Impulse response classification based on persistent homology

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1 Introduction

In the field of room acoustics, to classify impulse responses, energy-based statistical indexes are widely used. Recently, deep-neural-network-based method is one of the promising solutions [2]. By using these methods, certainly, it is possible to classify impulse responses but it is unclear to inspect the characteristics of impulse responses.

Here, to inspect the structure of impulse responses, we focus on the methods that analyze geometrical structure of signals by using topological data analysis (TDA) based on persistent homology (PH) where its effectiveness is shown on the time-series data [3]. This report applies PH to impulse response analysis and validates their effectiveness on two different reverberation conditions.

2 PH based classification

For PH, it is difficult to deal with one-dimensional data; thus, delay-time embedding [3] converts one-dimensional signal $\boldsymbol{x}$ into two-dimensional signal $\boldsymbol{X}$ with sliding window. To fix sliding window, three parameters (embedded dimension d, delay time τ, and window shift ΔT) need to be set.After centralization and normalization of this signal, PD is obtained by filtration.

Usual TDA estimates PD from point cloud, which shows the existence of connected components but does not show where the connected component is. Inverse analysis [1] can visualize connected component from PD, which is an inverse problem.

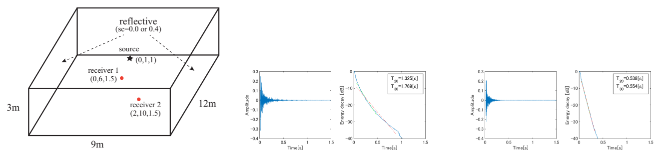
3 Experiments

Fig. 1 (a) shows a room shape for experiments (9m×12m×3m) simulating meeting rooms. Absorption coefficients of the walls are 0.1 for the lateral walls in the longitudinal direction and 0.4 for the other walls. We set low absorption coefficients to the lateral walls in longitudinal direction in order to intentionally increase flutter echos. Receiver 1 was used for evaluation. Reverberation time estimated by Sabine equation was 0.46 sec. After echo time patterns were generated by geometrical simulation, impulse responses were generated by amplitude modulation of white noise with band-pass filtering. In addition, for simulating diffusers on those walls, we set scattering coefficient (sc) to 0.4 and caused diffuse reflections according to Lambert's law.

Application of PH to time-series signals was refereed to the open codes[1]. Parameters of sliding window were $d = f_s/200 = 100$, $\tau = 100$, and $\Delta T = f_s/100 = 200$, respectively. We used an implementation of inverse analysis in homcloud (ver. 3.4.1). The setting of PH was refereed to the tutorial samples of homcloud.

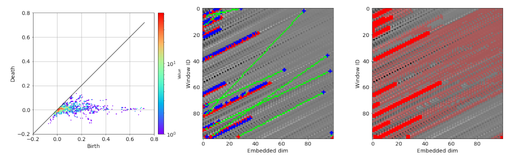
Fig. 1 (b) shows the impulse responses and energy decay curves when scattering coefficients were zero and Fig. 1 (c) shows those when scattering coefficients were 0.4. In the former case, there are apparent flutter echos. On the other hand, in the latter case, there were few flutter echoes and the reverberation time estimated from the impulse response was close to the reverberation time by Sabine's equation.

The left figures of Fig. 2 show 0th order PD. On the PD of Fig. 2 (a), points were more concentrated, which indicates that in the case of more echos, each point in $\boldsymbol{X}$ was farther and equally distant and that points were connected at the same time. On the other hand, in the case of less echos (Fig. 2 (b)), because the distance between each point in $\boldsymbol{X}$ was diverse, points were connected from earlier time to later time, sporadically. These characteristics of PD reflected the characteristics of impulse responses.

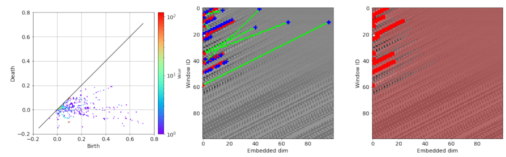


(a) Room shape (b) $sc = 0.0$ (c) $sc = 0.4$

Figure 1. Room shape and impulse responses and energy decay curves.



(a) $sc = 0.0$



(b) $sc = 0.4$

Figure 2. 0th order persistence diagram and results of inverse analysis.

The center and the right figures of Fig. 2 show the results of inverse analysis. The center figure shows the correspondence between birth and death. On the gray-scale image that visualizes 2D impulse responses by using sliding window, figure shows the points of birth and death, where red points were birth points and blue points were death points. Green lines were correspondences between birth and death points. Points on the bottom of the figure contained later components of reverberation. In the case of more echos (Fig. 2 (a)), there were more connections in the late reverberation part.

The right figures show the generation points with red and their generated connected components with light red. This indicates that there were more unconnected components in Fig. 2 (a) than in Fig. 2 (b). This shows that for characteristic echos such as flutter echos, corresponding region can be visualized.

4 Conclusion

To inspect the properties of impulse responses, instead of generally used energy-based method, we introduced persistent homology. We prepared two conditions with more or less flutter echos for the same absorption condition. Experiments show that the apparent difference are shown on the persistent diagram for two different reverberant conditions. In addition, inverse analysis [1] can visualize connected components and show the different shapes of the connected components depending on the reverberation conditions.

[1]https://github.com/rannbaron/TUMTopoTimeSeries2016

References

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