Macho Mengi (M2) – Eyes of the Universe

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Abstract - *Macho Mengi (means "Many Eyes" in Swahili) will be an interferometric observatory system that uses the combined assets of free-flying nanosatellite formations and Earth-based observatories to image stars, exoplanets and also track near Earth asteroids. It is being developed by the NSBE Houston Space Chapter in partnership with Texas A&M University, Charles Stark Draper Laboratory, Seal of Valor (501c3), and C3, Inc. We are currently in phase 2 of development which is to construct an interferometric telescope test bed built for the purpose of educating young engineers and promoting STEM career fields for students while using the development method of Systemic Intelligent Fast Failure (SIFF). The test bed will facilitate ongoing research and development to develop the systems in the nanosatellite telescopes (NSBESAT-2) in addition to extending the network of Earth-based observatories (serving schools and college campuses). For NSBE to grow and continue to gather support from industry we are showing that minority engineers are producers of new and advanced technologies. We are also demonstrating business leadership in managing the development of our innovations into new business ventures.*

Keywords: *Interferometric, aperture synthesis, nanosatellite, exoplanet, systemic thinking, Intensity Correlation Imaging, coherence.*

1 Introduction

1.1 The Vision

The Macho Mengi program is for the design, build, testing, and operation of an observatory system consisting of networks of both ground-based interferometric telescopes and space-based multi-satellite telescopes. [1] The ground-based system involves numerous telescopes around the country that would combine their total functionality to act as a large observatory system. [2] The space-based system involves formations of small, simple satellites that would combine their total functionality to act as a large space telescope. Both the ground and space-based systems will function together as one massive system. This new approach to space observation systems utilizes interferometry in which light information from multiple telescopes is converted to data and combined computationally to produce a single image comparable to that from a larger telescope. In space the satellites would be in a formation that provides the ideal arrangement to synthesize a large telescope aperture. We are looking to Flower Constellations [3] to fulfill this role of arranging independent free-flying space telescopes in a formation. Early formations may remain in low Earth orbit while future formations bay span the distance between Earth to the moon or Mars and beyond. [4]

This observatory system will be available for the community (including grade schools and universities) to schedule time to view a planet, star, or galaxy of their choice.

2 The Technology

The National Society of Black Engineers (NSBE) group will explore an optics technique explored by Dr. Dave Hyland of Texas A&M University. His team successfully demonstrated interferometry done electronically using Intensity Correlation Imaging (ICI) without having to physically combine the light from two separate telescopes (once viewed as nearly impossible). In 2009 his team imaged (1 meter resolution) a GPS satellite in space using two amateur 16 inch diameter telescopes. Dr. Hyland has commented that ICI can use multiple telescopes with optical primary sources as small as $10cm^2$.

2.1 Intensity Correlation Imaging (ICI)

The general term used to describe an image-forming system that uses multiple light gathering devices (i.e. telescopes) to achieve similar results to one large single light gathering device is called aperture synthesis. Two categories of synthetic apertures are:

- Focal Plane Detection: Light from several light-gathering devices is physically combined onto a common focal plane where some form of measurement is taken (electric field measurement, photo detection, etc.).

- Entry Pupil Processing: Light is gathered from a device and immediately subjected to some form of measurement. Measurement data from other similar devices observing the same object along with relative position and alignment data is collected and used to compute the image.

The process of interest for Macho Mengi is the "Entry Pupil Processing". This process begins by using the Hanbury Brown-Twiss Effect (see Figure 1) to measure the intensity correlation of pairs of light gathering devices, then calculating the magnitude of mutual coherence of two separate light-gathering devices (see Figure 2). [5]

