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Gravitational wave detector prototype based on Michelson interferometer

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Introduction

By means of theory interferometric gravitational waves detectors was developed a prototype detector based on the interferometer of Michelson, taking the main characteristics of the Laser Interferometer Gravitational-Wave Observatory (LIGO) and implementing a system of simulation that takes the signal of a known gravitational wave (GW150914), Recreates the effect of the wave acting linearly, both perpendicular and in parallel on the arms of the interferometer by the movement of the mirrors.

Methods

Gravitational waves are the perturbations of space produced by a massive body accelerated, with this premise, when a wave hits the interferometer affects the space between the arms of the interferometer. The theory of gravitational wave detectors shows that any variation in the length of an arm results in a corresponding variation of the power at the photodetector.The total power observed P at the photodetector is modulated by gravitational wave signal as:

$$P=P_0\cos^2[h(t)L(\pi/\lambda)].$$

Where P_0 is the initial power, L is the absolute length of the arm, λ is the laser wavelength and h(t) is the gravitational wave that causes changes in the length of the arms.

Experimental setup

From the Michelson interferometer we designed and implemented a simulation system, see Figure 1, constituted by Servo Motor Controller, Travel Motorized Actuators and Translation Stage Thorlabs, which are mounted on each of the mirrors of the interferometer arms.

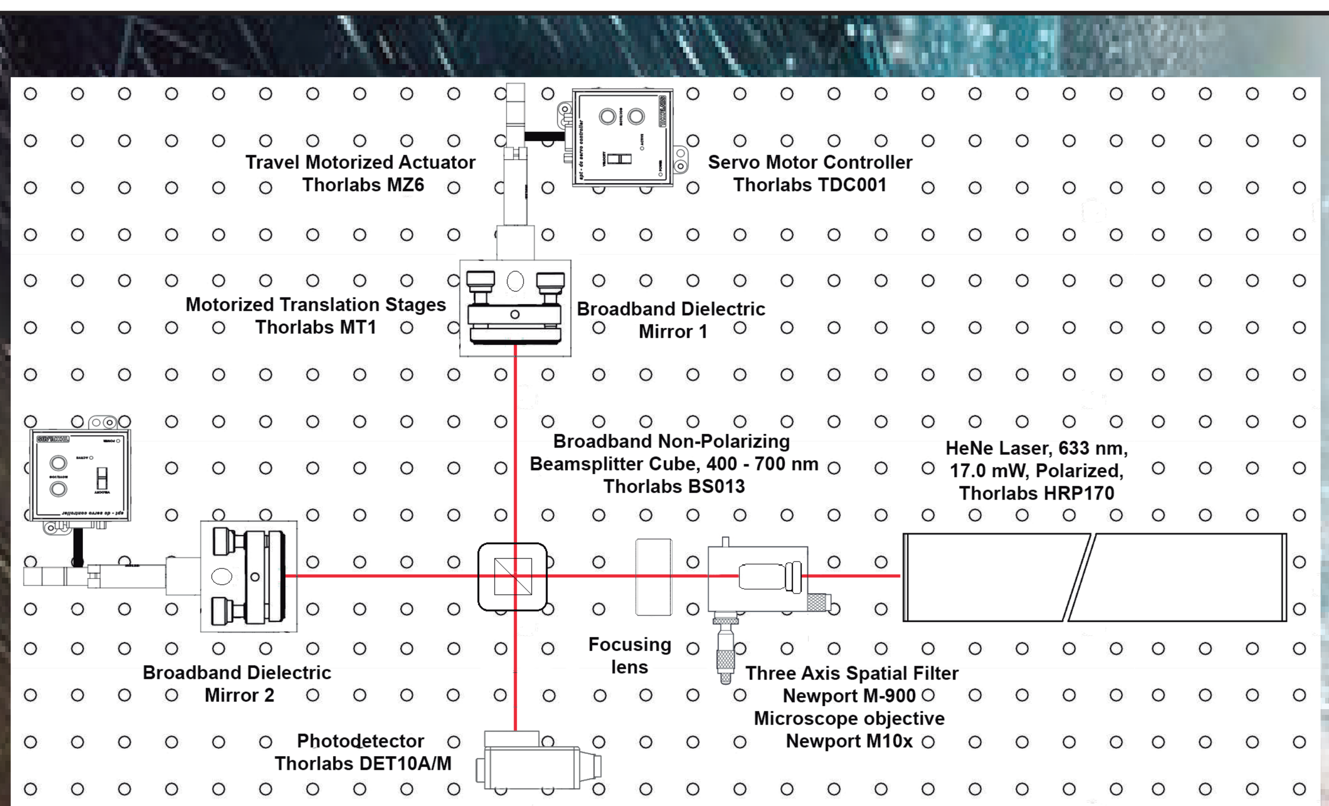

Figure 1. Prototype detector, Michelson interferometer with simulation system.

