

Gravitation Wave Identification

Using Metropolis Hastings Algorithm

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Problem Statement

Problem Statement

Given a time series strain data with added noise with the structure of a gravitational wave as given below

$$h(t) = \alpha e^t [1 - \tanh\{2(t - \beta)\}] \sin(\gamma t)$$

α, β, γ are parameters that signify the physical properties of the given wave. Their value ranges are

$$0 < \alpha < 2$$

$$1 < \beta < 10$$

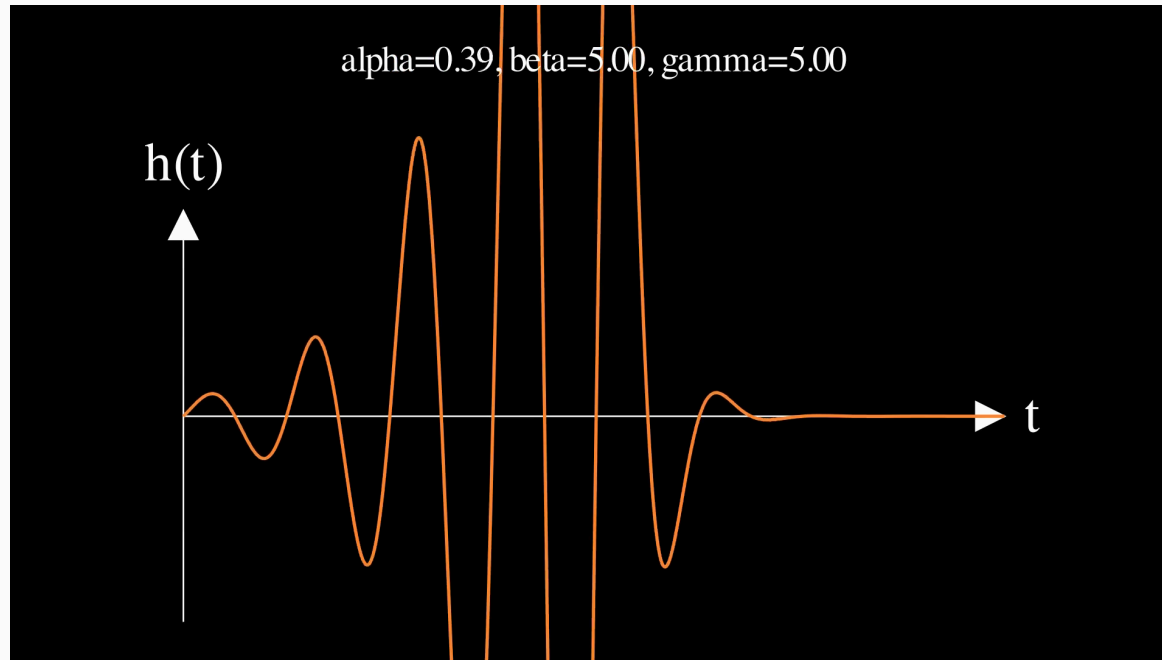
$$1 < \gamma < 20$$

We need to determine the parameter values using a **Metropolis Hastings** Random walk algorithm in the 3 dimensional space.

Understanding Wave Parameters

Let us visualize how the parameters α , β , and γ influence the waveform $h(t) = \alpha e^t [1 - \tanh(2(t - \beta))] \sin(\gamma t)$.

Animation Parameter effects



Methodology



Bayesian Statistics

1. **Initialization:** We start with initial parameter values at the midpoints of the given ranges so

$$\alpha = 1, \beta = 5, \gamma = 10$$

2. **Random Walk:**

For each iteration we propose a new set of parameters using

$$\theta_{\text{new}} = \text{normal}(\theta_{\text{initial}}, \sigma^2) \quad \text{where } \sigma = [0.01, 0.07, 0.07]$$

The new value is discarded or chosen based on an **Acceptance Probability** defined as

$$A(\theta_{\text{new}}, \theta_{\text{initial}}) = \min\left(1, \frac{\text{Posterior}(\theta_{\text{new}})}{\text{Posterior}(\theta_{\text{initial}})}\right)$$

The **Posterior** function is defined as the following

```
def likelihood_reduced(y_data: np.ndarray, y_prior: np.ndarray):  
    y_err = 0.1 * np.std(y_data)  
    Y = np.mean((y_data - y_prior) ** 2) / y_err**2  
    return -0.5 * Y
```

