Comfortable Measurement of Ski-turn Skill using Inertial and Plantar-pressure Sensors

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Keywords: Realistic Evaluation, Ski, Carved Turn, Inertial Sensor, Plantar-Pressure Sensor.

Abstract: This paper proposes a comfortable and easy way to measure skill in ski turns with inertial and plantar-pressure sensors. The inertial sensors were used to log the motion of skis, and the plantar-pressure sensors were used to measure plantar-pressure distribution and analyze how the feet transmit force to skis. One intermediate skier and one expert skier, both adult males, participated in this experiment. They skied in short turns in six trials totally. According to the results of the experiment, the data for skidded and carved turns were clearly different. Therefore, we consider that our proposed measurement method will enable skiers to conveniently analyze their ski-turn skills on their own.

1 INTRODUCTION

In recent years, carved turns have become mainstream in skiing because they are less decelerative than skidded turns. It is especially important for intermediate skiers to acquire skill in carved turns. However, it is hard for skiers to analyze their own turns while actually skiing. Realistic evaluation on the ski slope is an effective way for skiers to autodidactically learn how to execute turns. For this purpose, a simplified measurement method that doesn't disturb skiing action is required. In addition, the system should be comfortable to wear and allow easy measurement. Thus, it should be compact, and measurement items must be kept to a minimum. In this study, we measured the motion of skis and the force added to skis from the feet. The motion of skis was measured with inertial sensors (Fasel et al., 2017), and the plantar-pressure distribution, which shows which area of the plantar applies a load to skis, was measured with plantar-pressure sensors (Falda-Buscaiot et al., 2017).

This paper proposes a comfortable and easy way to measure skill in ski turns with these sensors.

2 METHODS

2.1 Participants

One intermediate skier and one expert skier, both adult males, participated in the experiment. The intermediate skier skis with skidded turns. On the other hand, the expert skier skis with carved turns. Before the experiment, they were provided with an outline of the general purpose of the study, which also informed them that they could withdraw at any time without penalty. All methods used in this study were approved by the Ethics and Safety Committees of NTT Communication Science Laboratories and in accordance with the Declaration of Helsinki. The protocol number of the Ethics and Safety Committees of NTT Communication Science Laboratories is H30-002.

2.2 Measurement Procedure

The participants skied down the slope several times to warm up before the experiment. There were six trials in total, and they skied in short turns in each trial. They were asked to try to keep the rhythm of their turns constant. In the experiment, they wore insole-type plantar-pressure sensors in their ski boots. An inertial sensor was mounted on each ski. Both sensors recorded data synchronously during each trial. Since these sensors are easy to wear and set up, it would be easy for skiers to set them up on their own. Each turn in each trial was extracted from the turn start to its end as one phase. We also shot movies at 60 fps from the top of the slope to verify the relationship between the body motion and sensor data.

Matsumura, S., Ohta, K. and Kimura, T.
Comfortable Measurement of Ski-turn Skill using Inertial and Plantar-pressure Sensors.
DOI: 10.5220/0006959301450148
In *Proceedings of the 6th International Congress on Sport Sciences Research and Technology Support (icSPORTS 2018)*, pages 145-148
ISBN: 978-989-758-325-4

2.2.1 Inertial Sensors

We used two nine-axis wireless inertial sensors (LP-WS1105, LOGICAL PRODUCT). The sensors were mounted on the skis in front of the bindings, as shown in Fig. 1. The x axis was perpendicular to the skiing direction, the y axis was along the direction of skiing, and the z axis pointed towards the ground. Right-handed screw rotation in the positive direction was positive rotation. The sampling rate was 1,000 Hz, and data were logged in each sensor's memory. We measured acceleration, rotation, and geomagnetism for all three axes to analyze the motion of skis. The data were passed through a 10-Hz low-pass filter for preprocessing. In this study, we focused on the angular velocity profiles based on the rotation data.

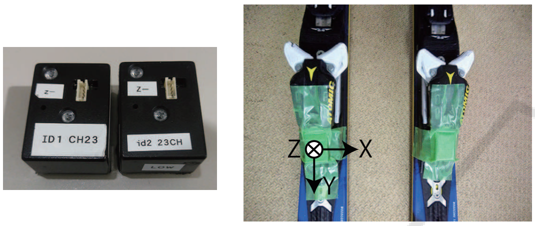


Figure 1: Inertial sensors (left) were mounted in front of the bindings.

2.2.2 Plantar-pressure Sensor

We used the pedar system (novel.de) as a plantar-pressure sensor. This system divides the plantar into 99 sections and measures the pressure in each section. The sampling rate was 100 Hz. In this study, we divided the plantar into four areas as shown in Fig. 2. The sensor's values in each area were summed up.

