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Sun avoidance strategies at the Large Millimeter Telescope.

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ABSTRACT

The Large Millimeter Telescope observatory is extending its night time operation to the day time. A sun avoidance strategy was therefore implemented in the control system in real-time to avoid excessive heating and damage to the secondary mirror and the prime focus.

The LMT uses an "on-the-fly" trajectory generator that receives as input the target location of the telescope and in turn outputs a commanded position to the servo system. The sun avoidance strategy is also implemented "on-the-fly" where it intercepts the input to the trajectory generator and alters that input to avoid the sun. Two sun avoidance strategies were explored. The first strategy uses a potential field approach where the sun is represented as a high-potential obstacle in the telescope's workspace and the target location is represented as a low-potential goal. The potential field is repeatedly calculated as the sun and the telescope move and the telescope follows the induced force by this field. The second strategy is based on path planning using visibility graphs where the sun is represented as a polygonal obstacle and the telescope follows the shortest path from its actual position to the target location via the vertices of the sun's polygon.

The visibility graph approach was chosen as the favorable strategy due to the efficiency of its algorithm and the simplicity of its computation.

Keywords: Large Millimeter Telescope, LMT, sun avoidance, telescope control

1. INTRODUCTION

The Large Millimeter Telescope (LMT) is a 50 meter diameter single-dish millimeter-wave telescope optimized for astronomical observations at wavelengths between 0.85 mm and 4 mm. The telescope is situated atop Sierra Negra, a 4,600 meter volcanic peak in the state of Puebla, Mexico, and is the joint effort of the University of Massachusetts at Amherst (UMASS) and the Instituto Nacional de Astrofísica, Óptica, y Electrónica (INAOE) in Mexico.

The LMT is a partner in the Event Horizon Telescope (EHT) project and it is desired that the LMT night time operations be extended to the day time to increase the overlap of the LMT EHT observations with the partner telescopes.

One of the issues with day time observing is the harmful exposure to the sun. Any extended periods of time where the telescope points to or near the sun can damage the secondary mirror or the instruments at the prime focus.[1]

While it is possible to rely on the users to schedule observations that avoid the sun, it is necessary to provide automatic protection at the control level to avoid human errors and miscalculations.

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2. LMT CONTROL SYSTEM

The LMT control system is composed of two sets of hierarchical control modules as shown in figure 1. The first set of modules takes as input the requested source coordinates and transforms them to corresponding azimuth and elevation positions. These azimuth and elevation positions are modified by the sun avoidance algorithm and then passed to a polynomial-based trajectory generator to produce a dynamically safe trajectory for the telescope. The second set of modules interpolate the trajectory and close the position and rate loops to finally apply individual torque commands to each drive motor.

The trajectory generator[2] and the servo control work[3] were both presented at the 2008 SPIE conference. This paper presents the work on the sun avoidance strategy.

