Appliance Fingerprinting Using Sound from Power Supply

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Overview

In this paper, we proposed a novel method based on the switching-mode power supply (SMPS) to identify domestic appliances.

Contributions:

- Recognize the working appliances using the inaudible high-frequency sound generated by the SMPS.
- Our method is non-invasive, can be applied to recognize most appliances, and use a COTS microphone for detection.
- Our preliminary experiments show that the method can successfully classify 18 appliances with the accuracy of 97.6%.

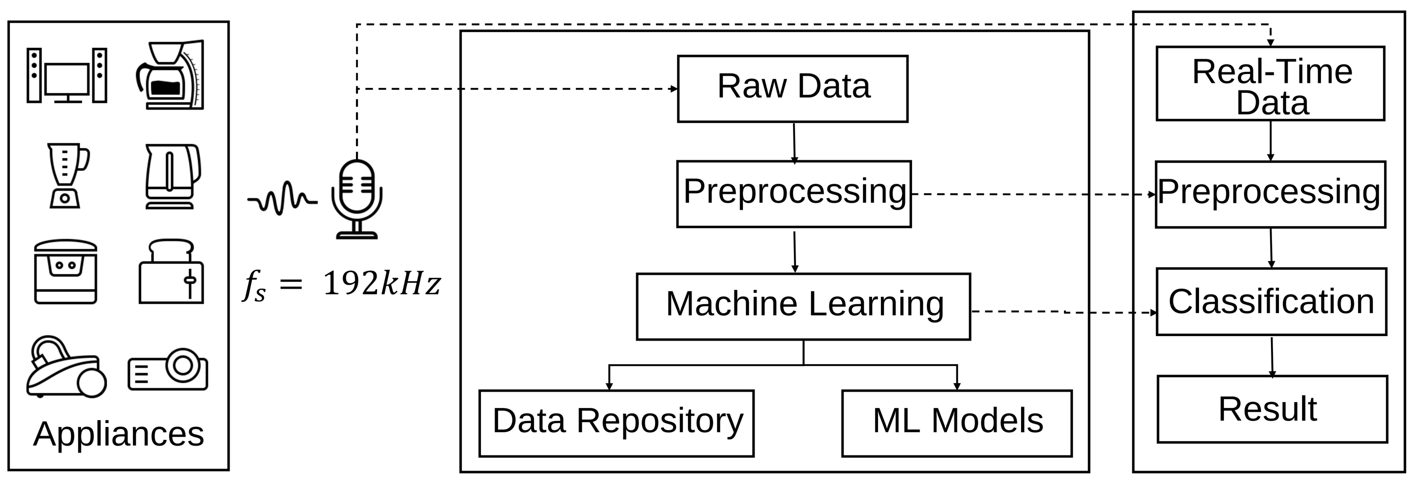

Figure 1: The system overview.

Principles of SMPS

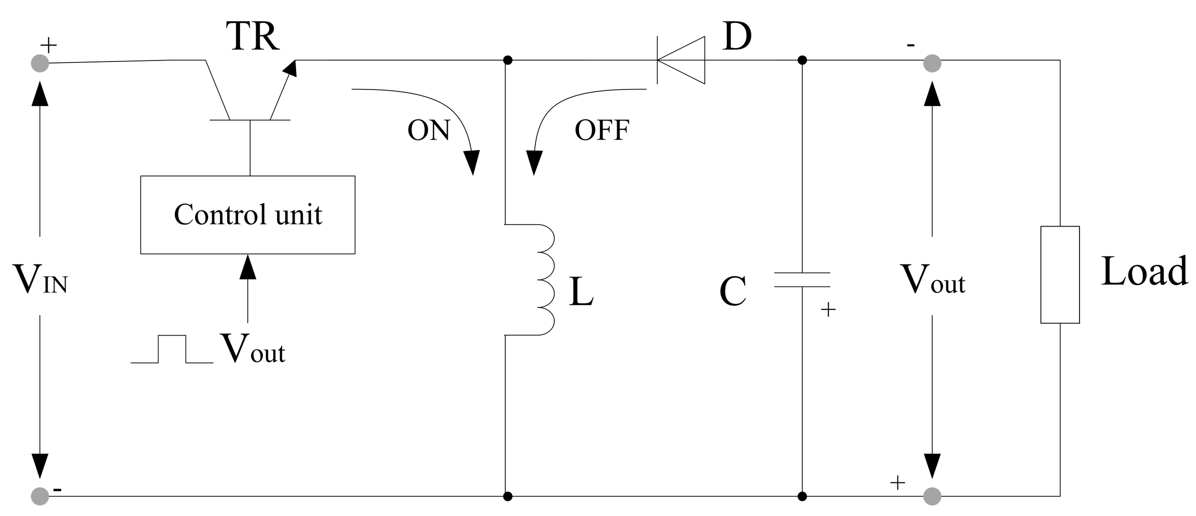

Figure 2: A typical buck-boost SMPS.

