The 8th
Pre-Mission Idea Contest
for Multiple Nano-satellites

CubeSat constellation for monitoring and detecting plastic wastes in water bodies & testing the moon-sun sensor

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Agenda

- Introduction
- Plastic Detection
- Moon-sun sensor
- Future work
- Questions

Introduction

Plastic wastes

- Lately plastic wastes have been such a major problem not only effecting marine life but also affecting us as humans.
- Examination Survey produced by the US Centers for Disease Control and Prevention concluded that BPA was found in 93% of urine samples taken from people above the age of six.
- can both decrease or increase endocrine activity in humans and cause adverse health effects.
- Breast milk of most women in the developed world contains BPA that have been linked to negative health effects.

Plastic wastes

- Animals are now colonizing the Great Pacific Garbage Patch, meaning that they are consuming the plastic waste and living in previously uninhabited areas. All these developments disrupt the natural marine ecosystem.
- Many animals at the base of the food chain eat microplastics. These animals are then consumed by others that humans eat.

Plastic Detection

SIMILAR PROJECTS

Consequently, Some space agencies for instance the ESA launched a mission (first of its kind) called the **Global Plastic watch** with the aid of Earthrise Media, to determine the size and scale of land-based plastic waste sites with the help of AI.

But the mission only includes countries from South-East Asia, Australia, and the countries identified by research published in Science Advances as accounting for high rates of plastic emissions into the ocean.

