

FORCE VECTOR ANALYSIS OF SKI RACING TECHNIQUE USING FUSION MOTION CAPTURE

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In this pilot study Fusion Motion Capture has been used successfully to capture the motion of an athlete through an entire giant slalom alpine ski course. The system allows a comprehensive set of measurements to be collected from each ski run and detailed biomechanical analysis can be extended from a short sequence of turns to an entire run. The results have been used to create a new tool for measuring alpine ski racing technique, based on colour coded Force Vector Analysis, independent of the stylistic constraints often imposed by the coach or athlete. Two ski runs completed by a member of the New Zealand ski team have been compared. The difference between the two run times was around 1%; however Fusion Motion Capture and Force Vector Analysis have been used to pick up the subtle changes in technique between the two runs.

KEY WORDS: Skiing, Forces, 3D, Inertial Measurement Units, GPS, Biomechanics

INTRODUCTION:

The biomechanical analysis of alpine ski racing is a difficult task because of the harsh alpine environment in which the athlete competes and the large volume through which the motion occurs. In addition the motion can not be replicated in a laboratory as the athlete may experience four to six times their body weight whilst cornering. Fortunately because race outcome is decided on time alone stylistic nuances can be ignored simplifying the analysis.

In the traditional approach, camera based systems are used to capture the motion between short sequences of gates, (Schiefermuller 2005; Vodickova 2005). However (Supej 2005) through an energy analysis, noted that athlete turn performance is dependant on the previous turns. If turn strategy is dependant on both the past and future turns then unfortunately race outcome and ultimately athlete performance can not be predicted on analysis of a turn sequence in isolation, especially when a time difference of one hundredth of a second between gates is significant.

In the past both instrumented skis and pressure sensitive insoles have been utilised to measure ground reaction forces for entire ski runs. Unfortunately without kinematic data from video analysis, the locally measured forces can not be interpreted in the global coordinate system. GPS has also been used to track athlete movement in ski racing (Ducret 2005) but the resolution of these systems, at present, appears to be too low to pick up the subtle differences that may decide race outcomes.

To overcome the limitations of current motion capture systems with respect to alpine ski racing, the authors are developing Fusion Motion Capture. Fusion Motion Capture is a composite motion capture system utilising data from inertial measurement units (IMUs), video, GPS, and an RS-Scan insole system to determine segmental and whole body kinematics and kinetics, (Brodie 2005). With Fusion Motion Capture it is possible to capture the 3D complex dynamic motion of an athlete over a large area such as a ski run, in some cases over 1km in length while maintaining high resolution. Previous work indicates that under good conditions changes of less than 1° in local limb orientation can be tracked successfully, (Brodie 2006).

METHOD:

Data Collection: A member of the New Zealand national team completed five runs through a ten-gate giant slalom training course at Mt. Ruapehu Ski Area. The course was over 250 metres in length. The athlete's body segment kinematics, angular velocity and local acceleration were obtained from 13 IMUs attached to the following body segments; head, torso, pelvis, upper and lower arms, thighs, shanks, and ski boots. An RS-Scan pressure

measurement system was used to determine plantar pressures. Video from a hand held digital camera was used as an external reference, and to confirm validity of the data.

Data Analysis: The data were processed using Fusion Integration algorithms (Brodie 2007) and the Biomechanical Man body model in MATLAB, (Brodie 2006). The resulting data allow determination of the full kinematics and kinetics of the athlete including; limb kinematics, ground reaction forces, CoM (Centre of Mass) trajectory, ski orientation, ground reaction forces, net joint torques, and net joint powers. From the five runs completed, three had to be rejected for various reasons including; equipment damaged from the athlete's aggressive race strategy, and flat batteries.

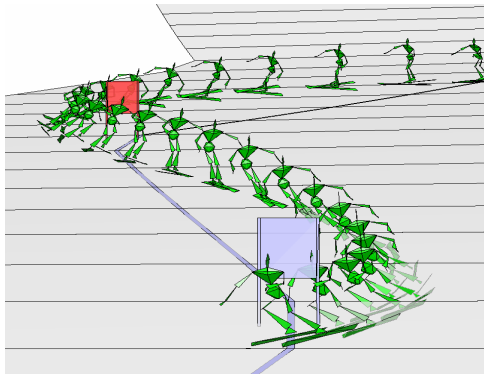


Figure 1: Fusion Motion Capure

RESULTS:

Race outcome is decided by minimum time. Figure 2, panel one shows the cumulated time of each run in seconds and the difference between the times for each run in 100ths of a second. The gate split time are show in the second panel. Time zero corresponds to gate 2. Run 5 is faster than run 3 by 0.14 seconds.

