# Error analysis for distributed fibre optic sensing technology based on Brillouin scattering

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# Abstract

This dissertation describes the work conducted on error analysis for Brillouin Optical Time Domain Reflectometry (BOTDR), a distributed strain sensing technology used for monitoring the structural performance of infrastructures. Although BOTDR has been recently applied to many infrastructure monitoring applications, its measurement error has not yet been thoroughly investigated. The challenge to accurately monitor structures using BOTDR sensors lies in the fact that the measurement error is dependent on the noise and the spatial resolution of the sensor as well as the non-uniformity of the monitored infrastructure strain conditions. To improve the reliability of this technology, measurement errors (including precision error and systematic error) need to be carefully investigated through fundamental analysis, lab testing, numerical modelling, and real site monitoring verification.

The relationship between measurement error and sensor characteristics is firstly studied experimentally and theoretically. In the lab, different types of sensing cables are compared with regard to their measurement errors. Influences of factors including fibre diameters, polarization and cable jacket on measurement error are characterized. Based on experimental characterization results, an optics model is constructed to simulate the Brillouin back scattering process. The basic principle behind this model is the convolution between the injected pulse and the intrinsic Brillouin spectrum. Using this model, parametric studies are conducted to theoretically investigate the impacts of noise, frequency step and spectrum bandwidth on final strain measurement error.

The measurement precision and systematic error are then investigated numerically and experimentally. Measurement results of field sites with installed optical fibres displayed that a more complicated strain profile leads to a larger measurement error. Through extensive experimental and numerical verifications using a Brillouin Optical Time Domain Reflectometry (BOTDR), the dependence of precision error and systematic error on input strain were then characterized in the laboratory and the results indicated that a) the measurement precision error can be predicted using analyzer frequency resolution and the location determination error and b) the characteristics of the measurement systematic error can be described using the error to strain gradient curve. This is significant because for current data interpretation process, data quality is supposed to be constant along the fibre although the monitored strain

for most of the site cases is non-uniformly distributed, which is verified in this thesis leading to a varying data quality. A novel data quality quantification method is therefore proposed as a function of the measured strain shape.

Although BOTDR has been extensively applied in infrastructure monitoring in the past decade, their data interpretation has been proven to be nontrivial, due to the nature of field monitoring. Based on the measurement precision and systematic error characterization results, a novel data interpretation methodology is constructed using the regularization decomposing method, taking advantages of the measured data quality. Experimental results indicate that this algorithm can be applied to various strain shapes and levels, and the accuracy of the reconstructed strain can be greatly improved. The developed algorithm is finally applied to real site applications where BOTDR sensing cables were implemented in two load bearing piles to monitor the construction loading and ground heaving processes.