SMPS uses a switching element to transform the incoming power supply into a pulsed voltage and then smooths.SMPS repeats the ON-and-OFF operation at high frequency of $100kHz \sim 6MHz$.

Why SMPS emits high-frequency sounds

Elements that can emit sounds: When the SMPS is working, the transformer, inductance and capacitors in SMPS can both generate high frequency sound, as shown in Fig. 4.

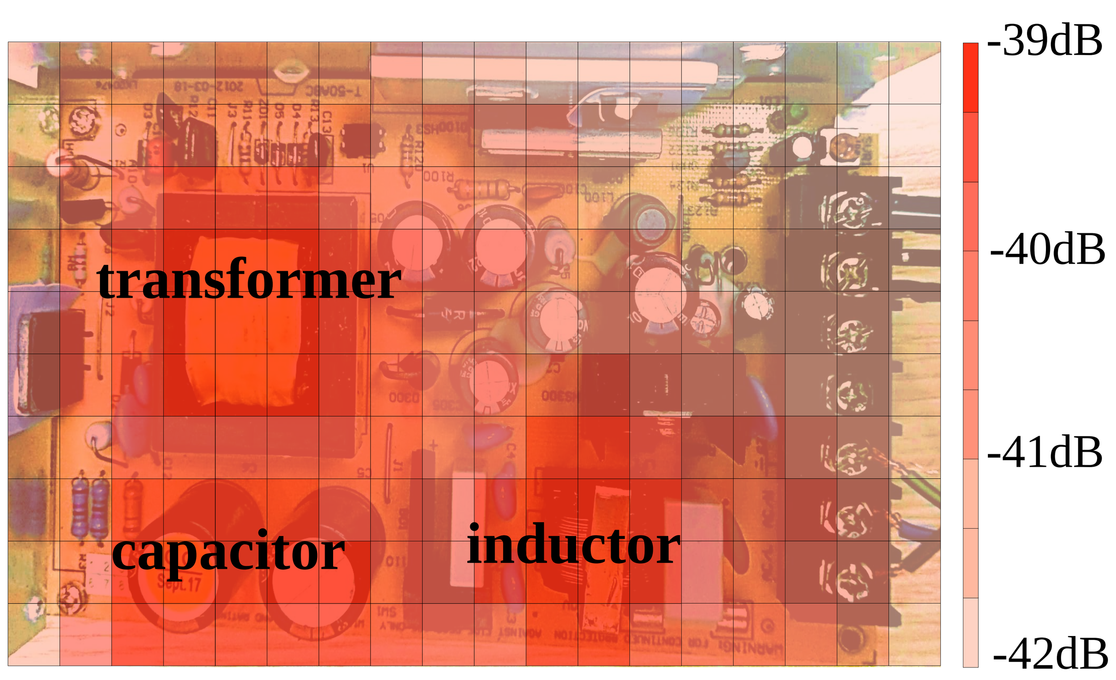

Figure 3: Sound strength over a power supply.

Sound generation principles: The high frequency switching of SMPS results in high frequency alternating current and strong alternating magnetic field. The magnetic core and coil inside a transformer is seriously affected by the magnetic field. Under the influence of magnetic force, if periodic vibration, friction, material deformation, etc. happen to those magnetic materials, then high-frequency sound is produced. The similar phenomena is with the capacitor and the inductor. As all insulating materials will deform under the pressure of electric field brought by high frequency switching of SMPS, cheap small ceramic capacitors usually produce piezoelectric effects even at normal operating temperatures. The mechanical structure of the circuit where the inductance is located is more complicated, and it is easier to emit high-frequency sound under the drive of high-frequency switching current.

