REAL TIME IMAGE PROCESSING BASED DISPLACEMENT MONITORING METHODS USING SMART DEVICES

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1. INTRODUCTION

During the 2011 Tohoku Earthquake, rubber bearings, very few in many, were found broken as first time in high way bridges. Though, numerical simulation of both structural seismic response analysis and ground motion simulation have been conducted for those bridges, it was very difficult to predict the behavior of both ground shake and structural response without any instrumental data measured nearby. This is a wakening call for the engineers and the researcher in both earthquake engineering and bridge engineering to aware the importance of structural seismic response measurements, especially, the deformation of some very key members of bridge structural such as isolation or energy dissipation devices, where the structural response and damage were focused at. However, traditional displacement measurement system, combined with displacement transducers, data log, hard disk, computer, power supply, modem and network connection, is high cost and difficult to install to very limited spaces such as top of piers.

Meanwhile, using smart devices can be one of the most cost-effective solutions to measure structural displacement and ensure a lot of valuable record data. Smart devices with their on-board computational and communication capabilities, improvements in built-in sensors and easy to offline or online programmable functionality, simplifies the collection of information about existing infrastructures and thus offers new opportunities in the field of structural vibration measurement with extremely low initial and maintenance cost. Built-in camera of smart devices is one of the most developed devices providing higher resolution and higher speed video features. Their powerful processors and memory allows on-board processing capabilities, eliminating the need for additional computers to perform extensive image processing. However, such advanced vision and embedded processing capabilities of smart devices have not been effectively utilized for dynamic displacement monitoring applications yet [1].

In this study, real-time structural displacement measurement methods by applying digital image processing techniques and using built-in camera of smart devices are developed. The effectiveness of proposed methods are verified by performing shaking table tests using sine wave loading. The reliable domain for frequency and amplitude measurement using different smart devices are clarified from those test results. The reliability of measurement has also been evaluated by and the advantages and limitations of the proposed methods have been summarized.

2. MEASUREMENT APPLICATION DEVELOPMENT FOR SMART DEVICES

Application programs were developed based on programming language of Objective-C and uniformed developing environment of Xcode for iOS application development. In order to measure real-time dynamic displacement, three most common image processing methods: Motion Detection, Corner Tracking and QR code tracking were applied to extract the structural displacement from images. The object of interest detected in video sequence is tracked by implementing above-mentioned image processing algorithm and with difference in the coordinate of target object in respective frames displacement measurement is obtained. The measured data is stored in the internal storage of the device as well as synchronized to cloud server using Dropbox sync API.

The motion detection method tracks the motion of all the moving objects in a video sequence. In this case tracking only the movement of specific target object becomes difficult. Meanwhile, corner tracking method and QR code tracking method tracks only the motion of corner feature and QR code feature respectively due to which these methods allow a robust solution for obtaining the movement of a desired target feature. Implementing the open source GPUImage framework library [2] to build the measurement application program allowed real-time processing of images with a stable sampling rate of 30 Hz with small deviation as shown in Fig. 1. This suggests that the sampling time accuracy offered by smart devices is quite consistent and reliable for measurement purpose.

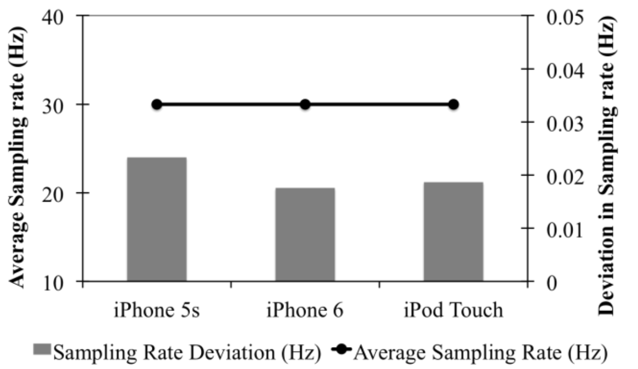

Fig. 1 Sampling time accuracy offered by smart devices

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3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The feasibilities and ranges of using smart devices for real-time displacement measurement using all the three methods were tested by simulating sinusoidal waves in a shake table as shown in Fig. 2. For this purpose smart devices' measurements were compared with laser displacement sensor used as reference.

