

Convenient Method for Detecting Ski-Turn Features with Inertial and Plantar Pressure Sensors [†]

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Abstract: Skiers need a convenient method that uses actual ski-turn data to determine their skill level quantitatively without impeding their movement. In this study, we propose a feature detection method designed to quantitatively assess the skill level involved in ski turns. Actual data were acquired from both expert and intermediate skiers while skiing by using a comfortable measurement system that uses compact inertial sensors attached to the user's skis and waist, and plantar pressure sensors. The changes in body posture and the behavior of the skis were examined using acceleration and angular velocity (each on three axes) data output by the inertial sensors. The plantar pressure distributions generated during skiing were also examined. The results show that it is possible to detect the relationship between the behavior of the skis and the changes in body posture or the plantar pressure distribution, which allows the skier's skill level to be quantitatively assessed.

Keywords: ski turn; inertial sensor; plantar pressure sensor; feature detection; actual field evaluation

1. Introduction

Skiing is an attractive sport and can be enjoyed more if the turns are well controlled. Proper control is based on maintaining the proper position of the body relative to the skis and loading the skis with the appropriate timing and strength.

Two training methods are now common: feedback from coaches and checking the videos captured while skiing. Neither, however, makes clear the detailed movement differences between the expert skiers and the skier him/herself. To make training more effective, it is important to quantitatively evaluate the movement of the individual while skiing.

Several studies have detailed methods for measuring body motion during skiing. One digitizes the motions of the body from camera data during ski jumping [1]. The other measures the motion by using inertial sensors [2]. It has been reported that plantar pressure distribution sensors can be used to measure how loads are applied to the skis [3]. However, showing the raw sensor data to the individual directly is not useful. The features of skiing movements should be extracted from the sensor data to establish effective training. In addition, the causality, that is, the relationship between

all the parts, should be explained using these features. Moreover, it is critical that the sensor system used should be unobtrusive such that the individual's movements while skiing are not disturbed.

This study proposes a method that can extract the features of ski turns by using a comfortable but effective measurement system. Inertial sensors are used to measure the motions of the body and skis. Plantar pressure distribution sensors are used to measure the plantar force, the loads placed on the skis. Experiments involving skiers of different skill levels have been performed and the features that show the skill level quantitatively have been extracted.

2. Materials and Methods

2.1. Participants

One expert skier (male, 22 years old) and one intermediate skier (female, 22 years old) participated in this study. These skiers were classified based on the official certification of skiing techniques as issued by the Ski Association of Japan (SAJ); see Figure 1. The expert skier was ranked “Technical prize” and the intermediate skier was ranked “1st degree”. The participants were provided with an information sheet that outlined the general purpose of the study and informed that they could withdraw at any time without penalty. All the methods employed in this study were approved by the Ethics and Safety Committees of NTT Communication Science Laboratories and were in accordance with the Declaration of Helsinki. The protocol number of the Ethics and Safety Committees of NTT Communication Science Laboratories is H30-002.

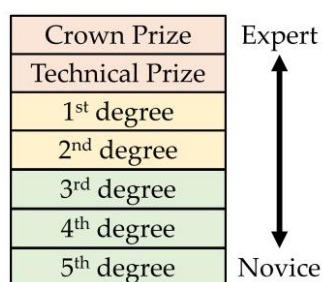


Figure 1. Certification rank of skiing techniques by Ski Association of Japan.

2.2. Instrumentation

Inertial sensors and plantar pressure distribution sensors were used in this experiment. All sensors were integrated in terms of temporal synchronization. In each trial, the temporal synchronization device sent a signal to trigger recording start in all sensors simultaneously. Data generated by each sensor were time stamped and stored in the sensor's own memory.

2.2.1. Inertial Sensor

Inertial sensors having a three-dimensional accelerometer and a gyroscope (Sports Sensing Co., Ltd., Fukuoka, Japan) were used to measure the motion of skis and body. Each sensor also calculated the quaternions to estimate the orientation of the plane on which the sensor was placed. The sampling frequency of each sensor was set to 1000 Hz. This study used three sensors: two on the skis in front of the bindings and one on the skier's waist at the L5-S1 position of the vertebral column as shown in Figure 2. The sensor on the waist captured the motion of body. Because of their small size, these sensors did not disturb the skier's movements during skiing.

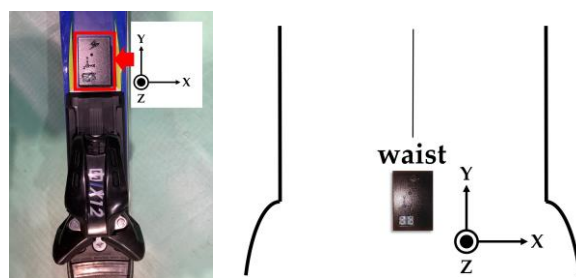


Figure 2. The inertial sensors were set on the skis in front of each binding (**left pane**) and on the skier's waist at the L5-S1 position of the vertebral column (**right pane**).