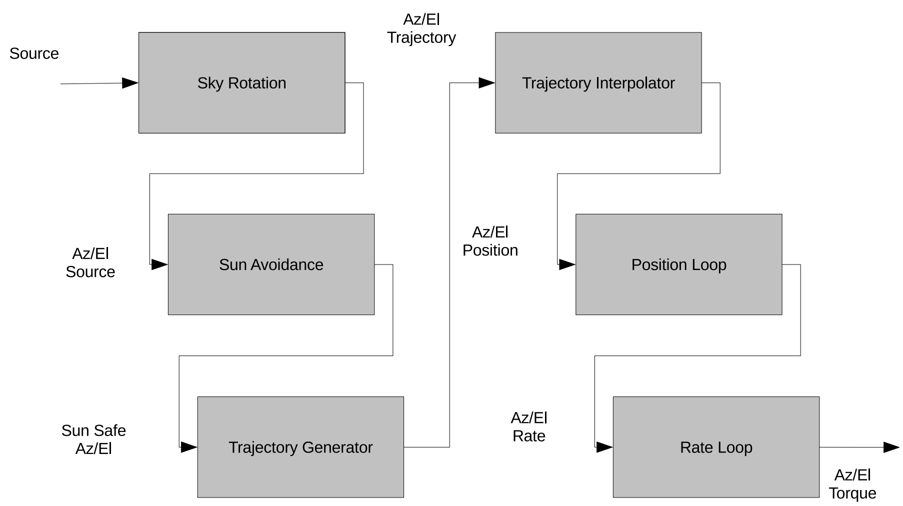


Figure 1. *The Large Millimeter Telescope Control System Modules*

3. SUN AVOIDANCE STRATEGIES

A typical LMT trajectory from an initial position to a target position is shown in figure 2. It is by design that the azimuth and elevation axes travel at the same rate. The trajectory generator does not require both axes to arrive to the target at the same time, on the contrary, the axis with the least amount of travel gets to its target position first and continues to track it until the other axis catches up. In this example, once the elevation axis reached its target position, it continued to track it until the azimuth axis caught up and started tracking it too.

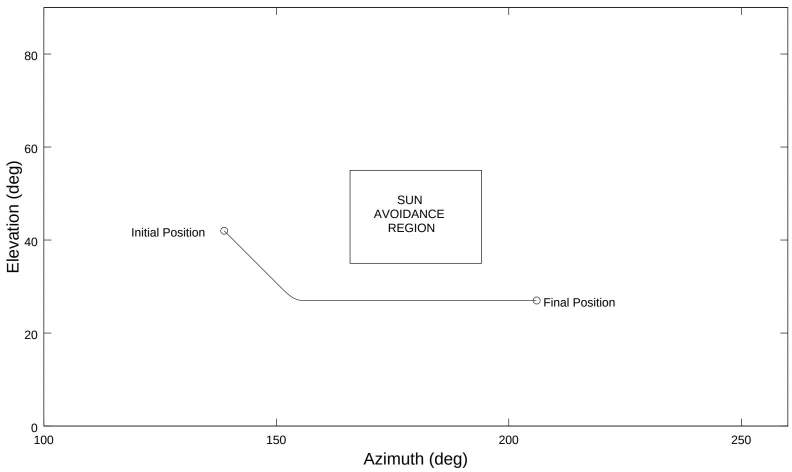


Figure 2. *Typical LMT Trajectory*

However, if the sun interferes with the trajectory, as show in figure 3, then an alternative path must be generated.

