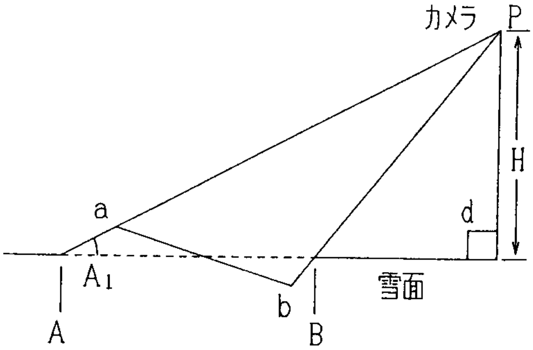

Fig. 14. Change in the length of the ski due to bumps and dips on the snow plane.

6. Problems in realizing diagram of ski descent

6.1 Problems

The diagram in Fig. 9(a) is a prototype diagram. Although the principle of the method of drawing was clarified, the following problems existed and the method was not practical.

(1) After determining A_0, other coordinates are obtained. Mistakes in reading and writing the above values produce errors. In addition, errors differ depending on whether the values are three-digit or four-digit numbers.. When the number of photographs is 10, then the number of coordinates becomes approximately 100.

(2) Loci of two skis are first drawn independently on different sheets of graph paper and then are redrawn on one sheet making use of a common object K in the two figures. Even though errors between the two loci are small, when 10 or more pairs of loci are arranged, the total error may increase. How much error is generated from which connection of loci ?

(3) As in Fig. 14, when there are bumps and dips on a snow plane, skis tilt. The length $(a\sim b)$ of the skis is expressed as $(A\sim B)$ when viewed by camera p. When skis with identical length are photographed, they are observed to be longer in the photograph, and the center angle A_0 increases. Other coordinate values also vary.

(4) When the height H from the snow plane to camera p is low, the effects of the bumps and dips on the snow plane increase.

(5) In Fig. 9(a), a bump and dip pattern was used as the coexisting object K. When it is cloudy, bump and dip patterns are not visible on a photograph (see Fig. 15).

6.2 Ski analysis and computation

Ski data are input as coordinates, as described using Fig. 8. Figure 9(a) shows an example of output drawn on a sheet of paper. Processing of data between the input and the output generates errors. If we perform all the processing within a computer, then problem (1) described above will be eliminated. We explain the principle of the use of a computer below. The origin of the input of a photograph is s in Fig. 5. The origin on the snow plane is o. In Fig. 7, if the origin is moved from o to d (i.e., the foot position), the difference between the two visual fields becomes only the difference in the rotation angle viewed from d.

Therefore, when we arrange as many as 10 photographs, we can produce a locus of the skis on a single coordinate (on graph paper) after correction of the rotation angle. In addition, the computer can produce a locus of ski descent directly on the CRT as well as on a sheet of paper using a plotter. These kinds of processes have been made possible due to the advancement of computer technologies (increases in memory and computation speed) , and their popularization (due to the decrease in cost).

However, in practice, large amounts of error were generated and the diagrams of ski descents were impossible to draw in many cases. It is difficult to clarify where the errors are generated. We developed various calculation programs in a trial-and-error manner, and investigated the magnitude of errors. It was a difficult task to accomplish and required many years.

7. Points to be improved for the production of diagram of ski descent

7.1 Weather

We usually do not pay much attention to the weather when we take photographs of ski descents. However, after looking at printed photographs, we were disappointed with photograph taken when the weather was cloudy. Figure 15 shows the difference in photographs due to weather. In this case, the weather changed from (a) sunny to (b) slightly cloudy and to (c) cloudy (overcast), during a period of only approximately 10 minutes.

