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USC

Predicting the Position of the Sun, across Earth's Horizon, prior to Sunrise, using Image Processing

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Outline

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- Background
- Motivations
- Prior Work
- Our Solution
- Results

- **Background**
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USC CUBESAT: OZ MISSION

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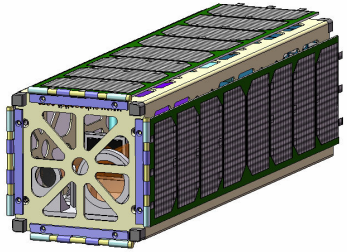
- **Mission Objective**
  - The measurement of the Ozone Column in the Earth's atmosphere, OZMOSIS



- **Method**
  - Measure the ratio of the intensity of light in the visible spectrum to the UV rays from the Sun – through the Earth's atmosphere – at Sunrise and Sunset
- **Platform**
  - Use a Three Axis Stabilized, sun pointing, 3U CubeSat

SYSTEM DESCRIPTION

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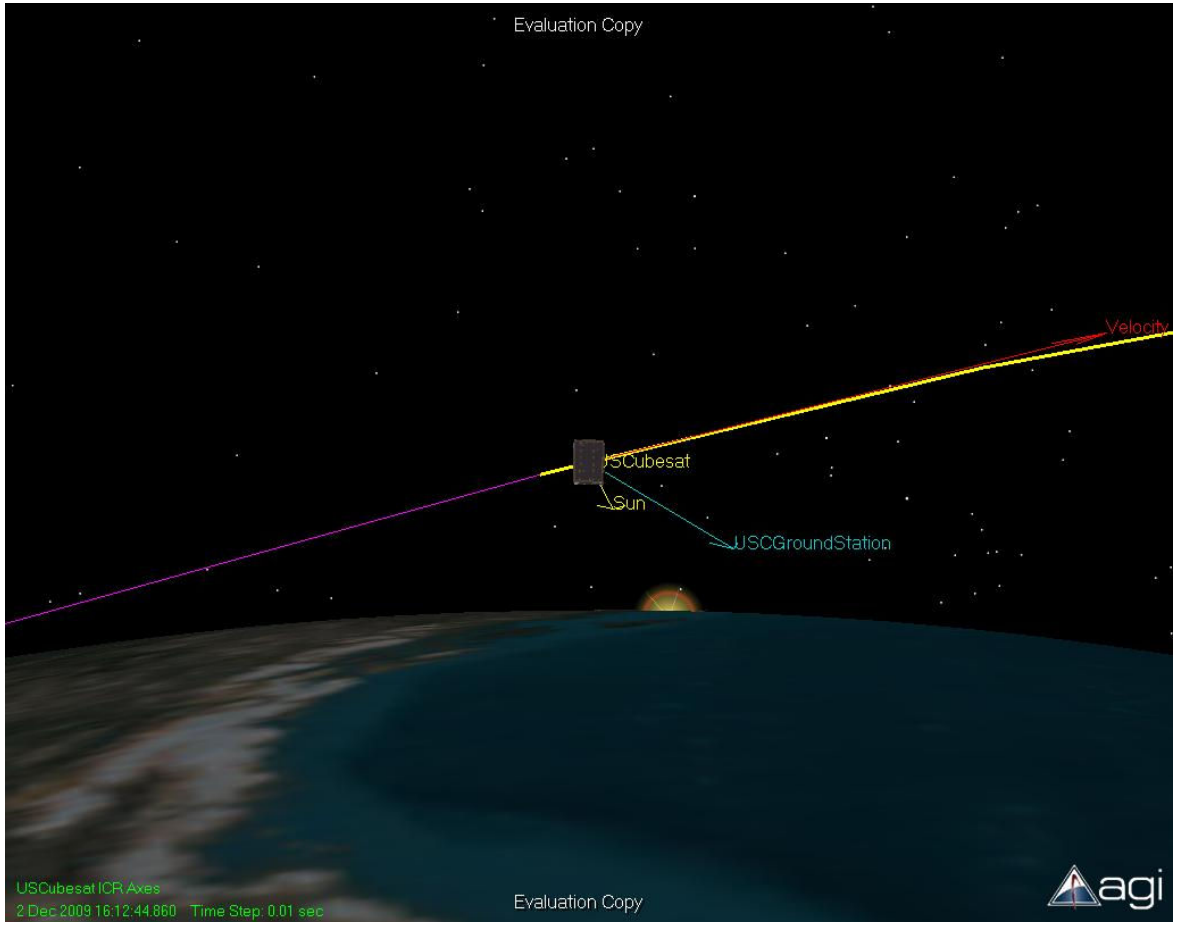
Mission Illustration



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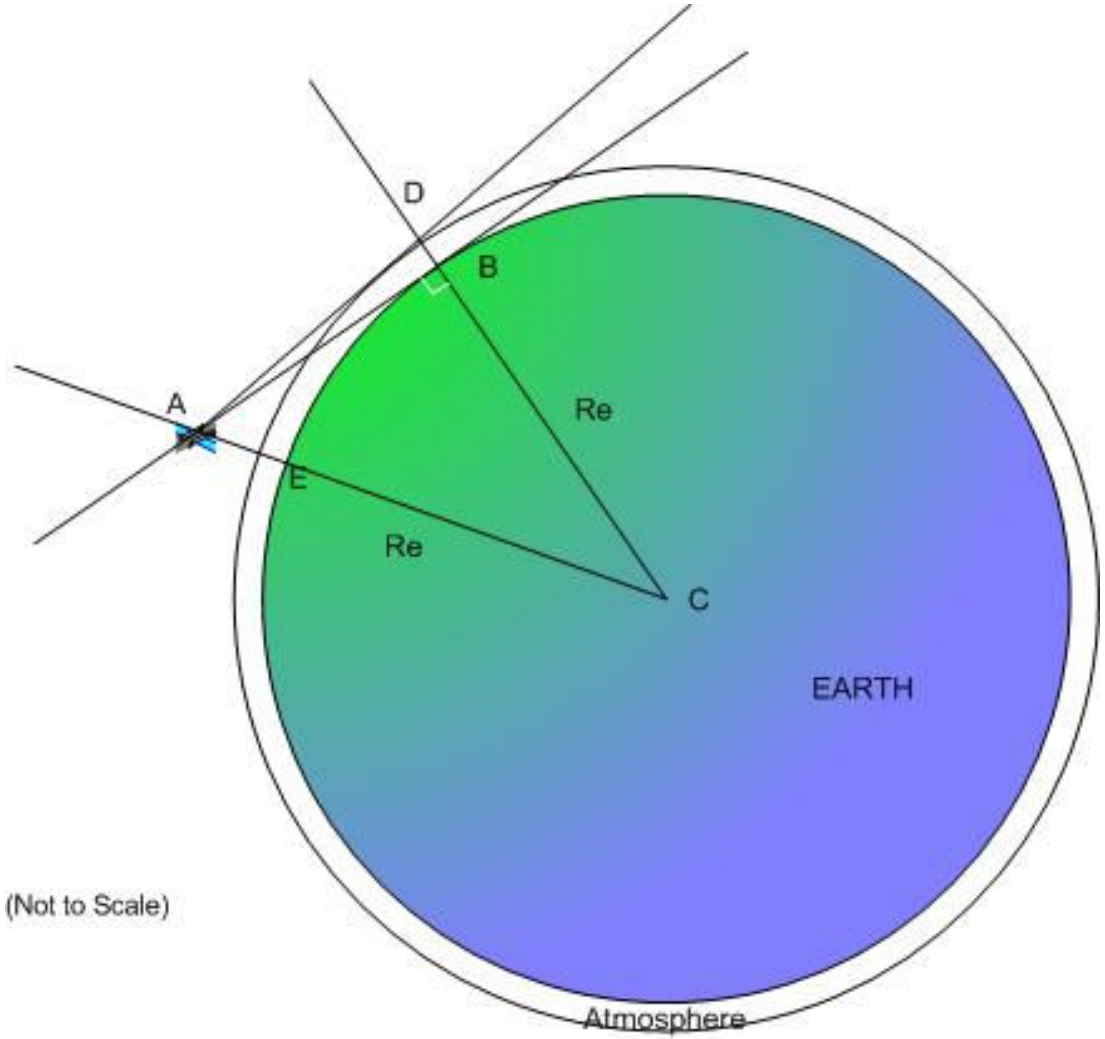
Mission Illustration



