LIGO-T050200-00-R

Improving Searches for Gravitational Waves using Signal Isolation Tests
SURF Progress Report 1: July 5, 2005

Sebastian Cassel

Supervisor: Peter Shawhan

I. INTRODUCTION

A brief review of the importance of this project will be discussed, with an outline of the work completed so far, as well as details of upcoming work. This project is concentrating on the selection of gravitational wave (GW) signals from binary inspiral systems. The behaviour of a GW from such sources is known. This allows their signals to be extracted from the LIGO data using a matched filtering technique.

A matched filter can be shown to be optimal in extracting signals with known waveforms from stationary Gaussian noise. The output(1) is known as the signal-to-noise ratio (SNR), and weights the frequency contributions according the amount of noise, S_n, present.

$$\rho(t) = \int \frac{\tilde{a}(f)\ \tilde{b}^*(f)}{S_n(f)} df \tag{1}$$

The expected waveform has a characteristic time associated with coalescence, t_c. The matched filter calculates the correlation with the Fourier transforms of the measured signal, $\tilde{a}$, and one particular waveform, $\tilde{b}$, where $t = t_c$. Appropriate normalisation is applied so that the expectation value of the SNR^2 is unity. This, together with a χ^2 test discriminator, has been seen to be effective in detecting signals. Unfortunately due to the non-ideal behaviour of the true noise, many false signals are present. This project aims to develop additional tests that screen out the false signals.

II. COMPLETED WORK

Over the last two weeks, I have been reading further material[1–5] that describes the method of signal detection within the LIGO data. This allowed greater understanding of the variables with the LIGO software, a necessary step before programming and developing tests. I have also begun work using the LIGO Algorithm Library (LAL), applying its routines in order to extract data to files.

A. Investigation of Noise Triggers

The inspiral analysis algorithm requires a period of 2048s of data in order to execute. Using Matlab, an arbitrary period of data was at first inspected. This was a confidence check to ensure that the code was ready to use and I knew how to inspect the data. Then I was directed to periods of data with large SNR (>30) triggers. The data quality (DQ) flags recorded in time periods surrounding the large triggers were investigated in order to try and explain these signals.

One period contained hardware injected signals. This is where the detector is driven according to how a GW would be expected to influence it. This period was at first neglected. Other periods contained seismic flags, and one had no DQ flags. The period with no DQ flags was selected for further study, and shall be referred to as Segment A.

There are already a number of tests that try to isolate environmental effects in order to veto triggers. A period with no DQ flags seemed as the most appropriate time to use in development of a signal based veto. A plot of the SNR^2 and χ^2 time series during Segment A is shown in Fig 1. As the expectation of having observed a GW in LIGO is negligible so far, it can be assumed that this trigger was due to noise.

It should be noted that the trigger with SNR > 30 was not detected. This was due to using a limited number of templates spanning a small region of the parameter space. Two adjacent templates produced a trigger during Segment A, but all 15 templates investigated showed the same behaviour for the SNR^2 and χ^2. The minimum SNR^2 threshold for a trigger was set at 36, and the maximum χ^2 value, 5.

This signal has a peak in the time series before the trigger, however it was not until the thresholds were satisfied that this event was recorded. Crossing tests[6], and time above thresholds tests[7,8] would have vetoed this trigger.

