CS486C – Senior Capstone Design in Computer Science

Project Description

Project Title:	**Telescope Mirror Communication and Control System**
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Project Overview:

The central goal of all astronomical observation is to better understand our universe and how it works. Earth and our solar system are just one possible astro-physical arrangement, so what we can learn by looking around our own neighborhood is limited. By observing the literally billions of other systems out there, we can develop a better understanding of what other arrangements are possible, how they might have formed, and the implications for potential future off-earth explorations.

Just as when you view the world with just one eye, there are limitations to viewing celestial phenomena from a single point, i.e., a traditional telescope. Observation of many 2D features benefit from combining multiple views of the target from points that are spread out spatially, a technique called interferometry. For example, the centroid of binary systems changes as one star orbits its partner, and it is the centroid of the binary system that a single telescope measures to generate a catalog of stellar positions; other applications include star-spots (which have yet to be seen!), accretion discs (as the stars spin and toss out matter of different temperature and mass), star rotations (what is the spin rate and orientation of polar axis?) and other interesting science that single telescopes simply cannot measure; we may eventually be able to use nulling interferometry for exoplanet detection.

Fig. 1. NPOI site, Flagstaff, AZ (Photo courtesy of Michael Collier).

The Navy Precision Optical Interferometer (NPOI), an astronomical long-baseline optical interferometer, has been in operation on Anderson Mesa, just outside Flagstaff, Arizona, since 1994. An aerial view of the site, shown in **Error! Reference source not found.**, illustrates the general shape and layout of the 2.2 m to 437 m baseline array. The NPOI has a unique capacity for detecting and determining motions and orbits of binary systems. Many regional partners collaborate with NPOI to take advantage of its unique capabilities, including Lowell Observatory, Northern Arizona University, New Mexico Tech, Seabrook Engineering, and Tennessee State University.

The NPOI collects and combines light from up to six apertures simultaneously to form a high spatial resolution synthetic aperture. The wavelength range of operation is currently in the visible spectrum, 400 nm to 800 nm, and will soon include infrared wavelengths. Reconfigurability of the array generates baselines from 2.2 m to 437 m, and the light collected at each station is transported as a 12.7 cm beam through evacuated pipes to a beam combiner. The light enters and exits the evacuated pipe system through 15.2 cm vacuum windows. Getting and maintaining the star light down and through the long evacuated pipe system is a challenge. The siderostat station control must be exquisitely accurate in its performance to maintain all six star beams in perfect alignment through the pipes, to reach their target hundreds of meters distant, and to hold stable as the atmosphere wiggles the trajectory and the earth (and therefore NPOI) spins under the stars. This problem has been solved in principle: through individualized high-precision control mechanisms, it has become possible to precisely and continuously align multiple mirror pointing and tracking systems from a single device. In short, the end user (astronomer) is able to point this "virtual telescope" at the target, and the control system software will do the rest, generating a perfect, unified image from all the contributing beams. The intelligent software control also allows for automating micro-adjustments in real-time to active mirrors to ensure extremely accurate star-tracking, a necessity to achieve high angular resolution imagery.

The Problem

For the past few years NPOI has been considering alternatives to the current control system which drives these mirrors, known as Narrow Angle Trackers (NATs) and Siderostats. NPOI uses six separate stations, each equipped with a NAT and Siderostat. The siderostats are driven through harmonic drives (precision anti-backlash gear reduction units) via stepper motors, one for the azimuth axis and one for the elevation axis. The Siderostat's role is to track the general position of a star. The azimuth and elevations axes of the NAT are actuated via piezoelectric driven devices and utilize quad cell feedback to inform minor angular adjustments for centering received light. Once the NAT adjusts to near its limit, it communicates with the Siderostat to reposition such that the NAT is able to continue making minor adjustments.

Because the trajectory of the incoming light has to be accurate to extreme angular resolution and each station must perform in perfect unison, NPOI's current setup is problematic. Using our current individualized remote stations, each with a separate computer and unique software for each mirror, causes a number of issues:

- There is no centralized control for the stations and individual stations have no means of communicating with each other. This limits internal monitoring and consistency in tracking.
- Implementing new software or pushing updates requires navigating to each remote station, editing, and recompiling, rather than accessing every device simultaneously from a single source.
- Having more machines introduces a higher chance for system failure, frequent network resets, costly part replacement, and constant observation.
- The current complexity makes it extremely difficult to track down and identify issues, and newly hired personnel require significant training to understand the fundamentals of the system.

Proposed project solution path:

The goal for this project is to replace the individualized controllers with one centralized device. This device communicates with and controls the mirrors at each station simultaneously. On this device, an application will need to be built to accomplish the following tasks:

- Access each station and its corresponding mirrors via IP address through the local network
- Access the necessary cameras and sensors (quad cells) used for the NAT feedback loop
- Read in camera frames and quad cell signals and process their respective data
- Execute each Siderostat tracking algorithm based on observer command, NAT feedback loop, and updated tracking information
- Execute NAT algorithm, utilizing quad cell feedback to reposition and update Siderostat control to reposition each mirror upon nearing actuator limit
- Issue commands to each piezoelectric actuator at up to 500 Hz according to algorithmic result

- Report tracking status for each NAT and Siderostat, as well as any unexpected behavior

Significance:

NPOI has the longest baselines of any optical interferometer in the world, which means during operation its instruments can also achieve the highest angular resolution among its peers. Due to NPOI's status as a joint project between the Naval Research Laboratory, the US Naval Observatory and Lowell Observatory, a successful system will provide each of these agencies with the ability to study stellar objects with high precision otherwise unachievable through conventional means. The research potential of this data is astronomical and will assist the path of discovery for decades to come. Even though this particular project is a small piece of a much larger system, adding a central control network will increase stability, reduce unnecessary complexity, lower maintenance effort and cost, and improve software capability going into the future.

Knowledge, skills, and expertise required for this project:

- Fluency in C/C++, specifically with accessing and controlling devices through input/output
- Knowledge of scheduling operations, specifically to synchronize devices
- Familiarity with PID and piezoelectric motors
- Experience with algorithmic analysis for achieving high data processing rates
- General understanding of networking
- Familiarity with Linux kernel
- Some experience with writing a GUI
- Experience with Multithreading (desired but not required)

Equipment Requirements:

- Device acquisition for an agreed-upon solution will be provided for, and no other external equipment or software should be required, other than a development platform and software/tools freely available online.

Basic Deliverables:

- A report detailing the design and implementation of the product in a complete, clear and professional manner. This document should exactly detail the development process such that an individual with no software experience can easily understand the solution.
- A kernel-level program (or GUI) capable of accessing each station, running their respective correction algorithm, issuing commands to individual mirrors both manually and automatically, and reporting mirror status back to the user.
- Professionally-documented source code, delivered to both NPOI's internal wiki and central computer.