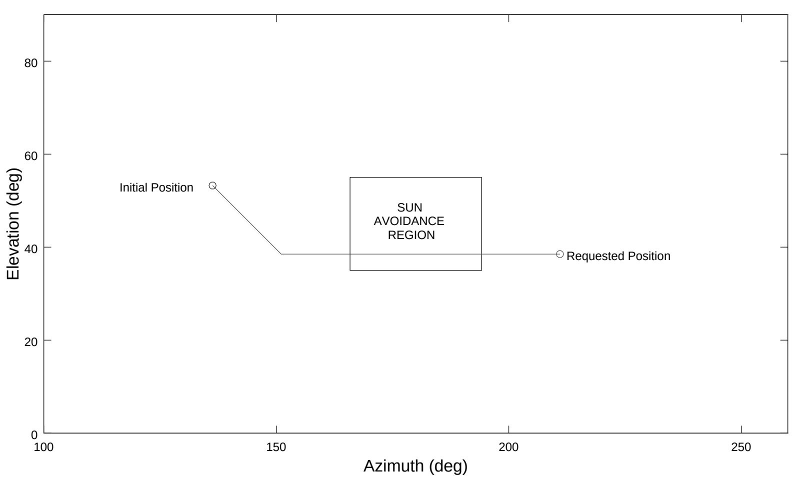


Figure 3. *LMT Trajectory with Sun Collision*

4. POTENTIAL FIELD APPROACH

Potential fields were promoted by Khatib[4] for path planning. Connolly, et al.,[5] and independently Akishita, et al.,[6] described the application of harmonic functions to the path-planning problem. Harmonic functions are solutions to Laplace's equation and can be used to advantage for potential-field path planning since they are smooth and do not exhibit spurious local minima. These harmonic potentials can be computed over arbitrary, discretized environments by very fast relaxation techniques consisting of repeatedly replacing each grid element's value with a weighted average of its neighbors until the computation converges. A simple streamline-following controller is then obtained by using the gradient of the harmonic function as a velocity command. For the sun avoidance problem, the sun is represented as a high-potential polygon in a 2-dimensional bitmap representation of the telescope's workspace and the telescope's requested position is represented as a low-potential point as shown in figure 4.

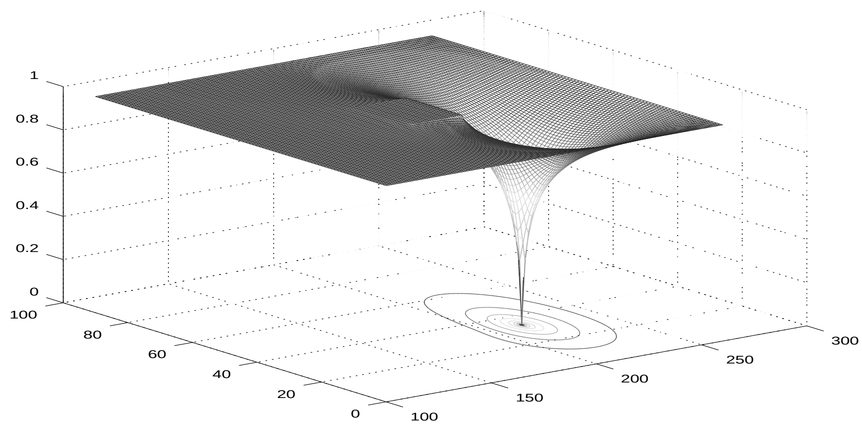


Figure 4. *LMT Workspace Represented Using Harmonic Functions*

Following the gradient of the harmonic function, the telescope's trajectory is presented in figure 5. Note that the path stays far from the sun due to the repelling forces which requires unnecessarily long travel of the telescope.

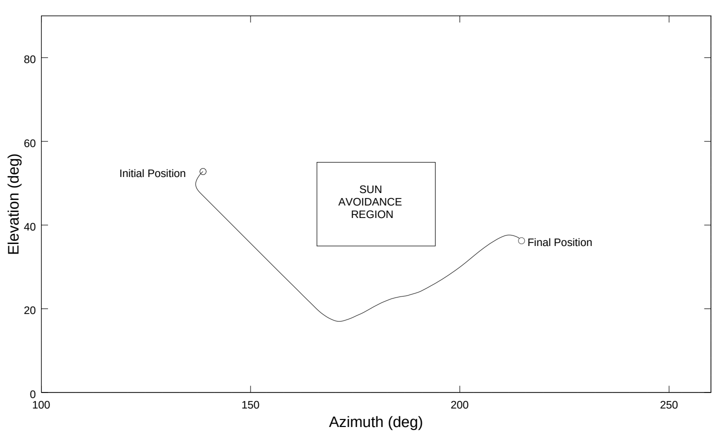
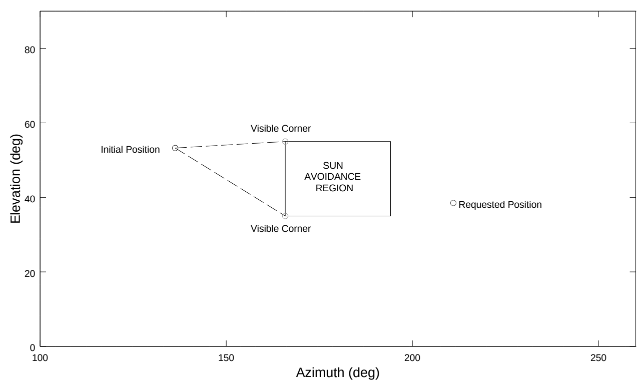