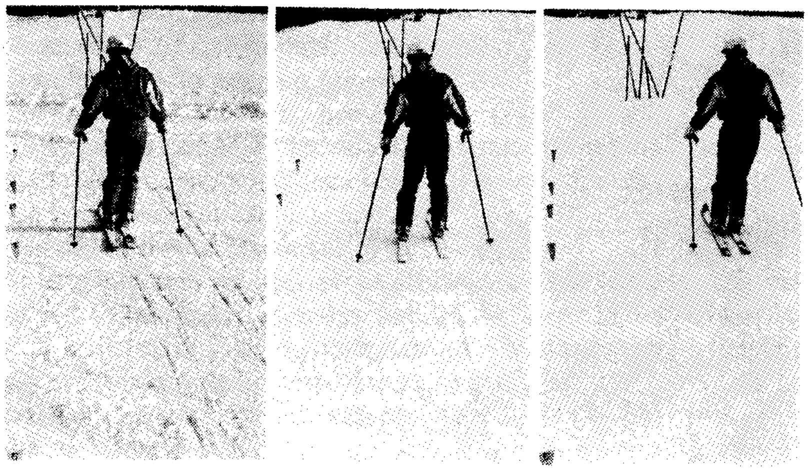

Fig. 15. Changes in photographs due to weather change.
Skier: Nakaya, at Hoonoki-daira Ski Resort, taken on January 27, 1992.

Fig. 16. Measurement of edging angle. Measurer: Sahashi, at Yamada Farm Ski Resort, taken on March 28, 1984.

Since we investigate the motions of a skier by examining the conditions of the skis and the snow plane in the photographs, we pay much attention to the weather and direction of the sun. In Figs. 3 and 15 (a), the sun is on the uphill side, producing a high contrast on the snow plane, and we can clearly observe conditions on the snow plane. In Fig. 16, the sun is on the downhill side, producing a low contrast, and it is difficult to identify conditions of the snow plane.

7.2 Marker

When it was not sunny, bumps and dips on the snow plane did not appear in the photographs. Therefore, we placed several markers near the line of descent. The markers are equivalent to the common object K in Fig. 7. The markers are shown in Fig. 15(a) as triangles on the left-hand side of the skier. It was demonstrated that more accurate A_0 values can be obtained using the markers than those obtained by the "ski-length method" described below. This was an unexpected result. The method of obtaining A_0 values using markers is as follows.

Assume that a marker is placed inside the plane apd in Fig. 5, and the distance between the foot position d and the marker is $(L+Y_2)$ in Fig. 6. This distance is measurable. By obtaining the angle B_2 using the marker in the photograph, A_0 can be determined using eq. (5). Since A_0 values are obtained using the distance to the marker, we call this the "marker method." When no marker is placed inside the plane apd in Fig. 5, the procedure becomes complex and therefore the explanation is omitted here. Refer to the ref. 24 for details. When several markers are placed around the skier, an average value of A_0 is obtained because the effects of both bumps and dips are eliminated. An A_0 value obtained using the ski length can also be referred to.

In the method described in Section 4, A_0 is obtained from the ski length; therefore, we call this the "ski-length method." In this method, errors due to the bumps and dips on a snow plane are easily generated. In the marker method, since the distance between the foot position d and the marker is actually measured, errors are generated between the marker and the skis. Meanwhile, in the ski-length method, errors are generated between the foot position and the skis.

7.3 Rotation of photographs

It was demonstrated that the rotation angle of a photograph can be determined using several markers. As the skier descends from the left to the right, the direction of the camera changes from the left to the right (Fig. 17). When the camera rotates up/down and left/right, the rotation axis (up/down, left/right) of the camera sometimes changes. If the rotation axis of the camera changes, the photographs are rotated, as shown in Fig. 18(b), from the original photograph in Fig. 18 (a). The apparent position of marker M_1 moves to a more distant position, and A_0 determined from this M_1 increases. Since M_2 is positioned at the center, the change in A_0 determined from M_2 is small. Since the apparent position of M_3 is closer, A_0 obtained from M_3 decreases. If the effects of bumps and dips are eliminated, by rotating Fig. 18(b) so that it looks the same as Fig. 18 (a), A_0 values obtained from the three markers become identical. By this process, the rotation angle of the photograph is determined.