2.2.2. Plantar Pressure Distribution Sensor

The pedar® system (novel GmbH, München, Germany) was used as the plantar pressure distribution sensor (left pane in Figure 3). The sensors of this system are shaped like a shoe's insole making it possible to set them in both ski boots. The data capture unit of this sensor is also wearable. Therefore, participants were able to ski without any restriction. This system divides each plantar into 99 areas as shown in the right pane of Figure 3. The pressure distribution across each plantar was recorded. Sensor sampling frequency was set to 100 Hz.

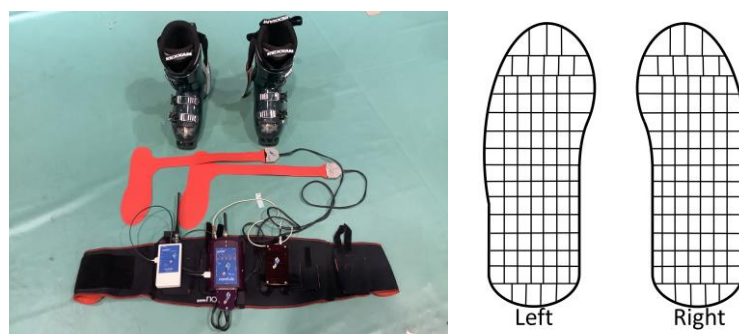


Figure 3. Plantar pressure distribution sensor set in each ski boot (**left pane**). The participants were able to ski without any restriction of movement. Each plantar was divided into 99 areas to measure the plantar pressure distribution (**right pane**).

2.3. Procedure

The experiment was conducted on a slope of an actual ski resort. The average grade of the slope was 25 degrees and the snow condition was moderately packed with no ice. Each participant was asked to conduct two runs. In each run, the participants were asked to ski down the slope with at least six turns. The procedure is described below; photos are shown in Figure 4. The participants stood still on a flat area at the top of the slope for five seconds to calibrate the sensors. After each run, they took the chair lift to return to the first position to repeat sensor calibration.



Figure 4. Experimental procedure in each run. Before skiing, the participant stood still for five seconds to calibrate the sensors. Then the participant moved to the top of the slope and started skiing.

2.4. Data Analysis

The analysis extracted each turn as one phase by referencing the angular velocity around the Y axis of inertial sensors placed on the skis. As shown in Figure 5, one ski-turn phase was extracted as bounded by the peak-to-peak values in the angular velocity around the Y axis. In this study, we focused on left turns and the outside leg for simplicity.

The posture change on the sagittal plane was estimated using the quaternions calculated by each sensor. This posture change describes the change from the body position in the calibration phase.

The plantar force was also calculated. We divided each plantar into two regions: front and heel side; see Figure 6. Each sensor's area was given as sensor's information and the plantar force was calculated using Equation (1) where “ F ” is the force in each region, “ A ” is the constant value of each sensor's area, and “ P ” is the pressure value in the area as output by the sensor.

$$F = \sum_{i=\text{target sensor's id}} A_i P_i \quad (1)$$

We examined the relationship between the skis' orientation change and the waist's orientation change or the change in the plantar force. The trigger generation device provided a recording start signal to all sensors so that all sensors were synchronized within 0.0001 s. To detect the plantar features impacting or determining how the skier loads the skis, the load ratio between the front and heel side was calculated. Moreover, to detect the features of body movements, the amount of the waist's orientation change, which indicates the direction of travel, was calculated. We plotted these relationships to identify the skill level from the differences in the distributions.