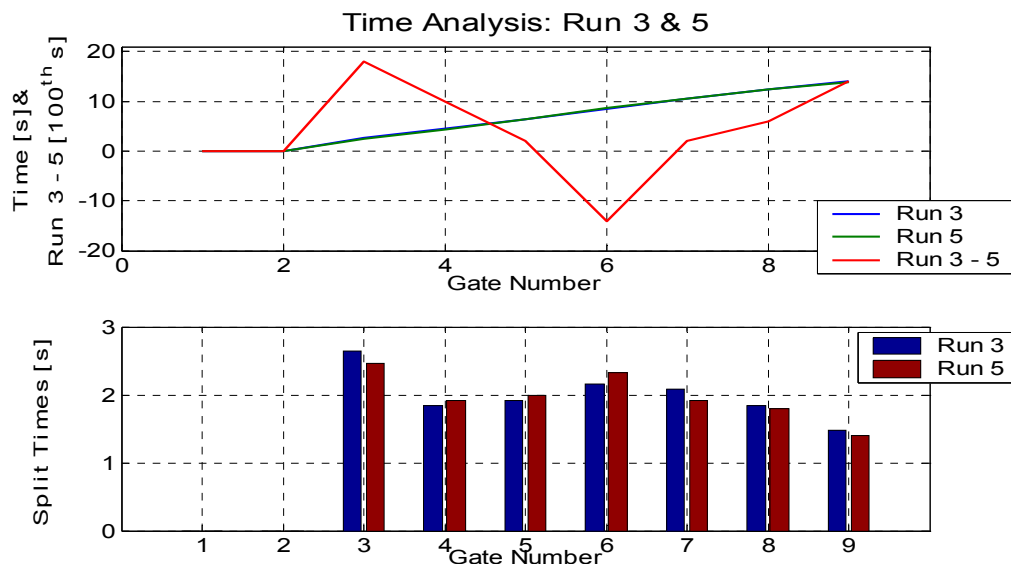


Figure 2: Time Analysis, cumulated, difference and gate splits.

A Force Vector Analysis of turn 6 is presented in Figure 3. Both run 3 and run 5 are compared. Turn 6 was chosen because there was large variation in its appearance between the two runs. The black dots represent gate locations. The solid blue line is the centre of mass trajectory. The thin lines represent the magnitude and direction of the resultant force vector acting on the athlete's centre of mass. The force vectors are colour coded, dark red

for retarding and light green for accelerating. There are more force vectors in run 5 as it was sampled at 50Hz whilst run 3 was sampled at 25Hz. The Energy Analysis, Table 1, shows that while gravity does positive work that accelerates the skier, wind drag, ground reaction forces and ski sliding friction do negative work.

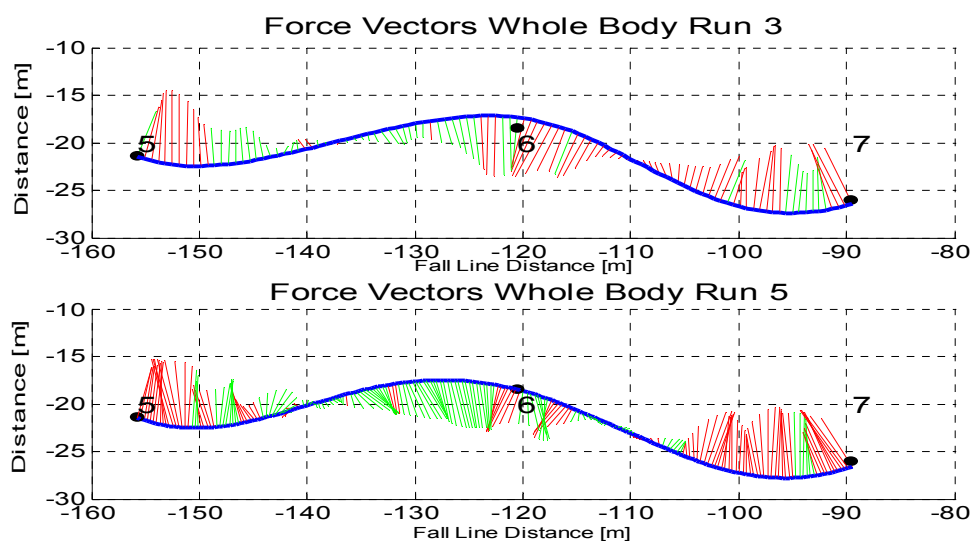


Figure 3: Force Vector Analysis, a close up of the turn 6 resultant force vectors

Table 1: Energy Analysis at the gate check points, Run 3 and Run 5.

