Jet Propulsion Laboratory

Space Interferometry Mission (SIM)

Harvey Mudd College Physics Clinic Proposal

Fall Semester
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Abstract

One subsystem of the *Space Interferometry Mission* (SIM) is to measure the small change in distance between two fiducial points to an error of approximately 50 pm. The method for determining this change in distance involves the use of a heterodyne interferometer. By dithering the beam of the interferometer in a known pattern about a fiducial point on the face of a corner cube, it is possible to align the beam such that the distance measured is minimized. This ensures proper alignment of the interferometer and proper measurement of the distance. We will focus first on creating a test setup here at HMC, and then on using this setup to break down all of our sources of error, such that in combination with the more expensive setup at JPL, we can meet the 50 pm requirement.

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Introduction

Company Background

Jet Propulsion Laboratory (JPL) is a research and development laboratory specializing in robotic space exploration. Previous missions undertaken by JPL include Voyager, Galileo, 2001 Mars Odyssey, and Genesis. The SIM mission, set to launch in 2009, will combine two telescopes to more accurate measure the relative positions of stellar objects with a resolution several hundred times better than any previous attempt.

SIM Background

SIM is designed to enable scientists to measure the positions of stars more accurately than ever before using optical interference technology. Combining the information from multiple telescopes separated by distances on the order of 10 meters, SIM measures the distance along a baseline with the resolution equivalent to that of a telescope 10 meters in diameter. Guide interferometers are used to determine motion in the baseline and to provide a reference for the system to determine the locations of various objects in space. To properly calibrate the system, changes in the measured pathlength between the telescopes need to be determined to picometer accuracy. JPL would like us to find a method to reduce the optical pathlength measurement errors due to pointing of the external metrology system to approximately 25 picometers.

Importance of Project

SIM will be used to find more accurate parallax measurements that will greatly enhance the first step in determining cosmic distances. Overall, SIM will give us a much finer view of the universe and allow us to perform astrometry with a resolution hundreds of times greater than our current ability.

Project Statement

We will concern ourselves with the special case of external metrology in SIM. Our goal shall be to determine how a beam launcher in a heterodyne interferometer can be guided to limit the product $\theta \cdot \Delta\theta$ to less than 10^{-11} rad^2, where θ is the mispointing of the launcher, and $\Delta\theta$ is the fluctuation around θ. The desired precision in $\theta \cdot \Delta\theta$ corresponds to an error of 25 pm in the measurement of the baseline. We will minimize the angle θ by dithering the beam around a point on one of the faces of a corner cube, and then measuring the distance the beam travels to the other corner cube and back to the beam launcher. The point where $\theta = 0$ radians corresponds to the place where the distance traveled by the launched beam is at a minimum. We will feed the information gleaned from dithering into an algorithm that will find the point where the distance traveled by the beam is minimized, thus minimizing θ.

Proposed Approach

Our proposed method of reducing the product of θ_$\Delta\theta$ to the project requirements of 10^{-11} rad^2 is to focus on reducing the static pointing error, θ. The major causes of the pointing instability $\Delta\theta$, such as thermal drift and mechanical jitter in our setup, may be identifiable and measurable, but it will be difficult to control them as effectively as in the experiments that are currently being conducted at JPL in vacuum and temperature controlled environments.

In order to develop a pointing solution, we will be setting up a displacement-measuring heterodyne interferometer similar to that used in the previous experiments at JPL. The basic hardware that will be required for this setup will include a beam launcher, a heterodyne laser source, an actuator to control the pointing, and a pair of corner cubes. A quad cell setup may also be used to monitor the performance of our pointing-by-dithering approach.

Setup and Experiment

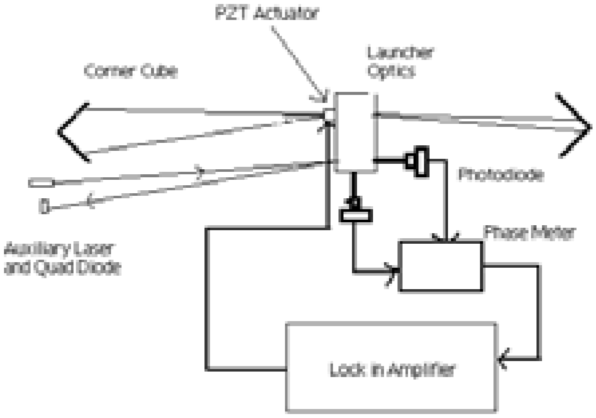


Fig. 1 Basic Setup

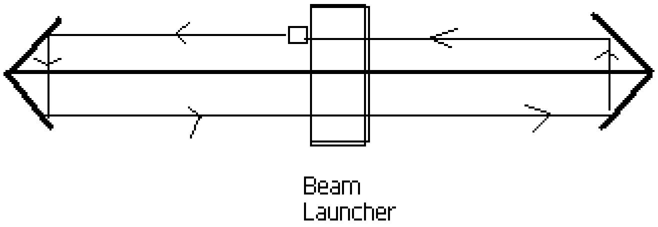


Fig. 2 a) Beam is aligned parallel to line joining the vertices of cubes.