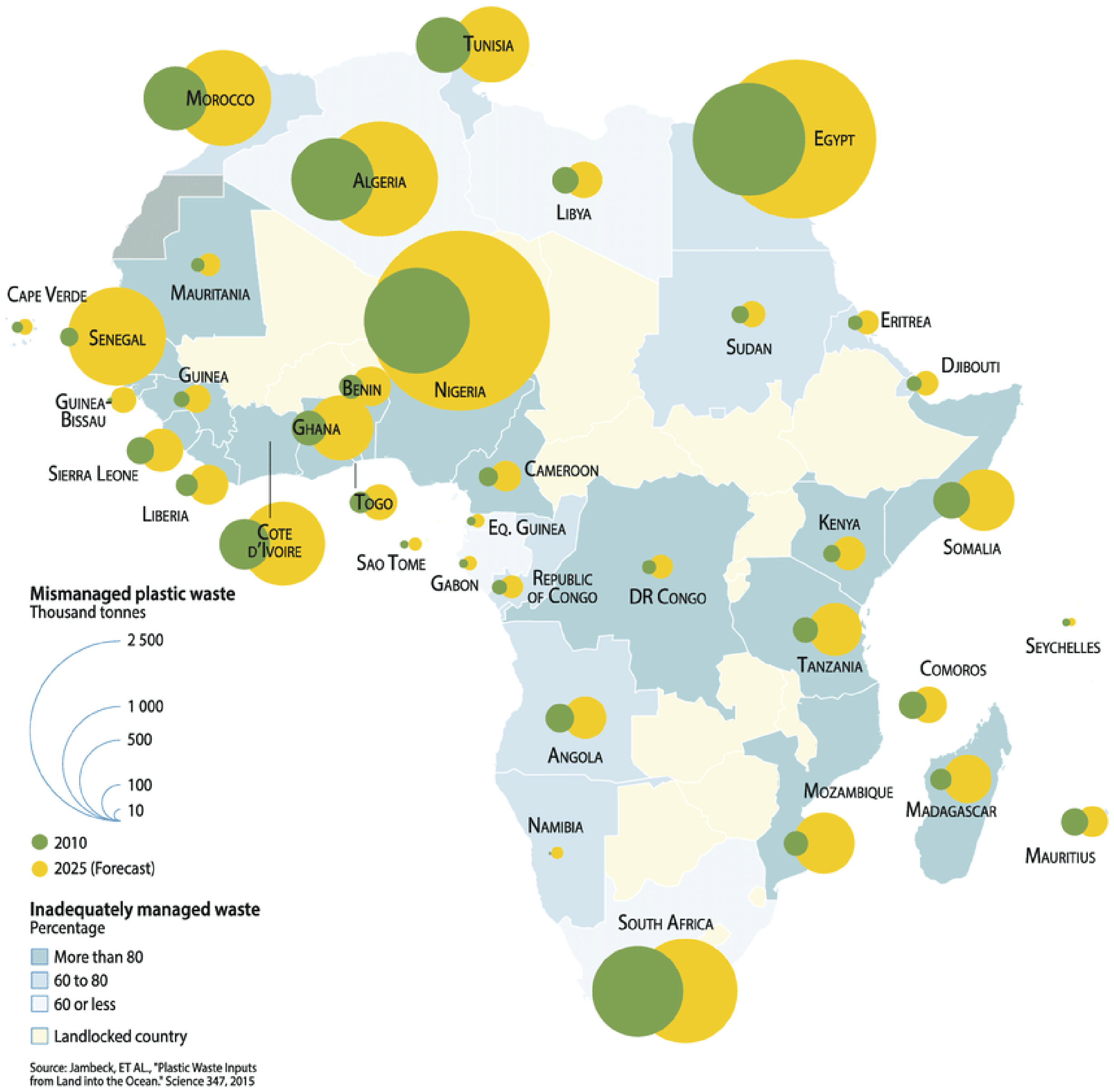
OUR MISSION

There are 5 African countries among 20 highest contributors to plastic marine debris in the world and this affects the Mediterranean Sea, the Red Sea, the Indian Ocean, and the Atlantic Ocean

But currently, Africa is leading the world in plastic bags ban

So, to aid this our mission will monitor and detect plastic waste sites from African countries

Additionally, trying to build a clearer path that the plastic wastes take until it reaches the plastic island in the Pacific Ocean.



How will we detect plastic?

- by using the unique infrared signals reflected by plastics we can even identify tiny scraps amongst vast stretches of sand and rocks. And hence we can even prevent plastic from heading into the oceans.

Moon-sun sensor

Usage of Image Processing

"The concept of an attitude sensor using images of illuminated celestial bodies has been pushed forward through the years." (“Planet–Sun Sensor Revisited | Journal of Spacecraft and Rockets”) .

The first one presented this idea was Daniele Mortari ,Rome University ,Italy on Journal of spacecraft and Rockets vol.34 No.3, May-June 1997. Based on a low-cost charged coupled device camera.

Most of the progress made in the recent years utilized deep learning

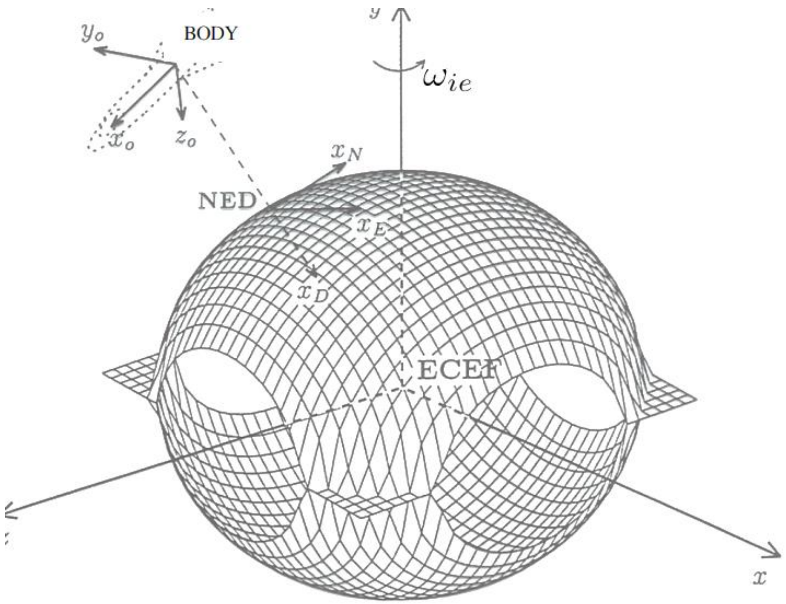
Most of the papers used Earth as a reference image

Attitude Determination

Estimating the Euler angles to transform between the S/C body frame to the ECI frame.

