FUSION MOTION CAPTURE: CAN TECHNOLOGY BE USED TO OPTIMISE ALPINE SKI RACING TECHNIQUE?

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Fusion Motion Capture has been used to capture 3D kinetics and kinematics of alpine ski racing. This research has overcome the technological barriers associated with athlete performance monitoring in an alpine environment. The biomechanical analysis of a New Zealand Alpine Ski Racing team member negotiating a ten gate giant slalom course over 300 meters in length has been undertaken. Results of the analysis may provide useful design parameters to ski equipment engineers and feedback to the athletes including; limb dynamics, Centre of Mass (CoM) trajectory, CoM velocity, and external forces through augmented reality animations. In-depth analysis of the changes in net joint torques with changes in athlete posture may be useful for the coaching of athlete specific technique changes to improve performance and reduce injury potential. In addition it is possible to extract key performance indicators about the athlete's physical and physiological limits such as his mean coefficient of wind drag, and his maximum inclination angle while turning which in the future may be used to optimise an athlete's race strategy.

1 Introduction

Biomechanical analysis of alpine ski racing is difficult due to the technological barriers associated with the resolution and accuracy of 3D video analysis through large volumes. Because an improvement of as little as 100th of a second between gates is significant to race outcome, the performance enhancement of an elite athletes may involve technique adjustments that are beyond the scope and resolution of video based systems. Therefore most research to date has focused on the analysis of a short turn sequence through two or three gates representing only part of a race course. (Schiefermuller *et al.*, 2005; Supej *et al.*, 2005; Vodickova *et al.*, 2005).

The purpose of the project was to overcome the technological barriers associated with athlete performance monitoring in an alpine environment. Its success proves it is possible to capture the motion and dynamics of alpine ski racing through an entire ski run, in some cases over1 km in length while maintaining high resolution. Previous work indicates that changes of less than 0.5° in local limb orientation can be tracked successfully (Brodie *et al.*, 2006b,c). In contrast contemporary 3D optical based systems would require many cameras to capture motion through such a large volume.

Fusion Motion Capture is a composite 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. The global motion of the subject is determined by fusing GPS data, the known location of check points (the course gates in skiing) and the double integral of Centre of Mass (CoM) acceleration. Previous research has used GPS measurements for downhill ski performance, (Ducret *et al.*, 2005) but we believe this is the first time GPS data has been fused with IMU data to obtain a continuous CoM trajectory.

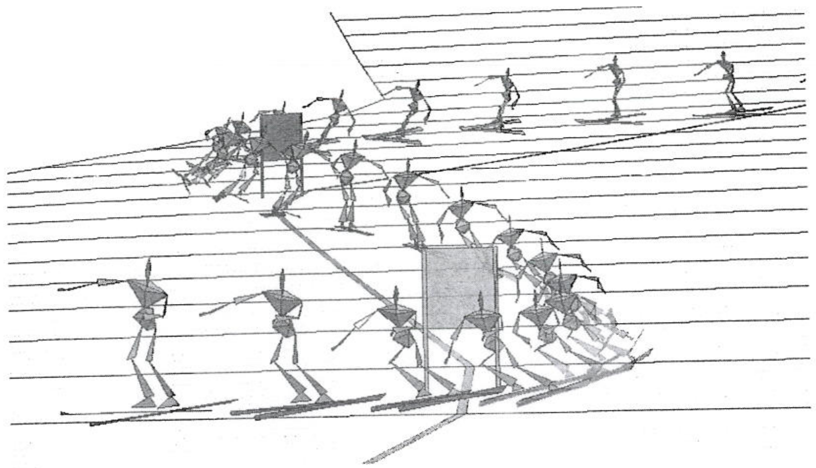


Figure 1. Fusion Motion Capture Output, Giant Slalom.

'he athlete's limb orientation is determined by thirteen IMU's attached to the athletes segments. The IMU's contain 3 gyroscopes, 3 accelerometers, 3 magnetometers, and ·mometer in a 35 gram box about the size of a matchbox. The manufacturer supplied man filter algorithm which can be used to extract orientation information from the raw however it was found that the Kalman filter algorithm produced errors of over 20° in tation for sustained athletic activity. Instead the author used a fusion integration algo- suitable for measuring the athletic movements in skiing, (Brodie 2007).

n order to calculate net muscle torques around each joint centre a body model of the :e is required. Athlete inertial parameters are obtained using the Biomechanical Man model, (Brodie *et al.*, 2006a) constructed from 3D anthropometry using a custom frame (see figure 2) and the scaled inertial parameters as suggested by Dumas and , (Dumas *et al.*, 2006; Reed *et al.*, 1999). This system is required both to model the :e's inertial parameters and to calibrate the attached IMUs. The local coordinate sys-)f each IMU is mapped to the local coordinate system of the athlete's limb (to which MU is attached) in the calibration process.