This system is controlled by a graphical user interface programmed in MATLAB which reads a template of a gravitational wave (GW150914) by normalizing it, then moving the Travel Motorized Actuators linearly in the .0001 m range at a velocity of .0001 m / s, figure 2. Two types of simulations were performed recreating the effect of a gravitational wave polarization h +, shown in figure 3.

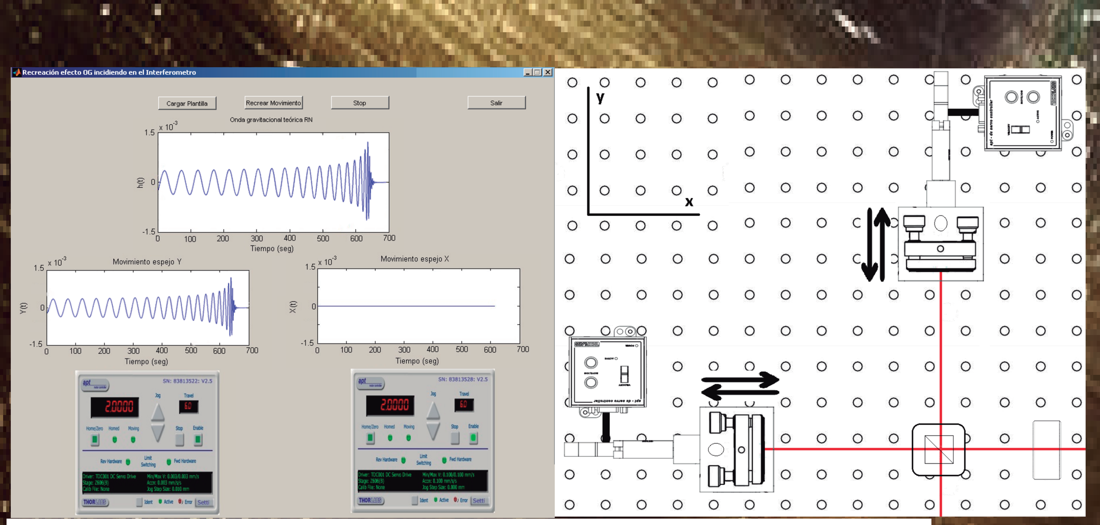

Figure 2. Graphical user interface and Mirror simulation motion.

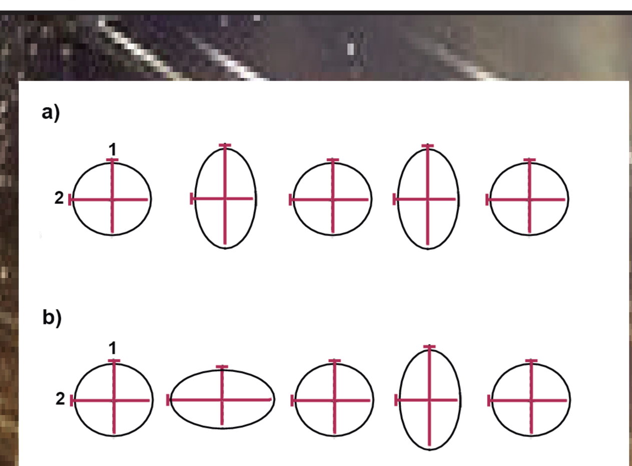

Figure 3. Simulations of a gravitational wave polarization h_+, a) Parallel and b) Perpendicular.

Results

The gravitational wave of the GW150914 event is of the order of 10^{-21}m with a duration of 0.45 s, with the limitation of this system, the optimal order of the gravitational wave to be recreated is of 10^{-4} m, therefore the original wave is scaled to this order. The optimal simulation and detection parameters are shown in table 1 and the characteristics of the prototype detector, see table 2.

Sampling frequency	4 Hz
Actuators movement	0.0001 to 0.01 m
Actuators velocity	0.0001 to 0.01 m/s
Photodetector power change	0.01669 to 0.6611 mW
Optimum range frequency	0.05 to 3 Hz
Frequency gravitational wave emulated	0.326 Hz
Visibility	0.9446

Table 1. Optimal paramters of simulation.

Type of laser and wavelength	HeNe, $\lambda = 633\ nm$
Arm length	0.5 m
Laser power	15.7 mW
Stored power arm 1	6.2 mW
Stored power arm 2	6.2 mW
Photodetector output power	4.2 mW
Diameter of the mirrors	0.05 m
Beam radius	0.98 mm

Table 2. Characteristics of Michelson protoytpe dectec-

The signals obtained during both simulations were processed by two filters, a Window based FIR Filter and a moving-average filter for the signal smoothing. After the data analysis process, it is observed that the signal extracted from the gravitational wave of the simulations has a great similarity with the original gravitational wave injected. Comparing the signals in Figures 4 and 5 shows the similarity.

