High-Quality Variable Speed Video for Stationary Cycling

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We propose an approach for efficiently producing high-quality video of outdoor trails for playback on a stationary cycling rig. Footage is captured in a single pass walking along a trail using hand-held, consumer-grade equipment. Intermediate processing is performed on the footage to produce output video sequences for a range of target cycling speeds. The approach yields virtually artifact-free video with smooth, judder-free motion and realistic motion blur over a range of cycling speeds.

The video is played back on a stationary cycling rig (Fig. 1, right) at a speed varied according to the pedalling speed of the user. Because of the large size, high resolution and close proximity of the display to the user, high image quality and stable motion are essential for quality of user experience. Video content of off-road trails available on the web is typically recorded using action cameras (e.g. GoPro) mounted to the bicycle/rider. While the convenience and low cost of such capture setups is attractive, the video quality is often subpar. On the other hand, high-end video cameras with 4D stabilization (e.g. [2]) are beyond the reach of casual content creators. The proposed approach uses a consumer-grade mirrorless hybrid camera (Panasonic GH6) with a custom light-weight stabilization rig for cost-effective capture of high-quality UHD footage (Fig. 1, left). This hand-held rig allows for capture of trails where bicycles or other vehicles may not be permitted. More-over, through judicious choice of capture settings and processing steps, only one pass of the trail need be recorded (at walking speed) for playback at a range of cycling speeds, while exhibiting stable, judder-free motion and consistent, realistic motion blur.

Figure 1: Hand-held video capture rig (left) and stationary cycling rig (right). A commodity 3-axis gimbal is augmented with a custom vertical stabilization system. The capture vantage point and field of view are matched to the 55” UHD display of the playback rig.

Stabilization Based on the principle ‘prevention is better than cure’, we aim to have the video captured as steadily as possible. We thereby avoid the need for any in-camera or post-processing software-based video stabilization, which could degrade image quality. The lens and in-body optical image stabilization systems onboard the camera are enabled, and the camera is mounted on a commodity hand-held 3-axis gimbal (DJI Ronin SC [3]). These are effective in reducing most of the camera shake, however there remains an undesirable ‘bobbing up and down’ motion in the video due to the walking of the operator. To mitigate this, we propose to augment the standard gimbal, with its 3 rotational degrees of freedom, by mounting it in a custom active vertical stabilization rig.

The vertical stabilization rig uses an RC servo to move the base of the gimbal according to the detected vertical motion. An accelerometer mounted on the actuated platform provides vertical acceleration measurements to a microcontroller (on a Raspberry Pi Pico), which controls the servo using a basic feedback control loop. This reduces the vertical motion of the camera. Field trials using tracked fiducial markers indicate that the system reduces vertical oscillation at a typical walking speed of 4 km/h by approximately 56% (from 25 mm down to 11 mm peak-to-peak), thus producing in more convincing simulated cycling motion than the 3-axis gimbal alone. We expect that further reduction in the vertical motion could be achieved with the same hardware by refinement and further tuning of the feedback control software on the microcontroller.

Retiming We aim to match the effective shutter angle of the output video to the de facto standard [4] of 180° at all playback speeds. A naive retiming of the input footage to an arbitrary speed by sampling from the nearest input frame would result in the effective shutter angle decreasing (and the motion appearing choppier) with increasing playback speed. In general, naively blending multiple consecutive video frames to simulate motion blur leads to artifacts. It is possible to retime video arbitrarily while simulating convincing 180° motion blur by using optical flow-based warping and blending of input frames (for instance using Adobe After Effects [1]). Optical flow is, however generally computationally expensive and is prone to fail in the vicinity of fine structures such as plant stems, potentially leading to objectionable image artifacts [5].

In our approach, the video is captured at 59.94 fps with the shutter speed fixed at $\frac{1}{60}$ s, yielding an input shutter angle close to 360°. Output frames are then synthesised with an effective continuous 180° exposure for output at even multiples of the capture speed (or close to 180° for odd multiples), by blending (averaging) input frames (Fig. 2). Note that the blending needs to be performed in linear (gamma expanded) space, otherwise the blended pixel values would be biased towards darker samples, resulting in artifacts. By capturing at walking speed, integer speedup factors from 2-8x can be used to achieve playback at a suitable range of cycling speeds without judder. These speed retimed sequences are pre-generated off-line and cued up at runtime for playback according to the user’s current pedalling speed (and virtual gear).

	Speed factor	Speed of travel (km/h)	Shutter angle (deg)	Frame	Sample output
Capture (walking)	1	4	360	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	
Display (stationary cycling)	**2**	**8**	**180**	1 2 3 4 5 6 7 8 9 10	
	3	12	240	1 2 3 4 5 6 7	
	4	**16**	**180**	1 2 3 4 5	
	5	20	216	1 2 3 4	
	6	**24**	**180**	1 2 3 4	
	7	28	206	1 2 3	
	8	**32**	**180**	1 2 3	

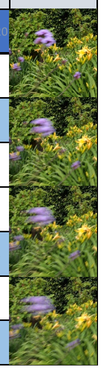

Figure 2: Input video sequence (walking at 4km/h), retimed to various target cycling speeds from 8-32km/h, by blending the appropriate input frames to produce judder-free output video with realistic motion blur.

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[2] DJI Ronin 4D. https://www.dji.com/uk/ronin-4d, . Accessed: 2022-08-31.

[3] DJI Ronin SC. https://www.dji.com/uk/ronin-sc, . Accessed: 2022-08-31.

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[5] Mingliang Zhai, Xuezhi Xiang, Ning Lv, and Xiangdong Kong. Optical flow and scene flow estimation: A survey. *Pattern Recognition*, 114:107861, 2021.