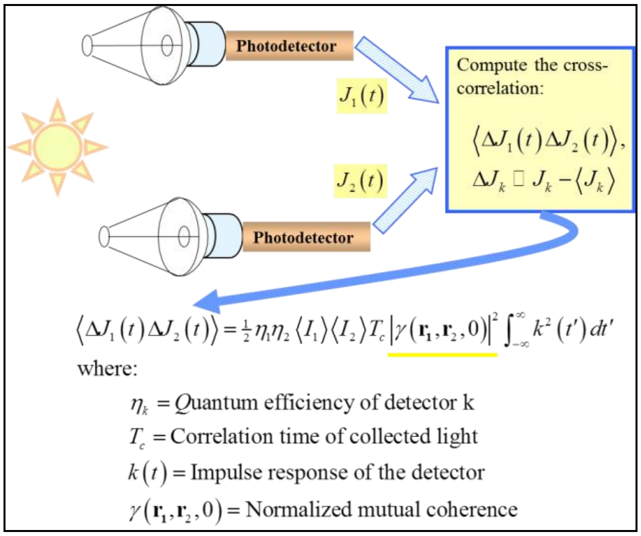

Figure 1: Hanbury Brown-Twiss Effect: Intensity Correlation and Mutual Coherence [5]

Image reconstruction is completed from the intensity Correlation Measurement.

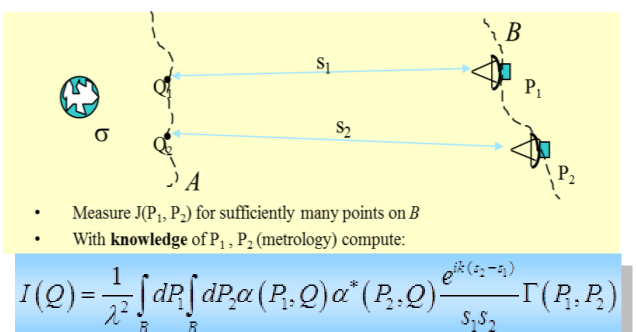

Figure 2: Image Synthesis from Mutual Coherence [5]

2.2 Observatory at Texas A&M University

During the summer of 2013, the NSBE team had the opportunity to visit Texas A&M University and view their ICI observatory. Texas A&M University uses two identical 16" reflecting telescopes each with a refracting telescope mounted to it - used as a star tracker (see Figure 3). A third, very small refracting telescope, mounted on the main refracting telescope is for visual tracking to see if you are pointing at the right object. Each 16" telescope is fixed on a computer controlled, motorized mount.

To demonstrate the power of the main telescope a viewing lens was temporarily attached allowing the observer to view Saturn with its rings and moons (looked like bright spots). The primary telescope is housed inside a shed with a retractable roof and the second (but identical) telescope system is in a trailer (see Figure 4).

Figure 3: 16" Telescope on Motorized Mount

In operation, the trailer unit is pulled and relocated to various points around the field to collect data at multiple baselines. Taking data at numerous baselines fills in the synthesized aperture, thus improving the overall image clarity.

Figure 4: Primary Telescope Shed (right), Secondary Telescope Trailer (left)

From the laptop, the operator clicks on an object on the star chart and the motorized mount automatically tilts the telescope towards that position (see Figure 5). The star tracking telescope uses a CCD camera to center the object in view aligning the main telescope. However, the operator acknowledged that due to temperature fluctuations in the materials, over time they can drift. This issue is doubled in interferometric mode and sometimes two people (one at each telescope) are needed to make fine adjustments. A computer to the far right (see Figure 5) shows what is visible from the CCD camera on the star tracking telescope.

A photon sensor is connected to each 16” telescope (see Figure 6). The photon sensor feeds data to the Data Acquisition (DAQ) computer on the left (see Figure 5) through a data acquisition card - this is what is used to gather the intensity correlation data. Once alignment is achieved and the image is centered on both telescopes, they select a data collection time duration (stop clock) and start collecting data. In upcoming visits to Texas A&M University, the NSBE team hopes to collect real data to produce images.

