An attempt of a new motion measurement method for alpine ski turns using inertial sensors

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Abstract

This paper proposes the motion measurement method of skiing turn using inertial sensor. This method calculates the joint angle of the skier gliding on the actual snow field using the information from the inertial sensor units. The sensor fusion estimates the 3D posture (Roll-Pitch-Yaw angle) of local coordinate system compensated drift error of gyro sensor output using acceleration sensor output. The unscented Kalman filter is used to apply the sensor fusion. The joint angle is calculated by applying inverse kinematics to the 3D posture.

In this study, the measurement experiment was conducted by the skier gliding on the actual snow field. The inertial sensor units were attached to body segments of skier. We obtained the joint angle of skier (Lumber, hip, knee and ankle). The results of motion analysis represented the major features of skiing turn, and the effectiveness of our proposed method was indicated.

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1. Introduction

Skiing has developed with improvement of equipments and techniques. There are several studies on skiing such as development of ski robot [1], simulation of skiing turn [2], characteristics analysis of ski [3] , state measurement of snow surface [4, 5] and the motion analysis of the skier [6]. In order to clarify the mechanism of skiing turns, it is important to analyze the motion of a skier gliding on an actual snow field. In the previous studies, we have conducted the motion measurement of ski turns using DLT method,
3D magnetic positioning sensor, inertial sensor (gyro sensor, acceleration sensor), magnetic field sensor and GPS receiver [7-10].

The measurement system by inertial sensor has a beneficial effect on the motion measurement of wide range such as snow sports. Therefore, it is necessary to develop the analysis method using inertial sensor. The 3D posture is obtained by calculating gyro sensor output. However, gyro sensor output includes drift error, and the calculation of the 3D posture includes time integration. Hence, the error of 3D posture increases with passage of time. The sensor fusion was applied to compensate drift error [11, 12]. However, the previous methods have not taken the effect of translational acceleration into consideration, and these methods cannot be applied to the motion measurement of ski turns which generate a lot of translational acceleration. Therefore, we have developed the sensor fusion method considering the effect of the translational acceleration [13]. The motion measurement of ski turns using this method can obtain the 3D posture of the skier compensating drift error.

This paper proposes the motion measurement method using inertial sensors. The measurement experiment is conducted by the skier gliding on the actual snow field, and we indicate the effectiveness of the proposed method using the results obtained by applying this method.

2. Measurement system

The measurement system is shown in Fig.1. This system consists of gyro sensors (Analog Devices, ADIS16110), an acceleration sensor (Hitachi metals, H30CD) and a PIC micro controller (PIC16F88). It measures 3-axis angular velocity and 3-axis acceleration. The PIC micro controller that is installed to this system transmits the information from the inertial sensors to a personal computer (notebook). The sampling frequency of this system is 100Hz.
The experiment was conducted by the skier gliding on the actual snow field. The measurement systems were attached to upper body, lumber, femur, lower thigh and ski boot of skier, respectively. Skier conducted periodical carving turn. The measurement time is 30sec.

The systems were attached to body segments (upper body, lumber, femur, lower thigh and ski boots) of skier. Setting position of the measurement systems is shown in Fig.2. The personal computer and battery were installed to the backpack of skier.

3. Theory

In this study, we used the sensor fusion to obtain the 3D posture of body segments. The sensor fusion estimates the 3D posture (Roll-Pitch-Yaw angle) of local coordinate system using the unscented Kalman filter (UKF). The nonlinear state equation (Eq.1) is established by the relational expression between joint angular velocity and angular velocity (Eq.2) and the relational expression between Roll-Pitch-Yaw angle and joint angular velocity (Eq.3), the nonlinear measurement equation (Eq.4) is established by the relational expression between the acceleration of link 

\[ x_{t+1} = F(x_t) + w_t \]

\[ x_t = \begin{bmatrix} i\varphi_{i+1} \\ i\theta_{i+1} \\ i\psi_{i+1} \end{bmatrix}, \quad F(x_t) = \begin{bmatrix} u_x + \sin i\varphi_{i+1} \tan i\theta_{i+1} u_y + \cos i\varphi_{i+1} \tan i\theta_{i+1} u_z \\ \cos i\varphi_{i+1} u_y - \sin i\varphi_{i+1} u_z \\ \sin i\varphi_{i+1} \sec i\theta_{i+1} u_y + \cos i\varphi_{i+1} \sec i\theta_{i+1} u_z \end{bmatrix} \]

