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Vision-based Hybrid 6-DOF Displacement Estimation for Precast Concrete Member Assembly

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Abstract. Precast concrete (PC) members are currently being employed for general construction or partial replacement to reduce construction period. As assembly work in PC construction requires connecting PC members accurately, measuring the 6-DOF (degree of freedom) relative displacement is essential. Multiple planar markers and camera-based displacement measurement systems can monitor the 6-DOF relative displacement of PC members. Conventional methods, such as direct linear transformation (DLT) for homography estimation, which are applied to calculate the 6-DOF relative displacement between the camera and marker, have several major problems. One of the problems is that when the marker is partially hidden, the DLT method cannot be applied to calculate the 6-DOF relative displacement. In addition, when the images of markers are blurred, error increases with the DLT method which is employed for its estimation. To solve these problems, a hybrid method, which combines the advantages of the DLT and MCL (Monte Carlo localization) methods, is proposed. The method evaluates the 6-DOF relative displacement more accurately compared to when either the DLT or MCL is used alone. Each subsystem captures an image of a marker and extracts its subpixel coordinates, and then the data are transferred to a main system via a wireless communication network. In the main system, the data from each subsystem are used for 3D visualization. Thereafter, the real-time movements of the PC members are displayed on a tablet PC. To prove the feasibility, the hybrid method is compared with the DLT method and MCL in real experiments.

Keywords: Displacement; 6-DOF; Vision; Monte Carlo localization (MCL); Precast concrete (PC)

1. Introduction

Construction affects many aspects of human life such as the environment, transportation, economy, and other social areas. It requires a huge budget and considerable amount of time. Accordingly, one of the most important issues in the construction industry is reducing construction time. In the past two decades, many studies (Yee and Chuan 2001, Pheng and Chuan 2001) were conducted to reduce construction period. Precast concrete (PC) and prefabricated construction methods have been widely used and are considered promising technologies to address this issue. For bridges, the average lifetime is approximately 50 to 100 years, whereas PC members should be replaced after 10 to 20 years because of live load (Caltrans 2004). Hence, PC members are replaced

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more than once during the lifetime of a bridge. The replacement of PC members is a burden to the economy and is time consuming. PC technology has led to significant advancement in manufacturing processes. However, the assembly of PC members still should be improved. Currently, a crane carries a PC member to a particular position, and subsequently, a worker brings it to the required location. In this circumstance, serious accidents can occur. Hence, it is important to develop a method that locates PC members quickly and safely.

In the field of civil engineering, numerous studies on vision sensor-based methods for estimating the displacement of infrastructures were conducted (Park *et al.* 2010, Ji and Chang 2008, Lee and Shinozuka 2006, Wahbeh *et al.* 2003, Olaszek 1999, Marecos *et al.* 1969). These methods are attractive candidates for guiding PC members. However, they are limited to 1D or 2D displacement measurement and cannot measure the 6-DOF (degree of freedom) relative displacement. Recently, several marker-based systems have been introduced to estimate the 6-DOF relative displacement of infrastructures (Jeon *et al.* 2010, Jeon *et al.* 2013, Jeon *et al.* 2014). Lee *et al.* (2012) estimated a 6-DOF relative displacement between a planar marker and a camera using the DLT algorithm. Myeong *et al.* (2014) applied this method to construction members, particularly for the rendezvous of the bridge members. Myeong *et al.* (2015) proposed a Monte Carlo localization (MCL)-based method for estimating the 6-DOF relative displacement of PC members. The DLT method for estimating 6-DOF relative displacement has several drawbacks. One of the problems is that when the marker is partially hidden, the DLT method cannot be employed for calculating the 6-DOF relative displacement because it cannot determine the minimum required number of corner point coordinates of the marker. Second, when the image is blurred, the DLT method cannot be used to determine the corner point coordinates of the marker easily because the image loses sharp shape at the corner of the marker. To overcome these problems, the MCL method is used for the cases where the marker is partially hidden and the image is blurred. However, this method shows some errors even if the image is not blurred because the method is based on the probabilistic localization method using particles. Hence, a hybrid method, which combines the advantages of the DLT method for homography estimation and MCL method, is proposed in this study. The hybrid method selects the 6-DOF relative displacement between the DLT and MCL methods based on which has a more accurate 6-DOF relative displacement.

2. 6-DOF relative displacement estimation with multi-markers

2.1 Multi-marker system for the rendezvous of PC members

The system proposed in this study is developed to estimate the 6-DOF relative displacement of two PC bridge construction members and visualize them with 3D graphics. For the assembly work of the PC members, the basic dimensions of the PC members range from 3 m to 20 m; hence, measuring the displacement of only one spot is insufficient for estimating the overall displacement of the member. Fig. 1 shows the subsystems, main system, and tablet PC of the proposed system. The multi-markers are installed on the static member, which is previously assembled, and the dynamic member, which is carried by the crane. Each subsystem consists of a camera, a single board computer (SBC), and a Bluetooth device. The camera captures the two markers, and the image processing and estimation of the 6-DOF relative displacement are conducted using the SBC. Generally, the worker of the crane is located approximately 20–30 m from the site of the assembly of the PC members, which is quite far. Hence, the 6-DOF relative displacement is transferred by