Weakly Supervised Approach to Defect Detection in Concrete Structures Using Hammering Test

Jun Younes Louhi Kasahara*, Hiromitsu Fujii†, Atsushi Yamashita*, Hajime Asama*
*Dept. of Precision Engineering
The University of Tokyo, Tokyo, Japan
Email: {louhi, yamashita, asama}@robot.t.u-tokyo.ac.jp
†Dept. of Advanced Robotics, Chiba Institute of Technology, Chiba, Japan
Email: hiromitsu.fujii@p.chibakoudai.jp

***Abstract*—The need to inspect concrete social infrastructures has put considerable attention on the automation of traditional methods such as the hammering test. In the past, supervised and unsupervised methods have been proposed for this task. However, they either require training data, and there heavy human involvement or additional sensors other than a microphone. In the present study, a novel approach to automation of the hammering test, using only a microphone and with only minimal human user involvement is proposed. The human user is asked for a couple of audio samples if they are similar or not and the audio feature space is shaped according to those answers. Experiment conducted using a concrete test block shows promising results obtained by the proposed method.**

***Index Terms*—concrete inspection, weak supervision, clustering, audio data**

I. Introduction

Concrete is heavily used in most modern societies, especially in critical social infrastructures such as tunnels, highways and bridges. It is subject to degradation by aging and environmental factors. Therefore, it is paramount to regularly inspect such concrete structures. Recent disasters such as the collapse of the Mirandi bridge in Italy [1] or of the Sasago tunnel in Japan [2] have raised considerable awareness on this matter. One popular method for inspection is the hammering test: the surface of the structure is hit with a hammer and the impact sound is listened by a human to assess the presence of defect underneath the surface. However, the hammering test requires heavy human involvement and therefore, its automation is highly desirable.

Previous works on this topic employed machine learning approaches. Most of them used supervised learning methods, as in [3] or [4]. Their inherent need for training data is a burden on human users that hinders the simplicity and attractiveness of the hammering test. Indeed, for example, in [4], a training dataset 10 times larger than the test dataset was employed. To bypass the burden of generating training data, unsupervised learning approaches have been conducted using audio clustering coupled with hammering position data in [5]. The obtained performance was high but an additional sensor is required in order to collect position data.

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Therefore, the objective of the present study is to propose a method for defect detection in concrete structures using hammering with minimal burden on human user and using only a microphone.

II. Method

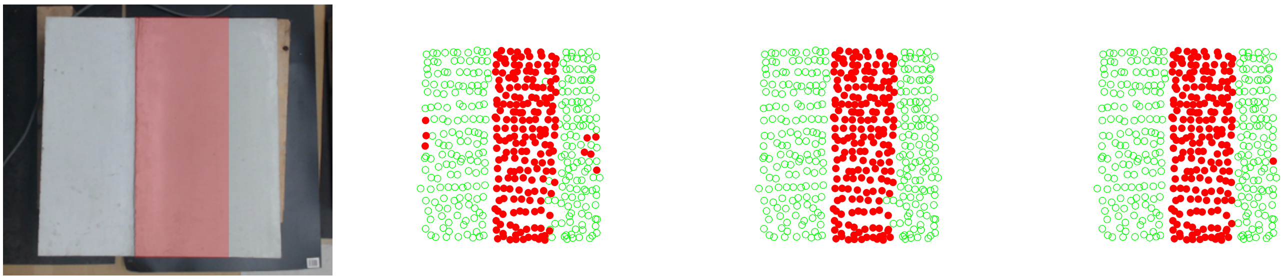
Generation of training data is difficult mainly due to the need to obtain true labels. Indeed, for a human, listening to an impact sound on concrete and immediately knowing whether the concrete is defective or not is a highly difficult task. On the other hand, listening to two sounds and answering if they are similar or not is a far easier task. In fact, when humans conduct the hammering test, it can be noticed that they hit several positions in quick succession and try to find dissimilar sounds rather than identifying each individual sound. Therefore, the proposed method uses positive human answers to queries on pairs of hammering sounds. Such information is known as *weak supervision* or *must-links* in the field of semi-supervised clustering.

First, in order to limit the influence of the hammering strike force, each hammering sample is transformed into Fourier spectrum and normalized to zero-mean and unit variance. Then, MFCC audio features, previously reported as adequate for hammering sound discrimination [6], are built.