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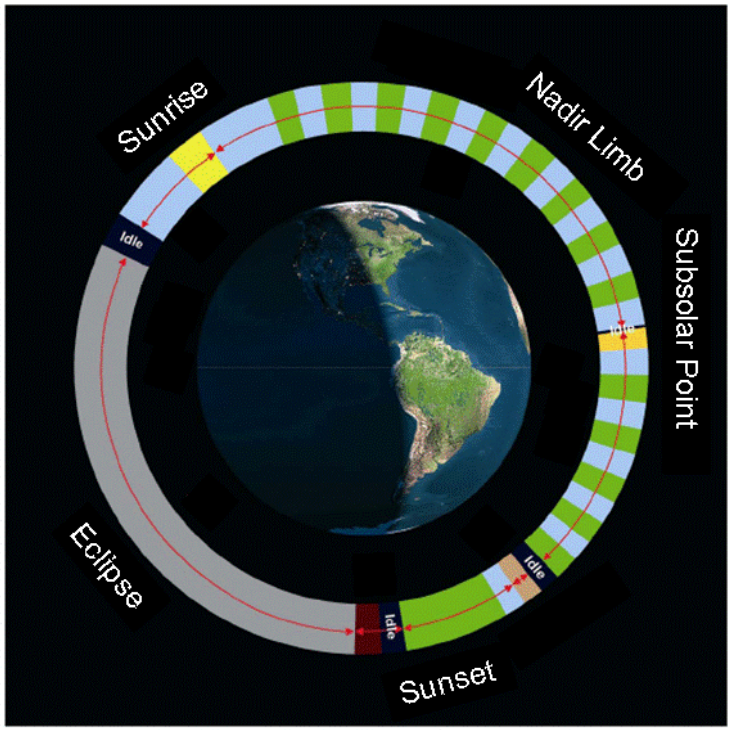
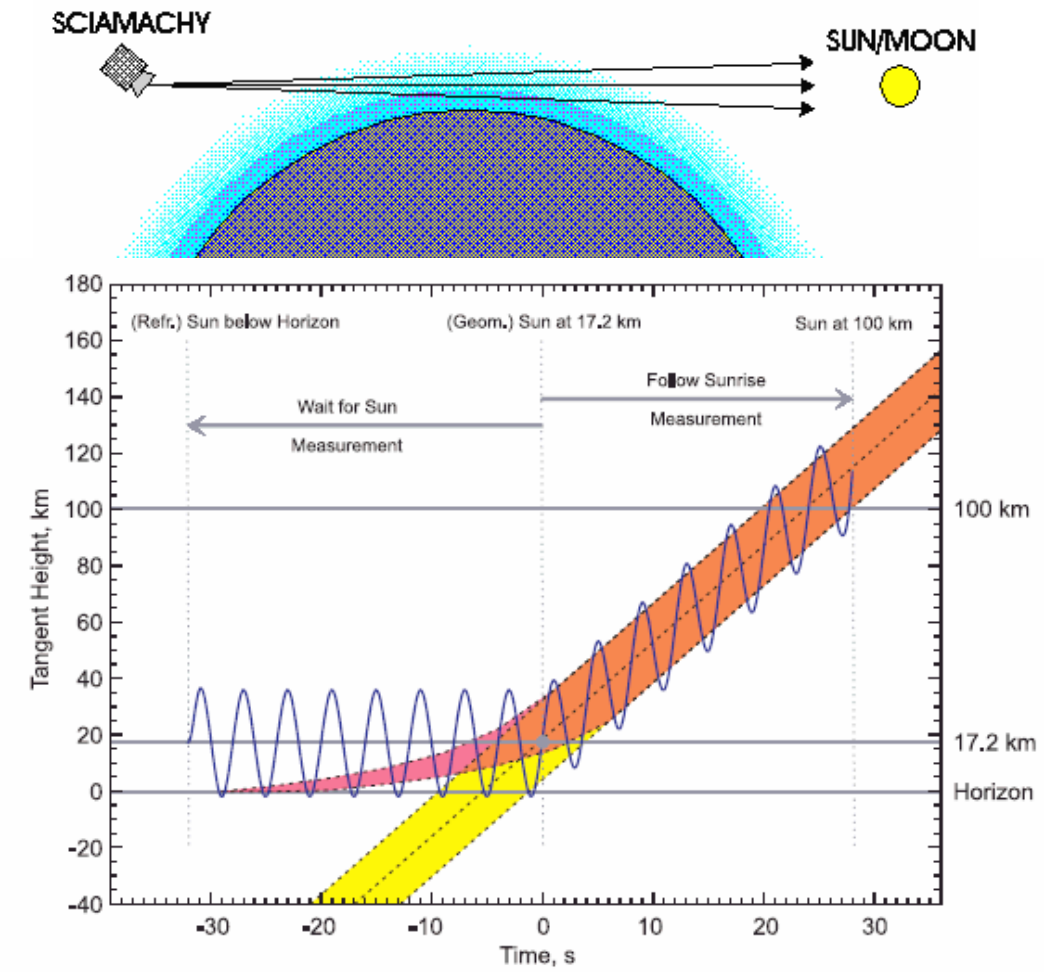
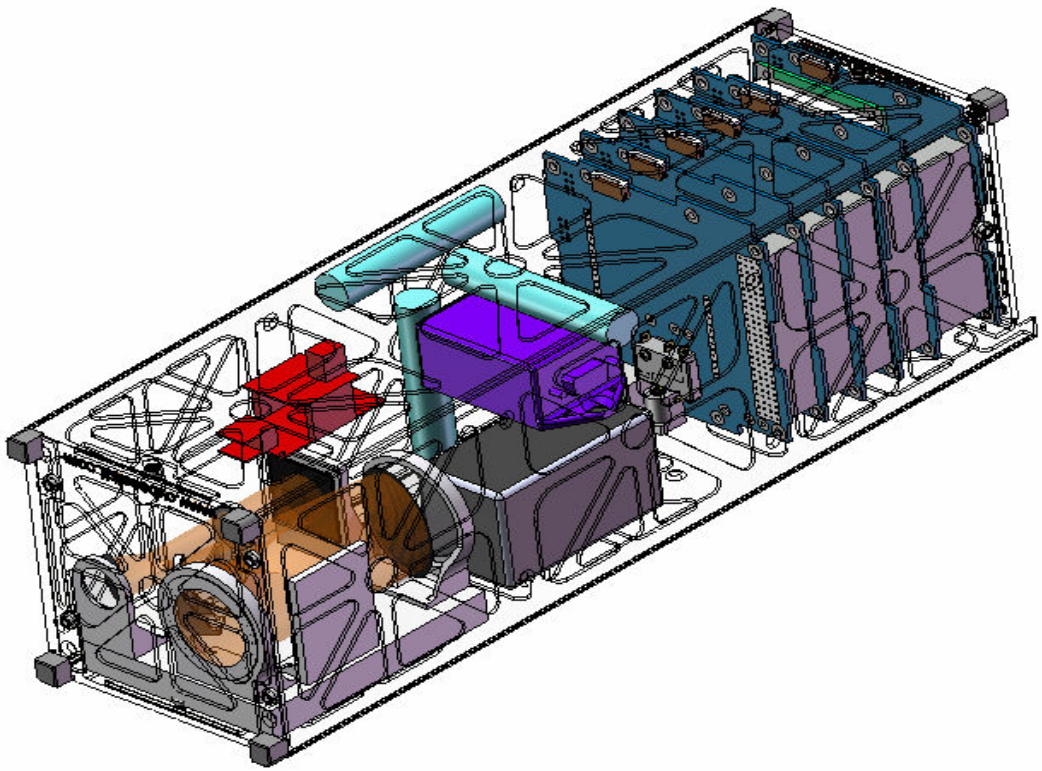
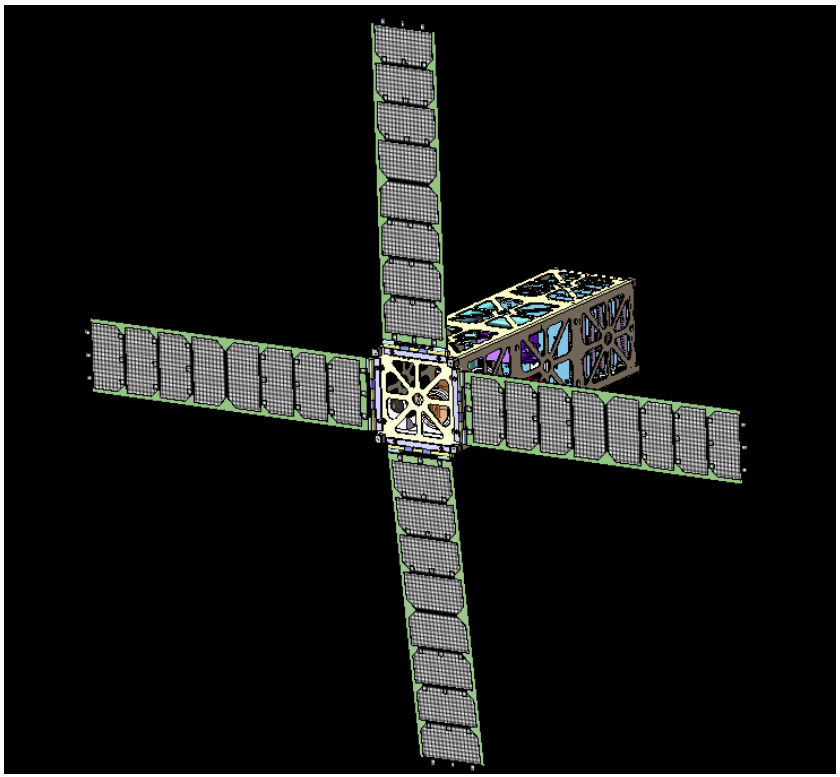