Attitude control is required for most S/C to function properly. Ex:

- Communication satellites
- Remote sensing satellites
- Space Telescope



Attitude Determination

Attitude is represented by an orthonormal matrix called the attitude matrix
Ex:

-0.0589464	-0.898433	0.435136
-0.0346558	-0.433789	-0.900348
0.997659	-0.0681523	-0.00556562

Usage of Image Processing

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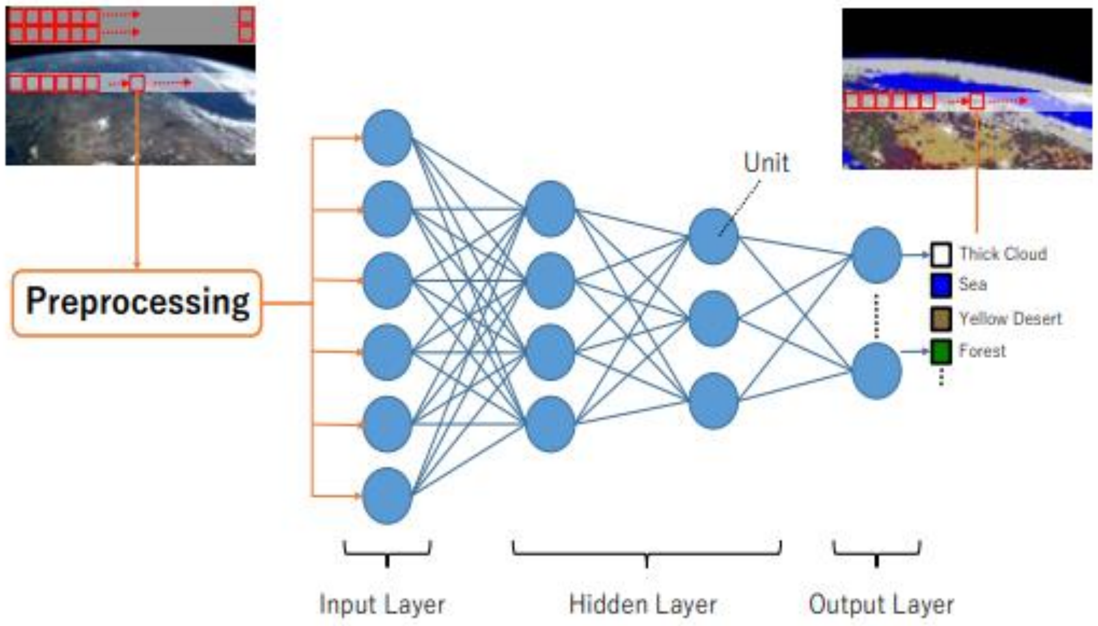
Usage of Image Processing

Development of Attitude Sensor using Deep Learning
Sho Koizumi et al. Tokyo Instutute of Technology



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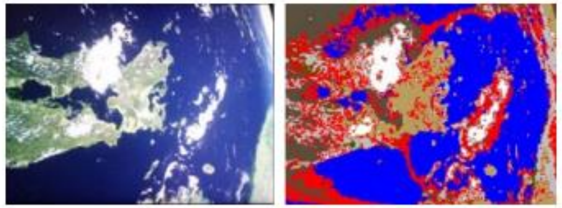
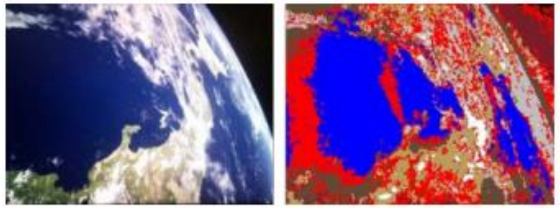
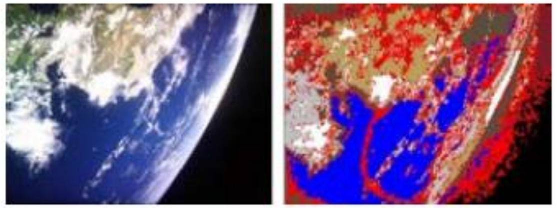
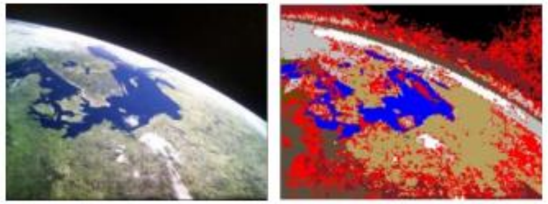
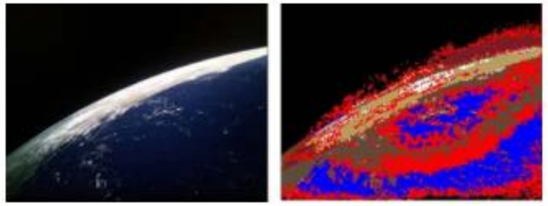
1	1.71	
2	0.79	
3	0.79	
4	0.88	
5	0.89	