In order to shape the feature space in accordance with the user-provided weak supervision, Relevant Component Analysis [7] is employed. RCA is a linear transformation of the feature space prior to clustering, similar to a whitening process. RCA is conducted based on chunklets, samples that are deduced to belong to the same cluster from the provided constraints using the transitive property of must-links.

Given hammering samples $\{\mathbf{x}_i\}_{i\in[1\ldots N]}$ and N_{chunklet} chunklets $\{\mathcal{M}_l\}_{l\in[1\ldots N_{\text{chunklet}}]}$, with $\mathbf{m}_l$ being the mean of elements in $\mathcal{M}_l$, RCA is conducted by substracting from each sample the mean of the chunklet it belongs to. The within-chunklet covariance matrix $\hat{\mathbf{C}}$ is computed as in (1), with N_{total} being the total number of elements contained in the chunklets. The whitening transformation associated with this covariance matrix is computed and applied to the whole dataset as in (2).

Clustering into two clusters is then conducted on the feature build by RCA using K-means. Finally, the cluster with the



(a) Considered concrete test block. The defect area is shown in red. (b) Result using K-means with MFCC, RI=0.937. (c) Result using method of [5], RI=0.987. (d) Result of proposed method, RI=0.996.

Fig. 1. Final defect detection results. Red dots represent samples classified as defects and green circles represent non-defects.

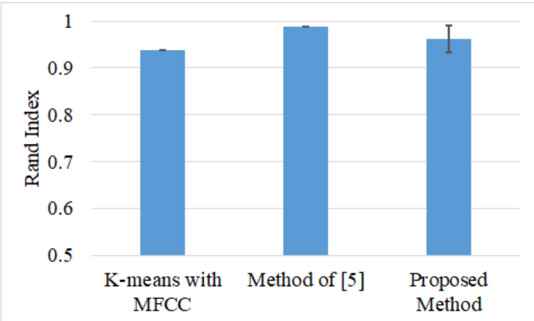


Fig. 2. Average clustering performance of K-means with MFCC 10 coefficients, the method of [5] and proposed method over 100 random initializations and sets of 20 must-links. Error bars corresponds to 1 standard deviation.

highest number of samples is identified as the non-defect cluster. The other cluster is identified as the defect cluster.

$$\hat{\mathbf{C}} = \frac{1}{N_{\text{total}}} \sum_{j=1}^{N_{\text{chunklet}}} \sum_{\mathbf{x}_i \in \mathcal{M}_l} (\mathbf{x}_i - \hat{\mathbf{m}}_l)(\mathbf{x}_i - \hat{\mathbf{m}}_l)^T \quad (1)$$

$$\mathbf{x}_i \to \hat{\mathbf{C}}^{-1/2}\mathbf{x}_i \quad (2)$$

III. Experiment

Experiment was conducted on a concrete test block containing a man-made defect, as shown in Fig. 1(a). The test block was hit at the upper surface on several locations, once per location. The used hammer was a KTC UDHT-2 (head diameter 16 mm, length 380 mm, weight 160 g), commonly used in hammering test by professionals and sound was recorded at 44.1 kHz using a Behringer ECM8000 microphone coupled with a Roland UA-25EX sound board. For weak supervision, 20 random must-links were provided.

IV. Results and Discussions

The Rand Index (RI) was used as performance measure. In Fig. 1(b), 1(c) and 1(d) are shown the final detection results obtained for the various considered methods and in Fig. 2 are reported average of performance over 100 random initializations and sets of 20 must-links.

While the method of [5] achieved the highest performance in average, the proposed method also largely outperformed the baseline represented by K-means. The standard deviation exhibited by the proposed method can be explained by the variation in the quality of the provided must-links, which play a major role in the quality of the achieved feature space. However, with the appropriate set of weak supervision, the proposed method can outperform the method of [5], as shown in Fig. 1. Therefore, it can be said that the proposed method is a good alternative to purely unsupervised approach when the additional sensors are not available.

V. Conclusion

A method for defect detection in concrete structures using only a microphone and minimal burden on the human user was proposed. Queries are asked to the human on pairs of hammering samples. Based on those for which the answer is positive, an additional feature space transformation has been conducted using RCA on the initial MFCC feature space. Experiments conducted with a concrete test block showed promising results, allowing our proposed method to obtain good performance only using a microphone and limited human involvement. As future work, an active query system is being devised in order ensure more consistent weak supervision quality.

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