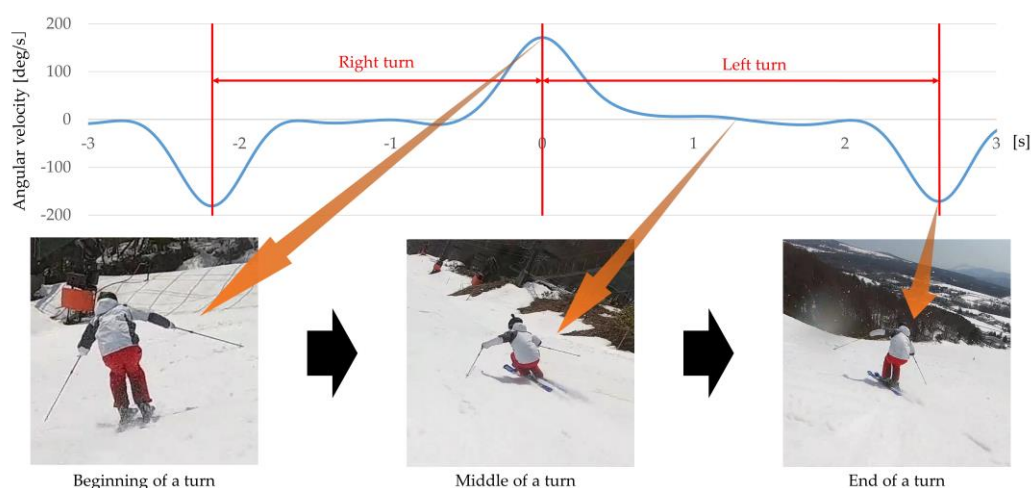


Figure 5. One phase of ski turn was extracted using the peak to peak of angular velocity around the Y axis of inertial sensor placed on the ski.

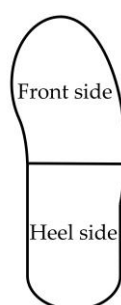


Figure 6. Plantar was divided into two regions, front side and heel side, and the plantar force was calculated for each region.

3. Results

3.1. Orientation Changes of Skis and Waist

The orientation changes of the skis and waist for one ski-turn phase were calculated for the direction of travel using quaternions of the inertial sensors; see Figure 7. The differences between maximum and minimum values for the expert skier were larger than those for the intermediate skier in both ski and waist data. The results suggest that the expert skier changed the waist and ski orientation to determine the travel direction more aggressively than the intermediate skier.

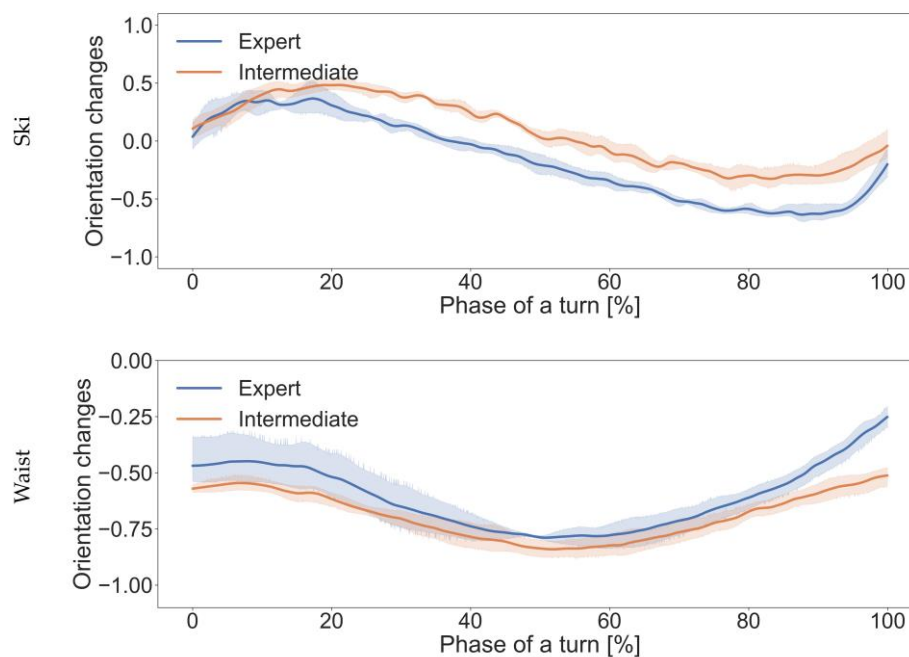


Figure 7. Orientation changes of ski and waist in one ski-turn phase for the direction of travel. Each orientation change was calculated from quaternions of each inertial sensor. The **(top)** plots ski data and the **(bottom)** plots waist data. The blue line is for the expert skier and the orange line is for the intermediate skier.

3.2. Plantar Force

Figure 8 plots the right plantar force distribution for the same left turn. For the expert skier, the total amount of plantar force in the heel side was larger than that in the front side, shown in the right pane of Figure 8. The results show that the expert skier used mainly the heel side to load the ski. On the other hand, for the intermediate skier, the total amount of plantar force in the front side was larger than that in the heel side, shown in the left pane of Figure 8. These results indicate that the expert skier mainly loaded the heel side of the ski, while the intermediate skier loaded the front side probably to avoid losing speed control.