CubeSat Internal View



CubeSat Deployed View



- Background
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MOTIVATIONS

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- **Image Processing is a highly computation intensive task**
- **Serial Implementations of Image Processing are very slow due to large n*n Matrix manipulations**
- **Embedded Control Systems require faster data processing than the onboard microcontrollers can provide**
- **Nano(Pico)-Satellites are prohibitively small for legacy sensors, so innovative new ideas are required**
- **The idea of putting a system in space is awesome**
- **Complete Image acquisition, filtering and data processing in under 500ms at relatively low power**

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Prior Work on Ozone Measurement

- **SCIAMACHY** (SCanning Imaging Absorption SpectroMeter for Atmospheric CartograpHY)
  - SCIAMACHY is an spectrometer instrument aboard ENVISAT launched by ESA in March 2002
  - SCIAMACHY has three different viewing geometries which yield total column values as well as distribution profiles in the stratosphere
- **POAM III** (Polar Ozone and Aerosol Measurement)
  - POAM III was launched on the SPOT 4 satellite in March 1998 and measures atmospheric transmission in nine wavelength bands
  - The POAM III experiment is a visible/near infrared solar occultation instrument designed to measure aerosols and trace constituents in the polar stratosphere

Prior Work on Sensor Selection

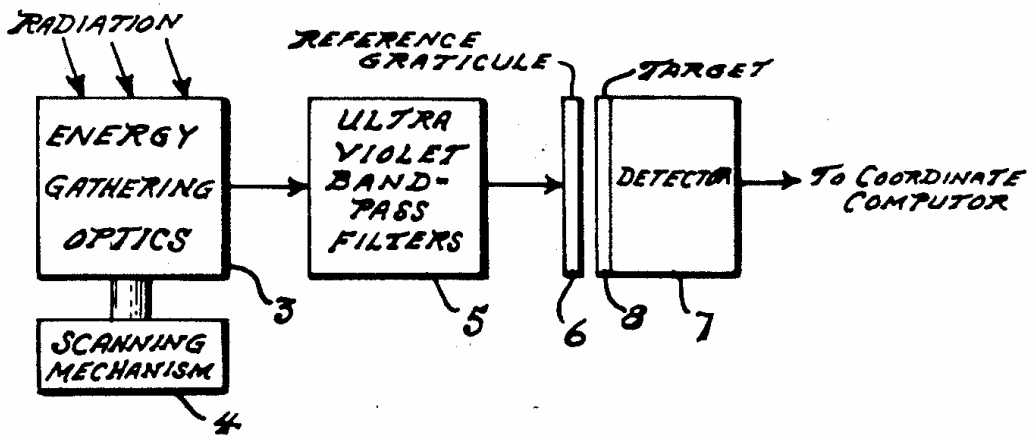
- **Star Sensors**
  - Determination of the Attitude by looking at the Stars and matching the data to a database for Navigation
  - Would not work for NanoSats, as most star-sensors have the same size as a nanosat
- **Magnetometers**
  - Gives a measurement of the magnetic field around them, which can be matched to the IGRF
  - Cannot work in Torque based Actuator systems
- **Inertial Measurement Units**
  - Inertial Measurement Systems provide rate of angular movements, which can be integrated to find attitude
  - The Drifts are too high, and without any other system, large errors would accumulate during the Eclipse time

Proposed Sensor Selection

- **Imaging Camera**
  - A low resolution camera with a wide angle lens and a mechanical aperture
  - Image Frames to be acquired and processed
  - Step 1: Find the Limb
  - Step 2: Find the most probable location of the expected sun-rise on the limb

Prior Work on Limb Pointing

- **"Space Vehicle System for determining Earth's Ultraviolet Radiation Limb", Drohan et al, United States Patent 3,715,594**
  - Abstract: An optical system is used to scan the Earth's horizon and project an image from which position information is derived for use in a space vehicle naviagation control system
  - The system utilizes the Earth's ultraviolet radiation limb as an earth-space boundary reference