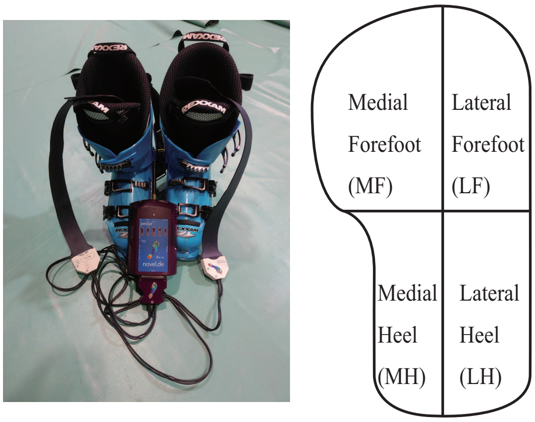


Figure 2: The plantar sensor and the four plantar areas. Pressure was calculated in each area. Right foot is shown.

3 RESULTS

3.1 Angular Velocity on Skis

Each turn was extracted from the turn start to end as one phase. According to the inertial sensor data, the time series of angular velocity differed between skidded and carved turns.

Figure 3(a) and (b) show the angular velocities of both skis along the x axis, which indicates fluttering of the skis perpendicular to the skiing direction. Large fluttering was observed in the middle of the turn phase in the intermediate skier, while stable behavior during the whole phase in the expert skier.

Figure 3(c) and (d) show the angular velocities along the y axis, which indicates tilting of the skies in the skiing direction. The results demonstrate that the changes in tilted velocities inward or outward were larger and jaggier in the intermediate than in the expert skier. Notably, the expert's turns stopped tilting the skis, and the tilt angle stayed the same in the middle phase.

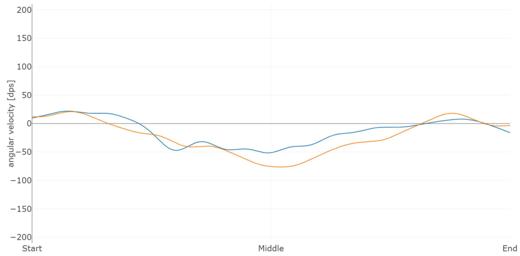
The z axis indicates skidding of the skis [Fig. 3 (e) and (f)]. The intermediate skier's turns showed the minimum peak in the middle of the turn phase. On the other hand, the expert's turns were stable, and the amount of change was also small. The amplitude of the angular velocity in skidded turns was larger than in carved turns.

These angular velocity results indicate that the intermediate skier skied with skidded turns, while the expert executed turns with very little skidding, which are characterized as carved turns.

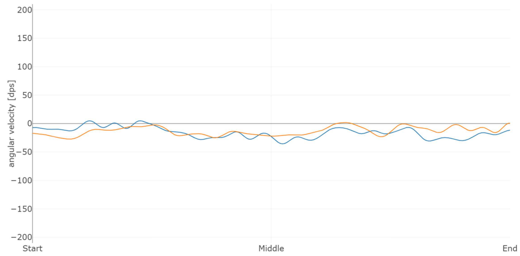
3.2 Plantar Pressure Distribution

Figure 4 shows the plantar pressure distribution in each planter area. The intermediate skier mostly used the outside leg to load the ski (upper map of Fig. 4), while the inside ski was little loaded. In particular, the medial forefoot of the outside leg loaded the ski in the first half of the phase, and then the lateral forefoot of the outside leg worked to load the ski in the last half of the phase.

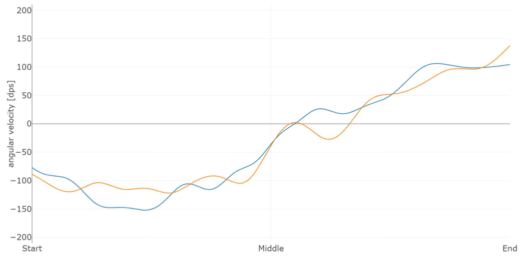
On the other hand, the expert used both legs to load the skis (lower map of Fig. 4). The medial forefoot of the inside leg worked strongly in the first half of the phase. In the last half of the phase, the medial heel of the inside leg was used and then medial heel of the outside leg was used. The leg putting the most load on the skis was switched from the inside to the outside leg during the last half of the phase, which was largely different from the intermediate skier's pattern.



