

Supplementary Material: Force from Motion: Decoding Physical Sensation in a First Person Video

Hyun Soo Park Jyh-Jing Hwang Jianbo Shi
University of Pennsylvania
{hypar, jyh, jshi}@seas.upenn.edu

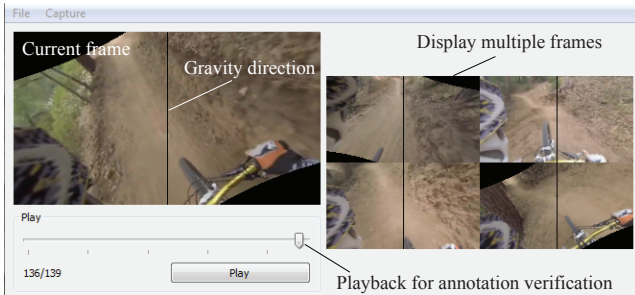


Figure 1. We annotate a gravity direction using our tool that allows us to annotate 100 frames at once.

1. Data Description

We collect 6 categories of sport activities from YouTube: mountain biking (MB), wingsuit flying (WF), skiing (SK), jetskiing at Lake Powell on the Colorado River (JS), speed-flying (SF), and urban bike racing in Taxco, Mexico (TX). We extract images and reconstruct scene geometry and camera trajectory in 3D using structure from motion. We assume that all videos have the same intrinsic parameter (fish-eye distortion [1], $\omega=0.001619$; focal length, $f_x=547.55$, $f_y=535.48$; principal coordinates, $p_x=640$, $p_y=360$) which we pre-calibrate with GoPro Hero 3 Black edition at the 1280×720 resolution. The dataset is summarized in Table 2, 3, 4, 5, 6. Note that multiple sequences (e.g., Bike 13-17) are extracted from one video as it contains multiple videos.

Gravity annotation We annotate the gravity direction of each sequence using our annotation tool as shown in Figure 1. Given a 3D reconstructed camera trajectory, our tool annotates 100 frames at once. It visualizes multiple frames with the projected 3D gravity direction. Also the annotated gravity direction can be verified over time via the playback function. This allows us to annotated a 5 min video (9,000 frames) in 3 mins.

Gaze affect In Figure 2, we compute the difference between the head angle, θ_h , and body angle, θ_b , as we approximate the body angle with the camera orientation aligned with the

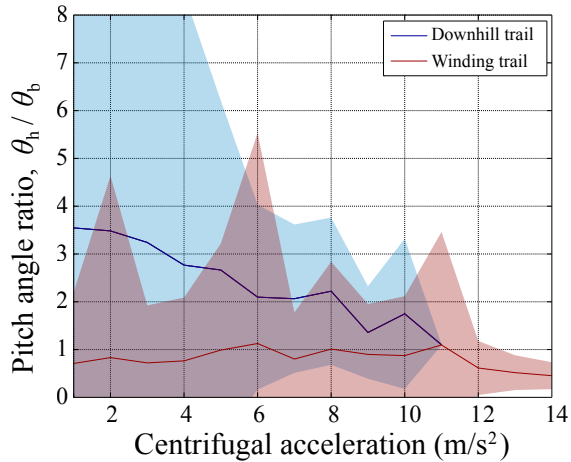


Figure 2. We analyze the relationship between the head angle, θ_h and body angle, θ_b in a banked turn. Two angles align at high speed.

head angle for the leaning angle computation. With our controlled experiments, we empirically show that the head angle is strongly related with the body angle at high speed, i.e., $\theta_h/\theta_b \approx 1$.

2. Inertial Setup

	MB	SK	WF	JS	SF	TX
Pivot length, l (m)	1.2	1.0	0.1	1.0	1.0	1.2
Mass, m (kg)	80	72	72	72	72	80
Moment of inertia, \mathcal{J} (kg·m)	\mathcal{J}_1	\mathcal{J}_2	\mathcal{J}_3	\mathcal{J}_1	\mathcal{J}_2	\mathcal{J}_1

Table 1. Inertial setup

$$\mathcal{J}_1 = \begin{bmatrix} 11.89 & -2.13 & 0 \\ -2.13 & 3.37 & 0 \\ 0 & 0 & 11.89 \end{bmatrix} \quad [2],$$

$$\mathcal{J}_2 = 72/80 * \mathcal{J}_1,$$

$$\mathcal{J}_3 = \begin{bmatrix} 3.75 & 0 & 0 \\ 0 & 6.57 & 0 \\ 0 & 0 & 3.75 \end{bmatrix},$$

