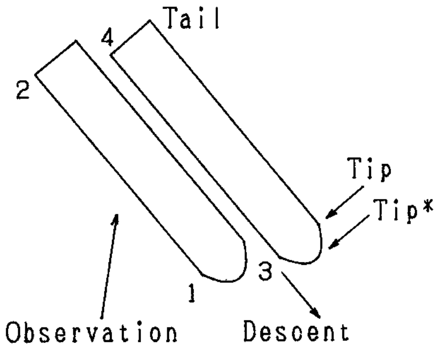

Fig. 7. Two skis, their four corner locations, direction of observation, and direction of sliding. "Tip" is the tip of the ski which touches the snow surface, and "Tip*" is the actual front tip of the ski.

cm. Reading of data was performed at the center of photographs; the error $\Delta U = U_2 - U_1$ was defined as the distance between $(U_1, V_1)=(0, 0)$ and $(U_2, V_2)=(0.01, 0)$, and the error $\Delta V = V_2 - V_1$ was defined as the distance between $(U_1, V_1)=(0, 0)$ and $(U_2, V_2)=(0, 0.01)$. Here, $\Delta X = X_2 - X_1$ and $\Delta Y = Y_2 - Y_1$ with units in cm. As can be seen from Table IV, ΔY is larger than ΔX, and ΔY depends on the height of the camera, H. As the value of H increases, the error decreases. If we set |reading error| <0.02 cm, $|\Delta Y| < 10$ cm within a range of L=5-10 m. The values of these $|\Delta Y|$ are quite similar to that of $|L_M - L_{MA}|$ described in §3.2.

4. Discussion

4.1 *Measurement accuracy*

In the experiment of Fig. 6, the error in the calculated distance between the foot of the camera and the marker, L_{MA}, was about 10 cm within the range of 10–15 m from the camera (Table I). The error of L_{MA} for the range between 5 m and 10 m was within 10 cm. We assume that the positional error of skis sliding downhill near these markers was on the same order as the error generated for the positioning of these markers. Approximate angular errors between different prints were within 0.2° (Table III). When the ski was 10 m away and facing the camera, the width of the ski (10 cm) corresponds to 0.6°. Accordingly, in a range of 5 m to 10 m, skis which move with time are considered to be drawn with the error range within 10 cm. Most of the error in marker distance L_{MA} shown in Table I might be generated by reading error of photographs (Table IV).

4.2 *Central angle A_0*

In this paper, we described three methods for the presentation of the central angle in §2. In the method of §2.2, the length of the ski can be used for S_L. For the analysis of ski photographs which do not include markers, this method is appropriate. However, as described in §3.3, the measurement accuracy of the length of the ski is not high with this method. Accordingly, the accuracy of A_0 is not high. The method described in §2.3, in which several markers were used, was employed for the analysis of the motion of skis in Fig. 6. The accuracy of these measurements is described in §4.1. When a zoom lens was used, the focal length was not always clearly defined. The method described in §2.4 is effective in such cases. Namely, if there are markers whose positions are measured at the center of the visual field (on the Y axis), A_0 can be calculated.

4.3 *Roughness of snow surface*

As shown in Fig. 8, if there is roughness on some section of the snow surface, the length a-b can be observed as A-B, and the results obtained from the print do not reflect reality. For example, if there exists a 1-cm-high bump (point a) on the snow surface, the error generated will be $(1/\tan 10°)=5.7$ cm in the case of $A_1 = 10°$. In this experiment, however, as the discrepancy between calculated and measured values of markers is small (as shown in Table I), bumps and dips of the snow surface are believed to be less than 1 cm. It is important to select snow surfaces that are as flat as possible.

Table II. Distance between the center of the ski and the foot of the camera, L_C, and the length of ski, S_L. Subscripts $_1$ and $_2$ represent the right and the left foot, respectively.

Ski number	Ski (cm)		Distance (m)	
	S_{L1}	S_{L2}	L_{C1}	L_{C2}
6	202	201	15.25	15.21
8	181	179	13.02	12.90
10	185	184	10.93	10.93
12	188	192	8.72	8.69
14	189	188	7.23	7.35
16	185	185	7.03	7.24
18	181	188	6.97	7.17

Table III. Angle between markers when viewed from the foot of the camera.

Ski number	Angle between markers (deg)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
6	0*	0.5	10.1	18.3			
8	0*	0.4	10.0	18.3	31.2		
10			10.0*	18.2	31.1		
12			10.0*	18.3	31.1		
14				18.3*	31.1	45.6	
16					31.1*	45.6	57.5
18							57.5*

Table IV. Errors on the snow plane, ΔX and ΔY, corresponding to the reading error of 0.1 mm at the center of the photograph. Size of the photograph: 18 cm × 13 cm, L_F=5 cm, L_V=28.1 cm. L is the distance between o and d in Fig. 2.

L	H=220 cm			H=110 cm		
	A_0	ΔX	ΔY	A_0	ΔX	ΔY
1247 cm	10°	0.45 cm	2.55 cm	5.04°	0.44 cm	5.00 cm
952 cm	13°	0.35 cm	1.52 cm	6.59°	0.34 cm	2.93 cm
494 cm	24°	0.19 cm	0.64 cm	12.55°	0.18 cm	0.81 cm

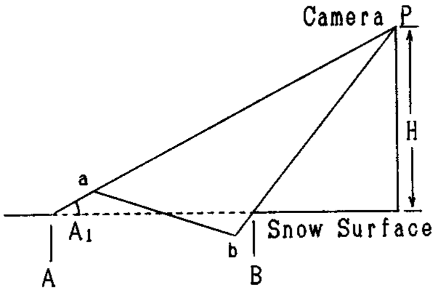

Fig. 8. Rough area on the snow surface. Point a is at the top of a bump and point b is in the depression. The distance between a and b appears through the camera as the distance between A and B.

4.4 *Height of camera*

As shown in Table IV, if the height of the camera, H, increases, the central angle A_0 also becomes large and the reading errors will be small. Therefore, H should be increased as much as possible.

5. Conclusions

Using a smooth ski slope in the experiment, the locus of ski movement shown in Fig. 6 can be obtained. This locus corresponds to the locus of a model ski sliding down a sand surface.[2] Thus, for the evaluation of the basic movement of a skier, quantitative analysis regarding time and location of movement of a ski can be carried out using this method.

Acknowledgment

The authors thank Mr. Kamihira in Hohnoki-Daira Ski Area, Gifu Prefecture, for the experiment on snow. Thanks are also due to Mr. Koido, the skier.

1) T. Sahashi and S. Ichino: Jpn. J. Appl. Phys. **26** (1987) 1185.
2) T. Sahashi and S. Ichino: Jpn. J. Appl. Phys. **29** (1990) 1203.
3) Y. Ikegami, S. Sakurai and K. Yabe: Jpn. J. Sports Sci. **10** (1991) 191 [in Japanese].
4) R. Shapiro: Res. Quart. **49** (1978) 197.