Convolutional Neural Network for Improving Spatial Resolution of BOCDR

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Introduction

Brillouin optical correlation-domain reflectometry (BOCDR) [1,2], which is one of the distributed fiber-optic sensors, has various advantages such as operation by single-end light injection, high spatial resolution, high-speed operation, and cost efficiency.

In BOCDR, the "measured BGS distribution" is given by the convolution of a so-called "beat-power spectrum" and the "intrinsic BGS distribution" [2], which is related to the Brillouin frequency shift (BFS) distribution. Determination of the BFS distribution, and hence of the strain and temperature change applied to the fiber under test (FUT) from the measured BGS distribution, therefore requires deconvolution of the latter. Conventionally, this calculation has been performed by computing the Fourier transform of the measured BGS distribution and the beat-power spectrum and then by applying deconvolution in the frequency domain [3]. However, this requires knowledge of the functions of both the measured BGS distribution and beat-power spectrum; otherwise, derivation of the intrinsic BGS distribution, and hence the BFS distribution, will be extremely difficult, if not impossible.

Several machine-learning algorithms, in particular artificial neural networks [4,5], support vector machines [6], autoencoders [7], and deep neural networks [8,9], have been proposed in BOTDA for more robust extraction of strain and temperature distributions. Yao et al [10] has also presented a concept of machine-learning-assisted BOCDR, but no specific results have been reported yet.

In this work, we aim to provide specific trial results of deep-learning-assisted BOCDR for the first time to the best of our knowledge. We employ a convolutional neural network (CNN) to obtain the intrinsic BFS distribution directly from the measured BGS distribution in BOCDR. By using this algorithm, actual spatial resolution of the system can potentially be enhanced compared with nominal resolution conventionally calculated using a convolved BGS distribution. We show that the spatial resolution can be at least 4 times higher than the nominal value.

Principle and Experiment

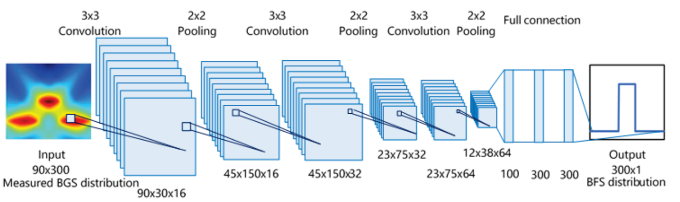
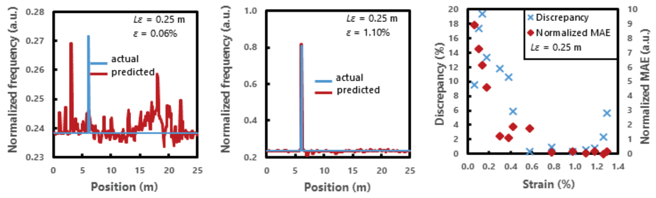


Fig. 1 Architecture of CNN used in this work.

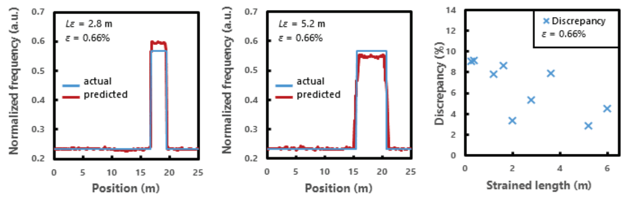
Here, 11520 90x300 arrays pertaining to the measured BGS distributions and their corresponding BFS distributions separated into 80% training, 10% validation and 10% testing sets were used. These were obtained from a MATLAB simulation free from noise, for various strains ranging from 0.06% to 1.36% applied to various sections along the length of the 25-m-long FUT. Note that here, we only considered the case where the FUT was strained along only a single section.

As shown in **Figs. 2(a)-(b)** the predicted BFS distribution shows good agreement with the actual BFS distribution at high applied strain, with only 0.57% discrepancy between the predicted and actual for 1.10% strain; contrary to low applied strain in which the predicted trend is not close to that of the actual. Both the evaluation parameters: percentage discrepancy at the midpoint of the strained section and mean absolute error (MAE) along the whole FUT normalized by the



(a) (b) (c)

Fig. 2 Actual and predicted BFS distributions when 0.25-m-long strains of (**a**) 0.06%, (**b**) 1.10% were applied at 6.0 m from the proximal end of the FUT. (**c**) Discrepancy and normalized MAE plotted as functions of strain (strain length = 0.25 m).



(a) (b) (c)

Fig. 3 Actual and predicted BFS distributions when 0.66% strains were applied to (**a**) 2.8-m-, and (**b**) 5.2-m-long sections at 18 m from the proximal end of the FUT. (**c**) Discrepancy plotted as a function of strained length (strain = 0.66%).

applied strain decreased with increasing strain. This indicates that BFS distributions at strains larger than a certain threshold (~0.4%), can be potentially predicted by the CNN even when the strained length is shorter than the nominal spatial resolution. In this simulation, 0.25-m-long strains were detected while the nominal resolution was 1.0 m, which is at least 4 times enhancement.

In **Figs. 3(a)-(b)**, all the results show the predicted trends being in good agreement with the actual trends but with some errors of strain magnitude. Although the trend for discrepancy versus strained length was not clear (somewhat decreasing with increasing strained length), the discrepancy was constantly less than 10% regardless of the strained length.

Conclusion

This paper provided the first specific trial results of BOCDR assisted by a deep-learning technique. A CNN was successfully trained and used in obtaining the BFS distribution from the measured (or convolved) BGS distribution in BOCDR. We showed that the spatial resolution predictable by this method is at least 4 times higher than the nominal value calculated using a convolved BGS distribution. We anticipate that this work will motivate future studies focused on performance improvement of BOCDR.

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