ID-CONDITIONED AUTO-ENCODER FOR UNSUPERVISED ANOMALY DETECTION

Sławomir Kapka
Samsung R&D Institute Poland
Artificial Intelligence
Warsaw, Poland
s.kapka@samsung.com

ABSTRACT

In this paper, we introduce ID-Conditioned Auto-Encoder for unsupervised anomaly detection. Our method is an adaptation of the Class-Conditioned Auto-Encoder (C2AE) designed for the open-set recognition. Assuming that non-anomalous samples constitute of distinct IDs, we apply Conditioned Auto-Encoder with labels provided by these IDs. Opposed to C2AE, our approach omits the classification subtask and reduces the learning process to the single run. We simplify the learning process further by fixing a constant vector as the target for non-matching labels. We apply our method in the context of sounds for machine condition monitoring. We evaluate our method on the ToyADMS and MIMII datasets from the DCASE 2020 Challenge Task 2. We conduct an ablation study to indicate which steps of our method influences results the most.

Index Terms— DCASE 2020 Challenge Task 2, Unsupervised anomaly detection, Machine Condition Monitoring, Conditioned Auto-Encoder

1. INTRODUCTION

Unsupervised anomaly detection is a problem of detecting anomalous samples under the condition that only non-anomalous (normal) samples have been provided during training phase. In this paper, we focus on unsupervised anomaly detection in the context of sounds for machine condition monitoring – i.e., detecting mechanical failure by listening.

Many techniques have been studied for detecting anomalous sounds. Among others there are solutions based on SVMs [1][2], sparse coding [3][4], GMMs [5][6], Neyman-Pearson lemma [7][8], signal processing [9][10][11], Interpolation DNN [12], and Auto-Encoders [8][13][14][15]. Beyond sounds, much more techniques for anomaly detection based on deep leaning can be found in the survey [16].

Unsupervised anomaly detection can be viewed as a special case of the open-set recognition [17]. In fact, since during training we are provided only with normal samples and we have to predict whether new samples are normal or anomalous, we can look at it as a binary classification problem with given only one class during training phase.

Recently, Class-Conditioned Auto-Encoder (C2AE) [15] has been introduced for the open-set recognition problem. According to the survey on the open-set recognition [19], it is currently the state-of-the-art in the open-set recognition problem. In section 2, we introduce an ID-Conditioned Auto-Encoder (IDCAE), which is the adapted version of C2AE applicable to the unsupervised anomaly detection.

Task 2 in this year IEEE AASP Challenge on Detection and Classification of Acoustic Scenes and Events (DCASE 2020) [20][21] focuses precisely on the unsupervised detection of anomalous sounds for machine condition monitoring. The data for this task is ToyADMS [22] and MIMII Dataset [23] which consists of sounds of six types of operating machines. In section 3, we develop the model for this challenge, and we evaluate its performance via an ablation study in section 4.

2. PROPOSED METHOD

Let us consider an arbitrary but fixed machine type, henceforth called the machine unless otherwise specified. We assume that we have various IDs of the machine. It is precisely the case in task 2 in the DCASE 2020 Challenge. In the nomenclature from [18] we treat machines with different IDs as distinct classes.

Our system constitutes of three main parts:

- encoder $E : X \to Z$ which maps feature vector $X$ from input space $X$ to the code $E(X)$ in the latent space $Z$,
- decoder $D : Z \to X$ which takes the code $Z$ from $Z$ and outputs the vector $D(Z)$ of the same shape as feature vectors from $X$,
- conditioning made of two functions $H_γ, H_β : Y \to Z$ which take the one-hot label $l$ from $Y$ and map it to the vectors $H_γ(l), H_β(l)$ of the same size as codes from $Z$.

During feed-forward, the code $Z$ is combined with $H_γ(l), H_β(l)$ to form $H(Z, l) = H_γ(l) \cdot Z + H_β(l)$, which is an affine transformation of the latent space conditioned by $l$ [24]. Thus, our whole system takes two inputs $X, l$ from $X$ and $Y$ respectively and outputs $D(H(E(X), l))$.

Given an input $X$ with some ID, we call label corresponding to this ID by the match and all other labels by non-matches. We wish that our system reconstructs $X$ faithfully if and only if it is a normal sample conditioned by the matching label.

Given an input $X$, we set the label $l$ to the match with probability $α$ or to a randomly selected non-match with probability $1−α$, where $α$ is predefined. Thus, for a batch $X_1, X_2, \ldots, X_n$ approximately $α$ fraction of samples will be conditioned by matches and $1−α$ by non-matches. If $l$ is the match, then the loss equals difference between the system’s output and $X$, that is $||D(H(E(X), l))−X||$. If $l$ is a non-match, then the loss equals difference between the system’s output and some pre-defined constant vector $C$ with the same shape as $X$, that is $||D(H(E(X), l))−C||$. In our setting $||·||$ is either $L_1$ or the square of $L_2$ norm.

To simplify the learning process further by fixing a constant vector as the target for non-matching labels, we can look at it as a binary classification problem with given only one class during training phase.

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During the inference we always feed the network with matching labels. If a sample is non-anomalous, we expect the reconstruction to be faithful resulting in low reconstruction error (see Figure 1). If the sample is anomalous, there may be two cases. If the sample is nothing like any sample during training, then generally auto-encoder wouldn’t be able to reconstruct it resulting in high reconstruction error. However, if the sample reminiscent normal samples with other IDs, then the auto-encoder will try to reconstruct the vector $C$ resulting again in high error (see Figure 2).

