial prototypes (Figure 3(a-d)). UI components like frame, dot, light, text were considered as well as attributes such as position, size and transparency [14, 19]. The color of the component indicates the emotion they were annotating currently [13]. Four colors (HEX values = #eecdac, #7fc087, #879af0, #f4978e for quadrants one to four respectively) provided feedback to users on which emotion they were currently annotating. We selected four colors based on a simplified version of Itten's



(a) Frame (b) GradientFrame (c) Text (d) Light

(e) HaloLight

(f) DotSize

Figure 3: Four initial prototypes were created: (a) Frame: color frame around entire viewport (b) GradientFrame: gradient color frame around entire viewport (c) Text: textual label in top-center of viewport (d) Light: gradient color light in bottom-right viewport. Final prototypes were: (e) HaloLight: shaded halo arc in bottom-right viewport, which varies in transparency with emotion intensity (f) DotSize: circle dot in bottom-right viewport, which varies in size with emotion intensity.

color system [34], which has been shown to be intuitive and easy for users to understand [13].

Co-design Session

Session and Procedure

To evaluate our prototypes, we follow a user-centric approach [24] with multiple iterative design rounds based on an expert co-design session [29]. This involved six participants (2f, 4m) aged between 25-39 (M=32.8, SD=4.8), where all had >1 year of VR research experience. Three are HCI researchers, one interaction designer, and two software engineers. All of them belong to the same institute (which is a limitation of this work). For the session procedure: first, we explained the key design principles and the research objectives to participants. Then we let participants try the four initial prototypes Figure 3(a-d), across videos with different V-A ratings (cf., Table 1) where they can annotate continuously using the joystick. After experiencing the prototypes, we invited discussion and co-creation on input device control, annotation feedback and distraction. This included the location of the visualization, emotion intensity visualization, and usage of a helper function for on-demand reference. The session lasted around 45 min., and was audio recorded and later transcribed. Data was analyzed using an open coding approach [9] by two researchers.

Key Findings and Design Considerations

We list below the key findings from the co-design session:

(1) **Frame and GradientFrame:** These two visual feedbacks (Figure 3(a - b)) were not found to be suitable. One participant mentioned "*seems very obtrusive...frame is annoying*". Another also mentioned that "*the color around the lenses is very subtle for me...I need to pay close attention*".

(2) **Text:** This prototype (Figure 3(c)) is also criticized by all the experts. One participant suggested that "*... it is a bad thing to indicate a label in the center...it is blocking the view...*". The suggestion given by another expert is to overlay the text. They mention "*...overlay the text in a semi-transparent way...*". At the end of the discussion, experts preferred to train participants with a color scheme rather than display text which can be distracting.

(3) **Visualization position:** A key design aspect is finding a suitable viewport position for the visual feedback. Participants were against using the entire viewport (e.g., Frame

and GradientFrame), or the center of viewport (e.g., Text). Instead, they preferred subtle feedback in a defined location (preferably the corners). One expert recommended that "*...instead of lighting the entire frame, you may consider only corners to minimize distraction..*". The final recommendation was to fix the feedback location to the bottom-right corner. As lighting all corners does not add any extra information and occupies more viewport estate, this option was discarded. While one expert recommended to "*... light the corner corresponding to quadrant position*", it was discarded later as it is too distracting and requires the user to visually attend at different locations.

(4) **Emotion (rating) intensity:** Another key design aspect is to provide feedback in terms of emotion intensity (low to high) of a given rating. We considered two schemes: (a) color intensity (higher opacity as rating increases) (b) size (increases as rating intensity increases). Although one expert mentioned that for intensity "*..size is more direct than increasing color opacity*", we retained both options. Color intensity was initially adopted in Light and later HaloLight (Figure 3(d - e)), and size in DotSize (Figure 3(f)).

(5) **On-demand reference:** One suggestion was to enable an on-demand helper function, so that users who forget what color corresponds to a quadrant with corresponding emotions can use it for easy lookup. One participant mentioned that "*what about turning it on and off...e.g., if you hold down a button, it shows up...*". Another expert mentioned "*.. to overlay the Circumplex plane along with colors...*". Given this, we enabled this on-demand reference functionality, activated through a joystick button press event. We show the helper function in Figure 2(c), where here we only include the most representative emotion keyword (by contrast to several keywords in Figure 1), that should serve as a reminder trigger for what a quadrant corresponds to.

Resulting Prototypes

In summary, we find three designs, initial Light Figure 3(d), and resulting HaloLight, and DotSize (Figure 3(e - f)) are suitable for continuous, real-time annotation of 360° VR video. All follow a fixed location (bottom-right corner) for annotation feedback. However, in the Light visualization (Figure 3(d)), the color intensity was deemed inadequate to indicate intensity, especially under similar light video background ("*...I would like to see the color a bit more intense...*"). Given this, we only keep **HaloLight** and **DotSize**. Whereas HaloLight uses color opacity to indicate intensity, DotSize uses the size of the filled circle to indicate intensity. However both are presented in the periphery of users' visual attention, where their position is fixed to the bottom right corner of the HMD viewport.

Next Steps and Research Agenda

This early work provides the basis for developing tools that are suitable for collecting more precise emotion ground truth labels for 360° VR videos. With the goal of providing real-time, continuous emotion annotation for 360° VR videos, our future work comprises different facets: First, we plan to investigate the usability of both HaloLight and DotSize in a controlled user study, where we test different video stimuli with varying valence and arousal ratings corresponding to each quadrant. Furthermore, we plan on collecting physiological data (heart rate and electrodermal activity), as well as head movements captured with the Oculus HMD. Finally, we aim on testing the reliability of our annotations through investigation of continuous annotation fusion methods, and compare with discrete ratings (cf., SAM [4] questionnaire). Also, presence will be measured through the Igroup Presence Questionnaire (IPQ) [30]. Together, the foregoing enables collecting more precise ground truth labels, that can be used for building more temporally precise 360° video-based emotion prediction models.

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