Sequence	Frame #	Time (mm:ss)	Youtube Link
Bike 1	3297	02:00	https://www.youtube.com/watch?v=aVJ45wIUE88
Bike 2	8092	06:11	https://www.youtube.com/watch?v=khY00zN9ny0
Bike 3	8060	04:29	https://www.youtube.com/watch?v=bKUOZ4bj7Mw
Bike 4	5395	03:20	https://www.youtube.com/watch?v=WAE0rWkYULo
Bike 5	2308	01:54	https://www.youtube.com/watch?v=WmysH8uTe7U
Bike 6	2398	01:25	https://www.youtube.com/watch?v=a7drg_5RspU
Bike 7	8992	38:52	https://www.youtube.com/watch?v=ZL0TYsFGuGM
Bike 8	10250	08:18	https://www.youtube.com/watch?v=igp9sJkuAnU
Bike 9	8092	05:21	https://www.youtube.com/watch?v=NF-abslkZmY
Bike 10	6894	04:27	https://www.youtube.com/watch?v=7bUBNK-st4
Bike 11	3000	04:59	N/A
Bike 12	5302	03:01	https://www.youtube.com/watch?v=r3kcPqmA760
Bike 13	17983	38:52	https://www.youtube.com/watch?v=ZL0TYsFGuGM
Bike 14	8992	38:52	https://www.youtube.com/watch?v=ZL0TYsFGuGM
Bike 15	8992	38:52	https://www.youtube.com/watch?v=ZL0TYsFGuGM
Bike 16	8992	38:52	https://www.youtube.com/watch?v=ZL0TYsFGuGM
Bike 17	8992	38:52	https://www.youtube.com/watch?v=ZL0TYsFGuGM
Bike 18	6594	04:32	https://www.youtube.com/watch?v=cccvvhQXjM
Bike 19	6594	04:32	https://www.youtube.com/watch?v=cccvvhQXjM
Bike 20	6594	04:01	https://www.youtube.com/watch?v=ZIYAf8qFvxU
Bike 21	8100	04:58	https://www.youtube.com/watch?v=gwjXOsiVGw4
Bike 22	6594	04:27	https://www.youtube.com/watch?v=7bUBNK-st4
Bike 23	7793	05:21	https://www.youtube.com/watch?v=NF-abslkZmY
Bike 24	8992	10:42	https://www.youtube.com/watch?v=8FleRgonxoI
Bike 25	10236	10:42	https://www.youtube.com/watch?v=8FleRgonxoI
Bike 26	7793	06:18	https://www.youtube.com/watch?v=sIhvuZW11s4
Bike 27	13787	08:10	https://www.youtube.com/watch?v=Wo0UuWJuT_M
Bike 28	1795	01:22	https://www.youtube.com/watch?v=FkzJ7CRS89s
Bike 29	5452	03:01	https://www.youtube.com/watch?v=r3kcPqmA760
Bike 30	47100	26:30	https://www.youtube.com/watch?v=RnUQf_kE6pw
Bike 31	14776	08:35	https://www.youtube.com/watch?v=qU5HkiTzD5I
Bike 32	14986	08:44	https://www.youtube.com/watch?v=POm-z-M.Kbg

Table 2. Bike sequences. Note that some sequences use different time intervals from the same video.

References

- [1] F. Devernay and O. Faugeras. Straight lines have to be straight: Automatic calibration and removal of distortion from scenes of structured environments. *Machine Vision Applications*, 2001. 1
- [2] J. K. Moore, J. D. G. Kooijman, M. Hubbard, and A. L. Schwab. A method for estimating physical properties of a combined bicycle and rider. In *International Design Engineering Technical Conferences Computers and Information in Engineering Conference*, 2009. 1

