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Vibrotactile Feedback for Preserving Feeling of Motion in Stabilized Videos

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概要: Videos recorded with action cameras let viewers experience extreme activities from a safe environment. Unfortunately, these videos can be uncomfortable to watch due to intense camera shaking. Here we propose using vibrotactile feedback to preserve the feeling of motion in first-person view videos that have been stabilized. First, we create vibrations from camera motion estimates for two vibrotactile actuators. Then, we conduct a pilot user study to assess viewers perception of motion in stabilized videos with and without vibrotactile feedback. We observed that video stabilization had a significant effect on perceived motion intensity only when it was accompanied by vibrotactile feedback, and that vibrations based on camera motion had a positive effect on comfort.

キーワード： Vibrotactile, Motion perception, Video stabilization

1. Introduction

First Person View (FPV) videos captured with action cameras open the doors for viewers to places and activities otherwise unreachable or too dangerous. These kind of videos often exhibit a considerable amount of trembling due to the intense nature of the activities being recorded. Such intense trembling can become a nuisance for some observers [4] but smoothing the video can instill in viewers a sense of lacking.

Camera trembling also plays a role in inducing a feeling of self motion, or vection, in viewers. In fact, vection starts sooner and lasts longer with vertical viewpoint trembling when compared to displays without trembling, [6]. Therefore, preserving the feeling of movement while creating a comfortable experience requires an approach different to video stabilization alone.

Here we propose using vibrotactile feedback for preserving the feeling of motion in stabilized videos. We use vibrotactile feedback because previous research has shown that vibrations are effective for modulating vection, [1], and for improving the experience of watching videos [3].

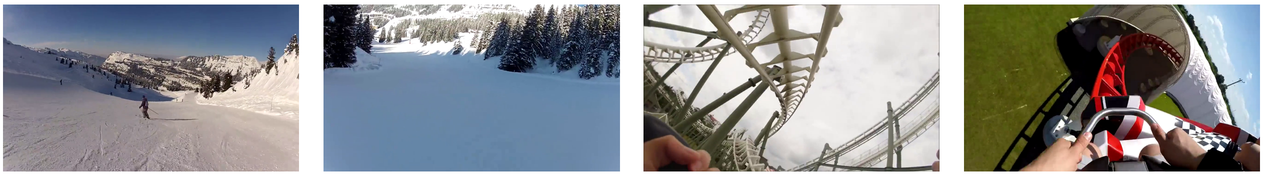
In this paper, we investigate the effects of vibrotactile feedback on the perceived motion intensity in stabilized FPV. To achieve this, we generate vibrations from camera motion estimates of FPV videos (Section 2.), and then we conduct a pilot user study (Section 3.).

図 1: Procedure. Participant watches a video while holding a vibrator on each hand. Pink noise was played throughout the experiment.

2. Vibrotactile representation of camera motion

We proposed a method to represent camera motion with two vibrotactile actuators in [2]. In our method, panning motion is felt as vibrations that travel from one hand to the other in the direction of motion in the video, and bumps or jumps are felt as short exponentially decaying vibrations on both hands. Our method has proven to be effective in increasing the perceived realism and satisfaction of First Person View (FPV) action videos.

In addition, we use a Kalman filter with a Constant Acceleration Motion Model (CAMM) to smooth the camera motion estimates. We modeled the process noise matrix



(a) Snowboard A (b) Snowboard B (c) Roller coaster A (d) Roller coaster B

図 2: Type of videos. Roller coaster videos show continuous rotations. Snowboard videos show rapid panning sideways due to head movements.

with a piecewise white noise model where the variance for the vertical estimates was set to 20 times the variance of the horizontal estimates to preserve fast vertical movements and smooth horizontal displacements.

3. User Study

This study consists of a total of six feedback conditions resulting from the combination of visual and vibrotactile feedback. Vibrotactile feedback is delivered on both hands and it is either random (*random*) or generated by our method (*motion*), we also consider a condition without vibrotactile feedback (*none*). The videos are either raw (*raw*), i.e. in its original form, or stabilized (*stable*) using [5] distributed with FFmpeg (`https://www.ffmpeg.org/`). Note that in this experiment random vibrations refer to vibrations that have no obvious connection with the video instead of vibrations generated from a random signal.