Energy Analysis, Cumulative Work [kJ] at each gate, comparison between Run 3 and Run 5										
Gate	Wind Drag		Sliding Friction		GR Forces		Gravity		Total Kinetic	
	Run 3	Run 5	Run 3	Run 5	Run 3	Run 5	Run 3	Run 5	Run 3	Run 5
1	0	0	0	0	0	0	0	0	0	0
2	0	0	-1	-1	-2	-1	6	6	3	4
3	-1	-2	-1	-2	-4	-2	15	15	9	9
4	-4	-4	-2	-4	-4	-4	22	22	12	11
5	-6	-6	-3	-6	-6	-5	27	27	12	10
6	-9	-9	-4	-8	-7	-5	33	33	12	12
7	-11	-11	-6	-9	-11	-6	38	38	10	11
8	-13	-14	-6	-11	-12	-7	45	45	13	13
9	-16	-16	-7	-12	-14	-7	52	52	15	16
10	-19	-20	-9	-16	-33	-26	61	62	0	0

DISCUSSION:

Fusion Motion Capture has been successful in capturing the motion of alpine ski racing through a 10 gate giant slalom course. The validity of the captured data is confirmed by agreement between computed kinematics presented in animated form and video images. Figure 1 is an example screen capture showing kinematics that is in agreement with the video camera footage.

Race outcome is decided by the time taken to ski the entire course. Figure 2 derived from the athlete's centre of mass trajectory, contains detailed information about the athlete's time profile for each run. The difference between the two run times, (red line) is scaled by a factor of 100 so the difference of 1% is visible. Run 5 is faster by 0.14 seconds or 1%. A 1% change between gates corresponds to about 200^{ths} of a second as shown in panel 2 of figure 2. This is a subtle difference to measure and if turn 4, 5 or 6 was analysed in isolation we would have assumed erroneously that run 3 was faster. Timing starts from gate 2 on the course because a sliding start was used. Between gate 2 and 3, run 5 is quicker as the athlete uses a more aggressive skating start. However between gate 3 and 6, run 3 is faster,

a consequence of harder snow conditions during the earlier run producing less sliding friction. Confirmation of this is found in Table 1; the difference in the negative work of sliding friction by gate 6 is significant, -4 kJ for run 3 and -8 kJ for run 5. Negative work, or breaking, is done by forces acting against the direction of motion. After gate 6 the faster run changes again and from gates 7 to 9 run 5 is faster. The reasons for this are due to both a different race strategy between gates 5 and 6 and the exceptionally good turn technique the athlete used about gate 6 in run 5. This demonstrates a general time lag between cause and effect often observed in the analysis of gate split times, (Ducret 2005).

The colour coded Force Vector Diagram was able to pick out the subtle difference in race strategy and technique between the runs around gate 6, figure 3. In run 5 the race strategy was changed, the athlete chose to make the apex of his turn well before gate 6, although the result was a longer centre of mass trajectory than run 3, it allowed him to ski straighter and accelerated him out of gate 6 where the snow rolled over into steeper terrain. As shown by more green accelerating vectors after gate 6 in run 5, see figure 3.

Kinetically the improved turn technique about gate 6 results in a smoother earlier development of horizontal ground reaction forces in run 5, most of which are accelerating the skier. The power analysis shows the difference is mainly due to ground reaction forces which do less negative work between gates 5 and 7, -1kJ for run 5 compared to -5kJ for run 3. Kinematic data from the athlete show that he uses a higher leg/snow angle or is leaning into turn 6 earlier on in run 5, and maintains a good inclination through the turn. In run 3 his peak leg/snow angle is greater at the apex of turn 6 but entering the turn he has less pressure on the ski, very little inclination and the ski is possible not carving as smooth an entry trajectory.

CONCLUSION:

Fusion Motion Capture and Colour Coded Force Vector Analysis appear to be useful tools for the analysis of alpine ski racing. The motion from two giant slalom runs was captured and compared successfully. Although the difference between the runs was less than 1% in time, the analysis was able to pinpoint the essential subtle differences between the two runs. Future work will involve larger volumes of data and attempt to define both an athlete and course specific optimum race strategy and associated optimum turn technique.

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