

## RESEARCH

# Pose estimation by extended Kalman filter using noise covariance matrices based on sensor output

Ayuko SAITO<sup>1\*</sup>, Satoru KIZAWA<sup>2</sup>, Yoshikazu KOBAYASHI<sup>2</sup> and Kazuto MIYAWAKI<sup>2</sup>

## Abstract

This paper presents an extended Kalman filter for pose estimation using noise covariance matrices based on sensor output. Compact and lightweight nine-axis motion sensors are used for motion analysis in widely various fields such as medical welfare and sports. A nine-axis motion sensor includes a three-axis gyroscope, a three-axis accelerometer, and a three-axis magnetometer. Information obtained from the three sensors is useful for estimating joint angles using the Kalman filter. The extended Kalman filter is used widely for state estimation because it can estimate the status with a small computational load. However, determining the process and observation noise covariance matrices in the extended Kalman filter is complicated. The noise covariance matrices in the extended Kalman filter were found for this study based on the sensor output. Postural change appears in the gyroscope output because the rotational motion of the joints produces human movement. Therefore, the process noise covariance matrix was determined based on the gyroscope output. An observation noise covariance matrix was determined based on the accelerometer and magnetometer output because the two sensors' outputs were used as observation values. During a laboratory experiment, the lower limb joint angles of three participants were measured using an optical 3D motion analysis system and nine-axis motion sensors while participants were walking. The lower limb joint angles estimated using the extended Kalman filter with noise covariance matrices based on sensor output were generally consistent with results obtained from the optical 3D motion analysis system. Furthermore, the lower limb joint angles were measured using nine-axis motion sensors while participants were running in place for about 100 seconds. The experiment results demonstrated the effectiveness of the proposed method for human pose estimation.

**Keywords:** Kalman filter, Motion sensor, Noise covariance matrix, Pose estimation, Sensor fusion

1		18
2	<b>Introduction</b>	19
3	Compact and lightweight nine-axis motion sensors	20
4	have been developed through advances in micro-	21
5	electromechanical systems technology; they have	22
6	come to be used for motion analysis in widely various	23
7	fields [1-8]. The nine-axis motion sensors are	24
8	applicable both indoors and outdoors because of their	25
9	portability. Several experiments have been conducted	26
10	to measure the motion of a skier gliding down a slope	27
11	and jumping off a hill using motion sensors [9,10].	28
12	The nine-axis motion sensors include a three-axis	29
13	gyroscope, a three-axis accelerometer, and a three-	30
14	axis magnetometer. Using information obtained from	31
15	the motion sensors, several sensor fusion algorithms	32
16	have been proposed for pose estimation: as one	33
17	example, a sensor fusion algorithm that can correct	34
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gyroscope drift using information obtained from the other two sensors has been used for human pose estimation during daily activities and exercise [11-13]. Furthermore, a sensor fusion algorithm able to correct the magnetometer output using information obtained from a gyroscope has been used for pose estimation in a variable magnetic field [14,15]. The Kalman filter [16-20] and the complementary filter [21-25] are some pose estimation methods using sensor fusion.

The Kalman filter estimates the system state with a small computational load. Nevertheless, determining the process and observation noise covariance matrices in the Kalman filter is complicated. For a case in which the process and observation noise covariance matrices are time-invariant, the estimation accuracy might decrease if the sensor output noise increases. Moreover, the noise of the sensor output might vary because of long-term measurements. For that reason, adjusting the noise covariance matrices based on sensor output is important.

# Extended Kalman Filter Based Methods For Pose Estimation

**Emilie Sanchez**



## **Extended Kalman Filter Based Methods For Pose Estimation:**

This book delves into Extended Kalman Filter Based Methods For Pose Estimation. Extended Kalman Filter Based Methods For Pose Estimation is a crucial topic that needs to be grasped by everyone, from students and scholars to the general public. The book will furnish comprehensive and in-depth insights into Extended Kalman Filter Based Methods For Pose Estimation, encompassing both the fundamentals and more intricate discussions.

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    - Chapter 4: Extended Kalman Filter Based Methods For Pose Estimation in Specific Contexts
    - Chapter 5: Conclusion
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