In general, the point of auto-encoder-based solutions for anomaly detection is to separate distributions of reconstruction errors for normal and anomalous samples. In our case, the distribution of reconstruction errors for anomalies is shifted further to the right due to the samples that reminiscent samples with other IDs. Thus, it indicates that our method should work at least as good as regular auto-encoder. Overall, distribution of reconstruction errors for anomalies with matching labels should be between distributions of reconstruction errors for normal samples with matching and non-matching labels (see Figure 3).

The additional advantage of our approach is that feeding the network with more IDs may result in better performance. In fact, in the section 4 we show that it holds in the case of machine condition monitoring.

3. MODEL

3.1. Features

In our model, we feed the network with fragments of normalised log-mel power spectrograms. Feature vector space $X$ consists of vectors of the shape $(F, M)$, where $F$ is the frame size and $M$ is the number of mels. Given an audio signal we first compute its Short Time Fourier Transform with 1024 window and 512 hop size, we transform it to the power mel-scaled spectrogram with $M$ mels, and we take its logarithm with base 10 and multiply it by 10. Finally, we standardize all spectrograms frequency-wise to zero mean and unit variance, and sample frames of size $F$ as an input to our system.

Table 1: The architecture of IDCAE

| Encoder ($E$) | Decoder ($D$) | Conditioning ($H_\gamma, H_\beta$) |
|--------------|--------------|-----------------------------------|
| Input $(F, M)$ | Input 16 | Input #IDs |
| Flatten | DenseBlock 128 | Dense 16 |
| DenseBlock 128 | DenseBlock 128 | sigmoid |
| DenseBlock 64 | DenseBlock 128 | Dense 16 |
| DenseBlock 32 | DenseBlock 128 | |
| DenseBlock 16 | Dense $F \cdot M$ | Reshape $(F, M)$ |

DenseBlock $n$: Dense $n$, Batch-norm, relu

As described in subsection 4 our model constitutes of the encoder $E$, the decoder $D$ and the conditioning $H_\gamma, H_\beta$. In our case, all these component are fully connected neural networks. Thus, we have to flatten feature vectors and reshaped the output to $(F, M)$ for the sake of the dimension compatibility. The dense layers in $E$ and $D$ are followed by batch-norm and relu activation function, while the dense layers in $H_\gamma, H_\beta$ are followed just by sigmoid activation functions. $E$ has three hidden dense layers with 128, 64 and 32 units followed by the latent dense layer with 16 units. $D$ is made of four hidden dense layers each with 128 units. $H_\gamma$ and $H_\beta$ have both a single hidden dense layer with 16 units. We summarise the architecture in Table 1.
3.3. Parameters

We used $\alpha = 0.75$, $C = 5$ (the bold-face denotes that it is a constant vector with value 5 everywhere) with a frame size $F = 10$ and number of mels $M = 128$. As for complexity for this setup, the encoder, decoder and conditioning has 175,792, 218,880 and 800 parameters respectively, making total of 395,472 parameters.

3.4. Training

We train our models using Adam optimizer with default parameters, setting mean absolute error as a loss function. For each machine, we train our network for 100 epochs with exponential learning rate decay by multiplying the learning rate by 0.95 every 5 epochs. For every epoch we randomly sample 300 frames from each spectrogram.

3.5. Ensemble

$\alpha$, $C$ and number of mels $M$ are hyperparameters for our model. Unfortunately, there is no single couple of these parameters that works best for all the machines. We set $F = 10$ and done a grid search with $\alpha \in \{0.9, 0.75, 0.5\}$, $C \in \{0, 2.5, 5, 10\}$, $M \in \{128, 256\}$ trying mean square and mean absolute errors. We selected 3 models for each machine that maximize mAUC (the average of AUC and pAUC with $p = 0.1$) on the test split from the development dataset, and for each machine we done an ensemble by selecting 3 weights such that the weighted anomaly score maximize mAUC. The ensemble is illustrated in Figure 4.

4. RESULTS

We develop and evaluate our system on the datasets from task 2 from DCASE 2020 Challenge [20], which consists of recording on 6 different machine types (Toy Car, Toy Conveyor, Fan, Pump, Slider and Valve). The available datasets consists of development and additional datasets. The development dataset consists of 3 or 4 IDs per machine while the additional dataset consist of 3 IDs per machine. All results in this section are evaluated on the test split from the development dataset using the area under the receiver operating characteristic (ROC) curve (AUC) and the partial-AUC (pAUC) with $p = 0.1$.

We conduct the ablation study starting from the DCASE baseline system and ending on the ensemble. We list the following steps, where each step is build upon the previous one:
We summarise the results of the ablation study in Table 2. Even though results vary over machines, we will focus on the average scores which is placed in the last two columns of the Table. Our architecture changes as in Architect and normalization Scaler have minor influence on AUC and pAUC scores. Adding conditioning layer in Condition significantly improves pAUC score, which proves that IDCAE is advantageous over standard AE. Moreover as expected, adding more IDs like in AddDataset improves both AUC and pAUC scores significantly. Finally, the ensemble from Ensemble due to its nature again significantly boosts both AUC and pAUC.

5. CONCLUSION

In this paper we introduce a method on how to enhance autoencoder designed for unsupervised anomaly detection. Assuming distinct IDs, we condition latent space in order to enforce autoencoder to reconstruct samples faithfully if and only if they are non-anomalous and conditioned with matching labels. Our method outperforms significantly the DCASE baseline system. In the ablation study, we proved that the conditioning we introduced is crucial for the performance improvement, and that feeding the system with more IDs gets even better results.
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