Sequence	Frame #	Time (mm:ss)	Youtube Link
Ski 1	1199	04:20	https://www.youtube.com/watch?v=pCcuKCIUpLs
Ski 2	1799	01:29	https://www.youtube.com/watch?v=RUuVhiXe33Q
Ski 3	5395	12:07	https://www.youtube.com/watch?v=RTsQwY9PCak
Ski 4	6294	07:09	https://www.youtube.com/watch?v=8niTlZ6JnPs
Ski 5	16973	09:45	https://www.youtube.com/watch?v=pkVE1qaxX0Y
Ski 6	7000	09:45	https://www.youtube.com/watch?v=pkVE1qaxX0Y
Ski 7	5646	03:13	https://www.youtube.com/watch?v=zKR_t6p3lto
Ski 8	2905	01:40	https://www.youtube.com/watch?v=8UYwW-C6ey4
Ski 9	14349	08:16	https://www.youtube.com/watch?v=h0dhYn7cJ2o
Ski 10	3383	02:14	https://www.youtube.com/watch?v=DqH233VvxA0
Ski 11	2938	34:23	https://www.youtube.com/watch?v=SXi56fP2dQk
Ski 12	900	34:23	https://www.youtube.com/watch?v=SXi56fP2dQk
Ski 13	2098	34:23	https://www.youtube.com/watch?v=SXi56fP2dQk
Ski 14	1199	34:23	https://www.youtube.com/watch?v=SXi56fP2dQk
Ski 15	1049	34:23	https://www.youtube.com/watch?v=SXi56fP2dQk
Ski 16	4796	03:33	https://www.youtube.com/watch?v=B48B9kxcr88
Ski 17	2338	06:55	https://www.youtube.com/watch?v=Zcc77hHgXZk
Ski 18	7473	06:55	https://www.youtube.com/watch?v=Zcc77hHgXZk
Ski 19	6714	07:28	https://www.youtube.com/watch?v=Wlr3_2yRKlY

Table 3. Ski sequences.

Sequence	Frame #	Time (mm:ss)	Youtube Link
Taxco 1	4652	03:47	https://www.youtube.com/watch?v=jPYUMiOgpfw
Taxco 2	500	00:29	https://www.youtube.com/watch?v=-yrS120ttS4
Taxco 3	7770	04:27	https://www.youtube.com/watch?v=0Ytt9xUQ8Fo
Taxco 4	5500	03:50	https://www.youtube.com/watch?v=-tjplrVlO_E
Taxco 5	4600	03:25	https://www.youtube.com/watch?v=HWs5h7rmkXE
Taxco 6	6654	03:49	https://www.youtube.com/watch?v=HptS2C-1mpw
Taxco 7	6354	03:55	https://www.youtube.com/watch?v=UNDUXl1UX2w
Taxco 8	5185	03:21	https://www.youtube.com/watch?v=nZcejtAwxz4
Taxco 9	6474	04:08	https://www.youtube.com/watch?v=sITW5tr7KQg
Taxco 10	750	00:26	https://www.youtube.com/watch?v=Dgrzu94UhJ0
Taxco 11	8782	06:39	https://www.youtube.com/watch?v=li5bRjDEJ7E
Taxco 12	5065	03:31	https://www.youtube.com/watch?v=oKbUry0HGJw
Taxco 13	5310	03:38	https://www.youtube.com/watch?v=rYpJt3pMWjo
Taxco 14	6240	03:40	https://www.youtube.com/watch?v=f3okpq3fQrc
Taxco 15	3447	03:05	https://www.youtube.com/watch?v=Ouvl0IHZfh8
Taxco 16	5815	03:52	https://www.youtube.com/watch?v=cwMGBC7dmd4
Taxco 17	4856	02:58	https://www.youtube.com/watch?v=yG3WHE_3k10
Taxco 18	5635	03:37	https://www.youtube.com/watch?v=vo8R6S5_zMY
Taxco 19	4826	02:46	https://www.youtube.com/watch?v=Cm0sQQWOaWg
Taxco 20	5905	03:37	https://www.youtube.com/watch?v=leHQvcU3Sko
Taxco 21	5065	03:11	https://www.youtube.com/watch?v=SPXqemrU-dc
Taxco 22	4946	03:20	https://www.youtube.com/watch?v=CkQ84Yy63wY
Taxco 23	4796	03:08	https://www.youtube.com/watch?v=JXYSQ6nSqM8

Table 4. Taxco sequences.