Methods

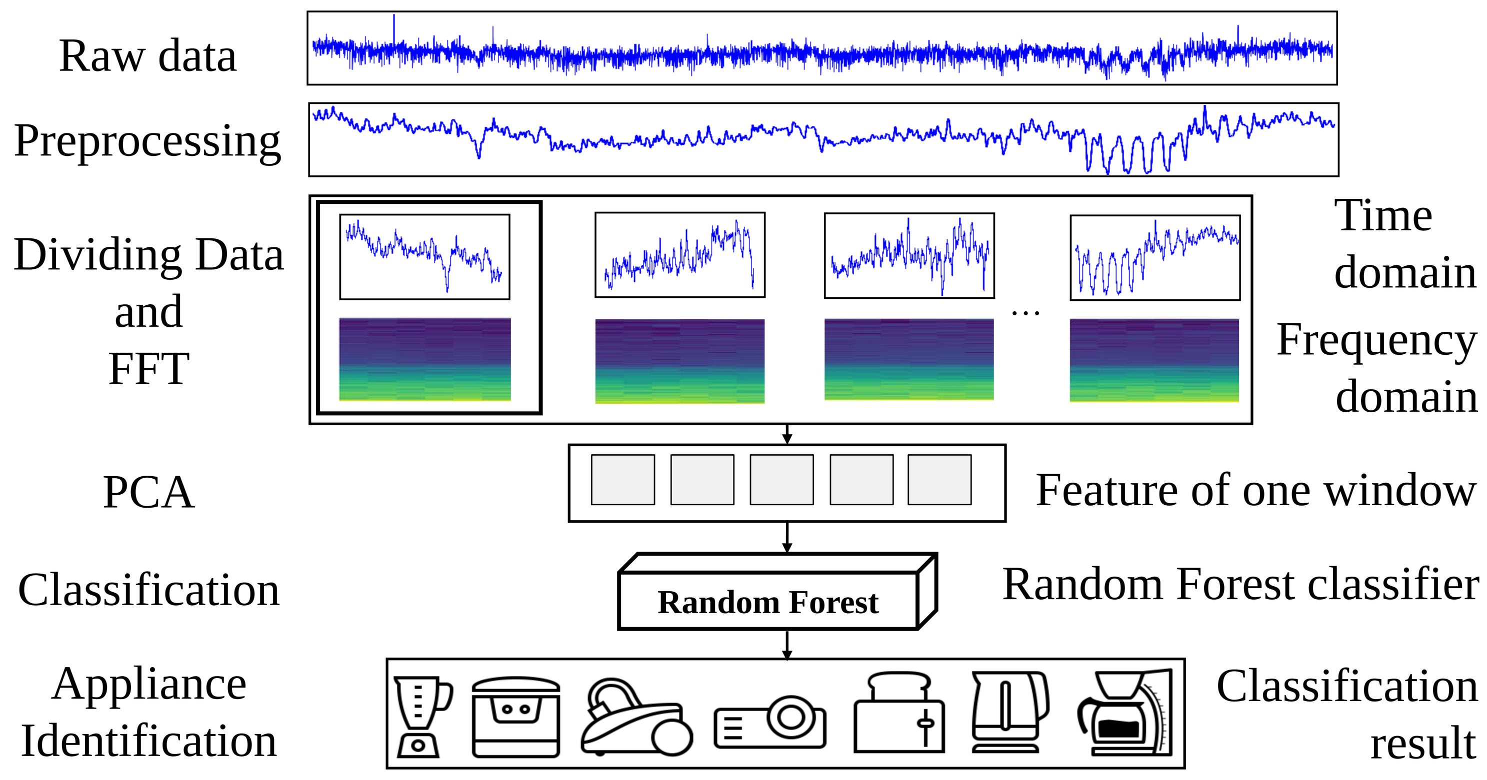

Figure 4: Details of method.

Data collection: We put a microphone near the SMPS of appliance to collect sound signals, and used a sound card with high sampling frequency of 192kHz to sample the collected analog signals.
Feature Selection: For each trace, we split the data into many tiny windows with length of 1 second. For each window of data, we used FFT to extract their frequency distributions. Because the frequency is as high as 96kHz, we used Principle Component Analysis to extract features and reduce the traces' dimensions.
Training and Classification: We employed a Random Forest classifier to classify the feature extracted traces. During a cross-validation procedure, the traces were in turn treated as training and testing set.The average accuracy of 5 cross validation was reported.The model was then saved for identifying real-time collected acoustic signals of appliances.