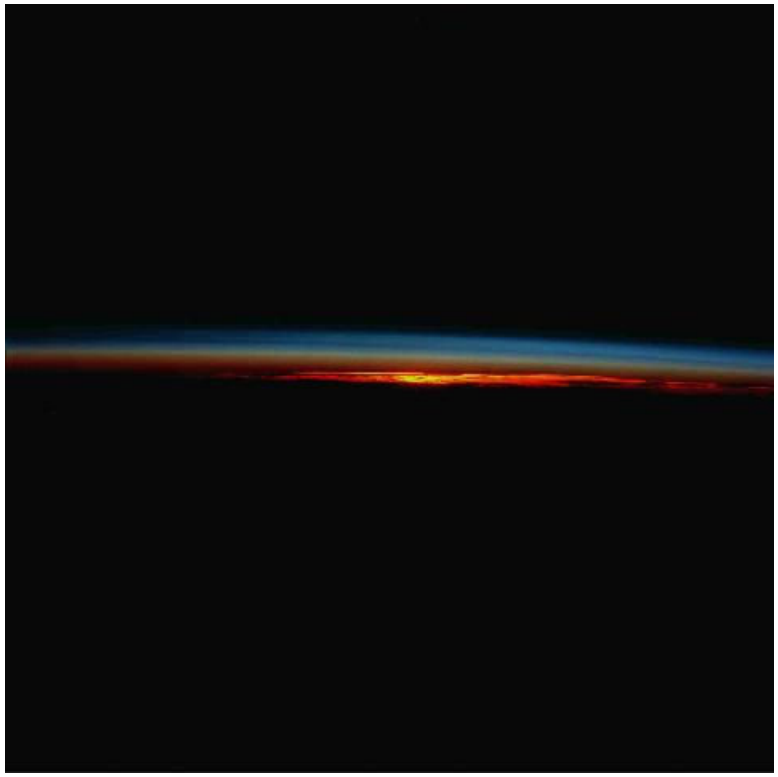


Prior Work on Image Processing

- **The Project would take some standard techniques used for image processing and have both Serial (standard software) and Parallel Implementations to incorporate into one algorithm.**
- **The following are some key previous research to be consulted for implementation of this project**
  - Parallel Image Erosion(Dilation): "Morphological Image Processing and its Parallel Implementation", He Sha, Chan Wah, ICSP 96.
  - Erosion Operations in segmented images: "Morphological Operations on Images Represented by QuadTrees", Reitsing Lin, Edward K. Wong, ICASSP 1996.
  - Original Sobel Edge Detection: "A 3x3 Isotropic Gradient Operator for Image Processing", Sobel, I., Feldman,G.
  - Parallel Sobel Edge Detection: "Performance Analysis of FPGA Based Sobel Edge Detection Operator", I. Yasri et al, ICED 2008.

Images for Processing

- ***Some of the images from previous space flights, used for testing the Algorithm***



Images for Processing

Images for Processing

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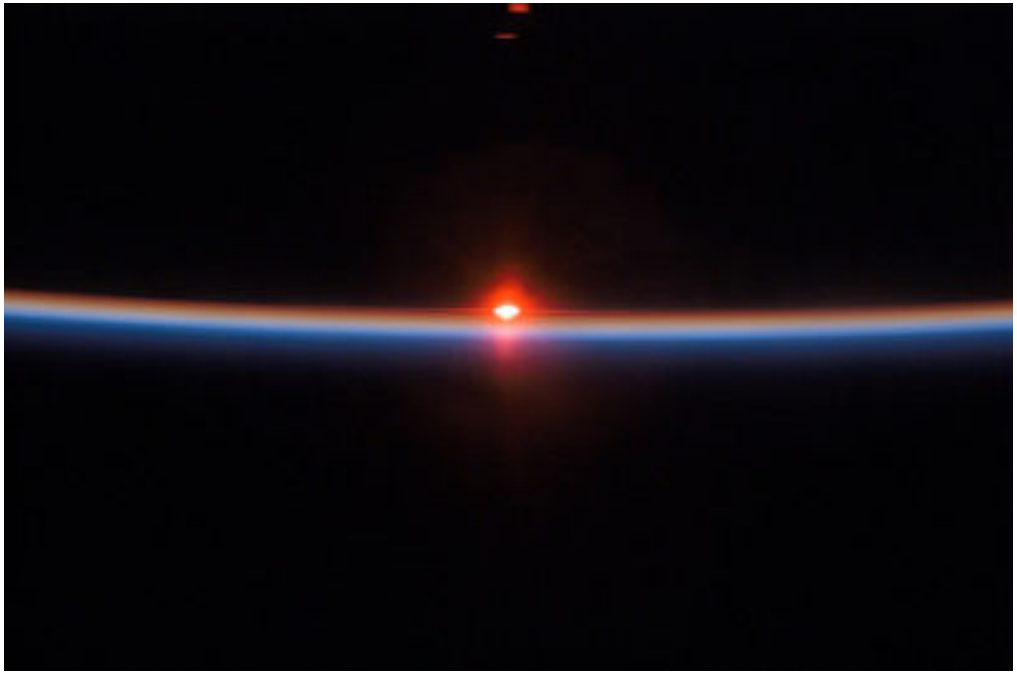

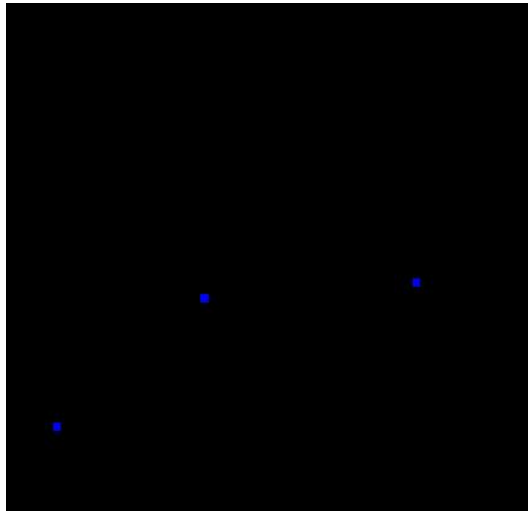

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SOLUTION

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- **Prediction by Image Processing**
  - A low resolution camera with a wide angle lens and a mechanical aperture
  - Image Frames to be acquired and processed preferably every Attitude Correction Control Cycle
  - Image to be processed to find the Limb of the Earth before Sunrise, by looking for the refracted Coronal light across the Horizon
  - Once the Limb/Horizon has been found, then traversing on the edge, to find the point of highest probability of Sunrise.
  - The point of Highest Probability would be found, by looking for the highest intensity point on the coronal image
  - After each point allocation, the spacecraft would be moved so that the proposed point is in the middle of the image
  - If no limb is found then the GNC would move in an outward expanding circular helix to look for the horizon