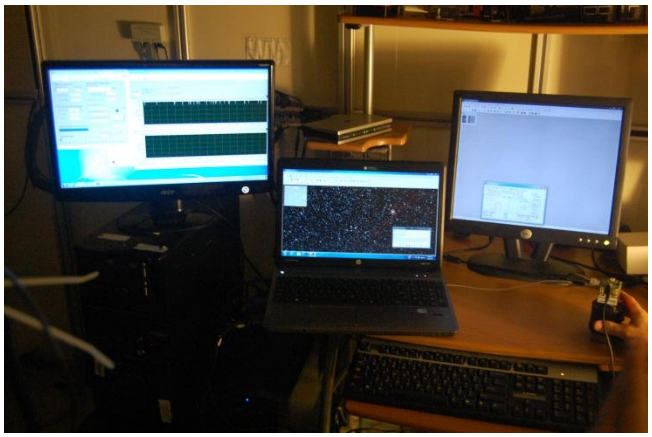

Figure 5: Data Acquisition PC (left), Star Tracking Laptop (center), CCD Camera Screen (right)

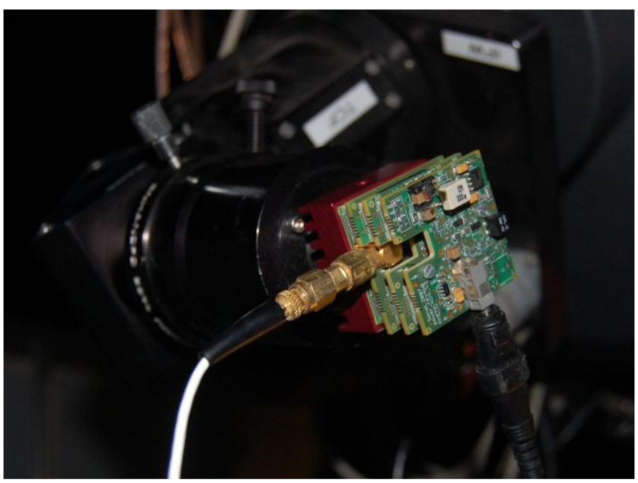

Figure 6: Photon Sensor [SensL APD SPM Mini 1020]

The picture showing the graph (in Figure 7) is the graphic representation of the data. Each line represents a photon strike on the detector plus a very small degree of noise. The data must be collected and hard drives removed and taken to a lab computer to run the analysis in order to produce an image.

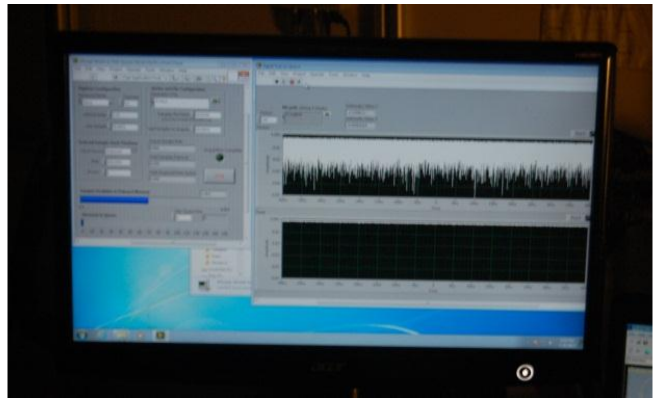

Figure 7: Data Acquisition Screen - Showing Photon Strikes and Intensity on Photon Sensor

2.3 Texas A&M Team’s Recommendation

Since this was their first outdoor prototype of an ICI imaging device, the Texas A&M team used the highest quality equipment affordable at that time (2009). The M2 can be much simpler; high quality optics are not a requirement. The motorized mount needs to be accurate but with simplified optics, may not be required to carry as much weight. Lightening protection was highly recommended. Some years back, lightning struck near the shed and caused significant damage. The rain water flooded the room and ruined the computers. The visit by the NSBE team was the first time the system has been operational since the storm.

3 Program Plan

The Macho Mengi system will be designed, developed, built and tested end-to-end as a complete system starting with the ground-based system (see Figure 8).

