Structural Analysis via Laser Lissajous Curves for LIGO Observatories

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With immense help from Stephen Appert

ROADMAP

01 Intro & Motivation

LIGO's need for analysis.

02 Methodology & Our Solution

Why lissajous curves generated by lasers

03 Process

The process of Lissajous curve measurement in real time

04 Discussion & Future Studies

Discussion, other applications & future studies.

LIGO Background

Laser Interferometer Gravitational wave Observatories (LIGO).

- “The Most Precise Ruler Ever Constructed”
- Uses precise destructive interference to measure minute disturbances.
- Distances have to be exaggerated and very accurate for amplified yet precise measurements.
- Tiny imprecisions can create extremely amplified noise.

Thing to take from this:
<u>Extremely sensitive & delicate.</u>

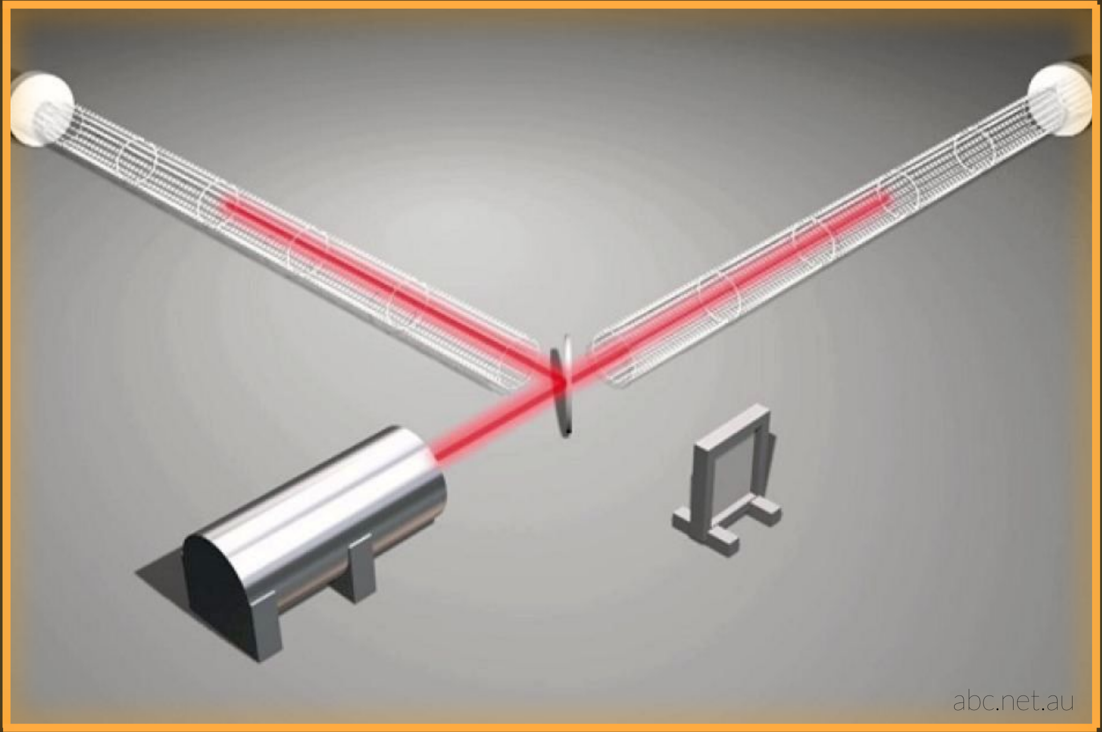


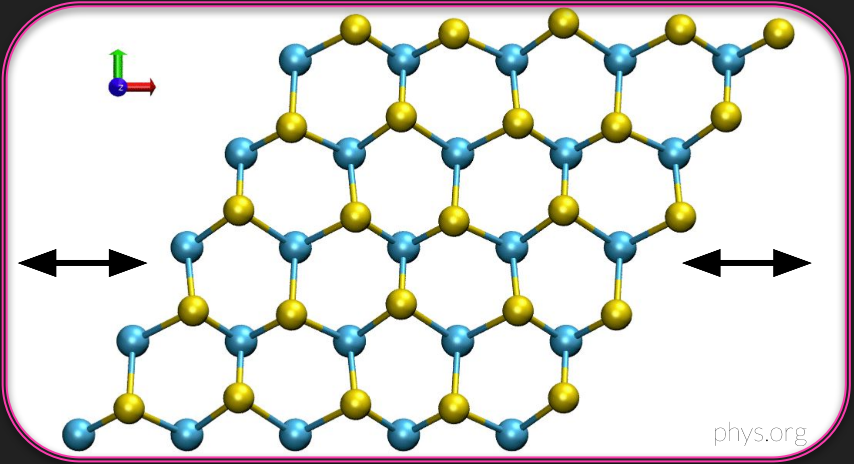
Diagram of LIGO Lasers.

The LIGO Observatories

LIGO Facilities in Louisiana & Washington, respectively.

Initial Motivations

1. Increase precision of LIGO's instruments by reducing error.