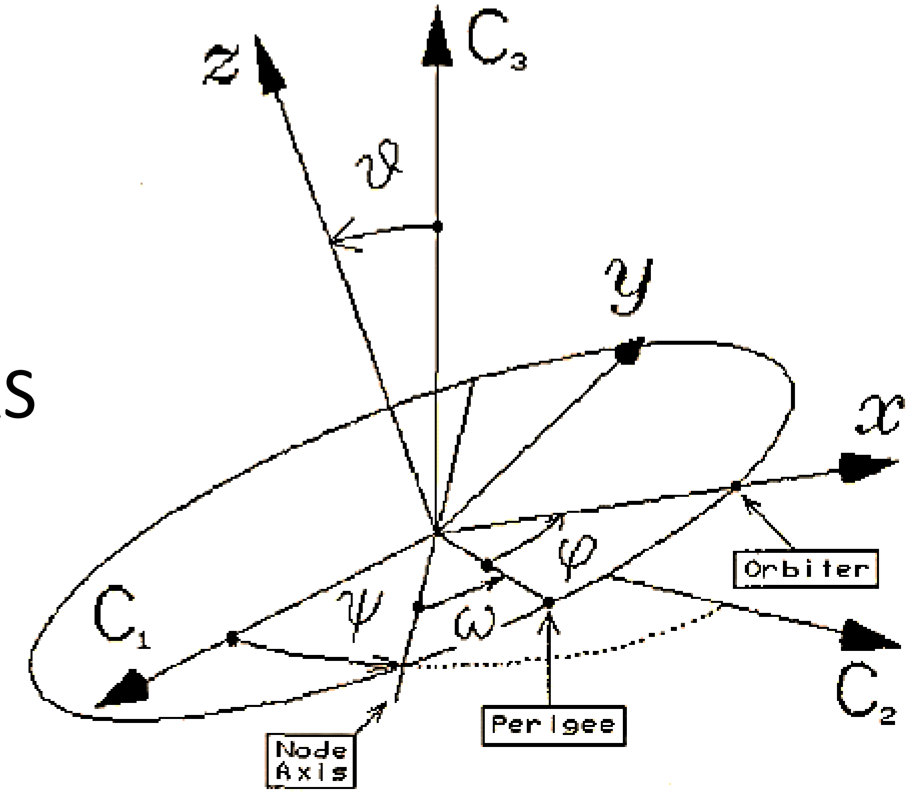
Proposed Sensor Concept

Moon images include sufficient data to determine attitude in three axes

Given the moon, sun and S/C orbital positions in ECI we can construct set of IRS vectors.

- The vectors can either be measured or estimated using orbit propagators.

Moon image is processed to obtain Euler angles to transform from IRS to SRS.