SOLUTION

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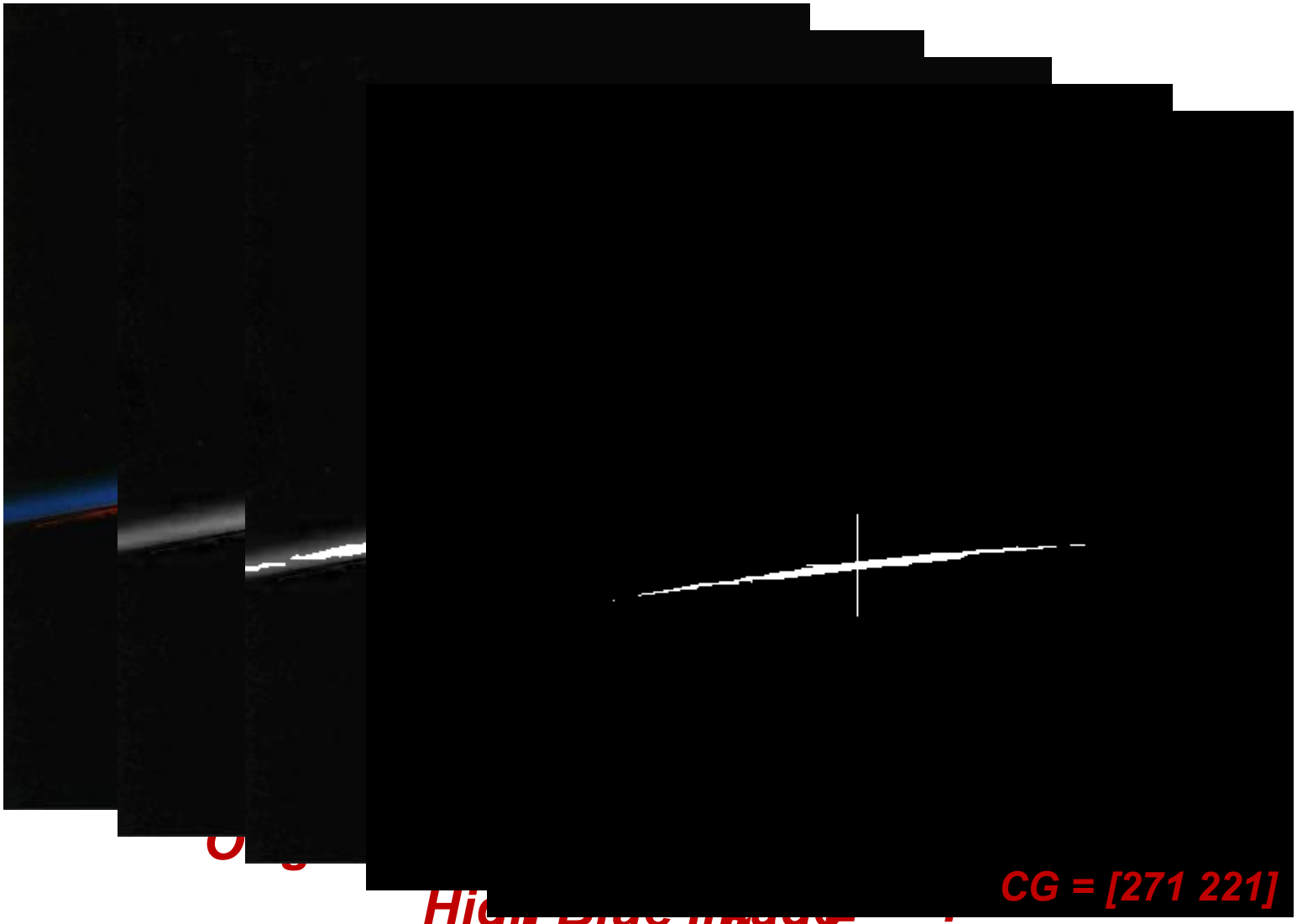
- **The Primary Assumptions**
  - The scope of the project assumes that there is a camera that has already been interfaced in some way to the Hardware
  - The camera has an RGB interface, and we have the ability to acquire a single coloured portion of the image
  - The image is a 100x100 pixel 2-D matrix
  - Each pixel is standard 8 bit entity

- **The Proposed Algorithm**
  1. Acquire the Original Image
  2. Obtain the Blue Image from the Original Image
  3. Apply a threshold filter on the Blue Image to convert it into a monochromatic image for all pixels > threshold A
  4. Apply multiple (three) iterations of 3*3 Rectangular Element Image Erosion to fade out noise and stars
  5. Return with the Message/Flag "Not Found", and CG=Previous CG, if
     - The number of nonzero pixels in the eroded image is less than threshold B
     - The number of non-zero pixels is greater than threshold C
  6. Find the Center of Gravity of the Pixels in the Eroded Image

MATLAB RESULTS



SOLUTION

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- **Matlab Implementation**
  - Implementation done iteratively for multiple processing steps to create one algorithm for the problem set
  - A single simple m-file function named WhereWouldTheSunBe() written
  - The Image Processing Toolset used
  - Final Algorithm selected on the basis of simplicity, accuracy of results and the ability to be implemented in parallel processing environment
  - Implementation Complete and results will be presented

- **Hardware Implementation**
  - Implementation of the Algorithm decided in the Matlab prototyping on a n-row and n-column matrix of 8 bit elements
  - All operations would be circular so the architecture would not proceed forwards; actually would rewrite the matrix with the new values, thus reducing the area needed to implement
  - Addition of Non-Zero Pixels: A binary tree adder implementation, which adds a one to the Sum, if the Pixel is non-zero. Since there are n^2 pixels, then the final sum can have a max value of n^2
  - Image Erosion:
    - Since Erosion is a neighbouring operation, it can be applied in parallel on the complete matrix, therefore the step can be completed in constant time

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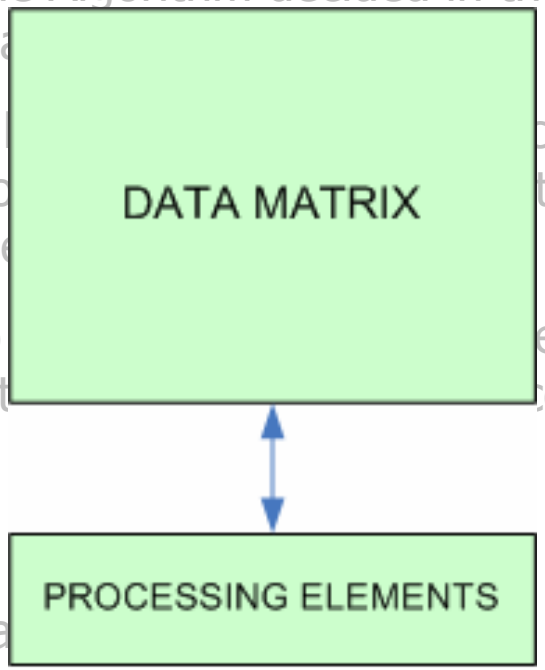

Compact Architecture

SOLUTION

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- **H[illegible]mentation**
  - [illegible] of the Algorithm decided in the Matlab prototyping on a n-[illegible]nn matrix of 8 bit elements
  - [illegible]ould be circu[illegible]ly would rev[illegible]a needed to
  - Addition of Non-Zero Pixels: [illegible]h adds [illegible]e the final sum can have a max va[illegible]
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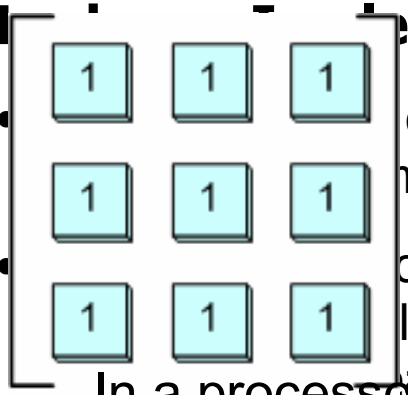
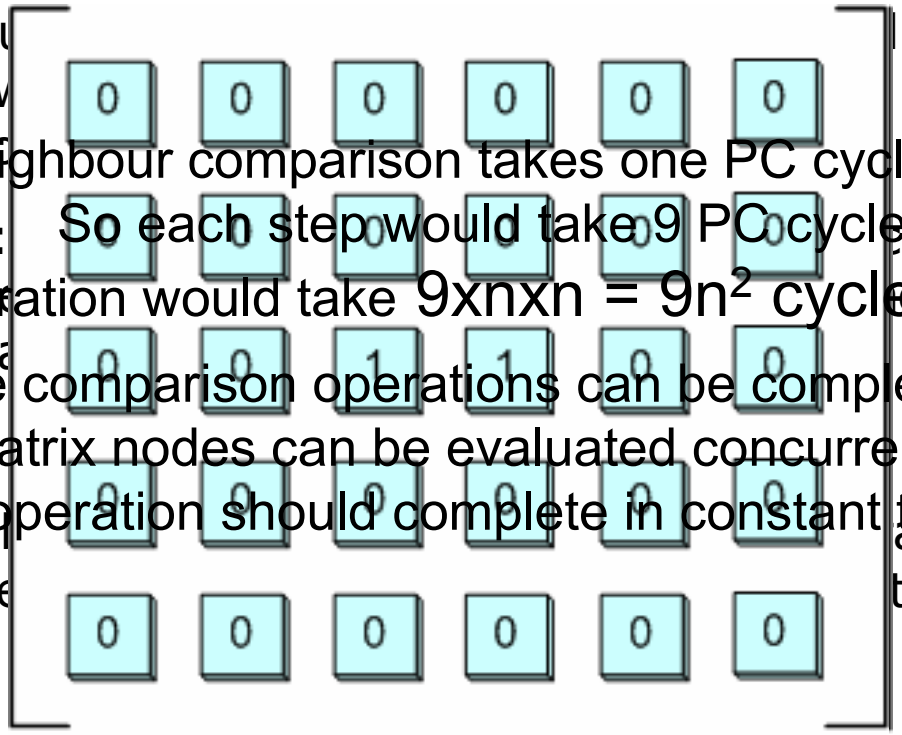
    - Since Erosion is a neighb[illegible]allel on the complete matrix, the [illegible]tant time