We used a four-question questionnaire to assess motion intensity, synchronization between video and vibrations, comfort, and satisfaction. Each question was followed by a seven-point Likert scale. The verbal anchors ranged from *Extremely weak* to *Extremely intense* for Q1, from *Completely desynchronized* to *Completely synchronized* for Q2, from *Completely uncomfortable* to *Completely comfortable* for Q3, and from *Completely dissatisfied* to *Completely satisfied* for Q4. Intermediate verbal anchors were *Slightly* and *Moderately* for Q1, and *Somewhat* and *Mostly* for Q2, Q3 and Q4. The central verbal anchor was *Neither... nor...* where ...are replaced by opposing qualifiers, e.g. *Neither weak nor intense*.

3.1 Participants and Procedure

Six male graduate students took part in this user study. They were instructed to sit down at about 80 cm of the screen, resting their arms on the arms of the chair, Fig 1.

The study lasted for approximately 30 min and it began with a brief instruction on how to fill the questionnaire. Then, to familiarize participants with the experimental conditions and to clarify what synchronism means in the context of this experiment, participants watched two 30 s videos with vibrations generated by our method, and with random vibrations. Once the second video was over, participants could either replay both videos, or start the experiment. During the experiment, participants answered the questionnaire (see Table 1) after watching 25 s videos. The next video started playing 10 s after the questionnaire was completed. This procedure was repeated 24 times (6 feedback conditions × 4 repetitions). For each of the four repetitions, participants were assigned to a feedback condition using a 6 × 6 Latin square balanced for first order carryover effects. We used a different video in each of the four repetitions, Fig. 2. The videos showed one of two scenarios from a FPV perspective: downhill snowboard, or rollercoaster. The presentation order was randomized for each participant.

表 1: Questionnaire. Participants used a 7 point Likert scale to answer the questions. Every point on the scale had a verbal anchor.

Q1: How intense was the movement of the camera?
Q2: How much were video and vibrations synchronized?
Q3: How comfortable was your experience watching the video?
Q4: How was your experience watching this video?

3.2 Stimuli

Vibrotactile feedback was presented to the palms using Linear Resonant Actuators (Haptuator - Tactile Labs) enclosed within a 3D-printed cylinder. Videos were presented using a full HD (1920 × 1080) 23.6-inch display. The relative viewing distance was 2.2 times the screen height. We used pink noise to block auditory feedback from biasing participant's judgements.

We obtained random vibrations for each video using the vibrations generated by our method. First, the timing of the impacts in a video was randomized but the number of impacts was kept unchanged. Then, vibrations for horizontal camera movements were reversed and, left and right channels were swapped. This way, random vibrations had no deliberate spatial or temporal connection with the video but they preserved the amount of energy in vibrations generated by our method. We did not use a random signal, e.g. white noise, because participants would have readily perceived the dissimilarities with the vibrations generated by our method.

4. Results and Discussion

The contingency tables are shown in Table 2. No participant selected the option *Extremely weak* to answer Q1. Participants were instructed to answer Q2 with *Neither synchronized nor desynchronized* in conditions without vibrotactile feedback.

A two sided Fisher's exact test for a significance level of 0.05 revealed that the ratings were not independent from feedback conditions (Q1: $p = .003$, Q2: $p < .001$, Q3: $p < .001$, Q4: $p < .001$). We conducted posthoc pairwise comparisons with Benjamini & Hochberg correction for multiple comparisons.

In what follows, we refer to specific pairwise comparisons using the row number in Table 3. As for the perceived motion intensity, Q1, the comparisons suggest that video stabilization alone is not enough to cause a significant difference in perceived motion intensity (10). However, video stabilization with random vibrations (15) or motion vibrations (1) appears to have a significant effect on perceived motion intensity. With video stabilization, ratings describing the motion as intense went down from 66.67% to 33.33% for motion vibrations, and from 83.33% to 33.33% for random vibrations.

As for the synchronism between video and vibrations, Q2, ratings for random vibrations and motion vibrations were significantly different (4,5,8,9). Motion vibrations were mostly (91.6% and 87.5% of the ratings for raw and stable videos, respectively) described as being synchronized with the video. Video stabilization alone did not have a significant effect on synchrony ratings for random vibrations (15) and motion vibrations (1).

