Realtime Sonification of the Center of Gravity for Skiing

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ABSTRACT

Control of body position is important in skiing. During turn, novice skiers often lean back and lose their control. Leaning back is natural reaction for people. They are afraid of the slope or speed. We develop a device to provide realtime sonification feedback of the center of gravity of the skier. The device guides the position of skier. A preliminary experiment shows possibility of improvements that the user become to be able to control their position immediately and even to overcome the afraid of slope and speed.

Categories and Subject Descriptors

H.5 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

General Terms

Design, Measurement, Human factors

Keywords

Augmented Sport, Sonification, Ski

1. INTRODUCTION

During skiing, control of body position is important. Novice skiers often lean back and lose their control. When the center of gravity (or more precisely, zero moment point) of the skier goes to backward, the front edge of the ski lose the contact to the snow. Therefore, the control of direction becomes difficult.

The importance of the position of the body on ski is taught very often in ski lessons. However, it is difficult to prevent the leaning back for novice skiers on steep slopes especially. To keep the correct position on slopes, skier must lean front. This means that skiers must overcome fear of falling down forward and lean their upper body to the downward of the slope. Moreover, the recognition of the center of gravity of the body is difficult for a skier. Slight displacement on the upper body changes the position of the center of gravity significantly. Of course, the pressure on feet changes according to the position of the center of gravity. However, it is not easy to find exact position during skiing.

We reach an idea that skiers need an additional feedback of body position or center of gravity. At first, in 2002, we tried to give third person's view to the skier, because the video recordings of skiing effectively teach the position to the skier [3]. We use a see-through HMD and a camera on the tip of a long pole (figure 1 The skier can see his/her realtime video image through the HMD. However, it is not easy to recognize the position of the center of gravity from the realtime video image during skiing. Perhaps, the skiing itself needs the processing of visual information and we cannot process the overlaid video image at the same time. Therefore, this time, we use the auditory channel.

2. RELATED WORKS

Sonification is one of popular methods in biofeedback. Chiari *et al.* [2] proposed audio biofeedback system for balance improvement. Hummel *et al.* [4] proposed sonificatoin of German wheel sports and improve the performance.

Some researchers have been focused on ski as a target of sensing, controlling and computation from 1970s. There are many patents on safety release of ski bindings and some of them employ sensors and electronic method [6]. MacGregor *et al.* [5] creates a ski binding with 6DOF force sensor and micro computer to record the force data. Their micro computer also controls the binding to improve the safety.

Brodie *et al.* [1] measures whole body motion and pressures on feet with GPS, inertial motion capture and insole pressure distribution sensors. They achieve capturing of entire body motion and external forces precisely. They also mention acoustic feedback of external force. However, they don't do yet and their purpose concentrates to speed up for racing and the idea is sonification of acceleration which will

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Figure 1: Ski with third person's view

not suit for position control for novice skiers. We focus on novice skiers who do not acquire sensation of body position or center of gravity on ski yet.

3. PROPOSED SONIFICATION

The position of the center of gravity can be obtained by force sensors. We need to design correspondence between the values of the force sensors and sound feedback. Control of ski is to speed down by turning or braking. Both turning and braking requires forward position. On the other hand, backward position loses control and increases the speed.

We employ a metaphor of engine sound. A lower pitch sound corresponds to a forward position and a higher pitch sound corresponds to a backward position. From the engine sound metaphor, the user easily recognizes whether the current position of the body increases or decreases the speed in realtime. In addition, a lower engine sound gives an image of larger torque and braking which gives the skier an image that the skier controls the ski with a large force. Because there are left and right feet, there are two engines. The balance of the volume of the two engine sounds corresponds to the balance of the total forces acting on feet. We also try to sonificate use of edges on each ski. We mapped use of edge to distortion of the feedback sound. When a skier uses an edge of a ski, the center of gravity of the ski comes near to the edge. Therefore, amount of use of edges is approximated by left and right position of center of gravity.