3x3 Square Matrix



In a processor each neighbour comparison takes one PC cycle,
So each step would take 9 PC cycles,
therefore the matrix operation would take $9xnxn = 9n^2$ cycles
On a parallel hardware the comparison operations can be completed in parallel, and all the matrix nodes can be evaluated concurrently, so the operation should complete in constant time

- **Hardware Implementation**
  - Implementation of the Algorithm decided in the Matlab prototyping on a n-row and n-column matrix of 8 bit elements
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  - Addition of Non-Zero Pixels: A binary tree adder implementation, which adds a one to the Sum, if the Pixel is non-zero. Since there are n^2 pixels, then the final sum can have a max value of n^2
  - Image Erosion:
    - Since Erosion is a neighbouring operation, it can be applied in parallel on the complete matrix, therefore the step can be completed in constant time

- **Hardware Implementation (contd.)**
  - Center of Gravity:
    - The first part of the calculation for the Center of Gravity would again be an adder implementation, once for rows and once for columns
    - The second part is classically division, to achieve the final X and Y CG values
  - Edge Detection (prospective):
    - An implementation of the Sobel Edge Detection using two sets of masks for Horizontal and Vertical Edges
    - Combination of the gradients for each point using approximation
    - Each application of the mask requires 9 shifts/assigns and 6 additions

Implementation Issues

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- **The memory allocation and handling**
  - How the data would reside and how would it be moved
- **Verification of the correct outputs based on simulation**
  - How can we be sure if the results match the expected results
- **Fixed I/O speed of Camera, conflicting with the variable time for algorithm completion**
  - Clock Mismatch requires time fixes in the UCF file and use of derived/buffered clock divisions

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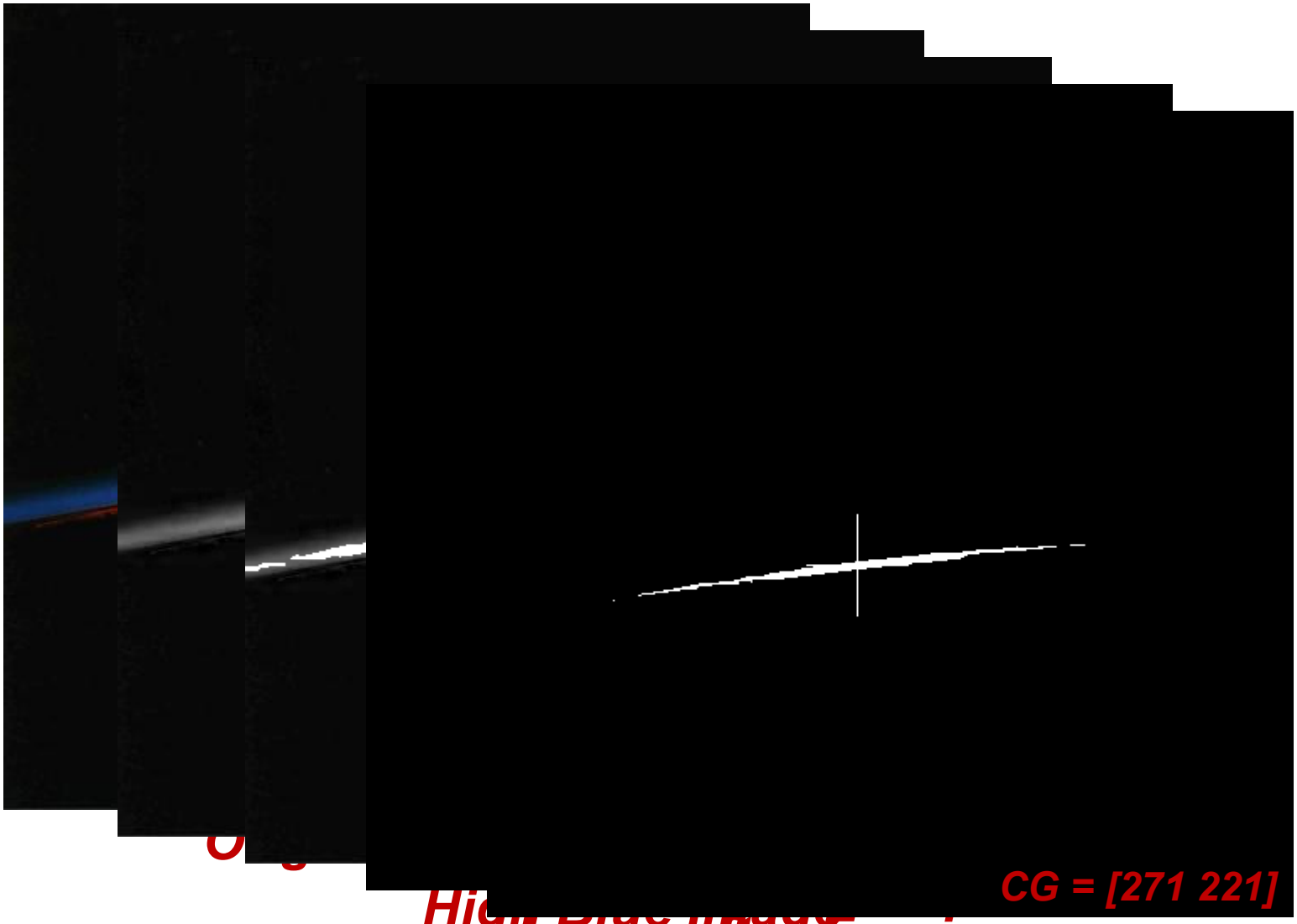