2. Identify structural resonance to reduce interference.



Resonance (Vibration) in a crystal lattice.

Things to Note

- **Resonances often resemble sinusoidal waves.**
- A method should be “quiet;” it shouldn’t create additional interference/noise.
- It shouldn’t have delay, real time measurement.

Goals, Research Questions, & Hypothesis

Things to look for:

We need to identify a way of solving for an unknown frequency.

- Reliable
- Real-time & Quick
- Adaptive

How might we be able to balance all of these goals?

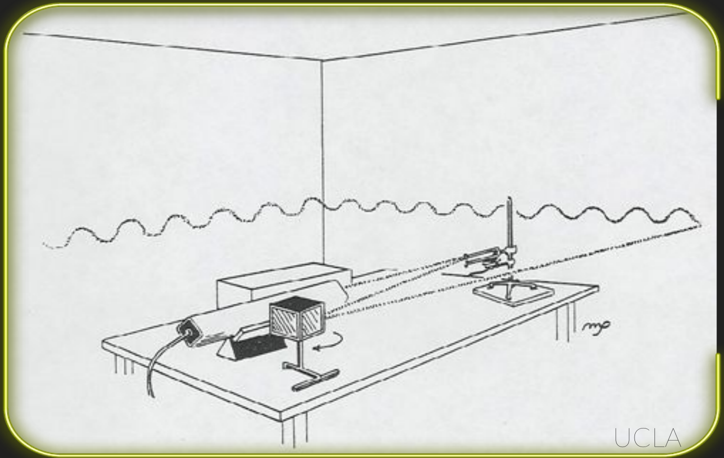
If an appropriate method can, then we should be able to calculate realtime frequencies of resonating objects. Such as tuning forks.

A Possible Solution

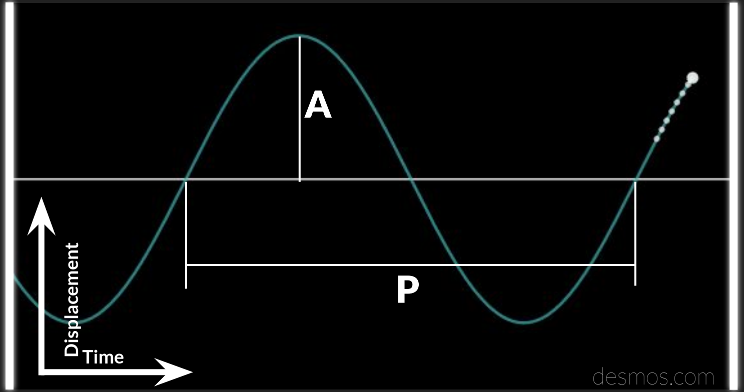
A laser on a reflecting, resonating object forms a sine wave, and we can measure the frequency that way, but:

- Requires precise image recognition and timing.
- Trying to alleviate the first over convolutes for a prototype.

However….



Demonstration of using a tuning fork and mirror to design a measurable sine wave.