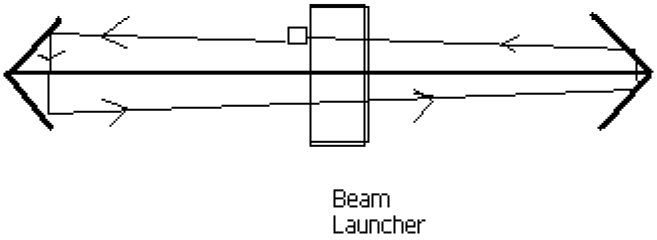


Fig. 2 b) Beam is slightly askew from parallel to line joining the vertices of the cubes.

For a fixed θ, the measured distance between the cubes is independent of the point where the beam hits the corner cube. The launched beam will be defined as perfectly aligned if it is traveling parallel to the line connecting the vertices of the two cubes. As the beam drifts from this perfect alignment (due to the inherent $\Delta\theta$ that we cannot completely eliminate), the measured distance between the cubes will change. In order to minimize this drift, and thus, the static pointing error θ, a pointing-by-dithering approach may be implemented. As the beam is dithered, it will have two components to its motion, one of which is the dithering pattern caused by the actuator, and the other is the natural jitter of the beam $\Delta\theta$. During this motion about the face of the cubes, a yet to be determined algorithm must monitor the measured distance between the cubes and attempt to move the pointing of the laser in such a manner as to minimize this measured distance. By minimizing this measured distance as the laser is dithered, we bring the path of the laser as close to parallel with the line joining the vertices of the cubes as allowed by the constraints of $\Delta\theta$, and thus maximize the accuracy in our determination of the actual distance L. (See Fig. 2).

In practice, there are several factors that will affect the performance of this approach. The corner cubes are not ideal. If the angles from the vertex to the face of each mirror are not exactly 90°, then the length of the path traveled by a beam parallel to the line connecting the vertices will no longer be the same as the length of the line connecting the vertices. This effect can be reduced by characterizing the corner cubes at JPL and by obtaining a precise measurement of the dihedral error. A geometric correction can then be incorporated into the method of pointing correction implemented by the team.

Another problem exists in the mirrors themselves. The corner cubes are not perfectly smooth and contain imperfections. This is compensated for by the fact that the beam is wide, which causes the measured distance to the cube to be taken over a large area. However, as the beam is dithered, the average changes because the beam illuminates a slightly different section of the mirror. Because of this, minimizing the measured distance may lead the beam into local minimums, or “pits” in the mirror’s surface rather than bringing it closer into alignment. In our attempts to locate a minimum close to the correct path, it might also be possible to lock onto an unwanted local minimum and remain stuck there. The method of alignment implemented by the team must attempt to prevent this misalignment from occurring.

In order to measure the stability of a pointing solution, a quad-cell setup may be used in order to provide a reliable reading on the orientation of the beam launcher over time. (See Fig. 1). If a method of alignment is working properly, then the orientation of the launcher should only deviate from the prescribed path of dithering by the inherent amount of $\Delta\theta$ in the system.

Deliverables

The team will provide JPL with a proposed solution to their pointing measurement problem. An experimental setup at Harvey Mudd College will be created to test and demonstrate obtainable values of θ and ${\Delta \theta}$. In addition to this physical model, the team will create theoretical and computational models of the system to show improvements which can be made upon our experimental setup. In particular, we will demonstrate a method of decreasing the product ${\theta \cdot \Delta \theta}$ to the order of 10\(^{-11} \) rad\(^{2} \) using the apparatus available to JPL.

If, during the course of our study, we find that this degree of accuracy is fundamentally unobtainable with the materials available and methods proposed, we will provide conclusive evidence of this fact and examine new designs and methods of measurement. In either case, we will create for JPL a thorough study devoted to minimizing ${\theta \cdot \Delta \theta}$. Our team will provide the SIM group with a thorough feasibility report on their proposed microradian scale displacement-measuring interferometer. If we find evidence supporting this design, we will provide a proof of feasibility based on theoretical and computational modeling. We will supply or demonstrate a working physical model of the set-up to the highest experimental precision achievable with the available resources.

Statement of Work

Preliminary examination of the project leads us to the following steps.

(1) Setup phase

We will work to create a functional experimental setup. This will be an essential phase, one which we would like to do as quickly as possible. By borrowing equipment from JPL and purchasing with our own budget, we will acquire all the equipment necessary to run the testing entirely at Harvey Mudd College. All of the necessary programming of the beam launcher, as well as the creation of any electronic circuits for the setup will be completed during this time.

