Interferometer Control System Code Simulation

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1 MOTIVATION

The goal of the Advanced Laser Interferometer Gravitational Observatory (aLIGO) is to definitively identify gravitational waves from cosmological events. That is, by using a Michelson interferometer, the system will directly observe the difference between the path lengths of two perpendicular laser beams. Because the measurement are extraordinarily small, extreme caution must be taken to ensure the functionality of the physical instruments as well the operational software. Having a series of simulations that can predict the behavior of the hardware as well as troubleshoot software coding could vastly improve the success of any future adjustments.

The LIGO Livingston and Hansford sites are currently undergoing a major renovation. New hardware systems are being equipped on site in order to yield far superior results than the previous installation. While some components are still being updated, other areas, such as the Dual Recycle Michelson Interferometer (DRMI), are being tested for functionality and stability. The project is moving into a commissioning phase which takes the newly installed hardware and adjusts it to its projected performance. Most of the work being done in my area of engagement is concentrated on getting the system fully functional in order to clear the commissioning phase. This is where our particular project can improve efficiency as well as generate a viable troubleshooting technique.

2 OBJECTIVE

The aim of this project is to successfully incorporate a working simulation of the control code to the cavity and suspension models of the interferometer. By using the same software used to control the interferometer, we should be able to better understand the overall system. This will be crucial in anticipating irregularities in the physical hardware as well as the actual control code. The ability to troubleshoot the overall system by using a simulation model is critical in effectively dealing with unforeseeable problems.

The simulation we are creating is for the control code. This defines what the analog system of the interferometer senses and transmits measurements using actuators and sensors. Various analog sensors are used to collect information about the degrees of freedom of the suspension or seismic isolation systems. The analog data from these sensors is digitized using

an analog to digital converter (ADC). The digital data is then utilized by the suspension and cavity system to correct abnormities in position due to noise. Using a large variety of filters helps to distinguish what events are causing seismic noise. The system can then reestablish its overall orientation by using precision actuators that meticulously align the components.

After the adjustments have corrected the orientation of the cavity and suspension, the resulting data is looped back into the control code. This data, which is in digital, is sent through a Digital to Analog Converter (DAC) and transmitted into the interferometer to start the process over. This is referred to as the real-time control code because the process is established in a timed sequence. By using the actual control code, we can better discover issues specific to that code and distinguish them more easily from issues that may arise in the hardware of the interferometer.

3 STRATEGY

The initial step to this project begins with understanding the disturbances that the interferometer deals with. There are two distinct noise sources that are prevalent in the system. These noises affect the stabilization of the components in relation to each other. One is displacement noise, usually coming from seismic fluctuations. Seismic noise has many forms. Major factors range from earthquakes to the ocean tides to basic human traffic. The other noise is sensing noise, which is the fluctuation in the vacuum field beating against the radio frequency sidebars. Other notable noises include electronic noise such as sensor noise as well as actuator noise. The goal of the project is to convert these frequency dependent transfer functions into equivalent frequency dependent filters to simulate the system. This process will successfully replicate a fully functional real-time operation.

The data we have used thus far is from the Horizontal Access Module Internal Seismic Isolation System (HAM ISI) embedded in an .frd (frequency response data) Matlab file. The data set is in the Cartesian basis, converted from a local basis for the purpose of uniformity. The set was recorded overnight as a continuous time domain function and interpreted into a discrete frequency domain matrix. The data consist of 6 actuators with 12 correlating sensors per actuator.

4 METHOD

All of the computer programing thus far has been performed using Matlab. The actual simulation is created using Matlab Simulink. Simulink is used as a graphical data entry tool that defines the controls algorithms. These algorithms are used to operate the real time code of the particular component needed or the entire system.

The LIGO lab uses a Matlab function called vectfit4 that takes a vector (transfer function data set, amplitude and phase) and fits it to a state-space model with a common zero and pole set. The lab also uses a tool named Foton (Filter Online Tool) that takes a zero pole gain (zpk) model and embeds a filter into a predefined Simulink filter block. The tool reads and writes coefficient files for the online system to use in the specified block.

The process outlined below is what we envision using to create individual filters that will simulate a particular seismic frequency response.

1. The frequency response data is to be extracted from the .frd Matlab file.
2. The data must be translated into a form in which vectfit4 can make an approximate zpk model.
3. The results are then converted into a form suitable for the Foton program.
4. A particular system block is embedded with the filter code into our Simulink model.
5. The data coming from the system into filter system block must be converted to align itself with the real-time code control.
6. Once the data leaves the filter, the data must be converted again to correlate with the main system block
7. This process will repeat creating a real-time outcome.