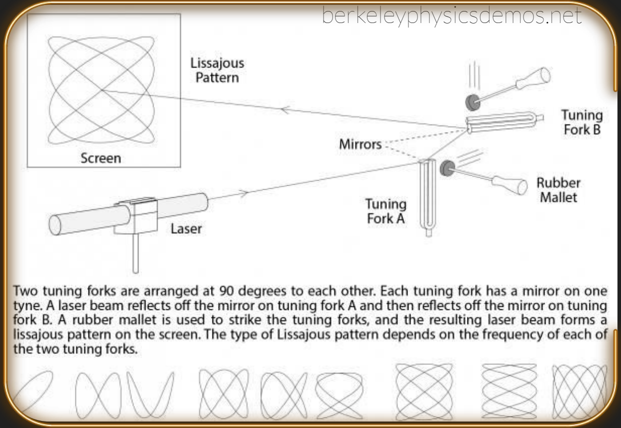
A Better Solution

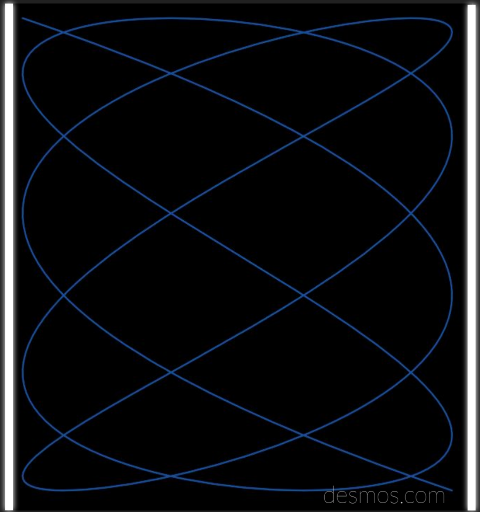
By adding a second, perpendicular, known resonating object, we can create a “Lissajous Curve.”

Parametric equations of the form:

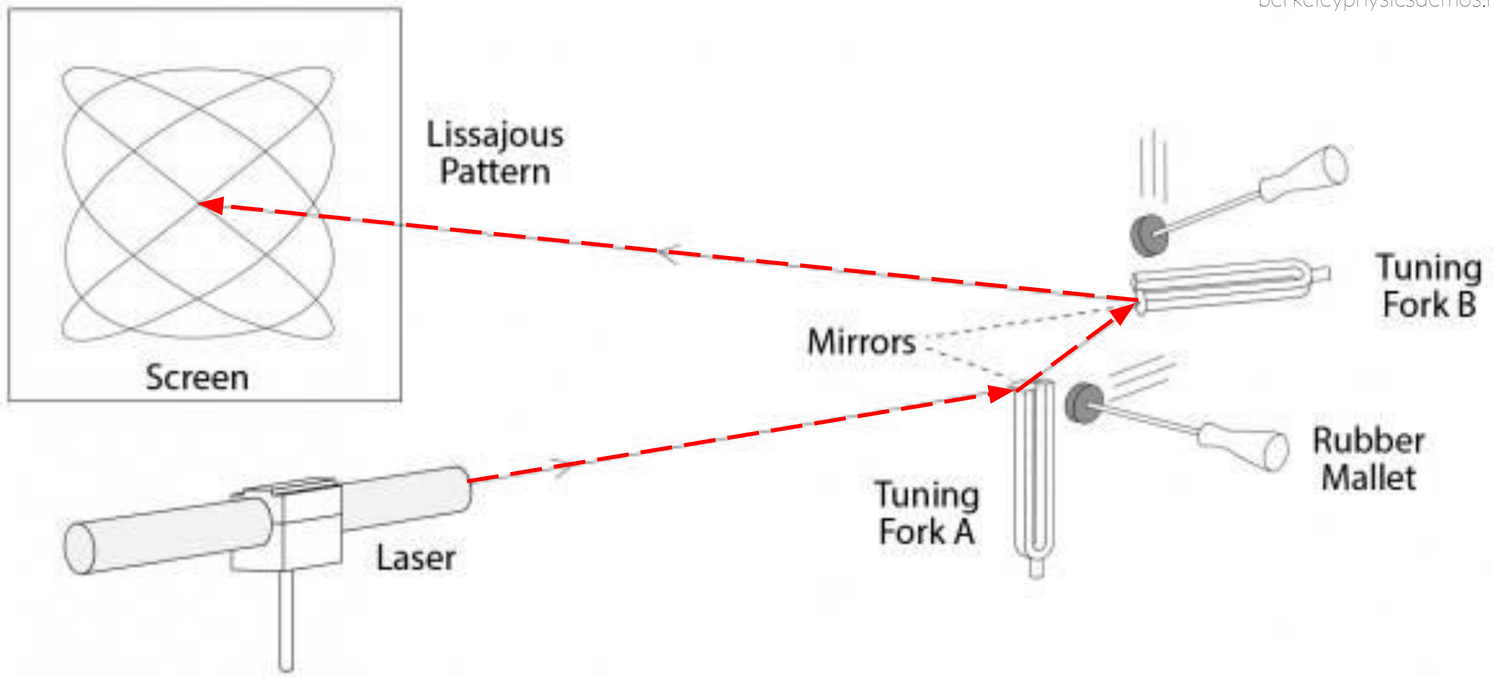
$$\left(\sin\left(\left(2\pi\right)\left(\alpha t-\delta\right)\right),\ \sin\left(\left(2\pi\right)\left(\beta t\right)\right)\right)$$