(2) Experimentation Phase

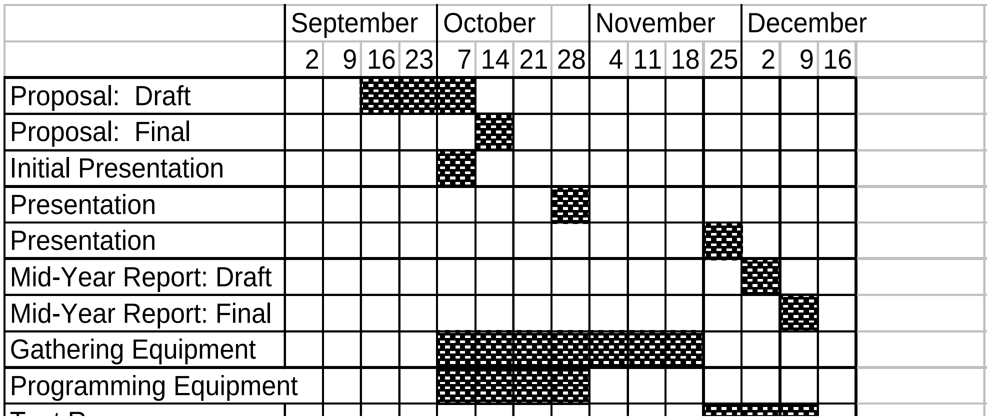
During this phase, we will successfully create the experiment in order to determine the error for the measurement of the distance between the corner cubes and the beam launcher. The phase will end with the successful testing of the beam launcher. Once this phase is completed we will be able to focus more on the specifics of the errors themselves.

(3) Error Identification Phase

We will dedicate our time during this phase to finding specific errors in the pointing of the beam launcher. We will try to ensure that all errors are accounted for, explaining our data set. As we identify these errors, we will devise a solution to all the areas of error in order to improve the data taken. After completing our identification of errors, we will begin to implement the solutions we proposed. If we are not satisfied with the results of our solutions, we will continue to experiment with other answers to the pointing problem.

Timeline

Timeline for Fall Semester



	September				October				November				December		
	2	9	16	23	7	14	21	28	4	11	18	25	2	9	16
Proposal: Draft			▨	▨	▨										
Proposal: Final						▨									
Initial Presentation					▨										
Presentation								▨							
Presentation												▨			
Mid-Year Report: Draft													▨		
Mid-Year Report: Final														▨	
Gathering Equipment					▨	▨	▨	▨	▨	▨	▨				
Programming Equipment					▨	▨	▨	▨							
												▨	▨	▨	

Timeline for Spring Semester

The timeline for second semester is unknown at this point, it depends on our progress first semester.

Key Dates:

Draft Final Report: April 26th
Projects Day Presentation: May 7th
Submit Final Report: May 10th

Budget

This budget is meant to serve only as a rough gauge of project expenses and expenditures. Exact numbers are quite likely to change as the project develops.

Optics Equipment	
Laser source	$3000
Phase meter & components	$1000
Acousto-optic modulators & drivers (2)	$10,000
Preamp, postamp, optic fibers	$1000
Experiment casing	$1000
Polarizing beam splitters	$600
Linear polarizer	$400
Software	$500
General supplies	$500
Travel, general expenses	$1000
Total	**$19,000**

Resources

Kyle Lampe is a senior physics major at Harvey Mudd who is very interested in foreign languages and travel. He spent his last semester abroad in Italy, and has spent a significant amount of time in Japan and Mexico as well. He is the team leader and has experience programming at Microsoft, as well as doing research here at Harvey Mudd college. He has much experience with several computer languages, including LabView and C++.

Daniel Gianotti is a junior physics/math major at Harvey Mudd College. He is particularly interested in experimental procedures and modeling. He has experience in industrial analytical laboratory work and technical writing and hopes to go on to a career in experimental physics.

Kristi Hultman is a senior physics major at Harvey Mudd College with an interest in applied physics. She has research experience with electrically tunable optical filters and using lasers to study properties of various materials. She has experience programming in IDL, LabView, and Java on multiple platforms, as well as programming PC interfaces for various devices.

Robert Seat is a junior physics major at Harvey Mudd College with an interest in applied physics and numerical computing. He has experience programming in several languages including Fortran 77 and C.

Eric Deyo is a junior physics major at Harvey Mudd College, whose interests run towards statistical physics and quantum mechanics. A theoretical physicist by bent, Eric nonetheless enjoys the challenge posed by any applied physics problem.

Karl Hedstrom is a senior physics major, math minor at Pomona College who is interested in applied physics. He has research experience with holography and interferometry setups. He also spent one summer at Cornell’s nanofabrication lab in Ithaca, and has experience programming with Java.