Evalution

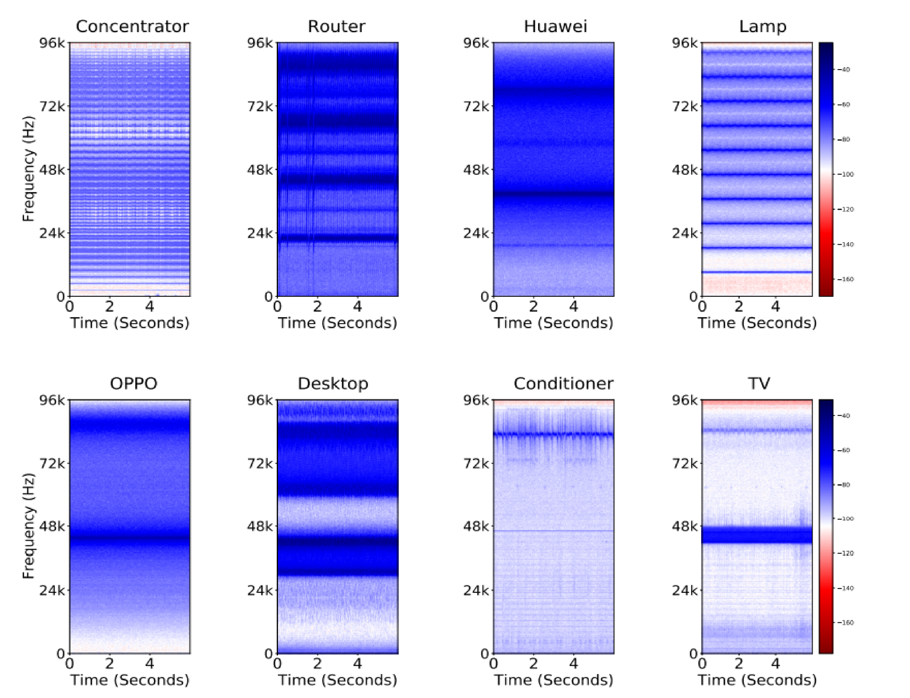

Figure 5: Spectrum of acoustics of 8 appliances. The y-axis is the frequency of sounds, the x-axis is collecting time.

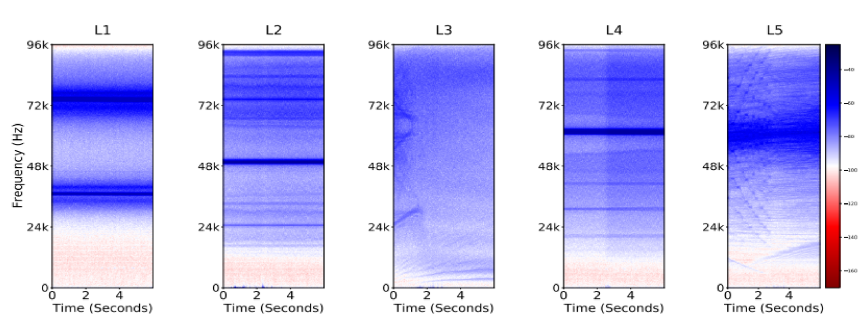

Figure 6: Spectrum of acoustics of different lamps (L1-L5) with the same adapter. The 5 lamps are all of the same model.

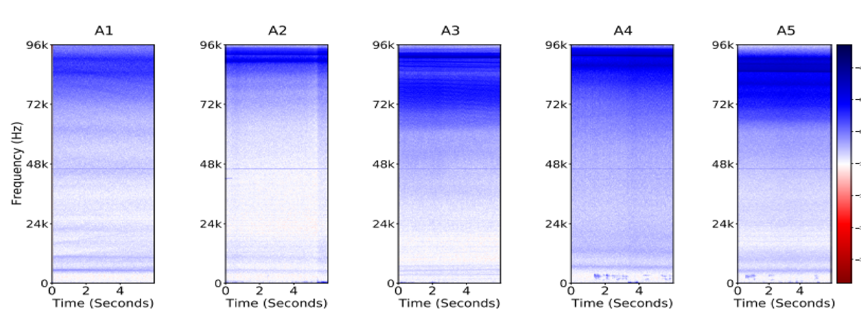

Figure 7: Spectrum of acoustics of the same lamp using 5 different adapters (A1-A5). The adapters are of same model.

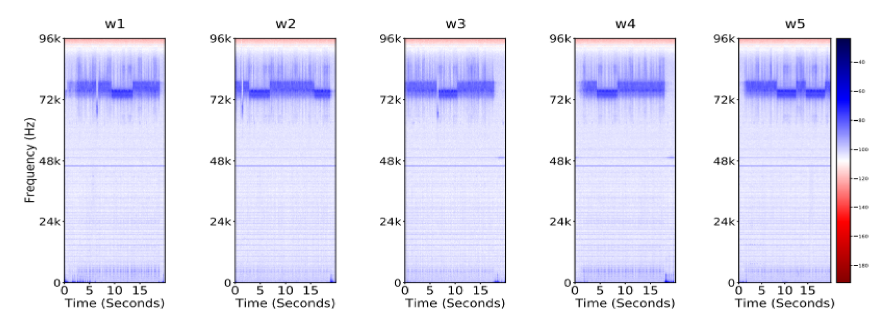

Figure 8: Spectrum of acoustics from appliance at 5 different weeks. Acoustics of the same air conditioner were collected 5 times at different week from W1 to W5.