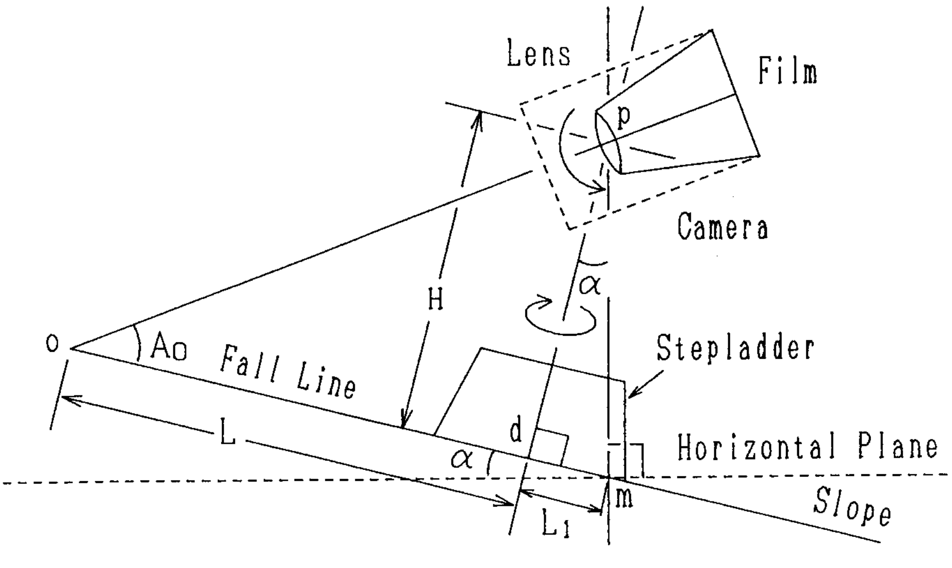

Fig. 17. Rotation of the camera up/down and left/right.

Such a rotation of photographs occurs when an image is enlarged onto photographic paper, and when the photograph is glued onto graph paper, as shown in Fig. 8.

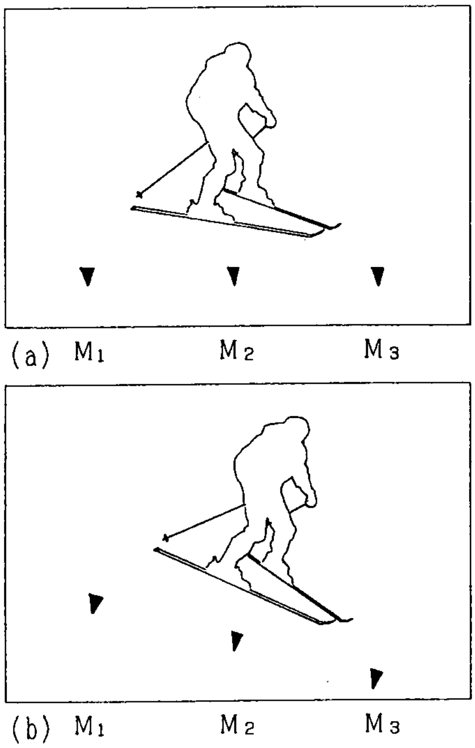

Fig. 18. Rotation of the photograph.

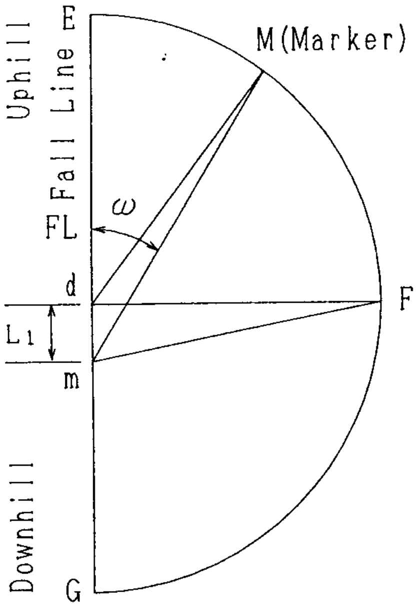

Fig. 19. Distance between the foot of the camera and the marker.

The rotation angle including such errors due to rotation of photographs can be corrected using several markers.

7.4 *Inclination of snow plane*

In the analysis of ski photographs, diagrams are produced based on the assumption that the snow plane (the plane ehjq in Fig. 5) is horizontal. However, an actual snow plane is inclined, as shown in Fig. 17. Therefore, the point vertically below the camera is not d, but m. It is difficult to determine the point d on a snow plane. Figure 19 shows a diagram of a snow plane. The line $(E\sim G)$ represents the fall line FL, and M is a marker. When the position vertically below the camera is represented by m, the distance $(M\sim m)$ between point m and the marker M, is measurable. There is a difference L_1 in the distances between $(M\sim d)$ and $(M\sim m)$. Assuming that in Fig. 17, the distance $(p\sim m)$ is approximately H, then L_1 is obtained by

$$L_1/H=\tan\alpha \qquad (7)$$

Based on the above data, the drawing sequence on the snow plane is explained below.