Figure 5. *Sun Avoidance Trajectory Using Harmonic Functions*

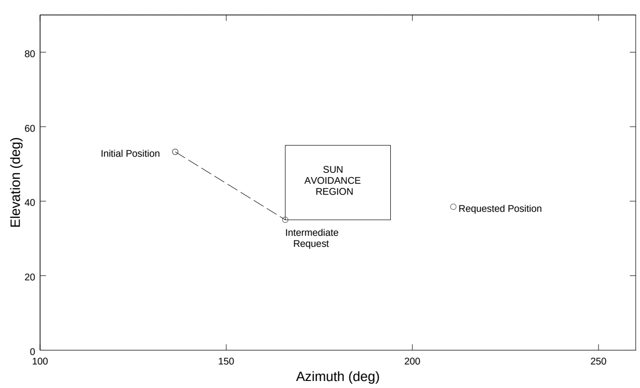
5. VISIBILITY GRAPH APPROACH

The sun-safe path is determined based on path planning using visibility graphs where the sun is represented as a polygonal obstacle and the telescope follows the shortest path from its actual position to the target position via the vertices of the sun's avoidance region. The algorithm is as follow:

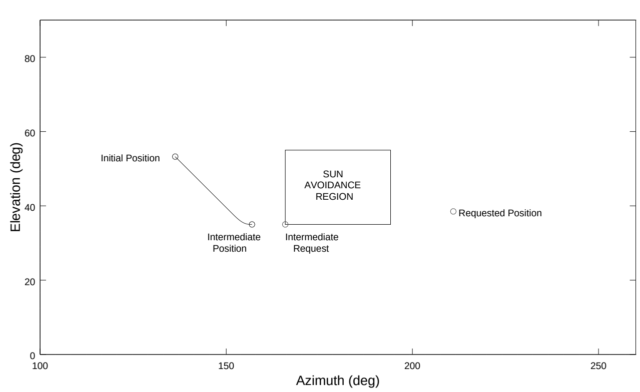
1. From the current telescope position, find the visible vertices of the sun avoidance region.



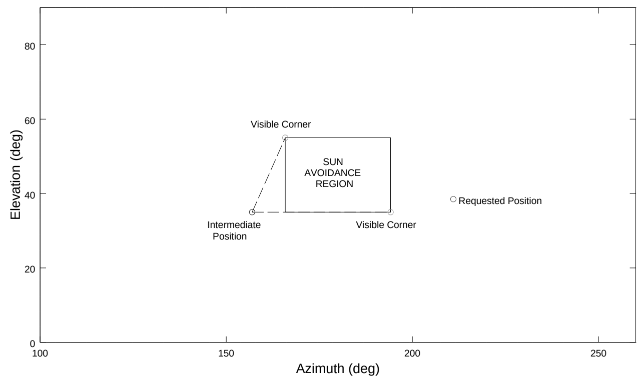
2. Select the vertex closest to the requested position as an intermediate request.



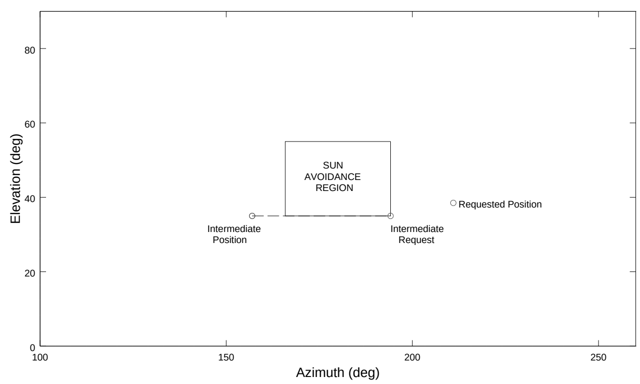
3. Follow a path to the intermediate request until one of the axes reaches their intermediate request. This means that the telescope has reached the boundary of the sun avoidance region.