As for comfort, Q3, ratings for motion vibrations with a stable video were significantly different to ratings obtained with random (8,9) and no vibrations (6,7) whether the video was stabilized or not. Motion vibrations with a stable video were mostly (58.3% and 75% of the ratings for raw and stable videos, respectively) described as comfortable. Random vibrations had no significant effect on comfort with respect to the condition without vibrotactile feedback (11, 12, 13, 14).

表 2: Contingency table for Q1-4 where condition represents the vibrotactile and visual condition pair.

	Ratings						
Condition	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Q1:							
motion_raw	0	1	2	5	4	12	0
motion_stable	0	3	8	5	6	2	0
none_raw	0	1	0	3	8	10	2
none_stable	0	3	6	5	6	4	0
random_raw	0	0	1	3	10	9	1
random_stable	0	2	7	7	5	3	0
Q2:							
motion_raw	0	0	2	0	12	9	1
motion_stable	0	1	2	0	6	13	2
none_raw	0	0	0	24	0	0	0
none_stable	0	0	0	24	0	0	0
random_raw	1	4	7	0	8	4	0
random_stable	2	6	7	0	4	5	0
Q3:							
motion_raw	0	2	7	1	12	2	0
motion_stable	0	1	3	2	12	4	2
none_raw	1	7	12	3	1	0	0
none_stable	0	2	8	8	3	3	0
random_raw	0	2	12	2	8	0	0
random_stable	0	2	12	3	3	4	0
Q4:							
motion_raw	0	0	6	3	13	2	0
motion_stable	0	0	2	4	10	8	0
none_raw	1	8	12	2	1	0	0
none_stable	0	6	6	5	6	1	0
random_raw	0	1	9	4	7	3	0
random_stable	0	1	10	5	6	1	1

As for the overall experience of watching the videos, Q4, ratings for motion vibrations were significantly different from ratings obtained with random vibrations (9) and no vibrations (7) when the video was stable. Motion vibrations were mostly (62.5% and 75% of the ratings for raw and stable videos, respectively) associated with satisfaction. Adding motion vibrations to both raw (2) and stabilized videos (7) had a significant effect on satisfaction ratings. Similarly, adding random vibrations to a raw video (11) had a significant effect on satisfaction. Raw videos were mostly (87.5% and 50% of the ratings for raw and stable videos, respectively) associated with dissatisfaction.

表 3: **Pairwise comparisons with Benjamini & Hochberg correction where significant values are shown in gray and — denotes comparisons that do not apply in Q2 due the abscense of vibrotactile feedback.**

		Adjusted p-values			
	Comparison	**Q1**	**Q2**	**Q3**	**Q4**
1	motion_raw : motion_stable	.03	.45	.53	.16
2	motion_raw : none_raw	.50	—	.01	<.001
3	motion_raw : none_stable	.18	—	0.04	.08
4	motion_raw : random_raw	.45	.03	.46	.47
5	motion_raw : random_stable	.10	<.001	.10	.30
6	motion_stable : none_raw	.02	—	<.001	<.001
7	motion_stable : none_stable	.95	—	.04	.02
8	motion_stable : random_raw	.02	.02	.04	.12
9	motion_stable : random_stable	.95	.01	.04	.02
10	none_raw : none_stable	.05	—	.07	.12
11	none_raw : random_raw	.95	—	.07	.02
12	none_raw : random_stable	.02	—	.15	.04
13	none_stable : random_raw	.09	—	.07	.36
14	none_stable : random_stable	.95	—	.53	.36
15	random_raw : random_stable	.03	.78	.23	.93

5. Conclusion

We proposed using vibrotactile feedback to preserve the feeling of motion in FPV that have been stabilized and we conducted a pilot user study to assess this proposal. We observed that video stabilization had a significant effect on the perceived motion intensity only when it was accompanied by random or motion vibrations. We also observed that video stabilization had no effect on the perceived synchrony between video and vibrations. In addition, we observed that motion vibrations with a stable video appear to be the most comfortable condition. We also noted that vibrotactile feedback, even if it is random, has a positive effect on satisfaction. Motion vibrations improved satisfaction when the video was either raw or stable, but random vibrations improved satisfaction only when the video was raw.

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