Motion analysis and joint angle measurement of skier gliding on the actual snow field using inertial sensors

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Abstract

This paper deals with the motion analysis of skier gliding on the actual snow field using inertial sensors. It is difficult to measure the motion of skier gliding on the actual snow field since the gliding velocity is fast and the measurement area is large. Therefore, few studies have analyzed ski turns in gliding on the actual snow field. It is necessary to analyze the skier gliding on the actual snow field in resolving the mechanism of ski turns. In our previous study, we developed the motion measurement method of skier using inertial and magnetic field sensors. The 3D posture is estimated by applying the sensor fusion method, and the method can estimate the 3D posture compensating the drift error of gyro sensor and reducing the effect of dynamic acceleration of accelerometer. Furthermore, we developed the sensor fusion method estimating the 3D posture in local coordinate by the information of inertial sensors attaching the body segments. The joint angle of skier in gliding on the actual snow field can be estimated by this method and inverse kinematics. We conducted the measurement experiment by skier gliding on the actual snow field. The inertial sensors and the GPS receiver were attached to the body segments and the top of skier, respectively. Skier conducted carving and skidding turns in this experiment. We calculated the joint angles of skier by the information of inertial sensors, and the switchovers of turns are estimated by the GPS receiver output. The results of motion analysis indicated the major feature of skier’s motion and the difference between carving and skidding turns. Therefore, the analysis results can be used to the skill rating, the clarification of the mechanism of ski turns and the suggestion of more ideal turning form.

Keywords: Ski; motion analysis; posture; joint angle; inertial sensor; sensor fusion
1. Introduction

Skiing has a high industry scale and popularity around wide age group. Therefore, many studies have been conducted in several special fields of study. There are several studies on skiing such as the development of ski robot [1], the simulation of ski turns [2], the characteristics analysis of skiing [3] and the motion analysis of skier [4] in the field of engineering. These studies have been conducted to clarify the mechanism of ski turns. It is necessary to advance these studies for contribution to further progress of skiing. In the studies about the motion analysis of skier, the motion analysis of skier gliding on the actual snow field is important to resolve the mechanism of ski turns. In the previous studies, we have proposed the motion analysis methods of skier gliding on the actual snow field by using the DLT method, the 3D magnetic positioning sensor and the inertial and magnetic field sensors [5, 6]. Furthermore, we developed the estimation method of gliding velocity by combining GPS receiver and inertial and magnetic field sensors [7], and the motion analysis using joint angles of skier and gliding velocity was conducted [8]. This method can estimate the 3D posture compensating the drift error of gyro sensor, and the joint angles of skier are calculated by applying the inverse kinematics. This method can reduce the effect of dynamic acceleration. However, the performance of this method is inadequately in the motion measurement of skier gliding at the high speed on the actual snow field. Therefore, we developed the estimation method of 3D posture using inertial sensors, and we calculated the joint angles of skier attaching the inertial sensors [9]. This method can estimate the Roll-Pitch-Yaw angles in local coordinate compensating the drift error and avoiding the effect of dynamic acceleration. We indicated the joint angles of skier conducting the carving turn. The major features of skier can be clarified by using this method.

In this study, we conduct the motion measurement and analysis of carving and skidding turns of skier gliding on the actual snow field. We indicate the major features and the difference between these turns by the results of motion analysis.

2. Theory

The 3D posture of skier (Roll-Pitch-Yaw angles in local coordinate) is estimated by the sensor fusion method using the Unscented Kalman filter [9]. This method can estimate the 3D posture avoiding the drift error and the effect of dynamic acceleration by focusing the information of local coordinate. The Unscented Kalman filter is a nonlinear Kalman filter that can estimates the optimal value in the nonlinear state and measurement equations. The nonlinear state equation and the nonlinear measurement equation are shown in Eq. (1) and Eq. (2), where \( \omega_i \), \( \omega_i^{+1} \) are the gyro sensor outputs (angular velocity) in link \( i \) and link \( i+1 \), respectively, \( R_{i+1} \) is the rotational matrix from link \( i+1 \) to link \( i \), \( u_i=[u_{ix}, u_{iy}, u_{iz}]^T \) is the joint angular velocity, \( \theta_{i+1}^{+1} \) are the Roll-Pitch-Yaw angle of link \( i+1 \) in link \( i \) coordinate, \( \lambda_i, \lambda_{i+1} \) are the acceleration sensor outputs on link \( i \) and link \( i+1 \) and \( \lambda_i, \lambda_{i+1} \) are the sums of centrifugal and tangential accelerations representing the rotational component of acceleration sensors attaching on link \( i \) and link \( i+1 \).