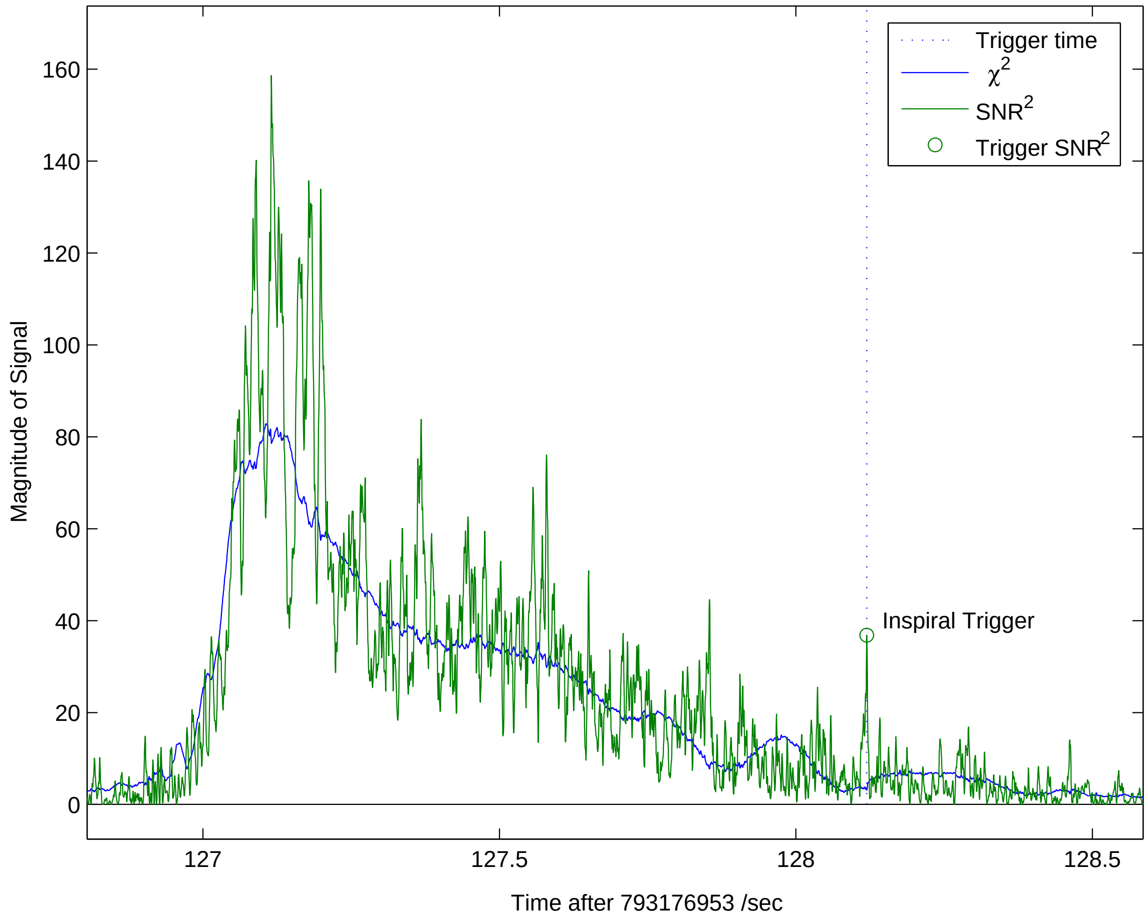

FIG. 1: Plot of SNR^2 and χ^2 time series during Segment A: Noise Induced Trigger

B. Investigation of Hardware Injected Signals

Periods containing hardware injected signals were then investigated. Hardware injected signals had been applied in groups of three. The set of signals chosen for investigation is listed in Fig 2. These signals were in periods of time where the only DQ flag was the injected signal. This should have allowed clean signals to be observed. The mass range used in the template bank was restricted to between 1.393 and 1.407 solar masses. This allowed a manageable amount of data to be extracted, which should have been able to identify two of the simulated signals.

Binary Masses / Solar Mass	Effective Distance / Mpc	GPS Start Time
1.4 - 1.4	20	795574427
10 - 10	40	795574547
1.4 - 1.4	2	795574667

FIG. 2: Sequence of Hardware Injected Signals

The template bank only included equal mass binaries, and was constructed to contain the template corresponding to an exact 1.4-1.4 solar mass system. Triggers were observed 25s after the first and third injected signals were initiated. These were studied and are plotted in Figs 3 and 4, for the 1.4-1.4 template. The time periods defined in the plots shall be referred to as Segment B and C respectively.

The event shown during Segment B set off triggers in seven templates (centered on the 1.4-1.4 shown). There was also another trigger in the 1.4-1.4 template five seconds later. The event shown during Segment C only set off triggers in the 1.4-1.4 template and the lower adjacent template (1.399-1.399). The three plots of the different Segments are very distinctive. It should also be noted that a trigger was recorded 30s after the 10-10 solar mass signal.

