DOI: 10.24904/footbridge2017.01010

FOOTBRIDGE DYNAMIC PERFORMANCE ASSESSMENT USING INERTIAL MEASUREMENT UNITS

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Summary

Dynamic performance of footbridges is still a great concern to designers, operators and users, with many structures requiring investigation before, during and after construction to manage performance.

We have been investigating the use of wireless inertial measurement units (IMUs) designed for biomechanics, health and sports science application for estimating human dynamic loads or ground reaction forces (GRFs) on structures. The aim has been to move from direct measurements using force plates and treadmills, via optical motion capture in the laboratory (with application of Newton's Second law), to unconstrained field conditions. Initially we used IMUs to evaluate pedestrian synchronisation, but we found that a single IMU attached to the C7 neck vertebra can provide a remarkably accurate estimate of vertical GRF. With an ability to communicate and synchronise within a group wirelessly, to identify orientation and transform accelerations into world coordinates, IMUs can identify both the GRF force vectors and their time varying location with a moving pedestrian. As a side-benefit, the signal to noise ratio and synchronisation accuracy are sufficient to enable low-cost wireless footbridge ambient vibration testing and monitoring. So far we have used IMUs for ambient and forced vibration testing (the latter using a human shaker), moving pedestrian load and response measurement and crowd tracking. There are many more possibilities.

Keywords: footbridge; dynamic monitoring; modal testing; wireless sensor; pedestrian loading

1. Introduction

With structural safety of footbridges well managed, the concern for designers has for the last two decades shifted to vibration serviceability. There have been some classic vibration serviceability failures [1-2] to perform adequately under human dynamic loads usually with large crowds, while a number of footbridges are lively even for a single pedestrian. While there are now advanced design codes for footbridge dynamic design [3-4] dealing with group and crowd loading as well as lateral vibrations, the reality is often different to design and experimental assessment of the as-built structure is frequently required. The Vibration Engineering Section (VES) at the University of Exeter has been involved in experimental studies of a significant number of footbridges either to confirm adequate performance or to provide information and guidance on such structures that are lively in one way or another.

These experimental studies have uncovered two cases of synchronous lateral excitation and a number of footbridges with performance on the edge of acceptability. In such cases even with code compliance, retrofit may be deemed necessary. In all these cases the experimental studies centred on system identification, or more specifically experimental modal analysis, to identify modal frequencies, damping ratios, shapes and masses, often with some form of proof testing by individuals or crowds. Where a footbridge has been retrofitted (with some form of damper) further experimental evaluation is required to prove effectiveness.