Moon Visibility

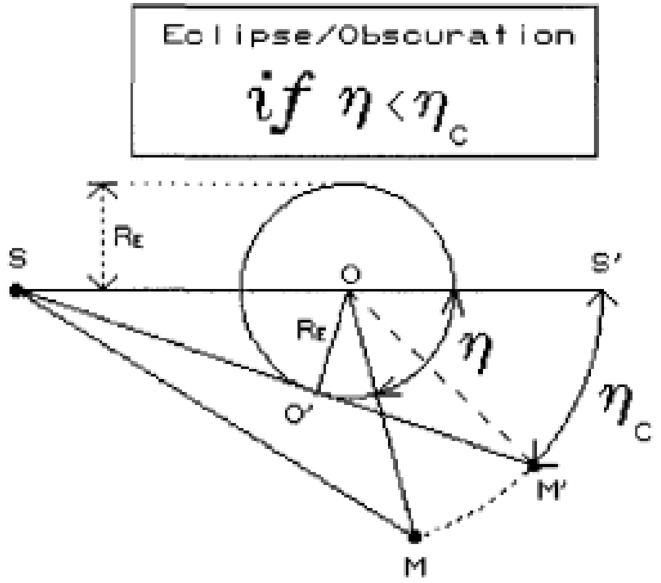
The moon is visible when the normal projection of the S/C to Earth vector on the S/C to Moon vector is of a less magnitude than the sum of the Moon and Earth radii or in term on angles:

$$\eta < \pi - \eta s - \eta m$$

Having

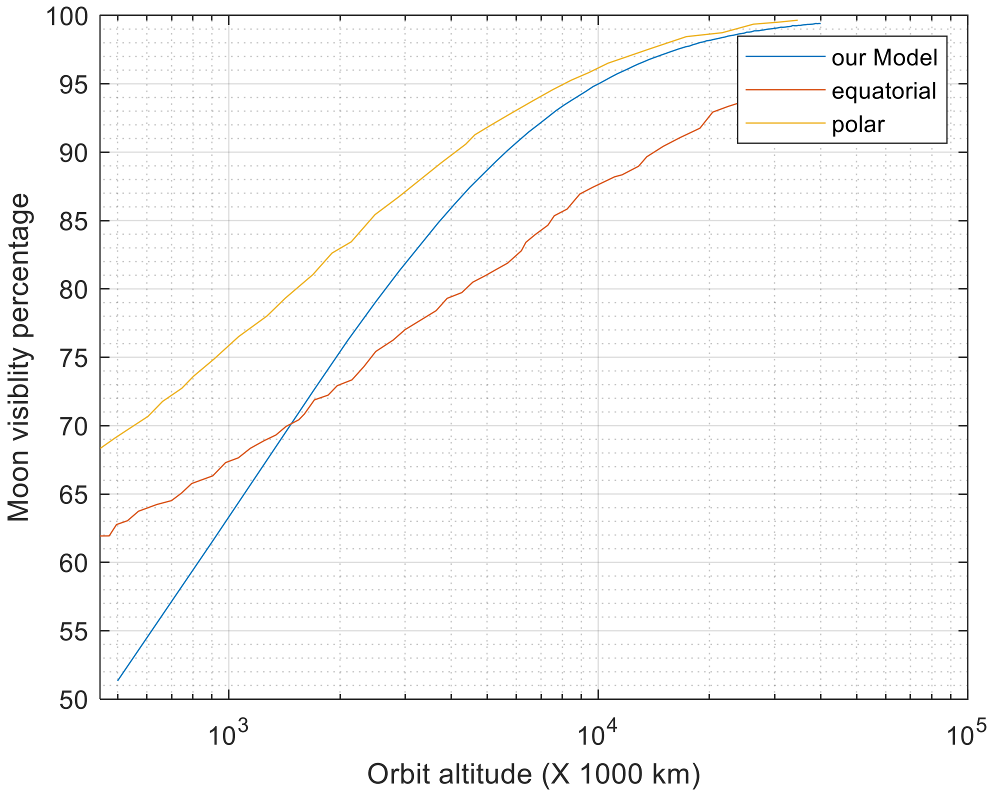
$$\eta x = \cos{-1} \left(Rx \; |Vx| \right),$$

$x \in \{m$ for the Moon, s for Earth $\}$



Moon Visibility

The analysis is done be propagating the Moon and S/C over 31 days and averaging the time the visibility condition yielded over the simulation time to get a point at a certain altitude, changing the S/C altitude for the different points on the graph.