(1) When the distance $(M\sim d)$ between the marker and the foot position is known, the center angle A_0 in the photograph in which M is included can be determined using the marker method described in section 7.2. The position of the ski can be determined from A_0. Each diagram of the snow plane corresponding to each photograph is drawn. By connecting the diagrams as shown in Fig. 7, a series of diagrams showing a ski descent is obtained (Fig. 20). Figure 19 is obtained from Fig. 20 of the ski descent.

(2) Since the measurement of the distance $(M\sim d)$ on the ski slope is difficult, the distance $(M\sim m)$ is measured instead. Using a method similar to that explained in (1) above, the diagram similar to Fig. 20 is drawn, and then Fig. 19 is drawn. The angle ω formed between FL and $(M\sim m)$ is measured, then the approximate $(M\sim d)$ distance is determined using the following equation.

$$(M\sim d)=(M\sim m)-L_1\cdot\cos\omega\,. \qquad (8)$$

Using the value of $(M\sim d)$ obtained from eq. (8), procedure (1) is repeated. Mathematically, this method is repeated until convergence (the error is decreased gradually) or divergence (the error increases) occurs. We performed this correction once.

Without this correction, the distance between the marker and the foot position on the FL of the uphill side is longer by L_1, and that of the downhill side is shorter by L_1. Due to the error by L_1, systematic errors are generated. After correcting L_1, it was demonstrated that the inclination angle α on the snow plane can be determined.

7.5 *Height of the camera*

It is desirable that the camera be placed at a high position. An easy way to take photographs at a ski resort without constructing any special equipment is to use a stepladder. Using a stepladder with a height similar to our height, the height of the camera was approximately 2.5 m. The camera with a motor drive has a focal distance of 50 mm, and is equipped with 35-mm 36-frame film. Using Figs. 20 and 21, the easy-to-shoot and easy-to-analyze distances are explained. Within a distance of less than 5 m from the foot position of the camera, the skis quickly go outside the visual field, and analysis is difficult. An easy-to-analyze distance is between approximately 5 m (center angle A_0=27°) and 10 m (A_0=14°). When the center angle is 10° or less, errors from bumps and dips of the snow plane are easily generated, resulting in