Where alpha and beta are frequencies and delta is the phase shift.

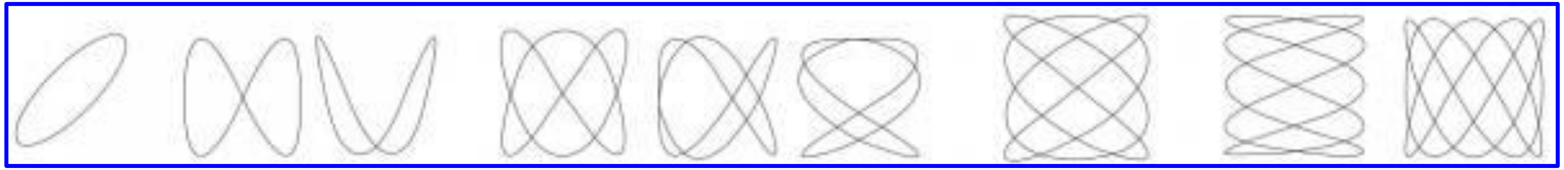




A 5:9 Lissajous Curve.



Two tuning forks are arranged at 90 degrees to each other. Each tuning fork has a mirror on one tyne. A laser beam reflects off the mirror on tuning fork A and then reflects off the mirror on tuning fork B. A rubber mallet is used to strike the tuning forks, and the resulting laser beam forms a lissajous pattern on the screen. The type of Lissajous pattern depends on the frequency of each of the two tuning forks.