Vectors in IRS

Moon vector

Sun vector

S/C vector

Moon Vector

a Keplerian orbit model does not describe the moon's motion sufficiently well.

Using American Ephemeris best fit approximation as:

$$\begin{cases} \varphi_m = & 270.434164 + 13.1763965268t + \\ & -8.5 \cdot 10^{-13}t^2 + 3.9 \cdot 10^{-20}t^3 \\ \omega_m = & 334.329356 + 0.1114040803t + \\ & -7.739 \cdot 10^{-12}t^2 - 2.6 \cdot 10^{-19}t^3 \\ \psi_m = & 259.183275 - 0.0529539222t + \\ & +1.557 \cdot 10^{-12}t^2 + 5 \cdot 10^{-20}t^3 \\ \vartheta_m = & 5.145396374 \end{cases}$$

t is the time difference, expressed in days, between the time at which the computation is required and the reference time (January 1, 1900 at 12:00, Julian date = 2415010)

Moon Vector

Eccentricity ranging from 0.044 to 0.067 (with average value of 0.054900489).

Orbit inclination with respect to the ecliptic plane ranging from 4°58' to 5°19' (average value of 5°8'43")

Sun Vector

The formulas are based on an elliptical orbit for the Earth, using mean orbital elements and a two-term approximation for the 'equation of center’.

Calculate parameters:

L = 280.4606184 + [(36000.77005361 / 36525) * d] mean longitude, in degrees

g = 357.5277233 + ([35999.05034 / 36525] * d) mean anomaly, in degrees

p = L + [1.914666471 * sin(g * pi / 180)] + [0.918994643 * sin(2*g * pi / 180] ecliptic longitude lambda, in degrees

q = 23.43929 - ((46.8093/3600) * (d / 36525)) obliquity of ecliptic plane epsilon, in degrees

Sun Vector

Calculate unit directional vector in ECI coordinates

u_x = cos(p * pi / 180)

u_y = cos(q * pi / 180) * sin(p * pi / 180)

u_v = sin(q * pi / 180) * sin(p * pi / 180)

Sun Vector

Calculate distance to sun and scale the unit vector

a = 1.000140612 - [0.016708617 * cos(g * pi / 180)] - [0.000139589 * cos(2 * g * pi / 180)]

distance from Earth's center to Sun's center in astronomical units (AU)

m = a * 149597870700

center-to-center distance from Earth to Sun in meters

v = m * u_v (or a * u_v)

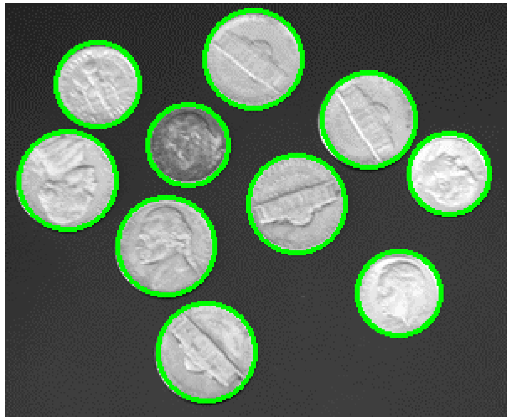
distance to sun in meters (or in AU)

S/C Vector

Using TLE with and SGP4 orbit propagator

3. Hough Transform

The **HoughCircles** filter is an OpenCV function used to detect circles in images



How it works?