Sequence	Frame #	Time (mm:ss)	Youtube Link
Jetski 1	2698	02:03	https://www.youtube.com/watch?v=mQg3hliED0
Jetski 2	7372	05:01	https://www.youtube.com/watch?v=_vcXsInDIP0
Jetski 3	5068	03:22	https://www.youtube.com/watch?v=77g7Nc4wS_0
Jetski 4	9681	09:35	https://www.youtube.com/watch?v=n94gBr2sa18
Jetski 5	4646	03:42	https://www.youtube.com/watch?v=hJzaVRyv2Ys
Jetski 6	5305	13:19	https://www.youtube.com/watch?v=H7L8QcxI4WA
Jetski 7	2548	01:50	https://www.youtube.com/watch?v=e8140yfp-Vs
Jetski 8	4659	02:45	https://www.youtube.com/watch?v=zgWUZI15VF0
Jetski 9	4496	03:03	https://www.youtube.com/watch?v=iWUkuo8znoc
Jetski 10	9531	05:19	https://www.youtube.com/watch?v=CilHsYGT9d0
Jetski 11	20500	11:33	https://www.youtube.com/watch?v=xEZOacWzmn4
Jetski 12	2398	01:23	https://www.youtube.com/watch?v=J7-XzvzFtfw
Jetski 13	1499	01:48	https://www.youtube.com/watch?v=XXe5fGgyB_w
Jetski 14	5491	04:21	https://www.youtube.com/watch?v=f33kpivo-Vc
Jetski 15	17267	09:59	https://www.youtube.com/watch?v=BUdkSeC12J8
Jetski 16	2758	02:22	https://www.youtube.com/watch?v=ZHiBFYRpA04
Jetski 17	6204	04:47	https://www.youtube.com/watch?v=0aFrWsyHPK8
Jetski 18	5305	03:16	N/A
Jetski 19	5485	03:25	N/A
Jetski 20	13607	08:28	https://www.youtube.com/watch?v=3Dri6i6OvUI
Jetski 21	6984	05:25	https://www.youtube.com/watch?v=QWDFz1_p2T4
Jetski 22	11359	06:22	https://www.youtube.com/watch?v=rw0JB4Y6E60
Jetski 23	10490	06:52	https://www.youtube.com/watch?v=M_52Ier5E10

Table 5. Jet Ski sequences.

Sequence	Frame #	Time (mm:ss)	Youtube Link
Wingsuit fly 1	1199	02:43	https://www.youtube.com/watch?v=-C_jPcUkVrM
Wingsuit fly 2	1199	02:04	https://www.youtube.com/watch?v=IM1vss7FXs8
Wingsuit fly 3	1199	11:01	https://www.youtube.com/watch?v=2fAvbqQWRWo
Wingsuit fly 4	1499	11:01	https://www.youtube.com/watch?v=2fAvbqQWRWo
Wingsuit fly 5	1619	11:01	https://www.youtube.com/watch?v=2fAvbqQWRWo
Wingsuit fly 6	2500	04:50	https://www.youtube.com/watch?v=RsV3bGPMTXo
Wingsuit fly 7	2000	04:50	https://www.youtube.com/watch?v=RsV3bGPMTXo
Wingsuit fly 8	2098	01:55	https://www.youtube.com/watch?v=bwMaqfwlER8
Wingsuit fly 9	2098	02:37	https://www.youtube.com/watch?v=_me1vneqZNE
Wingsuit fly 10	420	14:35	https://www.youtube.com/watch?v=rnvvsjstveM
Wingsuit fly 11	1440	14:35	https://www.youtube.com/watch?v=rnvvsjstveM
Wingsuit fly 12	570	14:35	https://www.youtube.com/watch?v=rnvvsjstveM
Wingsuit fly 13	900	14:35	https://www.youtube.com/watch?v=rnvvsjstveM
Wingsuit fly 14	1050	14:35	https://www.youtube.com/watch?v=rnvvsjstveM
Wingsuit fly 15	810	14:35	https://www.youtube.com/watch?v=rnvvsjstveM
Wingsuit fly 16	5695	04:10	https://www.youtube.com/watch?v=u1PUgWLRU5E
Wingsuit fly 17	4886	16:24	https://www.youtube.com/watch?v=GASFa7rkLtM
Wingsuit fly 18	270	16:24	https://www.youtube.com/watch?v=GASFa7rkLtM
Wingsuit fly 19	3987	16:24	https://www.youtube.com/watch?v=GASFa7rkLtM
Wingsuit fly 20	720	16:24	https://www.youtube.com/watch?v=GASFa7rkLtM
Wingsuit fly 21	720	16:24	https://www.youtube.com/watch?v=GASFa7rkLtM
Wingsuit fly 22	2338	16:24	https://www.youtube.com/watch?v=GASFa7rkLtM
Wingsuit fly 23	960	02:37	https://www.youtube.com/watch?v=b7qwBJH9QN0
Wingsuit fly 24	2175	01:59	https://www.youtube.com/watch?v=Um4ihGIIIFE
Wingsuit fly 25	5485	03:25	https://www.youtube.com/watch?v=Zf4MztOiD4c
Wingsuit fly 26	925	01:44	https://www.youtube.com/watch?v=tNpvxVj5Nro
Wingsuit fly 27	1409	05:17	https://www.youtube.com/watch?v=-W06yAufpNQ
Wingsuit fly 28	6744	04:22	https://www.youtube.com/watch?v=vNqx8XZIWnI
Wingsuit fly 29	2500	06:21	https://www.youtube.com/watch?v=-GOLm_f36bE