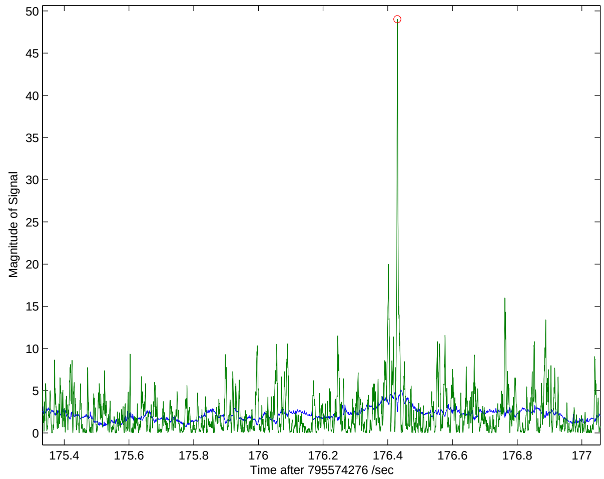

FIG. 3: Trigger after Injected Signal with $D_{\text{eff}} = 20$ Mpc

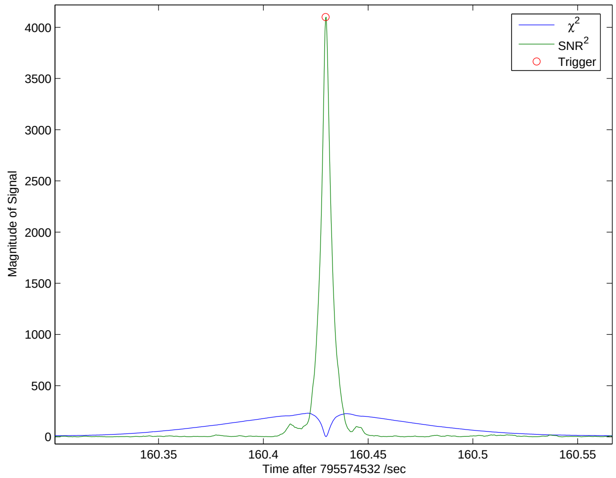

FIG. 4: Trigger after Injected Signal with $D_{\text{eff}} = 2$ Mpc

The very strong signal during Segment C has a negligible amount of noise. The time series have a symmetrical nature. The SNR^2 shows characteristic maxima off the main peak due to the nature of the waveform. The χ^2 has a large peak just before and after the trigger. It should also be noted that the scale for time in Fig 4 is much finer than in the other two.

The signal from the binary 10 times further away during Segment B, has similar behaviour, although the noise is much more noticeable. This signal is much closer the SNR^2 threshold of 36, and the χ^2 value is consistently below 5. Ther is still a dip in the χ^2 at the trigger time though. By considering the timescales involved in each event, distinctive differences can be noted. These differences will be used to develop a discriminating test for candidate events.

C. Development of LAL

It has been necessary to gain familiarisation with commands in UNIX, C, and Matlab. This is an ongoing process that will be necessary for efficient progress. I have begun to alter the LAL code with an intent to introduce a new test into the code. The location of the test is within the inspiral analysis segment that looks for the appropriate waveform.

An important step is identifying where the relevant variables are, and then incorporating them into the algorithm. This is mainly achieved by using the resources on the LAL website. This stage has almost been completed, and will then be used to test the new algorithm on the triggers already investigated.

III. FUTURE WORK

The code will be checked to be working as expected, and a discriminating test implemented. A personal certificate of authentication will be obtained in order to be able to use the large computing clusters. Extensive tests will also be carried out in order to set the most appropriate threshold for the parameters in the test. The test will eventually be applied to a full data run, and the effectiveness of the test determined. The characteristics of the false signals and simulated signals will continuously be investigated in order to produce the most reliable and appropriate test.

---

[1] B. Allen, Phys. Rev. **D71**, 062001 (2005)
[2] C. M. Will, A. G. Wiseman, Phys. Rev. **D54**, 4813 (1996)

[3] LIGO Scientific Collaboration, Phys. Rev. **D69**, 102001 (2004) [gr-qc/0308069]
[4] N. Christensen, P. Shawhan, G. González, Class. Quantum. Grav. **21**, S1747 (2004)
[5] N. Christensen, (2005) [gr-qc/0504067]
[6] P. Shawhan, E. Ochsner, Class. Quantum. Grav. **21**, S1757 (2004) [gr-qc/0404064]
[7] G. Guidi, Class. Quantum. Grav. **21**, S1767 (2004)
[8] A. Rodriguez, [http://www.lsc-group.phys.uwm.edu/iulgroup/investigations/s3index.html]