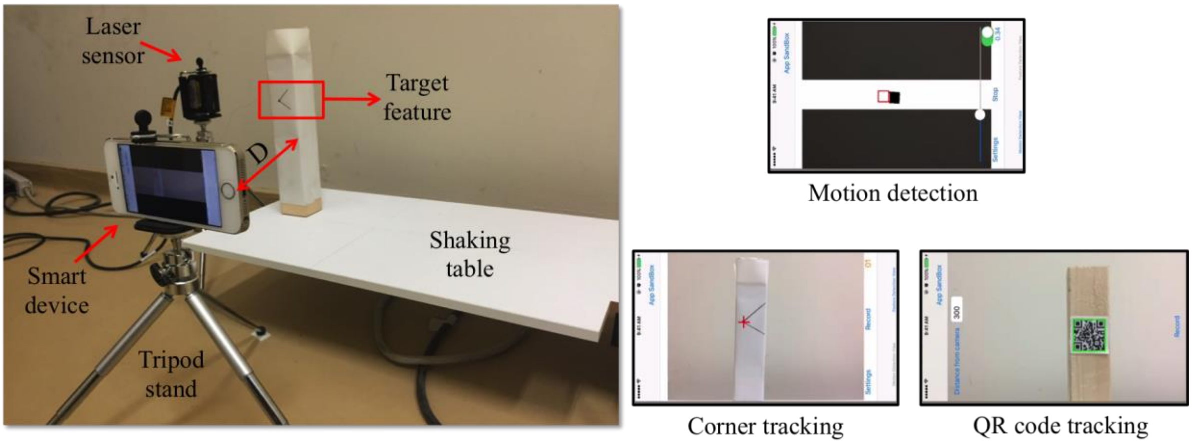

Fig. 2 Shaking table tests set up for image processing based displacement measurement

The comparison of displacement response measurement between smart devices and reference measurement for three different methods are shown in Fig.3. The test results showed that the Motion Detection method is highly sensitive to background noise. The Corner Tracking method is robust to the background noise. But it may also be difficult for practical applications in real field displacement measurement applications since the corner targets are not unique feature and hence false corners could be easily detected due to which error in measurement is bound to occur. Nevertheless, QR code tracking method can be said to have more practical applications, as this method is highly robust to background noise and because of its unique target feature, measurement is not affected.

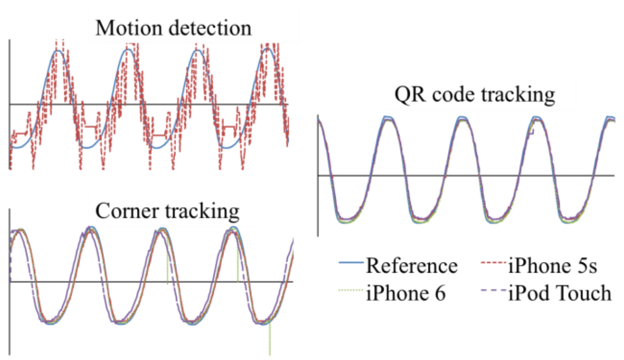

Fig. 3 Displacement measure plot at 0.2 Hz test frequency

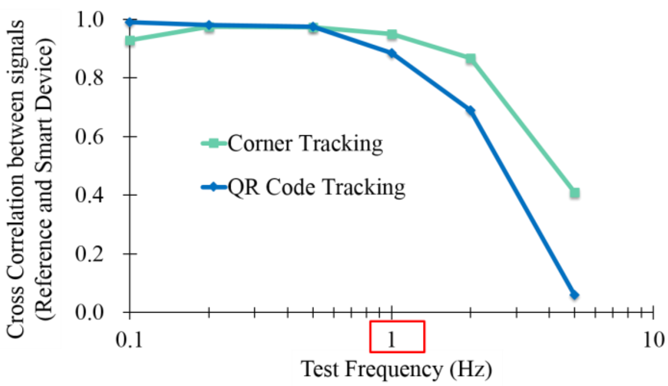

Fig. 4 Effect of test frequency on waveform measurement

From shaking table tests, it was also confirmed that all the methods of image processing used in current study could only be applied effectively for long period displacement measurement (frequency smaller than 1 Hz) as shown in Fig. 4. At higher frequency, real time images captured by smart device's camera lose its focus and the images become blurred due to which accuracy and probability of target recognition decreases and error in measurement increases.

4. CONCLUSIONS

The feasibility of smart device technologies for image process based displacement measurement and monitoring has been investigated in this study. Since the advanced measuring infrastructure are already integrated and expected to improve in future, design of a low cost yet computationally capable system for displacement measurement using smart devices is possible.

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