SURF Progress Report

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1 Introduction

The Laser Interferometer Gravitational-Wave Observatory (LIGO) project seeks to directly detect gravitational waves from astrophysical sources. My project is to develop and improve existing algorithms to correlate data from several detectors in the search for gravitational wave bursts. I will test these algorithms using simulations and on real LIGO data. A successful project will result in a useful tool for future LIGO data analysis.

1.1 LIGO and Gravitational Waves

General Relativity describes the universe as curved space-time in which massive objects create deformations. A gravitational wave, as predicted by General Relativity, is a ripple in space-time caused by accelerating mass. Due to a weak coupling with matter, gravitational waves have not been directly observed. Currently, the observations by Russell Hulse and Joseph Taylor of the orbit of a binary pulsar give the best evidence of gravitational waves [3]. They showed that the increasing frequency of the orbit matched the predictions from gravitational wave emission.

Gravitational wave detection will provide verification of the theory of General Relativity. It will also provide a new view of the universe. Studying gravitational waves will tell us information about far away astrophysical phenomena.

LIGO is one of several projects worldwide using a new generation of detectors based on Michelson interferometry. Other detectors include the

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British-German GEO600 detector, the Japanese TAA300 detector, and the French-Italian VIRGO detector. LIGO has three detectors; two are located in Hanford, Washington, and one is located in Livingston, Louisiana.

Each detector has two long (4 km), perpendicular tubes joined in an "L" shape. A laser at the vertex is split, travels along both arms, and reflects back. The two returning laser beams interfere. The intensity of the interfering lasers depends on the phase difference. A gravitational wave distorts space differently in perpendicular directions; it will elongate one direction and shorten the other. Depending on its direction, a gravitational wave incident at a detector will cause different distortions in each of the two perpendicular arms, thus causing a detectable change in interference of the two laser beams, which is translated into a digital signal to be stored on computers.

The amount of distortion a given distance experiences from a gravitational wave is expressed in the strain. Possible sources we hope to observe will cause strains on the order of 10^{-21}, corresponding to a displacement over the 4 km arm a thousand times smaller than the width of a nucleus of an atom [1].

1.2 Data Analysis

The difficulty of measuring gravitational waves requires precise instruments which are subject to many noise sources, including seismic motion, thermal noise, laser frequency variations, and light scattering from residual gas, among others [2]. Rigorous and accurate analysis of the detector signal is crucial to distinguish genuine gravitational waves from noise. LIGO is suited to detect gravitational waves from four main categories of sources, each requiring various data analysis techniques. Chirp signals are caused by the inspiral and collision of binary neutron stars or black holes. Gravitational waves from chirps have a well-characterized form that can be used as a template in searching the signal data stream. Burst signals can result from a supernova collapse or the swallowing of a star by a black hole. Since a burst waveform is unknown, burst searches rely on coincident detection from several interferometers. Periodic signals from neutron stars, though weak in comparison to the previous sources, can be detected by integrating the signal over time. Stochastic signals from the first moments of the universe are detected as background signals and also require correlation between different interferometers [1].

1.3 Burst Data Analysis

Burst data analysis can be described in a pipeline. The first step is to validate the data and determine which data can be used for analysis. An interferometer must be precisely controlled during observation time ("in lock"). Additionally, all interferometers must be in lock at the same time. The next step is to prefilter the data and identify *event triggers*, which signal places in the data stream to analyze further for possible bursts. Event triggers are checked with other interferometers. Since gravitational waves travel at the speed of light, real bursts will be simultaneous in all detectors, to within the time that light requires to travel the distance between detectors. Thus the third step in the pipeline is to determine if coincidence, both temporally and in waveform, of the event triggers exists. [4]. My project deals with this third step. At the end of this project I hope to have an efficient program for identifying the coincident events from any interferometers.

2 Methods and Resources

The overall plan of my project will be to understand existing methods for finding coincident burst events for different detectors, improve the algorithms by adding new techniques or increasing the efficiency of current ones, implement the algorithms in a program, test the new program using simulations and real LIGO data, and finally ready the program for more general use. This will involve computer programming in Matlab both to do the data analysis and to run simulation tests. Eventually my project may involve use of the LIGO Data Analysis System (LDAS) for larger computations. After many tests of efficiency and accuracy, the final version of the program will be implemented in the C programming language.

3 Progress and Goals

In the first two weeks I have familiarized myself with Matlab and have begun to understand the existing methods for identifying coincident bursts. I have written a simplified program to compute the linear correlation coefficient of two data sets, a statistic used to evaluate the likelihood of the data sets matching. I have also developed some methods for testing the efficiency of my method.

In the next month I will be developing a new method to identify strong correlations between data sets. By the end of July, I hope to have a working version that survives rigorous tests and shows an improvement over the previous methods. I also aim to add methods to filter the data to improve search efficiency.

4 Challenges

So far I have encountered the challenges of learning many new ideas quickly. There are aspects of Matlab that I have not encountered before, and I had little previous knowledge of signal processing or statistics.

The development of an algorithm that will actually succeed in finding bursts is full of challenges. One large problem is to determine the proper amount of time over which to search and correlate two time series. There is no obvious answer since we do not know much information about the burst duration. If the selected time window is too short, the program will not see the whole burst waveform. If the window is two long, the burst may be washed out by noise. Nor do we know a priori the direction or source of the burst. Thus we cannot know the difference in time of observation of the burst for two different detectors. To cover the possibilities, we must search all possible lags between signals from different detectors, up to the maximum time of gravitational wave travel from one detector to another. Finding the most successful parameters will require a large amount of thinking and testing.

References

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