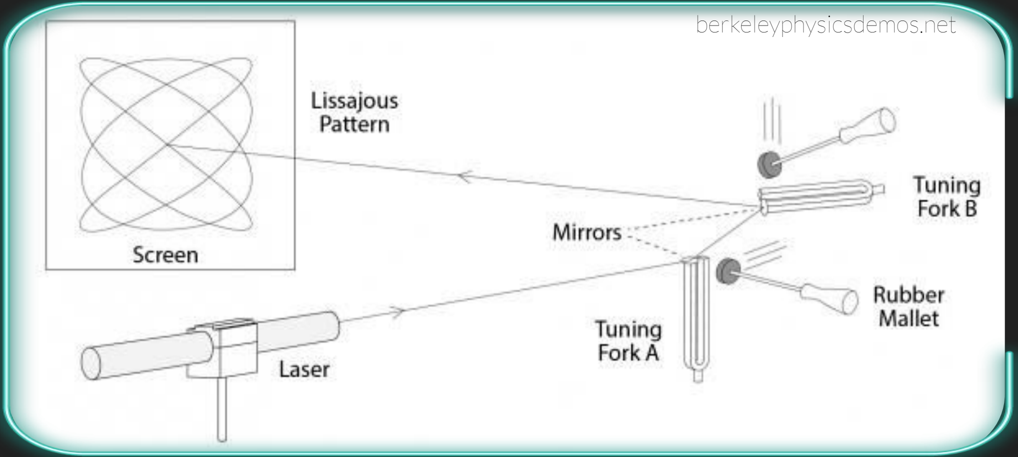
Materials & Setup

Ideal Conditions

- Sets of Tuning Forks
- Laser, preferably in optical spectrum
- Mirrors
- Raspberry Pi
- Camera

Practical Conditions

- Vises
- Projection board

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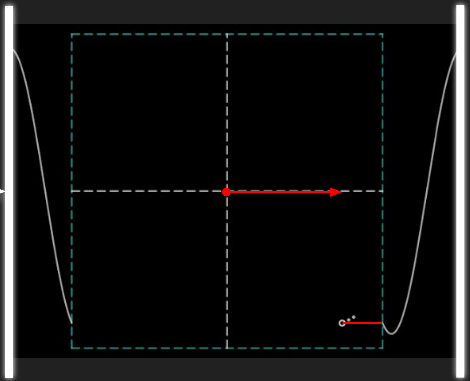
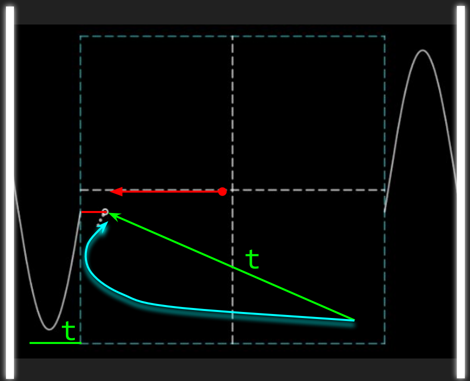
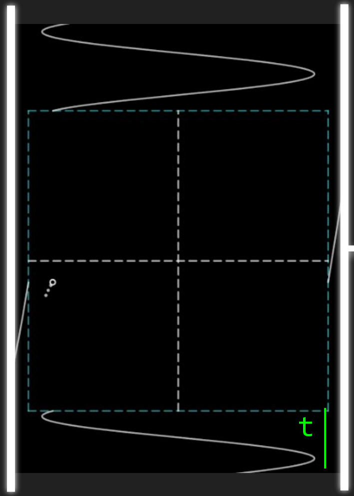
Processing & Code

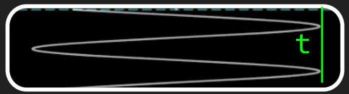


$t \approx t_1$



Assume the smallest possible frequency.





Best guess `t`, then use the known frequency to get an exact `t`.

```
# Position = Solutions of arcsine of (Displacement / Amplitude)
pos[0] = [np.arcsin((pos[0] - self.center[0]) / amph)]
pos[1] = [np.arcsin((pos[1] - self.center[1]) / ampv)]
```

Repeat one time to eliminate any unknowns or other possible solutions.

Discussion

Problems faced:

- **Mirror distortion**
- Tuning fork dampening
- Laser stand

Pros

- ~3 images in any time span for a measurement.
- Accurate & Precise.
- Decreases chance of error.
- Little to adjust after a permanent set up.

Cons

- Has to be pretty decent to get a noticeable Lissajous Curve.
- Intricate set up.
- Easily disturbed.

Future Studies

- Variable resonance
- Variable amplitude
- Identifying a structure's resonance.

Applications

- Structural Analysis
- Mathematics
- Optics
- Seismology

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Josiah Miller

Providing ideas and helping ensure quality.

Justin & Bob

For lessons on both Python & Mathematics

And you!

Thanks for being such a great audience.

Thank you!

And now,

Questions?