This method has 2 stages

1. Edge detection to find the possible circle centers
2. Finding the best radius for the detected centers.

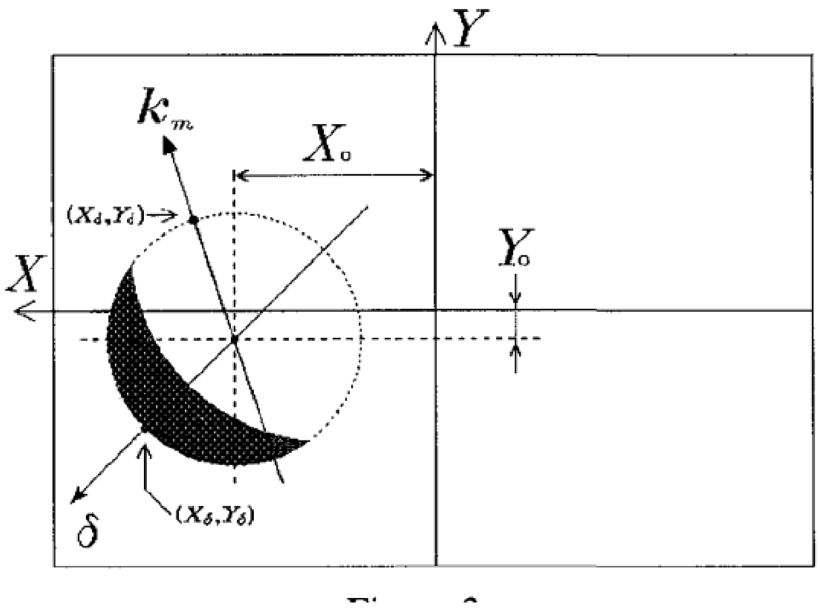
We can use HoughCircles function for the detecting the moon in the image where a and b are the coordinates of the center of the circle and r is the radius. In this case, the computational complexity of the algorithm begins to increase as we now have three coordinates in the parameter space and a 3-D accumulator. (In general, the computation and the size of the accumulator array increase polynomially with the number of parameters. Thus, the basic Hough technique described here is only practical for simple curves.)

$$(x-a)^2 + (y-b)^2 = r^2$$

Estimating Phi, Theta

The first two angle (φ and θ) are easily determined by calculating the location c the center of the moon in the image coordinates frame then transforming it i a reference frame measured from the ce of the image.

This makes the X coordinate of the moo center represent a scaled φ and the Y coordinate represent a scaled θ, having the scaling factor being the camera's FOV over the number of pixels in that coordinate direction.



4. Masking

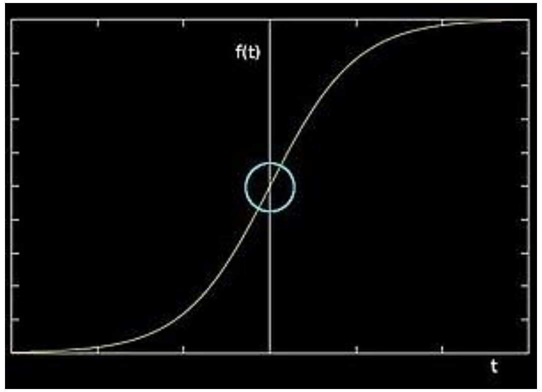
Description

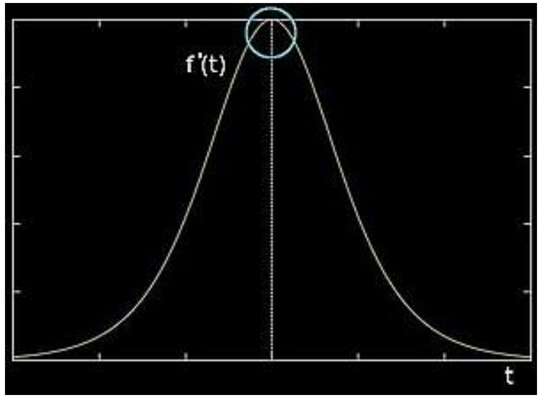
Now we can use the circular shape created by HoughCircles to mask the image and remove all the undesired noise leaving only the moon

5. Sobel edge detection

Sobel filter is an operator that approximately computes the gradient of an image.

