Measurement and analysis of body segment orientations during the flight phase of ski jumping using inertial sensors

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Intention

Currently, exact kinematic and dynamic properties of an athlete's body can hardly be measured quantitatively during a ski jump. Using motion capture techniques (as they became common for most motion tasks) still remains difficult and little explored for ski jumping due to the extremely large motion volume of a ski jump and natural weather and daylight conditions. As a consequence, computer based motion analysis methods also hardly exist and the kinematics of real jumps are rarely analyzed in training and competition so far. Therefore, the intention of this research project was to develop technologies that give accurate information on an athlete's motion during a ski jump based on portable, easy-to-use and ubiquitous sensors. Those can then be used for sophisticated motion analysis tasks and feedback systems in future applications.

Research details

Considering the specific motion characteristics of ski jumping, inertial sensors are the most reasonable choice for the motion sensor device: they can be used without much additional technology and are light and small (and hence unlikely to disturb the athlete during the performance), while they are also relatively cheap and therefore lend themselves to a use in general training. Inertial sensors measure acceleration and gravity of the body parts they are attached to and can generally not display all information necessary for a complete motion analysis. However, they can be further processed into estimates of orientations and angles of body segments for the analysis of meaningful kinematic properties. It is not clear though whether these existing technologies can be transferred one-to-one into the ski-jumping task due to the sport's occurring harsh temperature and wind conditions. By this research project, I tested and evaluated methods for orientation estimation and joint position determination with respect to their use for ski jumping. I furthermore adapted and set up the technology so that it is possible to perform complete kinematic analysis of a ski jump now.

The crucial part for this research was to conduct experiments under real conditions to gain experience with the data collection process under real-world conditions while obtaining multiple data sets of ski jumping data used for the system development. With data of several jump and training sessions from two experiments in summer and one experiment in winter season, I could collect sufficient fundamental data. Figure 1 gives an impression on the experiments in summer.

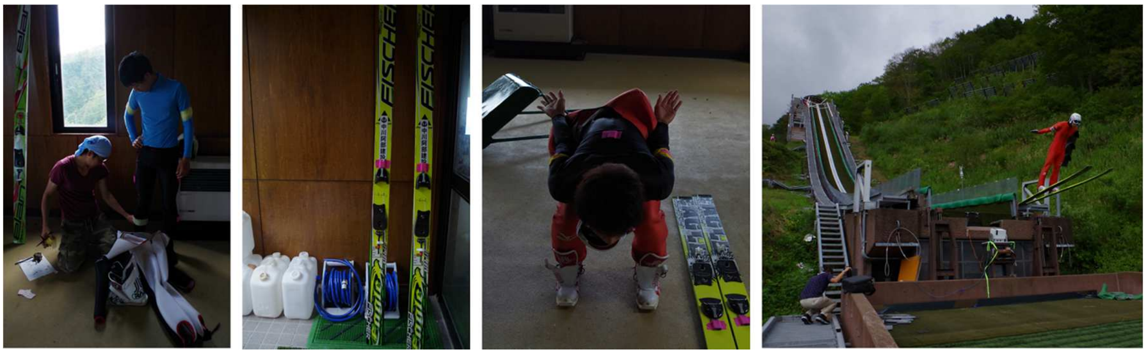

Figure 1: Experiment in summer at Myoko Kogen ski jump stadium. Sensor are attached to the athlete's body and skis and the athlete's body movements during jump captured.

Consequently, I was able to test several different orientation estimation methods that I implemented in a previous research project on the ski jumping data. Furthermore, the data was used to develop data analysis methods as well as methods for the analysis of motion parameters and typical flight properties.

Results

Practical results: While it was easy to capture data in summer season, it turned out to be very difficult to get useful data in winter season due to the harsh weather conditions. Cold temperatures around -10°C had a big impact on the duration of the sensors' in-build battery power. In addition, strong wind hindered the execution of regular practice, so that only very few data could be captured in winter. For future experiments in winter season, it is necessary to supply a measurement system that is better prepared to a use under those circumstances.

Technical results: Regarding the accuracy of the estimated positions and sensor orientations, I could conclude that the used algorithms are sufficiently good to be used as kinematic output data. To come to this conclusion, I used the following processes.