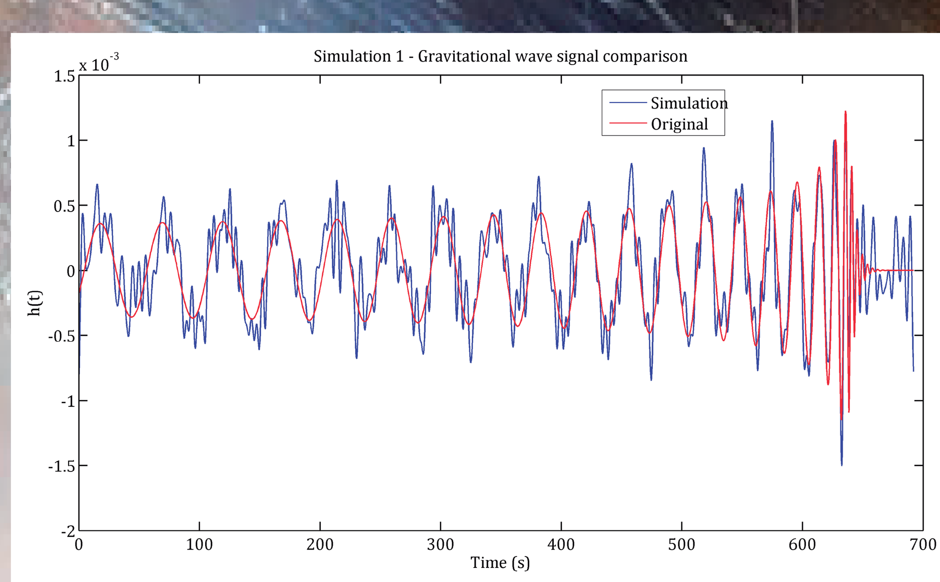

Figure 4. Processed signal of the gravitational wave in the simulation 1

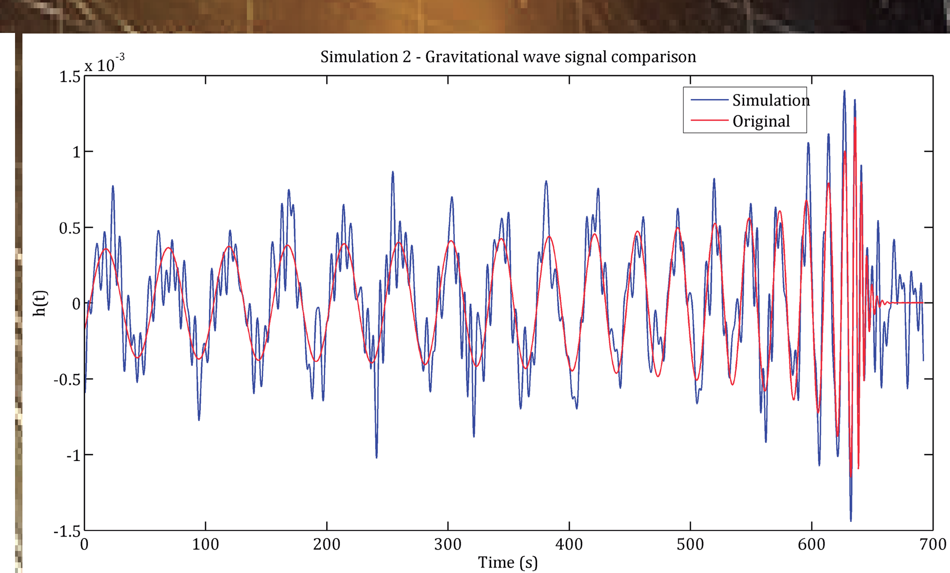

Figure 5. Processed signal of the gravitational wave in the simulation 2

With the results shown in the previous figures, the correlation between the gravitational waves extracted from the simulations and the original was evaluated, in addition the mean-squared error (MSE) was calculated.

The correction between simulated and original gravitational waves for simulation 1 is 0.77, and for simulation 2 it is 0.74. The EMC for simulation 1 is 0.31 and for the case of simulation 2 it is 0.32.

Conclusion

A functional prototype was constructed from a Michelson interferometer to simulate the interaction of gravitational waves with h + polarization at velocity and specific frequencies and from the obtained signal was processed by data analysis processes, to find the signal of the gravitational wave injected In the simulation. This is a work in progress, which will implement improvements to the sensitivity and the simulation system, as well as implement the use of Fabry-Perot cavities in the arms of the interferometer, also characterize the noise. For the moment, use of interferometer is academic and for informational use with subsequent improvements is expected to give way to a more formal investigation.

Acknowledgments

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A rendering of a neutron star merger Illustration: NSF LIGO