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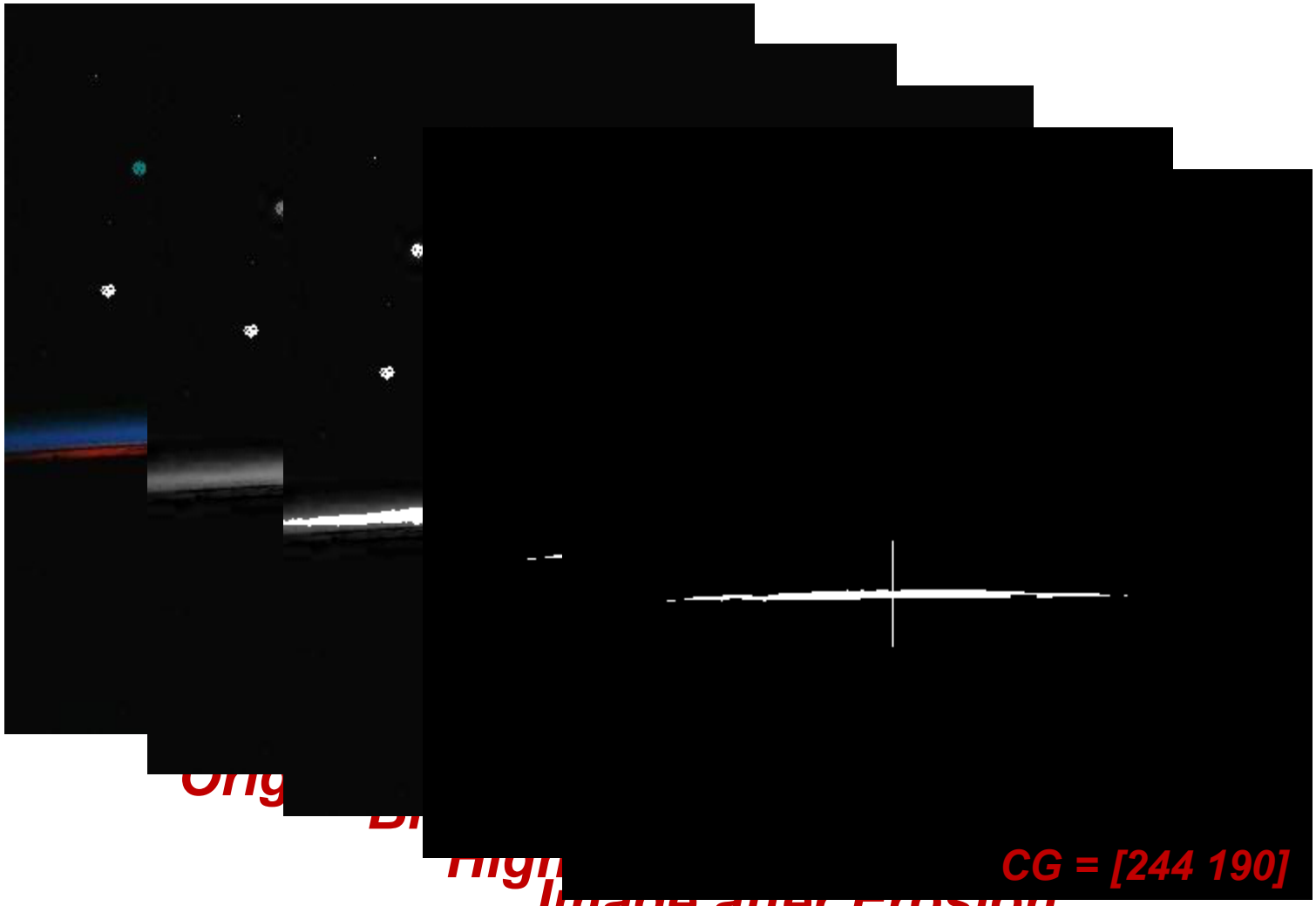

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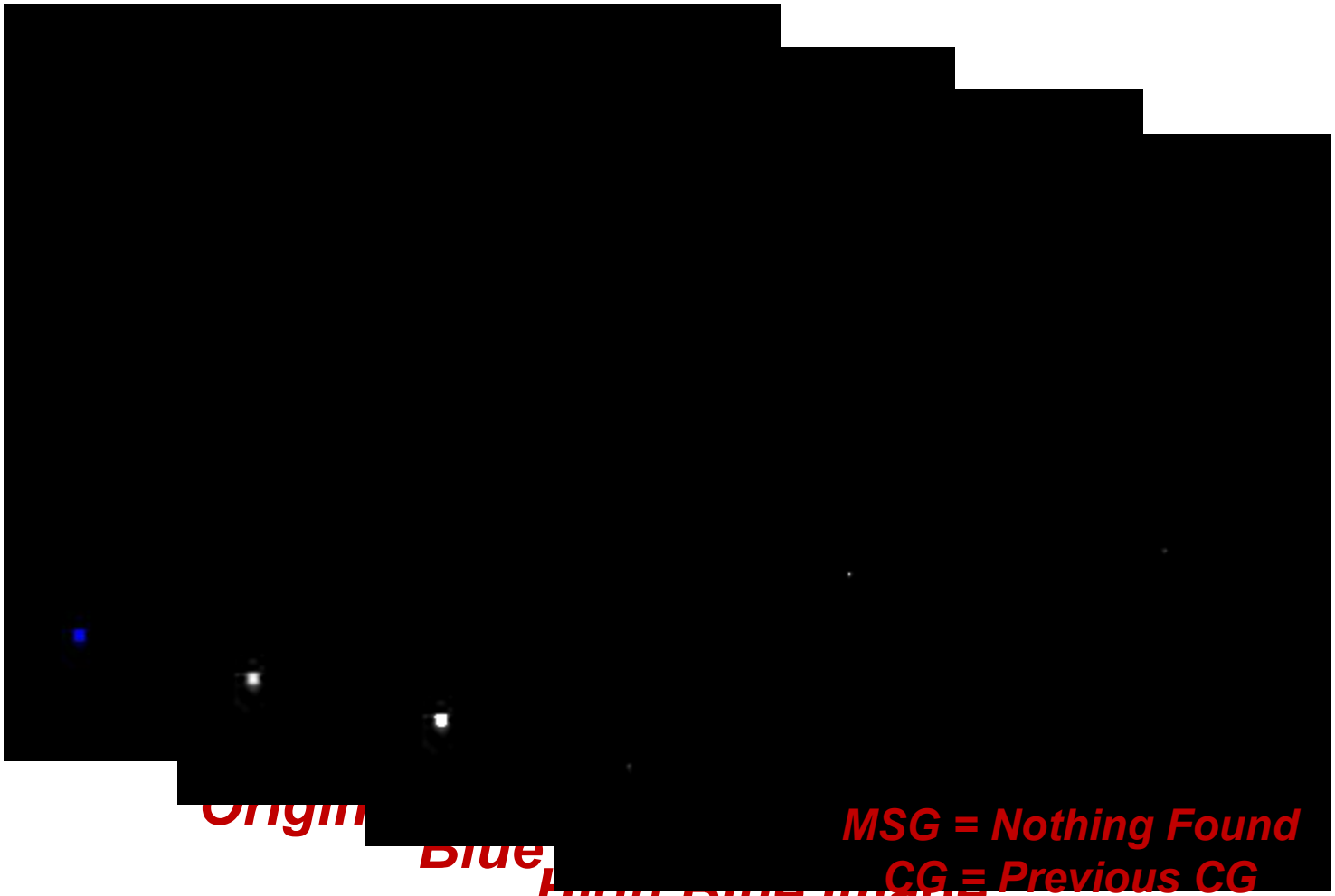

THANK YOU

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Predicting the Position of the Sun, across Earth's Horizon, prior to Sunrise, using Image Processing

QUESTIONS ?

