P. Kaps, W. Nachbauer, and M. Mössner,
Snow Friction and Drag in Alpine Downhill Racing,
4th World Congress of Biomechanics. 2002

Reference: P. Kaps[1], W. Nachbauer[2], and M. Mössner[3], *Snow Friction and Drag in Alpine Downhill Racing*, Abstract Book, 4th World Congress of Biomechanics (Calgary, CA), Aug 2002.

Introduction

For training purposes we want to visualize an Alpine downhill slope from the view of an elite skier. As slope we have chosen the Streif, a famous and difficult Alpine downhill run in Kitzbühel, AT. The surface of the slope between the starting area and the end of the Steilhang was geodetically surveyed. The length is approximately 700 m, the difference in height 300 m. The first 30 runners of the FIS World Cup downhill event 2002 were recorded by video cameras. With direct linear transformation we obtained the trajectory of the fastest skier as a function of the time. We call the trajectory with the time history a path. It depends not only on the trajectory but also on the velocity of the skier. It is well known that the speed depends on the drag and the snow friction. These parameters depend strongly on the situation and the skill of the skier. Minimal values occur during straight running when the skier takes an egg position. The snow friction is considerably increased during turns when the skier edges, especially, if the turn is not optimally carved. The drag is increased during difficult parts of the track when the skier takes an upright position. Additionally, the optimal path depends on the strength of the skier. The skier has to exert forces onto the snow to keep his trajectory. These forces are limited due to the constitution of the skier and the consistency of snow.

Methods

For the fastest skier, a video analysis was performed. A typical frame is given in Fig 1. Here, the trajectory is represented, additionally. In each frame, the positions of the toe pieces of the bindings as well as the visible control points were manually digitized. With help of the direct linear transformation the position of the skier was obtained in real 3D object coordinates. Finally, the path was obtained by smoothing. For dynamic analyses, the skier is modeled as a mass point. The equation of motion is established in descriptor form Eq 1. The constraint g is given by the trajectory of the skier.

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$$(1) \qquad \begin{pmatrix} I & 0 & 0 & 0 \\ 0 & I & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} x \\ v \\ a \\ \lambda \end{pmatrix}' = \begin{pmatrix} v \\ a \\ Ma - f - r \\ Gv - g' \end{pmatrix}$$

$$g(x,t) = 0, \quad G = \frac{\partial g}{\partial x}, \quad g' = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

The applied forces f are assumed in the form

$$(2) \qquad f = \begin{pmatrix} 0 \\ 0 \\ -mg \end{pmatrix} - \mu N t - \frac{1}{2} c_d A \rho v^2 t, \qquad \text{with} \qquad \mathrm{t} = \frac{\mathrm{v}}{\|\mathrm{v}\|}.$$

For the reaction forces r and the normal force N it holds

$$(3) \qquad r = -G^T \lambda, \qquad N = \|r\|.$$

We assume that the drag $c_d A$ and the snow friction μ are piecewise constant. The values are determined by a least squares argument: the error between measured and computed positions is minimal.

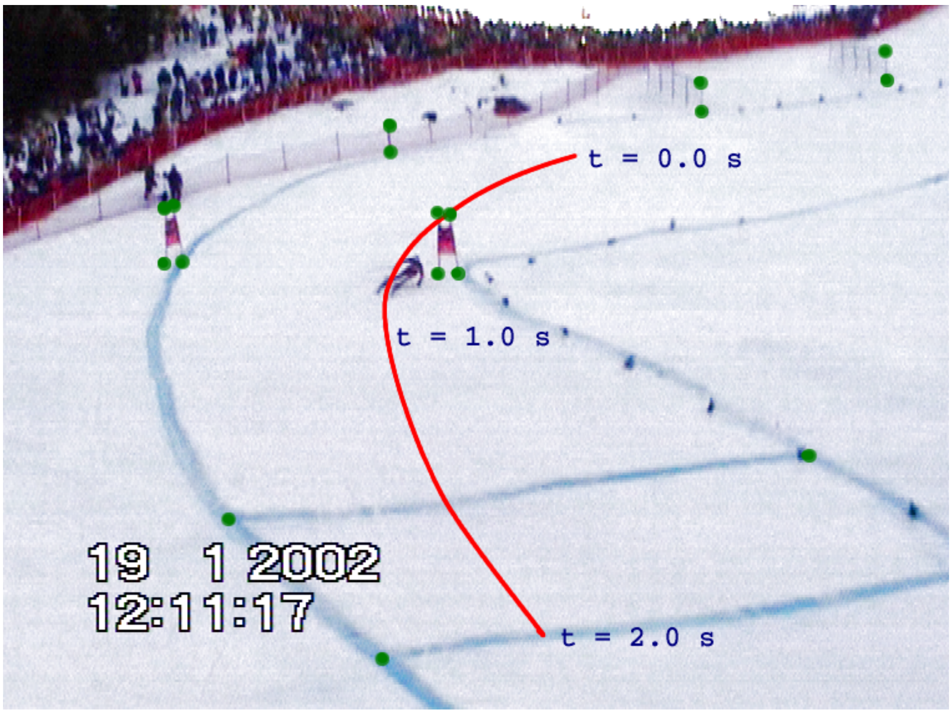

Fig. 1: Video frame with trajectory of the ski racer.

Results

We have computed snow friction and drag for the turn in Fig 1. The turn starts at t = 0 s end ends at t = 1.92 s. The results are given in Tab 1. The root mean square error is less than 2 cm.

	$t < 0.2$	$0.2 < t < 0.75$	$t > 0.75$
μ	0.2	0.45	0.05
$c_d A$	0.7	0.95	0.3

Tab. 1: Snow friction and drag for the turn in Fig 1.

Discussion

Despite of the short time passed since data collection we can present some preliminary results on a small portion of the investigated slope. We plan to visualize the downhill race from the view of a skier. We hope that the results can be used by the Austrian ski team for training purposes.

Acknowledgment

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