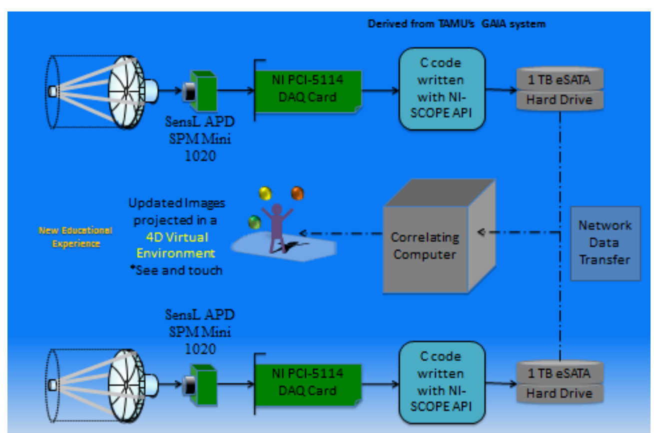

Figure 8: End-to-End System Testing and Integration

The system will be put together in the following phases with an estimate timeframe illustrated in Figure 9:

Phase 1: The Learning phase

- Complete a simple interferometer to understand basic optics principles and gain hands-on experience with optical equipment. This phase is 95% complete.

Phase 2: Build an imaging interferometer

- Gain hands on experience with a working Intensity Correlation Imaging system.
- Compare images from ICI vs. a single aperture telescope (or Amplitude Interferometer).

Phase 3: M2 Constellation Test-bed

- Build a table top version of M2 from original hardware specifications used by Texas A&M University.
- Add networked data transfer (Texas A&M University originally hand carried hard drives to processing computer).
- Lay out the complete end-to-end, integrated system on a table top in one room from telescopes to control center and observation system.
- Incorporate systems built by our partners as they arrive per schedule.
- Subsystems and components that are similar to space hardware should also be integrated and tested in the ground-based system as early as possible.
- Test out various imaging techniques to maximize image clarity and minimize time to produce a quality image. Show comparisons of images from M2 with those from a single telescope.
- Use Systemic Intelligent Fast Failure (SIFF) methodologies to design, develop, integrate, and test the entire M2 System exposing failures as fast as possible.
- Work on several versions of M2 subsystems in parallel. Resolve problems, integrate and reconfigure subsystems, and exchange subsystems components while striving to make the M2 System and subsystem(s) fail again.
- Repeat the process many times so that the end result is creative, innovative, robust, and high performing. The M2 System then arrives as an optimal solution and well understood based on lessons lived and learned via hands-on experience.

Phase 4: M2 Ground-based Initiation

- Distribute individual ground-based M2 units (grade schools, university campuses, home users).

Phase 5: Expansion of Ground-based system

- Expand on the ground-based system across the U.S. by adding ground-based units on participating campuses and sponsoring organizations buildings/properties.

Phase 6: Nanosatellite construction and testing

- Design and build Nanosatellite telescopes of M2
- Design of telescope ICI payload
- Thermal, Thermal Vacuum, Radiation, Structural and Vibration testing

Phase 7: Launch of nanosatellite constellations

- Expect launches at different intervals and possibly among different launch providers.
- Time needed for Flower Constellation to line up.

Phase 8: M2 Constellation Operations (Ground and Space-based integrated system)

- Operations, Maintenance, and Upgrades
- End-of-Life of outdated units

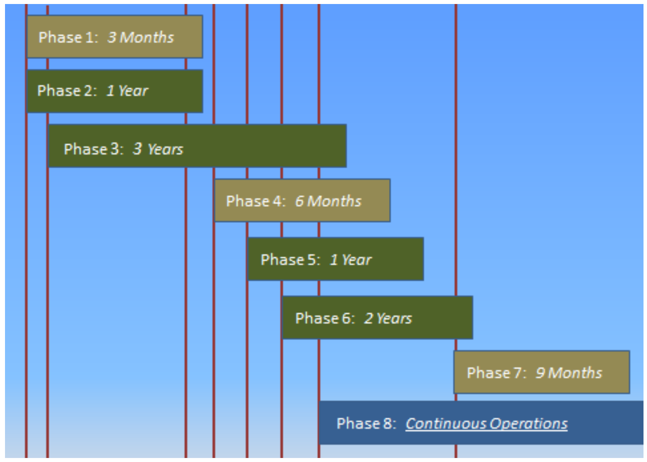

Figure 9: Estimated M2 Program Timeline

4 Systemic Intelligent Fast Failure (SIFF)

It is important that employers, universities, researchers, high schools, middle schools, and elementary schools students of the today as well as the future understand the importance of learning to "see the end from the beginning". Instead of working a problem from the "beginning to the end" based on traditional thinking, they must learn to work a problem "from the end to the beginning" which is called "Systemic Thinking and Dynamic Programming". [6] The beginning is connected to the end and the end is connected the beginning. Why? Because it is a "System".