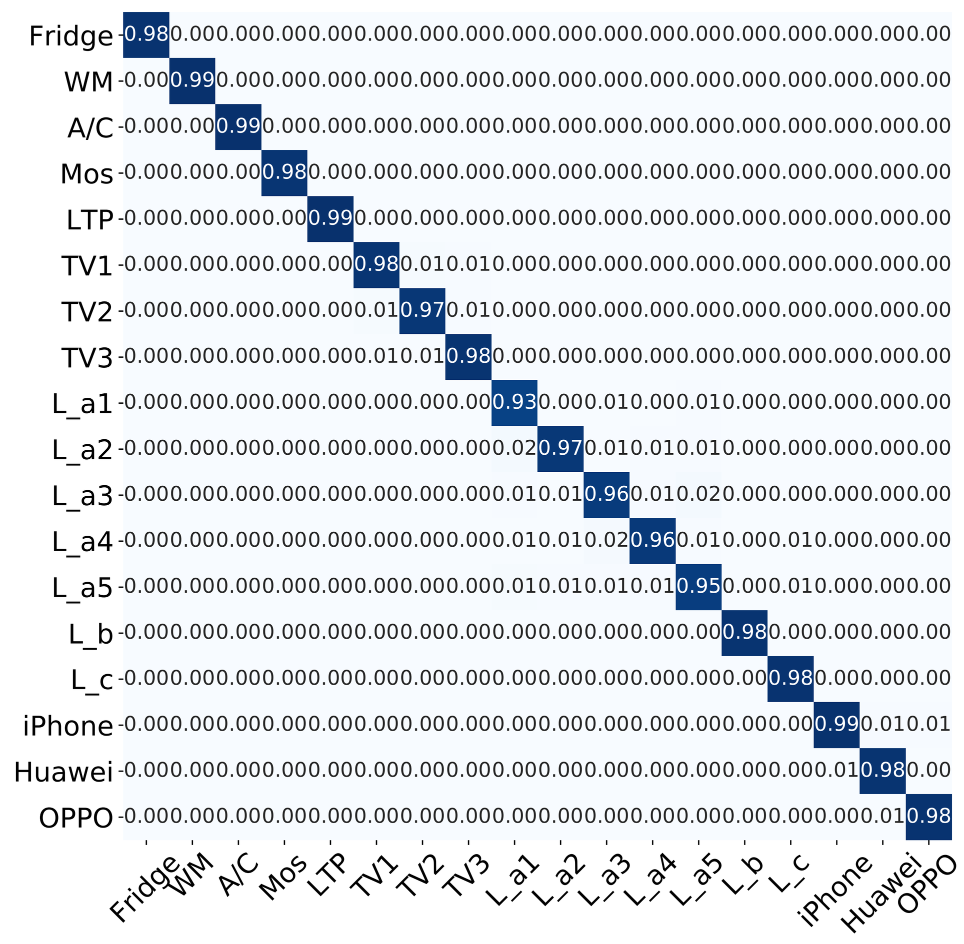

Figure 9: Confusion matrix of 18 appliances classification results. L_{a1}-L_{a5} are 5 lamps of the same brand of same company, while L_a-L_c are lamps of different type.

- **Whether common appliances can generate high-frequency sounds?**
  We visualized the sounds of 8 common appliances. As seen in Fig. 5 the 8 appliances can all generate detectable high-frequency sounds, and they are very different.
- **Whether the sounds are from adapters or the devices themselves?**
  As shown in Fig. 6 and Fig. 7, we found that difference in devices themselves can result in quite different sounds, while difference in adapters produces less different results.
- **Whether the sounds from the same devices are stable over time and space?**
  We collected the sound signals of one device (for example, air conditioner) over 5 weeks. Results in Fig. 8 show that the sounds are temporally consistent.
- **How SMPS-based solution performs on real-world appliances?**
  Fig. 9 shows the confusion matrix of 18 appliances' classification results using Random Forest classifier. Our method can achieve an average accuracy of 99% for different appliances, 98% for different model's appliance, and 95.4% for same model's appliance.