This is different from the function provided in the problem statement, we will explain why this is better in Section 4

Results

Covariance Scatter Plots and Histograms

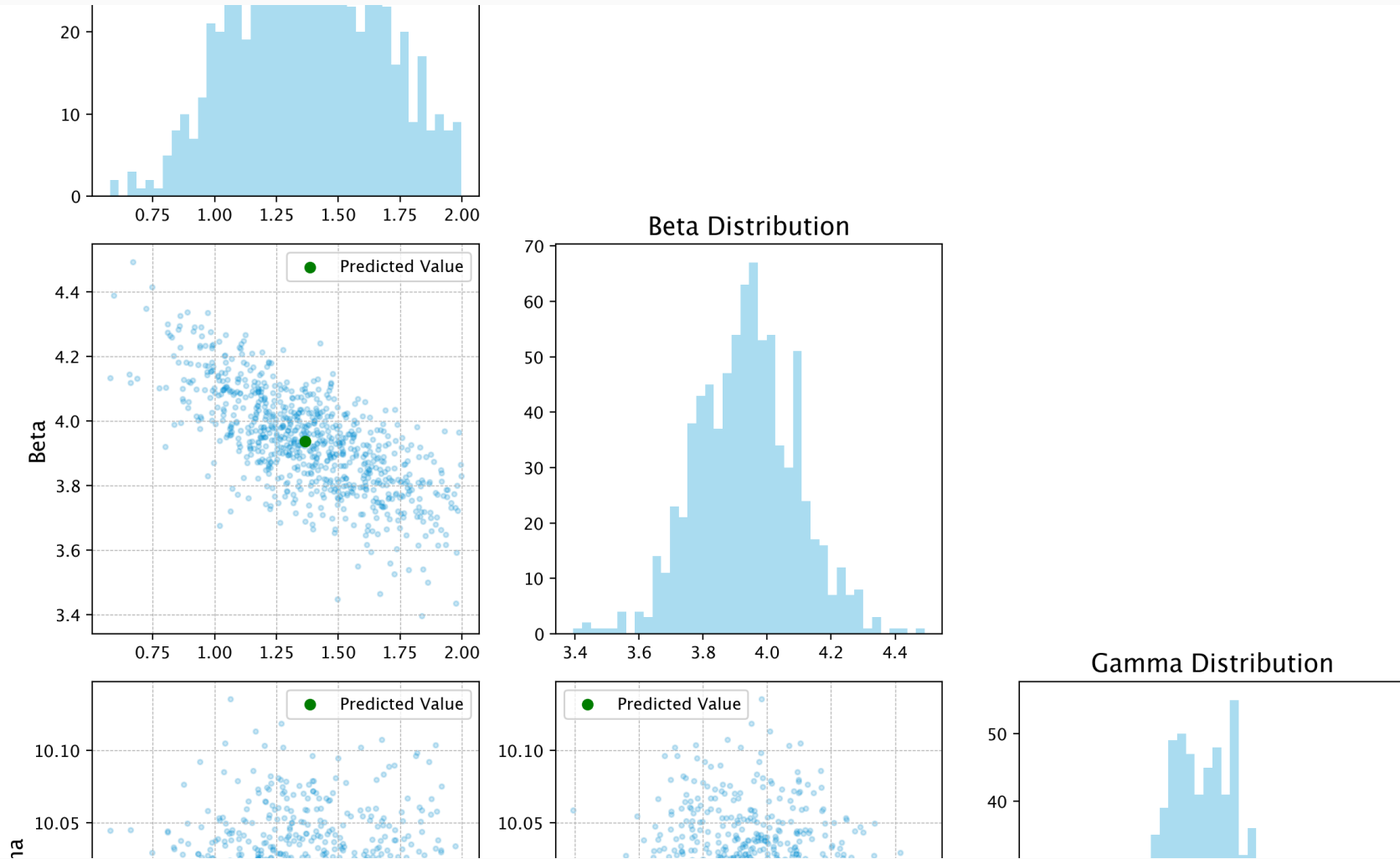


Figure 2: Covariance Scatter Plots of Parameters θ

Numerical Analysis

Parameter	α (alpha)	β (beta)	γ (gamma)
Median Value	1.36	3.94	10.00
95% CI	0.86 - 1.91	N/A	N/A

Something very important