5 PROGRESS

Significant progress has been made in obtaining a solid foundation of background knowledge required to deal with the data, filters and the system in general. A fair amount of research was required in order to comprehend the various components involved. Because of my background in Matlab coding, I was able to write several scripts that will help to create the initial test filters. The graphs below illustrate the outcome of the script that

approximates the vectfit4 function to a zpk model. The advantage of this script is that it takes the data from an .frd Matlab file and converts it to useful inputs for the vectfit4 function. The program also converges to establish an accurate model. The figures below illustrates the outcome of a particular data set that was iterated through the script.
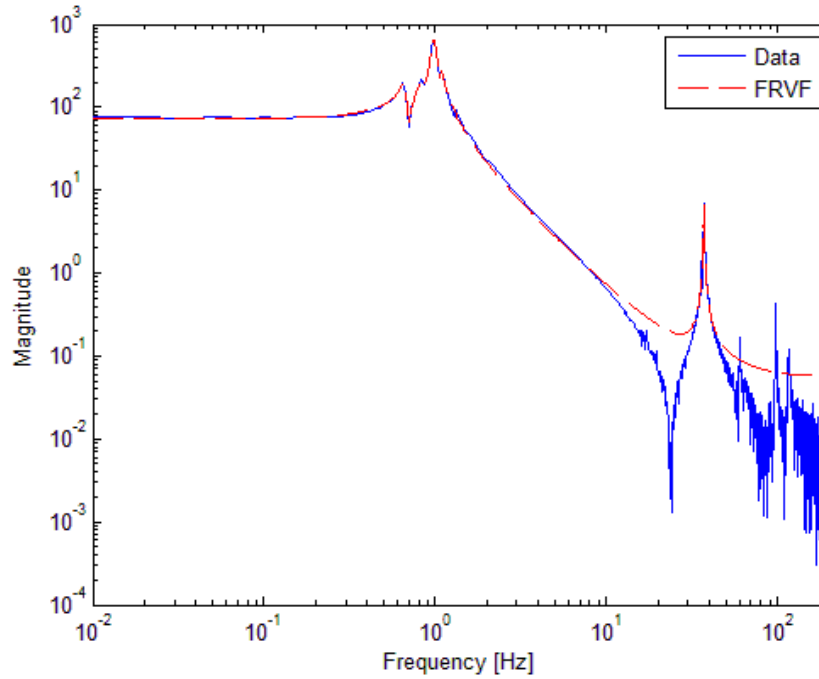

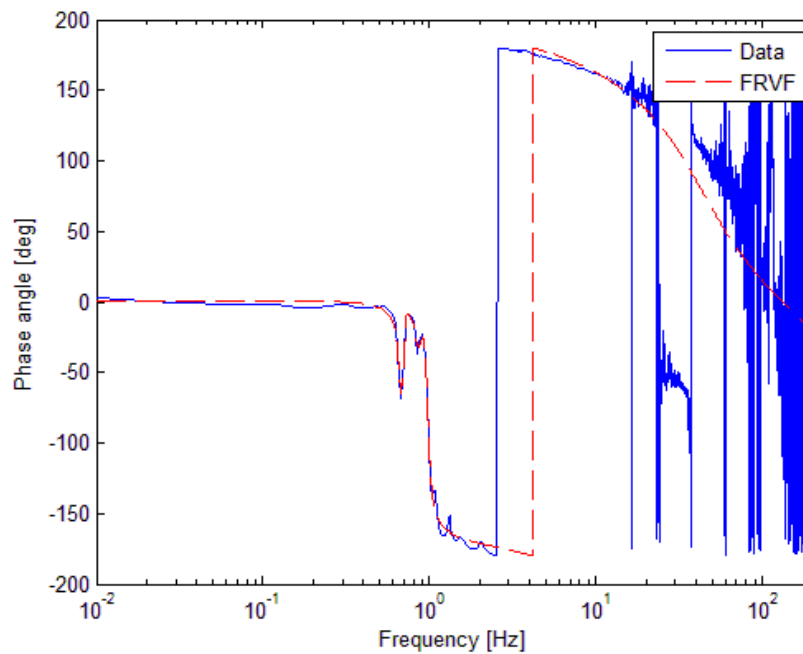**Figure 1:** Magnitude Plot - blue is actual data and red is approximation

Figure 2: Phase Plot - blue is actual data and red is approximation

The script achieved results that produce an accurate representation of the discrete data into a state-space representation.

We have also begun constructing an overall simulation for the HAM ISI component. By modifying a previous build for the model, we have begun to incorporate the noise filters into its electronics design. This model will require a total of 72 filters operating from 6 actuator and 12 sensors.

My goals for next month are to have these 72 filters for the HAM ISI operational within the system. I intend to write a Matlab script that will simply take an .frd file and launch the process for an operational system simulation. There should be little user interface required other than to initiate and verify its progress. I should also have other filters definitions that can also provide the same results. Our main objective is to successfully replicate the rest of the noise that the system incorporates. These goals will require the same methodology used. I do foresee minor differences because the data gathered can originate in various forms.

6 CHALLENGES

The challenges I have encountered are mainly procedural. Learning how to navigate through the LIGO directory system has been challenging. The system is well organized but there are many files associated with various processes that I have to familiarize myself with. This may also be compounded by the navigation system used in the lab. I have experience working on Linux and Ubuntu but have never used the command-line interface, Terminal. Because I have grown accustom to graphical user interfaces, I feel this initial limitation has complicated the challenge of navigating through the directories. None the less, I know this is ultimately beneficial and I find it rewarding to be learning a new skill. I look forward to learning from mistakes and resolving any future problems.

7 REFERENCES

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