3.1 System overview

Figure 2 shows the sonification system. The system has force sensors, headphones and a micro processor of SH7125 to measure forces and to generate the feedback sound. SH7125 have integrated 8 channels ADC and a multi-function timer pulse unit. The output of the force sensors are connected to

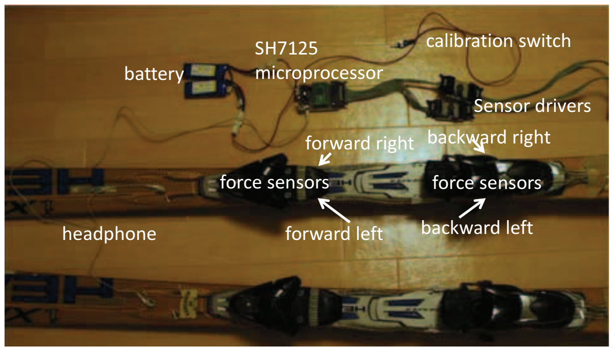

Figure 2: The sonification system

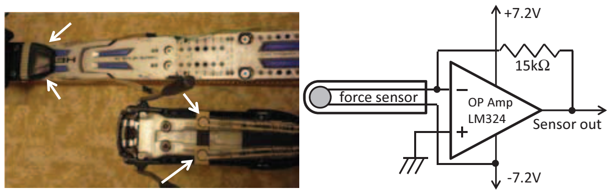

Figure 3: Force sensors and driving circuit

the inputs of ADC. The PWM function of the multi-function time pulse unit generates left and right signals to drive the headphone.

3.2 Force sensing

For the force sensor, we use FlexiForce ®sensors from Tekscan Inc. We put eight force sensors on skis, four for left and four for right. Because bindings are attached to skis by screw in most ski models, we can insert sheet type force sensors between the bindings and skis. The installation and the driving circuit are shown in figure 3.

3.3 Calculation of position of the center of gravity

The digital signals from ADC are averaged by IIR filter of 2 taps and scaled by minimum and maximum value of output signal calibrated beforehand. The center of gravity for each foot is calculated from this averaged and scaled signals by following equations;

$$x_{cog} = \Delta f_{fl} - \Delta f_{fr} + \Delta f_{bl} - \Delta f_{br} \quad (1)$$
$$y_{cog} = \Delta f_{fl} - \Delta f_{bl} + \Delta f_{fr} - \Delta f_{br} \quad (2)$$
$$s = \Delta f_{fl} + \Delta f_{bl} + \Delta f_{fr} + \Delta f_{br} \quad (3)$$
$$\Delta f_i = f_i - c_i \quad (i \in \{fl, fr, bl, br\}), \quad (4)$$

where, f_{fl}, f_{fr}, f_{bl} *and* f_{br} are the scaled and averaged signals from the forward left, forward right, backward left and backward right force sensors on the ski. c_i is a value of f_i when the user is on the center of the ski which is calibrated beforehand.

and s is sum of the forces on a ski. Then, the parameter for each (left or right) feedback sound is set by following expressions;

$$pitch = k_p y_{cog} \quad (5)$$
$$volume = k_v s \quad (6)$$
$$distortion = k_d |x_{cog}|, \quad (7)$$

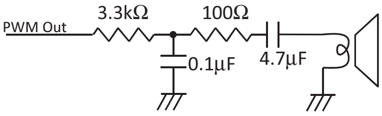

Figure 4: Low-pass filter and DC cut circuit for the sound output

where k_p, k_s, k_d is parameter to adjust sensitivity of the feedback sound.

3.4 Sound generation

The PWM function of the multi-function time pulse unit generates a pulse width of 0/1024 to 1024/1024 in 25kHz. The output is filtered by a circuit shown in figure 4. The width of the pulse is set by an interrupt of a timer. The interrupt program sets the pulse width to a value read from an array containing a wave data and increments the index for the array. Therefore, the pitch of the sound can be set by interval of the interrupt. The main program always reflects the *pitch* value to the interval of the interrupt. The interval T_{int} is

$$T_{int} = 128/(220(\sqrt[12]{2})^{pitch})[\mathrm{s}]. \quad (8)$$

The out sound is up and down along the chromatic scale.

The wave data is generated from the following expression;

$$pw = 512volume(0.4\sin(2\pi t) + 0.7\sin(4\pi t) + 1) \quad (9)$$
$$(t = \frac{0}{128}, \frac{1}{128}, ..., \frac{127}{128}),$$

where pw is the pulse width of PWM (0 to 1024) stored in the wave data. We make distorted sounds by limiting the pulse width by some maximum and minimum values. We prepare 16 waves which have different distortion levels. The interrupt program change the wave data to read based on the *distortion* value.