\[
\begin{align*}
\dot{x}_{i+1} &= F(x_i) + w_i \\
x_i &= \left[ \begin{array}{c} \theta_{i+1}^{+1} \\ \phi_{i+1}^{+1} \\ \psi_{i+1}^{+1} \end{array} \right], \\
F(x_i) &= \left[ \begin{array}{c} \phi_{i+1}^{+1} + u_{ix}(t) + \sin(\theta_{i+1}^{+1}) \tan(\theta_{i+1}^{+1}) u_{iy}(t) + \cos(\phi_{i+1}^{+1}) \tan(\theta_{i+1}^{+1}) u_{iz}(t) \\ \psi_{i+1}^{+1} + \sin(\phi_{i+1}^{+1}) \sec(\theta_{i+1}^{+1}) u_{iy}(t) + \cos(\phi_{i+1}^{+1}) \sec(\theta_{i+1}^{+1}) u_{iz}(t) \end{array} \right] \\
\end{align*}
\]
These equations consist of the relational expression between joint angular velocity and angular velocity, the translation expression from the joint angular velocity to the time differential of Roll-Pitch-Yaw angles in local coordinate and the relational expression between accelerations in link $i$ and link $i+1$ are shown in Eqs. (3) - (5).

$$ y(t) = H(x(t)) + v(t) $$  (2)

$$ y(t) = \begin{bmatrix} A_p^{i+1} + A_{ct}^{i+1} \\ A_p^{i+1} + A_{ct}^{i+1} \end{bmatrix}, \quad H(x(t)) = \begin{bmatrix} R_{i+1}(t)^T (A_p^{i+1} + A_{ct}^{i+1}) \\ R_{i+1}(t)^T (A_p^{i+1} + A_{ct}^{i+1}) \end{bmatrix} $$

The joint angles are calculated by applying the inverse kinematics to the 3D posture. The 3D rigid link model for the calculation of joint angles is shown in Fig. 1. This model consists of the lumber, hip, knee and ankle joints. The lumber, hip and ankle joints are defined as the 3 DOF joint. In this study, the lumber and hip joint angles are calculated. The definition of lumber and hip joints is shown in Table 1.
Table 1. Definition of joints

<table>
<thead>
<tr>
<th>θ₁</th>
<th>Lumbar extension (-), flexion (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>θ₂</td>
<td>Lumbar lateral fold to left (+), to right (-)</td>
</tr>
<tr>
<td>θ₃</td>
<td>Lumbar left rotation (-), right rotation (+)</td>
</tr>
<tr>
<td>θ₄</td>
<td>Right hip extension (-), flexion (+)</td>
</tr>
<tr>
<td></td>
<td>Left hip extension (-), flexion (+)</td>
</tr>
<tr>
<td>θ₅</td>
<td>Right hip adduction (+), abduction(-)</td>
</tr>
<tr>
<td></td>
<td>Left hip adduction (-), abduction(+))</td>
</tr>
<tr>
<td>θ₆</td>
<td>Right hip internal rotation (+), external rotation (-)</td>
</tr>
<tr>
<td></td>
<td>Left hip internal rotation (-), external rotation (+)</td>
</tr>
</tbody>
</table>

3. Experiment

We conducted the measurement experiment by skier attaching the inertial sensor units and GPS receiver. The overview of the inertial sensor unit is shown in Fig. 2, and the setting position of sensors is shown in Fig. 3. The inertial sensor units are attached to the body segments (Upper body, lumber and femur) of skier, and the GPS receiver is installed to the top of skier. Skier conducted the carving and skidding turns after the run up. We calculated the joint angles (Lumber and hip) by the information of inertial sensors, and we estimate the switchovers of turns by the GPS receiver output. The sampling frequencies of the inertial sensor units and the GPS receiver are 100Hz and 5Hz, respectively. The measurement time is 30sec.

Fig. 2. Inertial sensor unit overview

Fig. 3. Setting position of measurement systems
4. Result

Results for the joint angles (Lumber, left hip and right hip) of skier conducting carving and skidding turns are shown in Fig. 4-6, where the black solid lines indicate the switchovers of turns. The switchovers of turns were calculated by latitude, longitude and altitude of GPS receiver output. The results of one turn were extracted by the switchovers of turns.

The rotation angle in skidding turn was bigger than the one in carving turn to conduct the big rotational motion of the upper body in the results for lumber joint angles. The flexion angle of hip joint in carving turn was bigger than the one in skidding turn. The flexion angles of left hip in left turn and right hip in right turn indicated the high joint angles in carving turn. These results represent that the skier inclined the upper body to the center direction of turn. In the all results, the joint angles in skidding turn were more vibration than the joint angles in carving turn. These results indicate that the skier cached on the effect of the vibration generating with the side skidding of ski. Therefore, the change of joint angles in carving turn was smooth. Therefore, this method can be used to clarify the motion of skier gliding on the actual snow field, and the analysis results indicated the major features of skier in the difference turns.

Fig. 4. Lumber joint angles (a) Carving turn; (b) Skidding turn

Fig. 5. Left hip joint angles (a) Carving turn; (b) Skidding turn
5. Conclusion

In this study, we conducted the motion analysis of skier gliding on the actual snow field using inertial sensors. We conducted the measurement experiment by skier conducting carving and skidding turns on the actual snow field, and the joint angles of skier were calculated by applying the estimation method of 3D posture. The motion analysis using the joint angles of skier indicated the major features of skier and the difference of motion in turns. Therefore, the results of this study can be used to the development of new teaching methods, the skill rating, the clarification of the turn mechanism, and the suggestion of more ideal turning form.

References


