VIRGO LOGO?

LIGO LOGO?

UF/ SAPEINZA LOGO?

Study of a method to detect r-mode signals in white noise

Avi Vajpeyi[1], Andrew Miller[2,3,4], Pia Astone[3], Sergio Fresca[3,4]

[1]The College of Wooster, Ohio, USA
[2]The University of Florida, Florida, USA
[3]National Institute for Nuclear Physics, Italy
[4]Sapienza University, Rome, Italy

Abstract

We present an investigation of r-mode gravitational waves which could be important to detect isolated neutron stars. We use 2D-FFT filters and convolutional neural networks. We show that we can achieve an enhancement in the quality of an r-mode signal using filters that do not match the exact parameters of the signal present in white noise, contrary to what is required with typical matched filtering methods.

Simulating r-mode data

Frequency and amplitude evolution

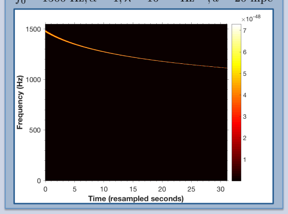
$$f(t) = \left(\frac{f_0^6}{1 + \lambda \alpha^2 f_0^6 \; (t - t_0)} \right)^{1/6} \; \mathrm{Hz}$$

$$h(t) = 1.8 \times 10^{-24} \; \frac{20}{d} \; \left(\frac{f(t)}{1000} \right)^3 \; \alpha$$

$f_0 \rightarrow$ Source frequency
$\alpha \rightarrow$ Saturation amplitude
$\lambda \rightarrow$ Dependant on size and density
$d \rightarrow$ Distance of from detector

Signal Power Spectra

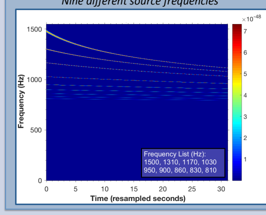
$f_0 = 1500$ Hz, $\alpha = 1, \lambda = 10^{-20}$ Hz^{-5}, $d = 20$ mpc



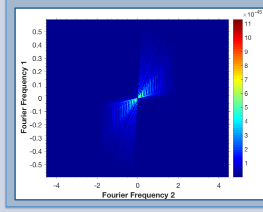
Filter generation

Summed Signal Power Spectra

Nine different source frequencies

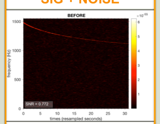


FILTER = |2D-FFT(power spectra)|



Filtering Process

SIG + NOISE



Power Spectrum

2D-FFT

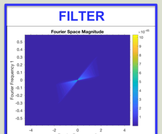
SIG + NOISE

$$\bar{z} = re^{i\theta}$$

2D-FFT

*

FILTER



Magnitude 2D-FFT

MULTIPLICATION

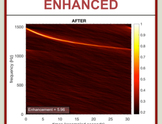
ENHANCED

$$\bar{z}' = r' e^{i\theta'}$$

2D-FFT

INV. 2D-FFT

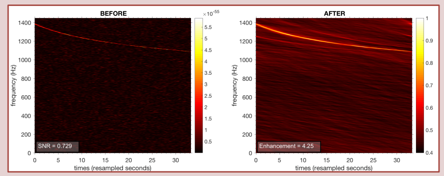
ENHANCED



Power Spectrum

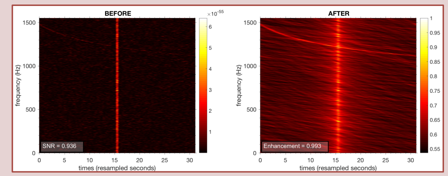
Filtering Results

Filtering data = signal + white noise



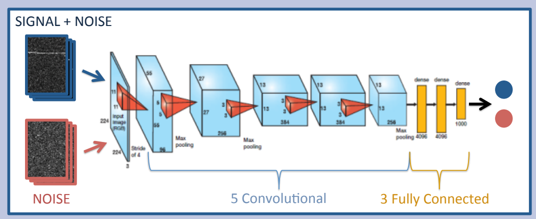
The data that is filtered contains a signal with source frequency of 1400 Hz, a source frequency that is not used to generate the filter. This demonstrates that the 2D FFT filter does not need to exactly match the parameters of a signal in data to enhance the signal.

Filtering data = signal + white noise + glitch



The data that is filtered contains a glitch in amplitude – a phenomenon that can occur while recording gravitational wave data. We see that applying the 2D FFT filter on the data can help enhance the presence of the signal in comparison to the glitch.

CNN to detect signals



On training with 1000 simulated datasets and testing with 230 unseen simulated datasets we obtained an accuracy of 99.57%. The architecture for the CNN used is AlexNet. The loss function is a categorical cross entropy function.

Parameter estimation with the same network architecture but a mean-square loss function has not yet provided accurate results.

Future work

- Investigate a method to parameter estimate with 2D FFT filters
- Determine use of the phase of the 2D FFT for filtering
- Improve calculation for enhancement
- Create a CNN that can be used for parameter estimation
- Study the improvement of signal detection by the CNN if filtered images are used..

Acknowledgements

We would like to thank the University of Florida and the National Science Foundation for helping fund this work.