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Structural Displacement Estimation through Multi-rate Fusion of Accelerometer and RTK-GPS Displacement and Velocity Measurements

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Abstract

For civil infrastructure monitoring, RTK-GPS sensors are commonly used to measure dynamic displacement. However, these sensors have poor precision (around 0.5 to 5 cm in the vertical direction) and a low sampling rate (up to 20 Hz). Furthermore, both the accuracy and the precision of the RTK-GPS sensors deteriorate when signals from satellites are not properly received by the sensors due to multipath, bad weather, signal blockage, etc. In this study, a new dynamic displacement estimation method is proposed so that the accuracy, precision, and sampling rate of dynamic displacement can be improved by combining the acceleration measured by a force-feedback accelerometer and the velocity and displacement measured by a low-cost RTK-GPS sensor. The uncertainty levels in the displacement and velocity measured by the RTK-GPS sensor are evaluated based on the quality of the received satellite signals, and the measurement from the RTK-GPS sensor is fused with the acceleration measured from the accelerometer using a two-stage Kalman filter. The performance of the proposed method is validated through a series of lab-scale tests and a field test conducted on Yeongjong Grand Bridge in South Korea. In the tests, the accuracy of the estimated vertical displacement was about 2 mm, and displacement, velocity, and acceleration are all simultaneously estimated at a sampling rate of 100 Hz.

Keyword(s): displacement, Kalman filter, RTK-GPS, accelerometer, data fusion

1. Introduction

Displacement is one of the key physical quantities necessary to understand the behaviors of civil infrastructure. For example, displacement has been measured for bridge load rating tests [1]. During earthquakes, structural damage of building structures is mainly produced by lateral displacement [2], and the building damage is assessed by estimating inter-story displacement [3]. Also, displacement has been widely used in building loss estimation [4], seismic design [5], and damage localization [6, 7]. Other applications, where displacement measurement is necessary, include structural control [8, 9], system identification [10, 11], and structural health monitoring [12-15]. Therefore, a number of sensing technologies have been developed for displacement measurement and estimation, and some of these sensing technologies are reviewed briefly.

The Linear Voltage Differential Transformer (LVDT) is one of the most widely used sensors for displacement measurement of civil infrastructure [16]. The sampling rate and the precision of the LVDT is theoretically infinite, but its precision can be limited by the performance of a power supply and a data acquisition. Tariq *et al.* [17] developed an LVDT system whose precision is within 0.01 mm. However, the application of the LVDT to large-scale civil infrastructure becomes challenging, because one end of the LVDT needs to be in contact with the target measurement point and the other end should be connected to a fixed support. Therefore, the LDVT often requires scaffold installation, and its typical application is limited to small to middle size structures.

Laser Doppler vibrometer (LDVs) is gaining popularity because it does not require any direct contact with