"Systemic Thinking" is 21st Century thinking and the employers, universities, researchers, high schools, middle schools, and elementary schools of today and tomorrow must have it or they will become obsolete, not be able to make a difference in society or compete, and in the United

States of America creative and innovative thinking will be stagnated. Why? Because the problems of today and tomorrow are systemic and very complicated. Therefore, the innovators and problem solvers of today and tomorrow must be "Systemic Thinkers and Innovators" where they understand what, why, when, who, where, and how relative to solving complex problems and developing creative and innovative systems.

- What: Problem to be solved.
- Why: Importance/Relevance of the research and technology.
- When: Timeline/Schedule.
- Who: Audience and Customers.
- Where: Environments to execute the experimentation process.
- How/Methodology: Systemic Intelligent Fast Failure (SIFF) and Dynamic Programming allows for engineers, scientists, researchers/students, etc. to solve complex problems and systems by "working the problem backwards; i.e., working from the end to the beginning".

4.1 The Importance of "Systemic Thinking"

Existing and future employees in the workforce cannot see the whole; they only see the pieces. They optimize the pieces, but cannot integrate the pieces into a whole. Existing and future employees in the workforce must start with the whole and learn to think using both the left and right sides of their brains simultaneously which supports "whole brain" thinking. Basically, they must see the problem as the whole right from the start. One of the ways complex problems and systems will be solved today as well as in the future is by integrating the pieces and/or disciplines. Each of the pieces and/or disciplines must understand where they fit into the whole. They all must understand that the solution to the pieces does not make the whole. Why? Because of all the interdependencies and inter-relationships of the pieces and/or disciplines. This type of thinking is the beginning of "Systems Integration".

4.2 Methodology

Systemic Intelligent Fast Failure (SIFF) and Dynamic Programming. Systemic Thinking defines the what, when, why, where, who, and how. Intelligent Fast Failure (IFF) is used to get to the knowledge acquisition curve as quickly as possible during the experimentation process understanding what works and what does not work. [6] All components of the system, i.e., the pieces and/or disciplines, must be worked in parallel. Any change to any piece and/or discipline affects the other pieces and/or disciplines. Basically, a "rippling affect" occurs throughout the system and the behavior of the system is altered. The existing and future employees in the workforce cannot proceed to the next step until all the pieces have been rectified and re-integrated per this rippling effect. Once that occurs, the parallel experimentation process continues. Dynamic Programming is the process of working the problem backwards instead of forward.

- Advantages of performing Systems Integration: Running the pieces and/or disciplines in parallel reduces risks, cost, and optimizes the systems behavior as well as increases performance. The outcome is a quality system and/or product.
- Disadvantages of not performing Systems Integration: Bringing the pieces and/or disciplines together at the end instead of the beginning, increases risks and cost, and performance is impacted. At this point, the students are experiencing "Slow Stupid Failure (SSF)" as well as sub-optimal outcome.

4.3 Creative & Innovation Forums

4.3.1 Objectives

The educational objective behind the M2 program is preparing students for college, as well the future workforce. Students will be paired in teams and connected with government and industry partners.

Fresh ideas will be gathered from each team. Next, we will integrate the teams for "fresher ideas" and multi-disciplinary experience: "Systemic Thinking, Dynamic Programming, and Systems Integration". The teams will develop components of M2 in the lab to gain hands-on experience via Intelligent Fast Failure. Teams will contact commercial vendors for loaner components - hardware / software and consultation. Using these loaner components offers a cost effective way to build, test, and integrate the various M2 systems – real-world experience. Teams will develop documentation (Concept of Operations, Functional Requirements, Systems Architecture and Design, Test Plans and Procedures) and conduct technical demonstrations of their progress to solicit more support.