Firstly, I evaluated the general accuracy of all methods implemented and contained in the analysis system by non-ski jumping experiments with sensor and optical motion capture data. In those experiments, different types of motion like jumping, throwing, walking and kicking have been performed in the SFC motion capture studio. The optical motion capture data served as the ground truth data to which the estimates from the sensor data were compared. In total, the distance between ground truth and estimate was determined with four different error measures. All estimation methods show sufficiently high accuracy (meaning small deviation between real and estimated data) that allow for a use for all kind of motions similar to the ones performed in the experiments. Table 1 shows the averaged accuracy values for all experimental test data.

Table 1: Averaged error values between estimated orientations and truth data from an optical motion capture system.

Method	Error Quat Diff	Distance inner product	Distance inner product °	Error RMSE
GI	0.6186	0.2064	37.1520	0.1575
CF1	0.3599	0.1069	19.2420	0.1026
CF2	0.1378	0.0263	4.7340	0.0618
KF	0.2015	0.0543	9.7740	0.0871

Secondly, since no optical control data is available for the ski jumping, I compared the software estimates to two-dimensional video data and the technical specifications of the ski jumping hill and additionally visualized them as a stick figure for visual display and control. I assume the combination of those two 'control measures' to be a useful indicator for the reliability of the methods when used with ski jumping data input, since the general accuracy of the estimates already got proven in the first step. The approximate body angles from the video data turned out to be identical to the ones from the sensor estimates up to few degrees. Given that natural measurement errors already occur when estimating the angles from the video data, this comparison offers satisfying results. Stability and reliability in the estimates is further confirmed when comparing the inclination angles of the jumper's ski to the technical specifications of the inrun and outrun slopes of the ski jump hill construction. For example the inclination angles of the inrun are determined as 35°, whereas the estimated sensor angles are estimated as -145°, which corresponds to the same slope under different rotation directions.

In the stick figure display, the ski jump with its different phases (start, inrun, takeoff, flight phase, landing and outrun) is clearly visible and the estimated positions of the displayed body joints appear to follow a natural way. The stick figure visualisations for the inrun, flight and landing phases can be found in Figure 2.

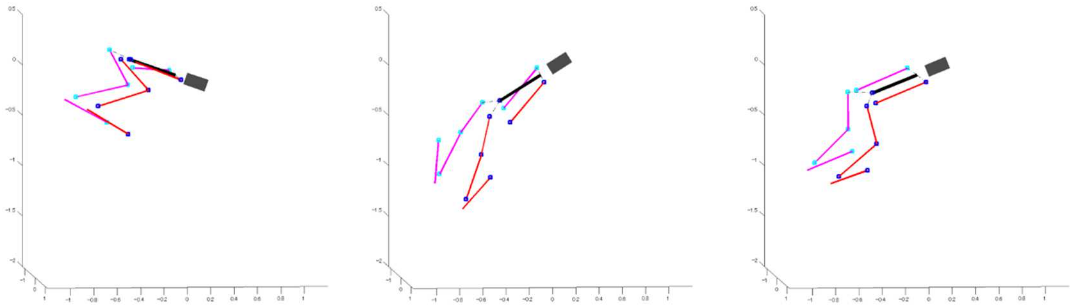

Figure 2: Stick figure visualization of a ski jump with selected frames for (a) inrun (b) flight phase and (c) landing.

Future work

From the practical point of view, additional technology should be developed in the next year that supports the easy and mobile use of the inertial sensors, such as automatic start systems for the sensor or more convenient battery charging. Furthermore, it is necessary to develop a technology to keep the sensor devices warm to assure sufficiently long battery power in future winter experiments. The system and technology will then be used in next summer and winter season for the analysis of ski jumps, and follow-up methodologies such as different kinds of feedback systems as for example for performance evaluation in competitions. Those methods and feedback algorithms are to be developed in the course of the next months so that they are available in the following ski jump experiments providing new motion analysis possibilities.

Conference Presentations

As outcome of my research, I have given an oral presentations at a conference in Australia last summer and will give a second speech at a conference in Italy this March. I am furthermore currently in the process of summing up all my work from the past two years in a journal paper that will hopefully be published this summer.

Heike Brock, Yuji Ohgi. **Evaluating Orientation Estimation Methods from Inertial Sensor Data for Sports Motion Analysis**. International Association of Computer Science in Sports (IACSS) Conference 2014, Darwin, NT, Australia, June 2014

Heike Brock, Yuji Ohgi. **Estimating Kinematics in ski jumping using inertial sensors.** Conference of International Society of Skiing Safety (ISSS) 2015, San Vito, Italy, March 2015