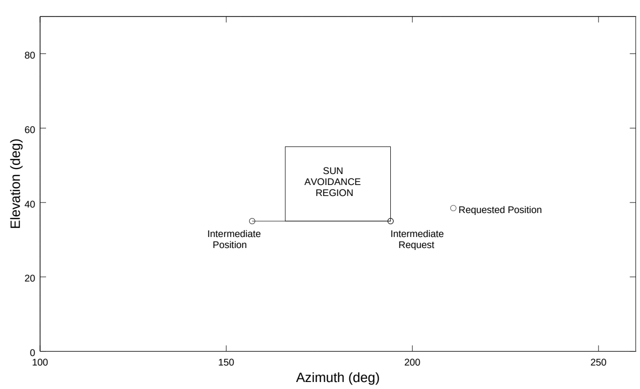
4. Find a new set of visible vertices of the sun avoidance region.



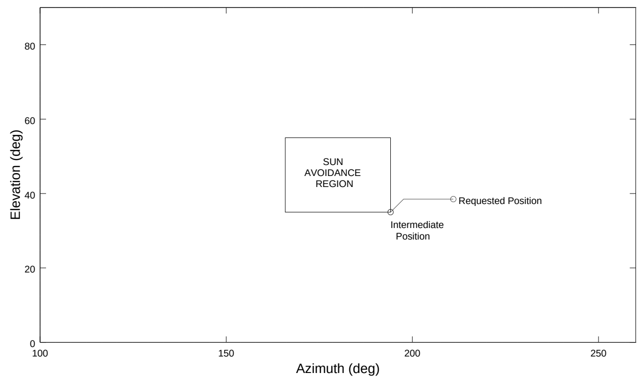
5. Once again, select the vertex closest to the requested position as an intermediate request.



6. Follow a path to the intermediate request until one of the axes reaches the boundary of the sun avoidance region.



7. Generate a new path from the second intermediate position to the requested position and follow it.



The total path therefore is a composition of the three intermediate paths as shown in figure 6. Note that the path gets as close as possible to the sun which minimizes the distance the telescope has to travel.

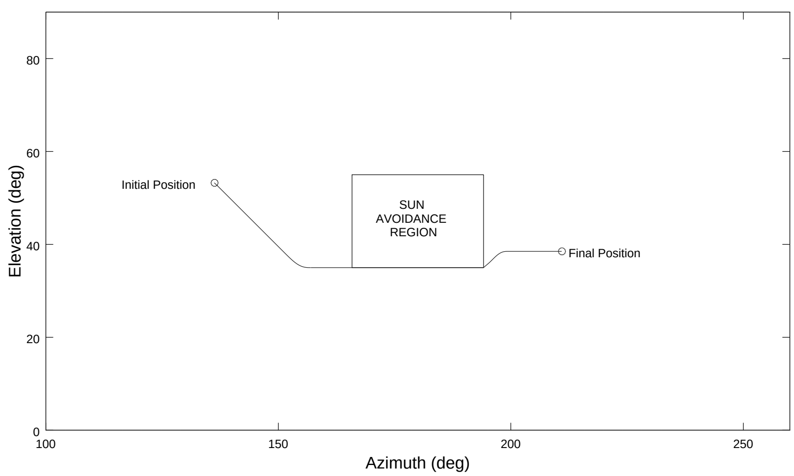


Figure 6. *Sun Avoidance Trajectory Using Visibility Graphs*

6. CONCLUSION

Two methods were evaluated for the sun avoidance path planning at the LMT. Both methods were successful in generating a trajectory clear of the sun. The visibility graph method was preferred to the potential fields method due to its ease of repeated computation and the efficiency of the path it generated.

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