4.3.2 Define Problem Statement

Identify a real world problem. Existing and future employees and students learn how to think creatively and innovatively using both the left and right side of the brain per "whole brain" thinking to solve complex problems and systems relative to defining the Concept of Operations, Functional Requirements, Systems Architecture and Design, and Integration and Testing supporting mission and space operations.

I. Idea Generation

   A. Brainstorming

   B. Hunting & Gathering

   C. Visual Connection

D. Guided Fantasy

E. Stupid Ideas (Positive Opposite)

II. Intelligent Fast Failure (IFF)

A. Innovate or Die [Book – 1996, Jack V. Matson] [6]

B. Task #1: Take a minimum of "7" ideas that were generated to solve the problem statement and give four different ways to implement each idea.

**Encourages students to think "systemically" by considering multiple parallel solutions (21st Century Thinking) simultaneously. Different from Linear thinking (20th Century Thinking) -> Slow Stupid Failure (SSF)

1. Critical
2. Analytical
3. Linear

C. IFF allows the students to get to the "Knowledge Acquisition Curve" as quickly as possible understanding what "works" and what "does not" work while building confidence, enthusiasm, and excitement.

III. Paradigm Shifting ("A flip in thinking")

A. The Best Idea is nothing if you "cannot" sell it!

B. Handling Idea Opposition

C. Business Aspect

IV. Organization [Team]

A. What do you need to make it happen?

B. Let them build something based on "hands-on" experience

1. Define the Components of the M2 System
2. Contact Vendors for components
    a. Hardware
    b. Software
    c. Test Plans
    d. Operational Procedures

C. Test Ideas in a Real World Labs

D. Develop Failure Resumes

1. Real World [Application] versus Theory

5 Educational Outreach and Utilization

The opportunity presented for the integration of university students with the M2 Program opens the doors for re-establishing the Research and Development infrastructure that seems to be escaping the Institutes of Higher Learning here in the United States.

A study, which was spearheaded by the American Society for Biochemistry and Molecular Biology (ASBMB), is the latest to highlight the extent to which years of stagnant or declining budgets, made worse by sequestration, have damaged the world of science in the United States [7]. In an effort to taper off the erosion of the R&D infrastructure, the current White House Administration has provided a path for re-development [8]. This opportunity will allow research programs like Macho Mengi (M2) to fill the gaps and inspire the next generation of scientists and engineers based on Science Technology Engineering Math (STEM). The next step is how…

The M2 Program partners industry professionals, techniques, and best practices in the areas of system engineering and integration, project management and leadership, risk management, etc. with University students who have the latest in research theory. This partnership will allow for creativity and innovation on all levels and rapid expansion to program milestones and goals while introducing students to "applied research" via hands-on experience.

The program objectives for the M2 Program integrates science and engineering in the areas of math, physics, astronomy, and robotics. Local schools and universities can utilize these areas to help develop those technical areas of expertise that the United States is falling behind on.

Focusing on a program based learning environment, reveals four advantages for the M2 Program: (1) Transfer of knowledge and skills to real world problems with industry professionals (2) increased excitement, enthusiasm, and motivation for applied learning for local schools and university students (3) improved math and science scores for students, and (4) introduce students to the importance of failure in the design process.

This is recognized as a networked think tank between universities and partnered companies. The companies provide real world problems, applications and resources while the local universities provide the students who apply class theory and research time to present creative and innovative solutions.

6 Conclusions

The overall systems architecture has now been defined. We can begin the process of acquiring components and assembling M2 according to the major subsystems defined by Texas A&M University's working model and use of existing components. As we apply SIFF methodology and gain a better understanding of M2 we will discover parallel paths to explore and new concepts to integrate and test there-by failing faster while optimizing M2.

For NSBE to grow and continue to gather support from industry we are showing that minority engineers are producers of new and advanced technologies. Not only that, but we are demonstrating business leadership in managing the development of our innovations into new business ventures. In these hard economic times, industry is looking for true innovators that can also perform – now is the time to show our creativity and innovative thinking to the world.

Acknowledgment

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