Iethod

:mber of the New Zealand national team completed three runs through a ten-gate giant m training course at Mt. Ruapehu Ski Area. The course was over 300 metres in length. athlete's body segment kinematics, angular velocity and local acceleration were ned from 13 IMUs attached to the following body segments; head, torso, pelvis, upper ower arms, thighs, shanks, and ski boots. An RS-Scan pressure measurement system ısed to determine plantar pressures. Video from a hand held digital camera was used external reference, and to confirm validity of the data.

The data were processed using Fusion Integration algorithms and the Biomechanical Man model in MATLAB. The resulting data allow determination of the full kinematics and

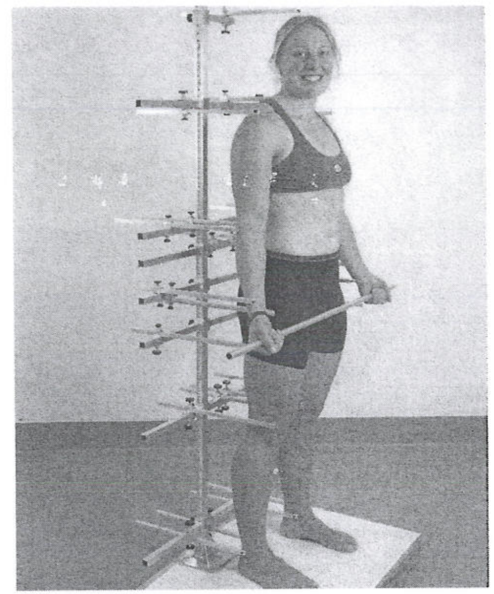


Figure 2. 3D Anthropometry and the Biomechanical Man.

kinetics of the athlete including; limb kinematics, ground reaction forces, CoM trajectory, ski orientation, ground reaction forces, net joint torques, and net joint powers.

In ski racing the dissipative forces of wind drag and ski-snow friction have a large effect on athlete performance. It was assumed that the dissipative forces could be calculated from the residual between measured ground reaction forces and the resultant external force acting on the athlete's CoM. The resultant external force was determined from the athlete's mass and CoM acceleration, which was determined from a weighted sum of the individual limb segment's acceleration measured by the IMUs. The magnitude and direction of the major component of the ground reaction force under each foot was calculated from the RS-Scan data and the measured orientation of the athlete's feet. The residual forces were assumed to be due to wind drag and ski-snow friction. Friction was modelled by equation 1, where F_{GRF} is the GRF component normal to the athlete's foot, $K_{Friction}$ is the coefficient of friction due to sliding resistance, and $\mathbf{NV}_{Foot}$ is the normalised velocity vector of the athlete's feet. Wind resistance was modelled by equation 2, where $\mathbf{V}$ is the COM velocity vector and K_{Drag} the lumped coefficient of wind drag.

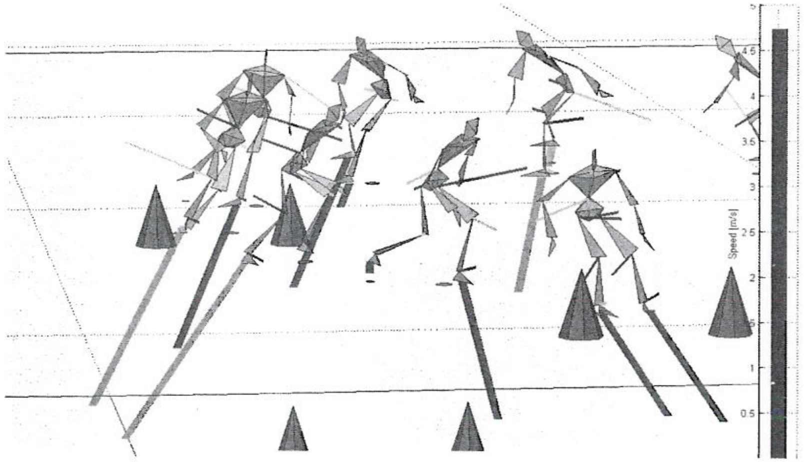
$$\mathbf{F}_{\mathbf{Friction}} = F_{GRF} K_{Friction} \mathbf{NV}_{\mathbf{Foot}} \quad (1)$$

$$\mathbf{F}_{\mathbf{Drag}} = -\mathbf{V}^2 K_{Drag} \quad (2)$$

3 Results

While the data from Mt. Ruapehu collected at the end of October 2006 are still being analysed, some preliminary results are available. For example, an animation of the Biomechanical

3. Diagnostic checking of the fusion motion capture system before a trial. Mt Ruapehu ski area.



4. The Near Optimum Turn. Net accelerating ground reaction forces out of the gate, (thick ɔctors) followed by net retarding ground reaction forces (thick dark vectors) and both eccentric hin vectors) and concentric muscle torques (dark thin vectors) are visualized.

ıegotiating the giant slalom course from which a freeze-frame is shown in figure 1. ıalysis will include both ground reaction forces, and net muscle torques such as the blading example of a near optimum slalom turn, figure 3. The animation may be used ɜent the complex information in an understandable way to the general audience.

qualitative analysis has revealed that a combination of high ground reaction forces ıdicular to the CoM trajectory and high angular acceleration about the CoM trajec- ɜsults in a faster more direct route through the gates. These two parameters and the limb dynamics through each turn will be compared to determine the more efficient ınd discover the dynamics that produce them.