Table 6. Wingsuit fly sequences.

Sequence	Frame #	Time (mm:ss)	Youtube Link
Speed Flying 1	5695	03:35	https://www.youtube.com/watch?v=UwWLnaME0CI
Speed Flying 2	2398	01:31	https://www.youtube.com/watch?v=Dg55JIyBcRU
Speed Flying 3	2880	02:24	https://www.youtube.com/watch?v=226js2nxmNE
Speed Flying 4	3300	03:25	https://www.youtube.com/watch?v=oDvhIEQewhY
Speed Flying 5	7553	04:47	https://www.youtube.com/watch?v=EkFV3nNU370
Speed Flying 6	4106	02:34	https://www.youtube.com/watch?v=aOVYdwbv-5g
Speed Flying 7	570	01:30	https://www.youtube.com/watch?v=UZfdAzwZX5E
Speed Flying 8	1709	01:20	https://www.youtube.com/watch?v=RZiY2iJqIXA
Speed Flying 9	7343	04:50	https://www.youtube.com/watch?v=Gc5qEZjIMuo
Speed Flying 10	5625	04:31	https://www.youtube.com/watch?v=8bVo8vGSA5g
Speed Flying 11	3327	02:54	https://www.youtube.com/watch?v=hl3iKGd4Yqo
Speed Flying 12	2050	04:39	https://www.youtube.com/watch?v=RIyO72_E8ok
Speed Flying 13	6234	03:50	https://www.youtube.com/watch?v=._3ehKn9jsaA
Speed Flying 14	7425	04:58	https://www.youtube.com/watch?v=GKdMWEY62ZA
Speed Flying 15	6354	04:37	https://www.youtube.com/watch?v=tt0Q1BPTE7k
Speed Flying 16	3627	02:49	https://www.youtube.com/watch?v=nnfFTjiz6MM
Speed Flying 17	2368	01:31	https://www.youtube.com/watch?v=SfoaJ7b7KE8
Speed Flying 18	8302	04:57	https://www.youtube.com/watch?v=UGKmp5thh24
Speed Flying 19	4256	04:33	https://www.youtube.com/watch?v=W-VG9IEY1qY
Speed Flying 20	1199	03:13	https://www.youtube.com/watch?v=OYK4DWcFIJ8
Speed Flying 21	6264	03:43	https://www.youtube.com/watch?v=1f0rZx5IfGY
Speed Flying 22	550	06:21	https://www.youtube.com/watch?v=-GOLm_f36bE
Speed Flying 23	2925	01:37	https://www.youtube.com/watch?v=ZzVJTt8JdrY
Speed Flying 24	2278	01:32	https://www.youtube.com/watch?v=VLcPPDe-3x4
Speed Flying 25	4586	05:00	https://www.youtube.com/watch?v=WpUxLA2pw6A
Speed Flying 26	12438	07:32	https://www.youtube.com/watch?v=sazQB7G0gck
Speed Flying 27	8602	05:06	https://www.youtube.com/watch?v=857g2xz_3jc
Speed Flying 28	5150	03:34	https://www.youtube.com/watch?v=Iw0oqz2c4UA
Speed Flying 29	2098	01:26	https://www.youtube.com/watch?v=pCJpUfbhbe8
Speed Flying 30	2908	01:46	https://www.youtube.com/watch?v=aOyg_Kn1BmU

Table 7. Speed Flying sequences.