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Re-Weighted Adversarial Domain Adaptation For Vibration-Based Structural Damage Identification

Xiaoyou WANG, Yong XIA

Deep learning (DL) techniques have been developed for structural damage detection by training the network to dig damage-sensitive features from big data, which may comprise the structural dynamic responses only without knowing the excitation forces. This is promising for practical applications because the ambient excitations are commonly uneasy to measure. Despite the progress, most DL techniques suffer from the limitation that the network needs to be re-trained by re-collecting labeled data when the environmental conditions or structural sizes change. This limits the application of DL techniques to damage detection of practical structures, since many bridges may have the same topology but different sizes, whereas re-collecting labeled damaged data is expensive and often infeasible in structural health monitoring. The reason behind the performance degradation is that the datasets of different structures typically follow different distributions in feature spaces. Transfer learning, which is a subfield of machine learning, allows the knowledge transfer between different data distributions. As a subcategory of transfer learning, unsupervised domain adaptation (DA) aims to handle the data distribution divergence between source and target domains. Thus, knowledge learned from the labeled source domain could be intelligently applied to the unlabeled target domain. The unlabeled target data can be classified accurately by adapting the features with those of the labeled source data. This study explores the knowledge transfer from one structure with labeled damage data to the other different structure without any labeled data for damage identification. In common DA, the source and target domains are assumed to share an identical label space. However, structural damage is a rare and irreversible event during the service period, which usually occurs at limited positions. Therefore, the target label space may be one of or a small subset of the source label space that comprises all possible DSs, leading to the inconsistent label space between the source and target domains. In this regard, this study develops a re-weighted adversarial DA (RADA) network considering label space inconsistency for unsupervised structural damage identification. The proposed RADA network consists of a generator G and two classifiers, of which Generator G adopts the architecture of DenseNet with three dense blocks, each having three convolutional layers, and two classifiers are composed of two fully connected layers. The generator and two classifiers are trained in an adversarial manner. A weight parameter is introduced to loss function to mitigate the importance of irrelevant source classes in DA, which promotes the positive transfer by matching the feature distribution in the shared label space. The proposed method is applied to the knowledge transfer from one structure to the other with different sizes. With the proposed RADA method, the accuracies of the two classifiers are significantly improved compared with those using the network trained on the source data directly. Examples show that the RADA network significantly improves the classification accuracy in transfer learning problems with inconsistent label spaces, as compared with the networks without DA or without the re-weighting mechanism.