\[ u_i = \omega_i - i^{-1} R_t^T \omega_{i-1} \]

\[ \begin{bmatrix} i\varphi_{i+1} \\ i\theta_{i+1} \\ i\psi_{i+1} \end{bmatrix} = \begin{bmatrix} 0 & \sin i\varphi_{i+1} \sec i\theta_{i+1} & \cos i\varphi_{i+1} \sec i\theta_{i+1} \\ 0 & \cos i\varphi_{i+1} & -\sin i\varphi_{i+1} \\ 1 & \sin i\varphi_{i+1} \tan i\theta_{i+1} & \cos i\varphi_{i+1} \tan i\theta_{i+1} \end{bmatrix} \begin{bmatrix} u_{ix} \\ u_{iy} \\ u_{iz} \end{bmatrix} \]

\[ y_t = H(x_t) + v_t \]

\[ y_t = \begin{bmatrix} A_{pi} + A_{ci} \\ A_{pi+1} + A_{ci+1} \end{bmatrix}, \quad H(x_t) = \begin{bmatrix} i R_{i+1}^T (A_{pi+1} + A_{ci+1}) \\ i R_{i+1}^T (A_{pi} + A_{ci}) \end{bmatrix} \]
4. Results

Results for the joint angles of lumber vertebra (rotation) were estimated by the sensor fusion and calculated by the gyro sensor output are shown in Fig.4, where joint angle of lumber vertebra is angle between the measurement system attaching to upper body and the one attaching lumber. The result calculated by the gyro sensor output includes drift error, and the error increases with passage of time. The result compensating drift error was estimated by the sensor fusion.

\[
\begin{align*}
\mathbf{R}_{i+1} &= \begin{bmatrix}
\cos'\psi_{i+1} & -\sin'\psi_{i+1} & 0 \\
\sin'\psi_{i+1} & \cos'\psi_{i+1} & 0 \\
0 & 0 & 1
\end{bmatrix} \cdot 
\begin{bmatrix}
\cos'\theta_{i+1} & 0 & \sin'\theta_{i+1} \\
0 & 1 & 0 \\
-\sin'\theta_{i+1} & 0 & \cos'\theta_{i+1}
\end{bmatrix} \cdot 
\begin{bmatrix}
1 & 0 & 0 \\
0 & \cos'\varphi_{i+1} & -\sin'\varphi_{i+1} \\
0 & \sin'\varphi_{i+1} & \cos'\varphi_{i+1}
\end{bmatrix}
\end{align*}
\]

Fig. 4. Joint angle of lumber vertebra rotation (sensor fusion and gyro sensor)

Results for the joint angles (lumber vertebra, hip, knee and ankle) are shown in Fig.5-8. In the all results, the joint angles were compensated the drift error by the sensor fusion. In the results of joint angle of lumber vertebra (Fig.5), the time of peek values of lateral fold joint angle approximately corresponded to the one of rotation joint angle. The hip and knee joints (Fig.6 and Fig.7) flexed during turn in order to maintain the head bent forward. The change of flexion-extension angles of right hip (Fig.6 (a)) and right knee (Fig.7 (a)) was bigger than the change of flexion-extension angles of left hip (Fig.6 (b)) and left knee (Fig.7 (b)). This result indicates that the motion of dominant foot is bigger than the motion of another foot. The change of ankle joint angles was smaller than other angles because of fixing of ski boot.
Fig. 5. Joint angle of lumber vertebra

Fig. 6. Hip joint angle (a) Left hip joint angle; (b) Right hip joint angle

Fig. 7. Knee joint angle (a) Left knee joint angle; (b) Right knee joint angle

Fig. 8. Ankle joint angle (a) Left ankle joint angle; (b) Right ankle joint angle
The results by the proposed method indicated the major features of skiing turn. Therefore, the proposed method is effectiveness the motion measurement of skiing turn.

5. Conclusion

In this study, we proposed the motion measurement method of skiing turn by inertial sensors. It is possible to calculate each joint angle of the skier using this method. The measurement experiment by the skier gliding on the actual snow field indicated quantitatively the joint angles of the skier in carving turns. This proposed method is possible to analyze the fast glide of skier because the effect of translational acceleration was taken into consideration. The major features of ski turns can be analyzed by the proposed method, which can be used as an effective method for suggesting a more ideal turning form and skill rating.

References