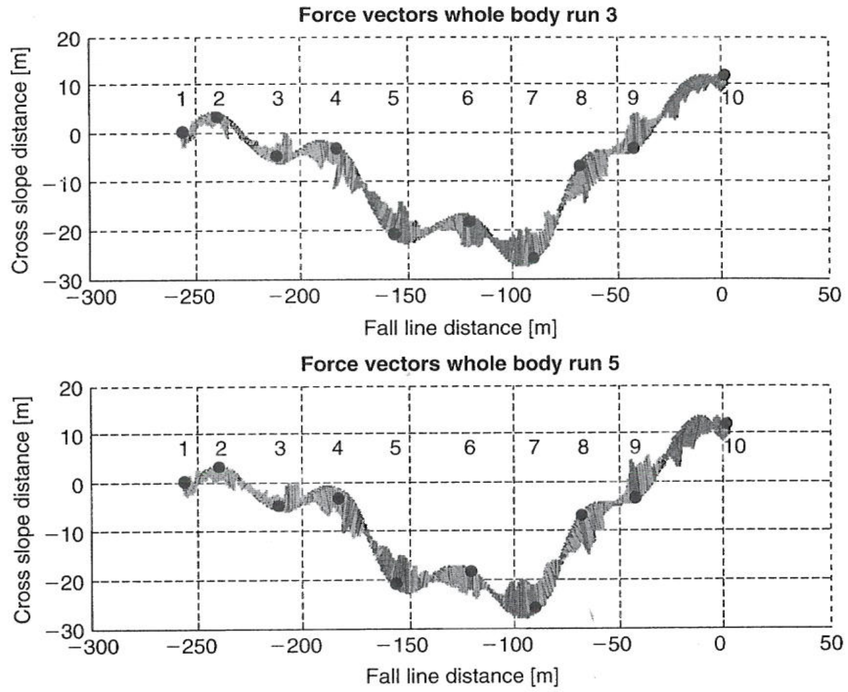


Figure 5. Force Vector Diagram, A comparison of Run 3 and Run 5.

Force vector diagrams showing the magnitude and direction of forces acting on the athletes CoM will be presented (see Figure 5). The resultant force vectors are colour coded; light for an accelerating force, and dark for a retarding force. A turn with less "dark" forces and more "light" forces is considered better. Run 5 is faster than run 3 the principal reason for this is that turn 6 of run 5 is better than turn 6 of run 3, with more accelerating forces.

Contributions of external forces to the resultant external force and athlete power will be presented, Figure 6. The power analysis shows that while gravity produces a net positive power, all other external forces including show friction, wind drag and ground reaction forces have a net negative power or slow the athlete.

4 Discussion and Conclusions

It is not yet possible to draw conclusions from the 2006 data until analysis is complete. However it is believed that the results will demonstrate the relative importance of ground reaction forces, ski-snow friction and wind drag at various stages through the course and turn. Contra intuitively it appears that while ground reaction forces are essential for changing athlete direction they do not produce a net increase in speed during downhill skiing. The progression of lower limb dynamics through each turn may also give insights into how alterations to an athlete's stance can reduce the dangerously high knee torques in ski racing, with minimal effect on performance. The measurement of joint torques and powers may be

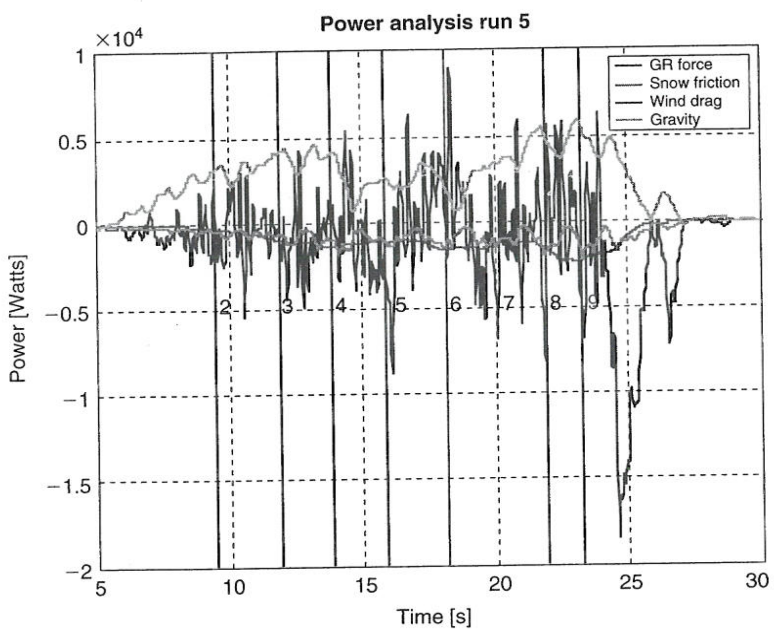


Figure 6. Power Analysis of Alpine Ski Racing.

ful for developing more specific physical training programs by indicating the dominant scle groups and their mode of action during the turn.

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