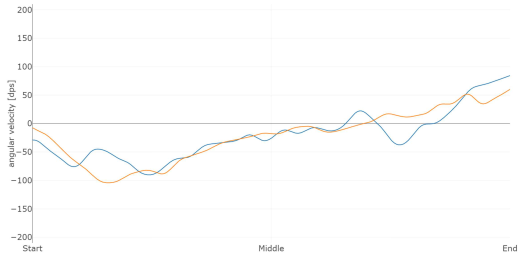
(a) X axis in the intermediate skier.



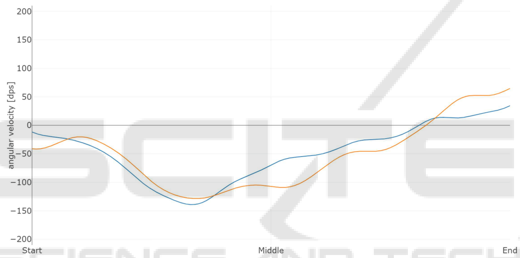
(b) X axis in the expert skier.



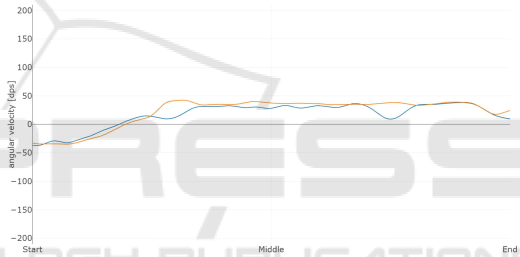
(c) Y axis in the intermediate skier.



(d) Y axis in the expert skier.



(e) Z axis in the intermediate skier.



(f) Z axis in the expert skier.

Figure 3: Angular velocity along three axes in skis. The horizontal axis shows the phase of a turn. The blue line shows the outside ski, and the orange line shows the inside ski.

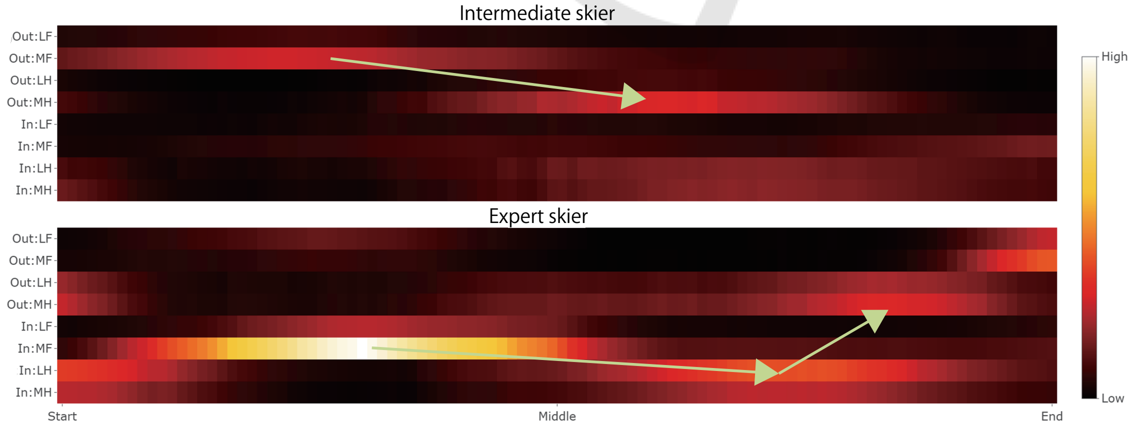


Figure 4: Plantar pressure in the four areas of both feet during a turn. The horizontal axis shows the phase of a turn. The upper map is for the intermediate shier; the lower map is for the expert skier. Meanings of the acronyms on the vertical axis are as follows. Out: outside leg for a turn. In: inside leg for a turn. MF: medial forefoot. LF: lateral forefoot. MH: medial heel. LH: lateral heel. E.g., Out:LF means "lateral forefoot of the outside leg for a turn".

4 DISCUSSION

In the experiment, we found that skidded turns in the intermediate skier were executed mostly with the outside ski. Moreover, the minimum peaks in the middle of the turn phase on the rotation of x and z axis indicated the fluttering and skidding of the skis.

On the other hand, the carved turns of the expert skier were executed with both skis. Ski motion in the carved turns was moderate and stable. This means that they were executed with a steady posture.

5 CONCLUSION

The proposed measurement system, consisting of inertial and plantar-pressure sensors, is comfortable to wear and makes it easy to measure ski-turn skill. According to the results of the experiment, data for skidded and carved turns were clearly different. Therefore, we consider that our proposed measurement will enable skiers to conveniently analyze their ski-turn skills on their own.

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