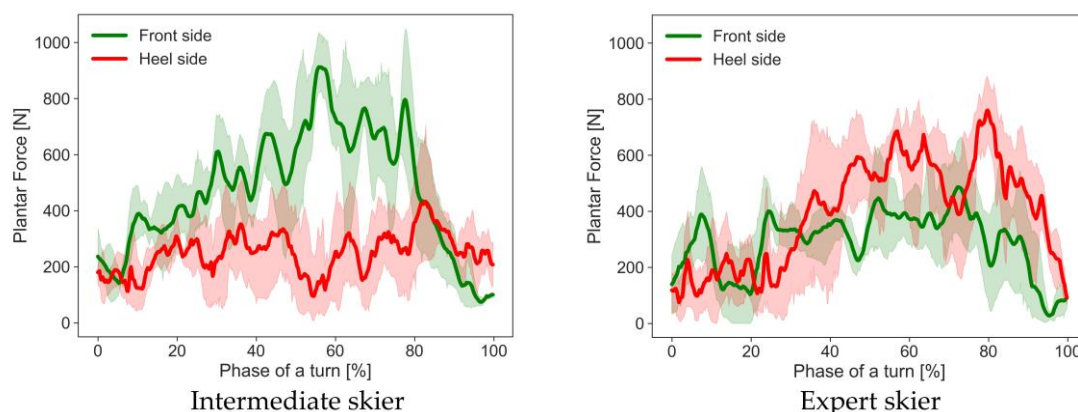


Figure 8. The right plantar force for the front and heel side during the left turn. The (**left pane**) is for the intermediate skier and the (**right pane**) is for the expert skier. The green line is for the front side and the red line is for the heel side.

3.3. Relationship between Ski-Turn Features and Orientation Change of Ski

The load ratio between the front and heel side components of the plantar force was calculated as the feature of ski loading. The relationship between this feature of the load ratio and the orientation change of the ski is shown in the left pane of Figure 9. Each dot shows each trial's data. We found that the expert skier tended to load the heel side of ski and to change the ski's orientation more widely. The amount of the waist's orientation change was also calculated as the feature of the orientation change, which represents the body movement. The relationship of the amount of the orientation change between ski and waist is shown in the right pane of Figure 9. The expert skier had larger waist orientation change than the intermediate skier. In addition, those features of the expert skier were related to larger ski orientation changes compared with those of the intermediate skier. These results suggest that, for the expert skier, using the heel to load the ski and making large changes in the waist's orientation yielded large changes in the ski's orientation.

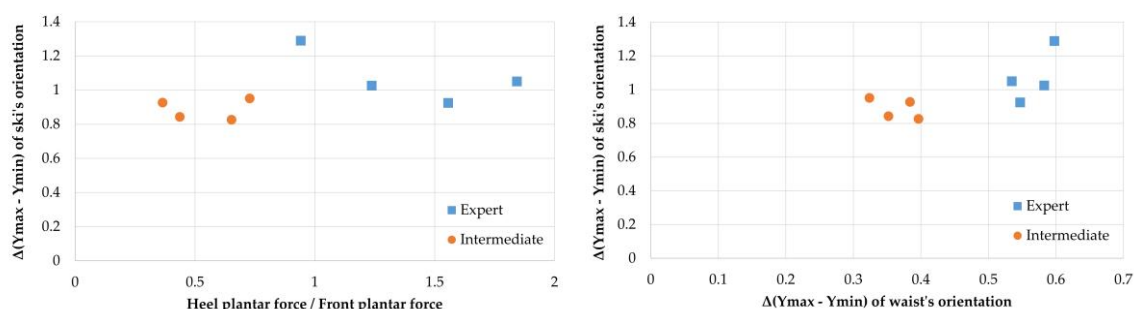


Figure 9. Relationship between two ski-turn features and orientation change of ski (calculated as the difference between the maximum and minimum values of the orientation). The (**left pane**) shows the load ratio between the front and heel side of the plantar force as the feature of ski loading (defined as the heel plantar force divided by the front plantar force). The (**right pane**) shows the amount of the waist's orientation change in the direction of travel as the feature of body movement.

4. Discussion

We found that the expert skier changed the skis' orientation aggressively in the direction of travel. The expert skier also loaded the outside ski with the heel, which would allow the waist to move into the proper position and yield effective ski loading. These characteristics were not demonstrated by the intermediate skier. Little is known about using wearable devices to extract features that can assess the skiing level. Our method can detect the features that are indicative of an expert skier and has the potential to yield highly effective learning interfaces.

5. Conclusions

We proposed a convenient system for assessing ski-turn features; it uses small inertial sensors and wearable plantar pressure distribution sensors. An experiment confirmed that the proposal could extract the features indicative of skillful skiing. We found that the expert skier changed the skis' position aggressively in the direction of travel. Our method has the potential to judge the skill level of ski turns conveniently and quantitatively.

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Conflicts of Interest: The authors declare no conflict of interest.

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