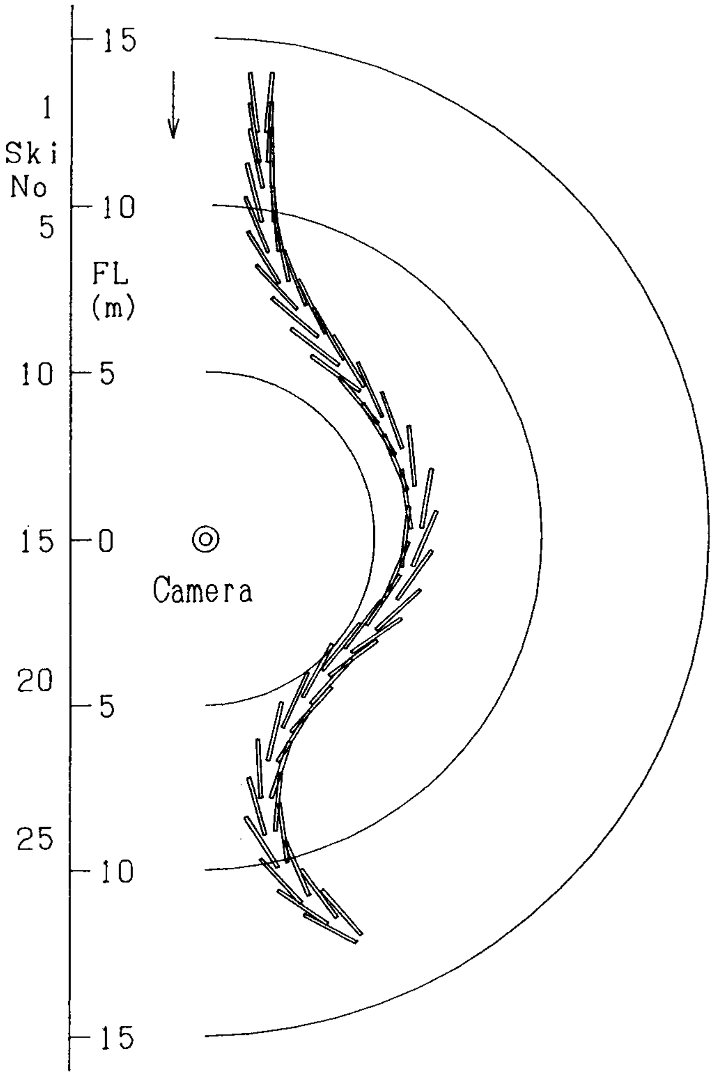

Fig. 20. Locus of snow plow; time interval between pairs of skis is 1/4 s.

difficulty in the analysis. When the center angle is 5° or less, analysis was almost impossible due to bumps and dips of the snow plane. Similar tendencies arose when using a video camera.

When the height H of the camera is low, bumps and dips of the snow plane easily affect the analysis. However, the effect of L_1 is small. When the height H is high, the opposite tendencies are observed.

We have endeavored to make the error on a diagram of ski descent drawn on a sheet of paper, 10 cm (width of a ski) or less. Namely, we aim to distinguish whether the skis are parallel or crossing.[24-26] With respect to the length of photographs and skis, easy-to-analyze conditions (with small errors) are that the ski length is approximately 1/3 the length of the photograph, and there are about 5 markers aligned laterally in the photograph. When the length of the ski is approximately 1/10 of the photograph, analysis becomes difficult.

7.6 Conditions of the snow plane

Most of the surfaces of snow planes used in the experiments were flattened by snow-press vehicles (Fig. 22). When new snow falls and accumulates, large bumps and dips are formed on the snow plane, making the analysis of photographs difficult.

7.7 Others

The above-mentioned points of improvement are significant items in the analytical techniques. We should be able to draw a diagram of ski descent such as that shown in Fig. 9 or 20 using these methods. However, many detailed analytical techniques remain to be explained. Further details can be obtained by contacting the authors directly.

8. Locus of skis drawn on a sheet of paper

The principle of reproducing the motion of the skis/skier on a snow plane using photographs involves drawing a geometrical diagram, as shown in Fig. 6, by determining the center angle A_0. In this paper, we explained two methods for the determination of A_0, the ski-length method in section 4.2 and the marker method in section 7.2. The former method is easily affected by bumps and dips of the snow plane. However, in principle, any photograph can be analyzed if the entire length of skis is included, which is convenient. The latter method provides highly accurate values of A_0, because the distance between the foot d and the marker is actually measured.

Using the marker method described in section 7.2 and correcting the rotation angle of the photograph (section 7.3) and L_1 (section 7.4), the practically usable locus of skis can be obtained. Figure 20 shows loci for the snow plow,[23] where the camera position is indicated by the double circles. Figure 22 shows photographs of a skier for the even ski numbers between 6~22 shown in Fig. 20.

The analysis method we developed is primitive. Some people have advised us to use a sensor to measure the positions of skis, and to input data into a computer. If what we are doing manually (analysis of Fig. 8) can be automated using a computer, input and analysis of the data can be completed instantaneously, which will be useful at the site of ski descents. This would be ideal for our analysis.

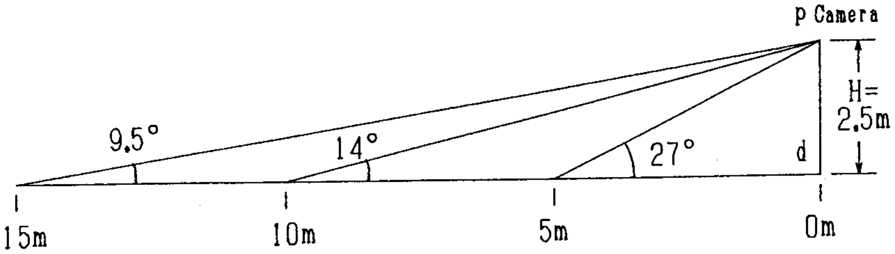

Fig. 21. Height of the camera H and center angle A_0.