Improving Gravitational Wave Detection with 2D Convolutional Neural Networks

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BACKGROUND

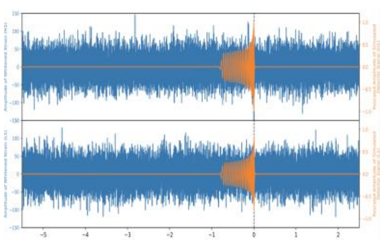
Sensitive gravitational wave (GW) detectors such as that of Laser Interferometer Gravitational-wave Observatory (LIGO) realize the direct observation of GW signals that confirm Einstein's general theory of relativity. However, it remains challenges to quickly detect faint GW signals from a large number of time series with background noise under unknown probability distributions.

LIGO has two sensitive detectors which can sense the GW signals in the universe. The time-series received by LIGO is composed of noise and GW singal:

$$s(t) = h(t) + n(t)$$

OBJECTIVES

To quick detect the GW signal from LIGO data (which is 1D time-series)

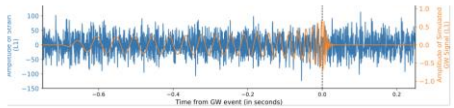


The challenge includes:

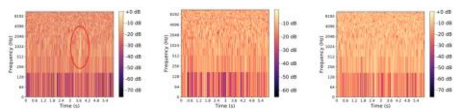
- Faint GW signal
- Real-time (data amount)
- Confusing noise

METHOD

- The input data is pre-processed to form a 2D spectrum by Short-time Fourier transform (STFT), where frequency features are extracted without learning.

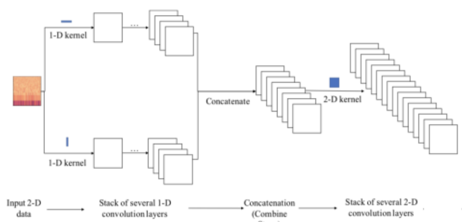


STFT



(a) window size = 64, SNR = 17 (b) window size = 64, SNR = 2 (c) window size = 64, pure noise

- The model carries out two 1D convolutions across time and frequency axes respectively, and concatenates the time and frequency feature maps with equal proportion subsequently, then the frequency and time features are treated equally as the input of our following two-dimensional convolutions.

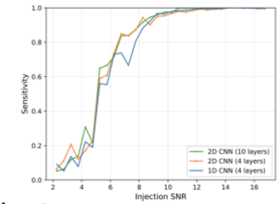


RESULTS

This paper use Sensitivity (Recall) at the fixed false alarm rate as the evaluation metric. The fixed false alarm rate is set as 0.6% in our experiments.

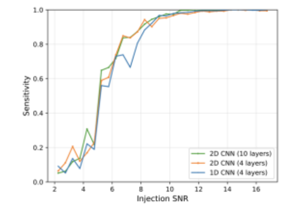
Comparison between 1D and 2D models

Model (layers)	Combine stage	Sensitivity (%)
1D CNN (4)	none	75.9
2D CNN (4)	2	77.8
2D CNN (10)	4	77.7



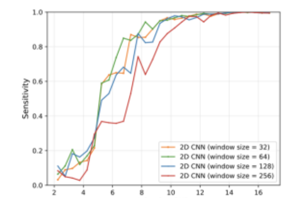
Comparison between different combine stages

Model	Combine stage	Sensitivity (%)
2D CNN	0	74.7
2D CNN	1	74.3
2D CNN	**2**	**77.8**
2D CNN	3	77.2



Comparison between different STFT window size

Model	Window Size	Sensitivity (%)
2D CNN	32	76.2
2D CNN	**64**	**77.8**
2D CNN	128	74.8
2D CNN	256	68.1



CONCLUSIONS

- This paper firstly introduces 2D CNN to explore the GW detection in deep learning for performance improvement while keeping the balance of time features and frequency features.
- Sate-of-the-art sensitivity. The proposed method averagely outperforms its 1D CNN counterparts, whose sensitivity is improved from 75.9% to 77.8%.
- Fast enough to achieve real-time. An eight-second time series can be processed online within milliseconds.