4. EXPERIMENT

A novice and an advanced skier used proposed system on a piste. The users bring a backpack which contains the sonification system and a PC to record data and video. We recorded sensor values, output sounds and two video images, one from the skier and one from outside. On the top of the piste, the user calibrates the system. It takes one or two minutes to calibrate maximum and minimum values of force sensors and center position. After that, the user skis to the end of the course and rides the lift and skis the course repeatedly. The equipment almost did not interfere to the user's activity.

Figure 5 and figure 6 show the center of gravity during some turns without and with sound feedback. Figure 6 shows that the center of gravity is kept forward with sound feedback, while it tend to be backward in figure 5. Figure 7 shows the position of the novice skier with and without sound feedback during the turn. The position of the novice skier is remarkably changed by proposed sonification of center of gravity. In my opinion, his position with the feedback is too forward. But, it will be easily able to teach. The user reported a lot of impressions eagerly during riding the lift. Followings are some of the impressions;

- The correspondence between change of the pitch and change of the speed is very intuitive. The correspondence between volume of the sound and balance on left and right is understandable. (They did not notice the changes on distortion of the sound.)
- The sound feedback gives evaluation of current position very quickly.
- Even in high speed or steep slope, I'm relieved by the feedback, because I understand that current position is good.
- I can control my center of gravity by tuning the pitch of the sound to a target level.
- When I get tired, it is difficult to tune the pitch to a target level and this tells me I'm tired.
- The fluctuation of the sound is quick but I can average and understand it.
- I notice the changes of the position of the center of gravity before and after small bumps from the changes on the pitch and this is interesting.

During the experiment, both users enjoyed skiing with sonification very much.

5. CONCLUSION AND FUTURE WORK

First of all, we find that sonification of the center of gravity is simple and very effective method to improve position of body in skiing. The metaphor of engine sounds effectively tells the effect of current operation of ski. The experiment in this manuscript is very preliminary one and is limited

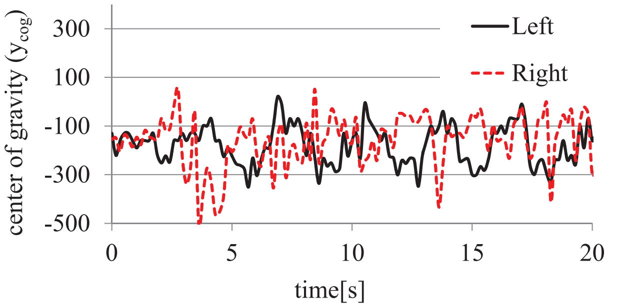

Figure 5: Forward and backward component of the position of the center of gravity (y_{cog}) on novice skier without sound feedback

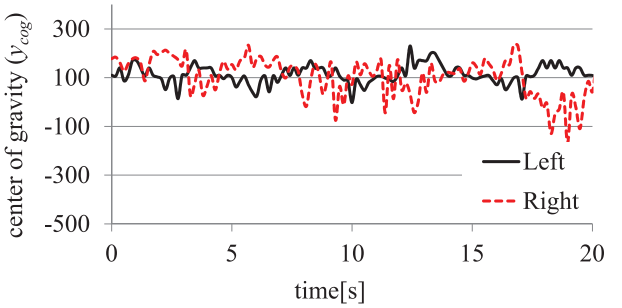

Figure 6: Forward and backward component of the position of the center of gravity (y_{cog}) on novice skier with sound feedback

in number of subjects, controlling and variation. We will conduct further study as soon as possible.

The feedback sound is not very sophisticated one. However, the users enjoy even such a simple sound. We should design a better sound feedback which entertains the user more.

Current implementation is already portable and suitable in pocket and has good usability in ski piste. The work of insertion of force sensor between bindings and skis may be difficult for end user. The cable between the skis and the backpack may be another problem. We will try to develop a binding with sensors and wireless transmitter by remodeling bindings in market. We believe that proposed sonification system will open a new era of ski lessons and skiing and will let many people know real fun of skiing.

Figure 7: The position of the novice skier with and without sonification. The directions of the photos are adjusted referring direction of trees and poles on the piste.

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