SOLUTION

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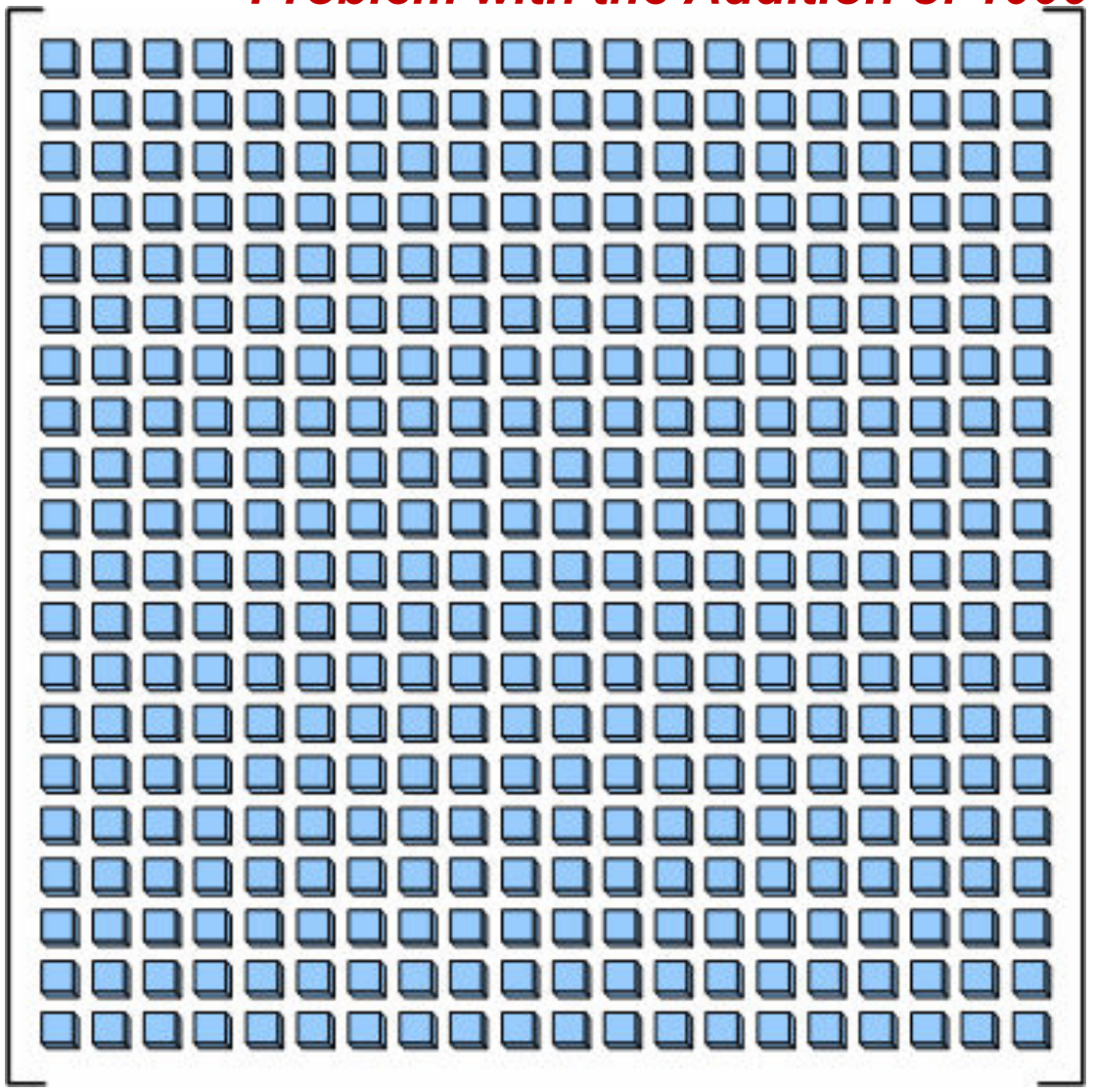
Problem with the Addition of 10000 data points

- **Level 1**
- **Level 2**
- **Level 3**
- **Level 4**
- **Level 5**
- **Level 6**
- **… .**



SOLUTION

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Problem with the Addition of 10000 data points

- **Generalize**
  - Number of levels: $\log_2 (n^2)$
  - Number of bits in the result: $\log_2 (n^2)$
- **Specifically**
  - Number of levels: 14
  - If implementing with 4 bit CLAs
    - 50 cycles of addition stages
    - Very Huge Architecture of CLA Adders

Level 1	5000 additions	1 bit each: 1CLA+1FA
Level 2	2500 additions	2 bit each: 1CLA+1FA
Level 3	1250 additions	3 bit each: 1CLA+1FA
Level 4	625 additions	4 bit each: 1CLA+1FA
Level 5	312 additions	5 bit each: 2CLA+1FA
Level 6	156 additions	6 bit each: 2CLA+1FA
… .		

SOLUTION

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New Algorithm for the Addition of 10000 data points

- **Divide**
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  - Ste
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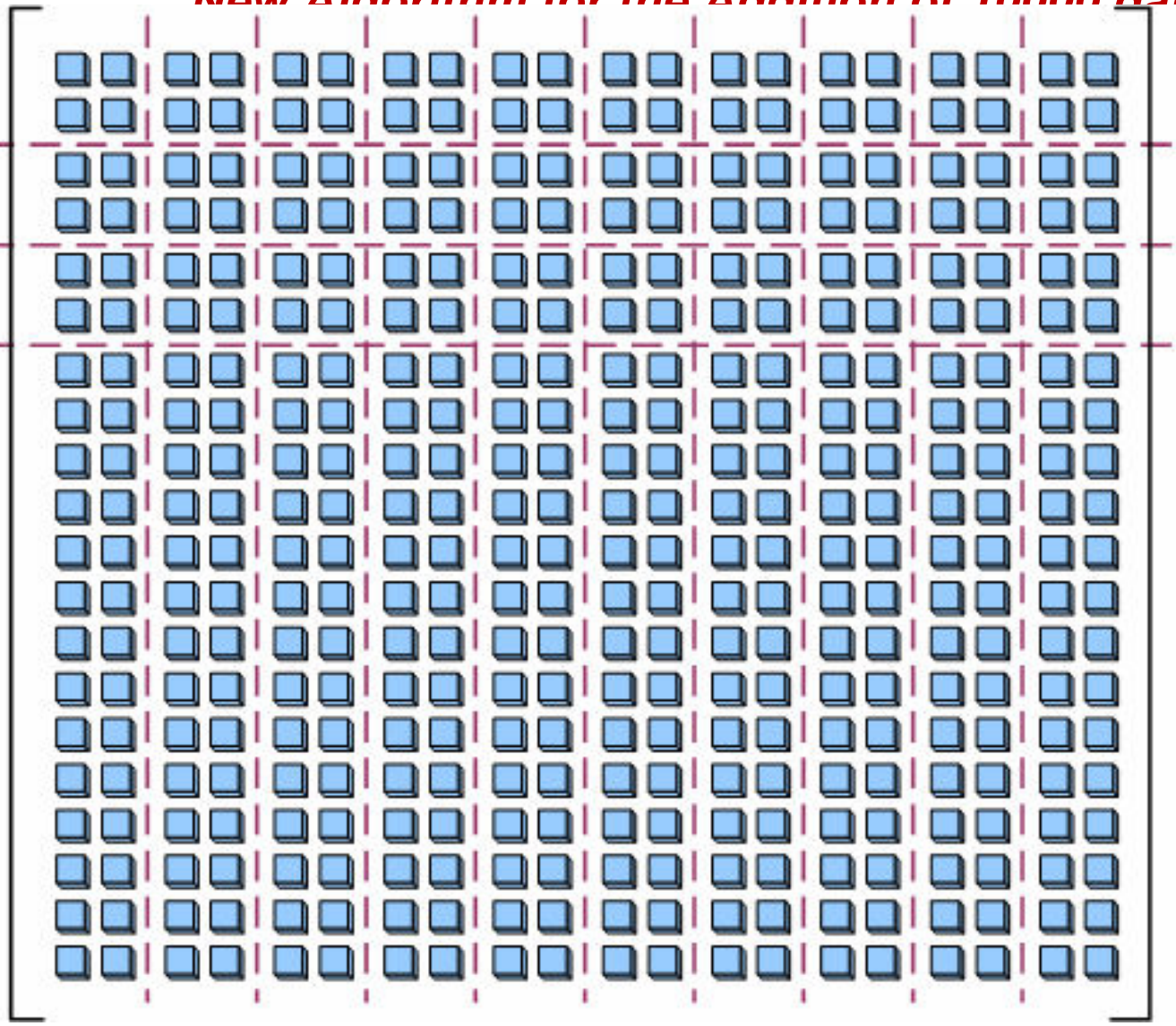
  - **Har**
  - **The**



bit is 1
s 1.