Gradient is the change in intensity along the image





Procedure

1. Computing the horizontal & vertical Sobel derivatives
2. From them to get the gradient magnitude and orientation

Horizontal &Vertical derivative

- Applying Sobel filter in the X-direction & Y-direction to the image

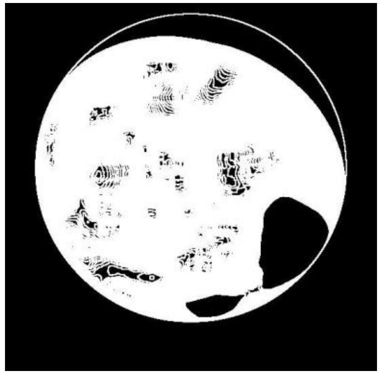
Sobel X-derivative for moon image

Sobel Y-derivative for moon image

The Gradient magnitude

Combining Sobelx & Sobely to get the gradient magnitude for the image

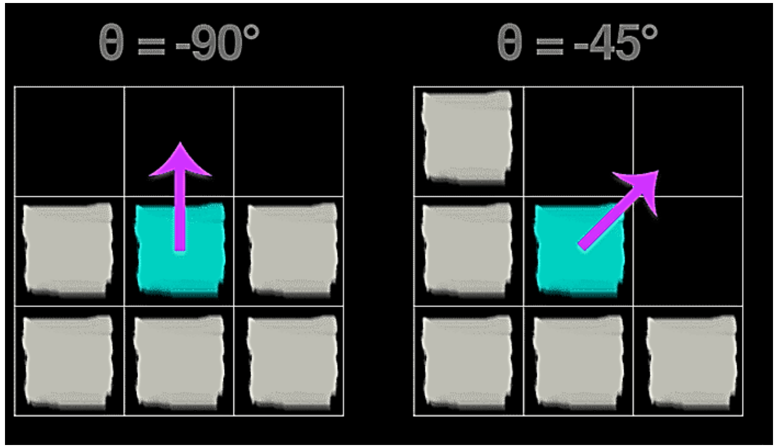
$$G = \sqrt{G_x^2 + G_y^2}$$



The Magnitude gradient

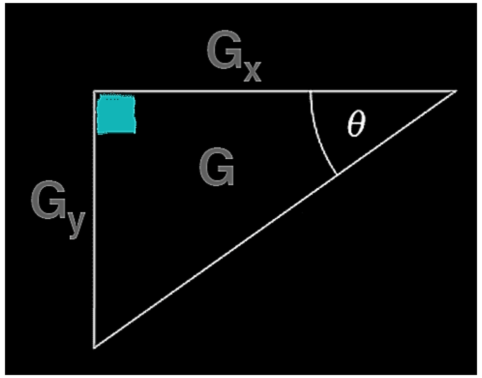
The Gradient orientation

It indicates the direction which the change in intensity is pointing



How its calculated

$$\theta = \tan^{-1}\left(\frac{G_y}{G_x}\right) * \frac{180}{\pi}$$



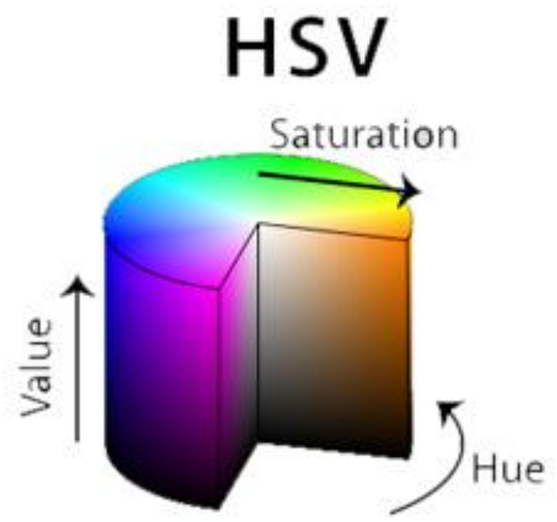
HSV (**Hue**, **Saturation** & **Value**) representation

HSV is a cylindrical color-space

The Hue represents degrees

The Saturation is the circle radius.

Value is the height of the cylinder represents magnitude



Application

We can use the **Hue** to encode the orientation
And the **Value** for the magnitude.

HSV representation

The final image contains a color-coded representation of the image.

Where

- The gradient orientation is represented by the Hue
- The gradient magnitude is represented by the Value

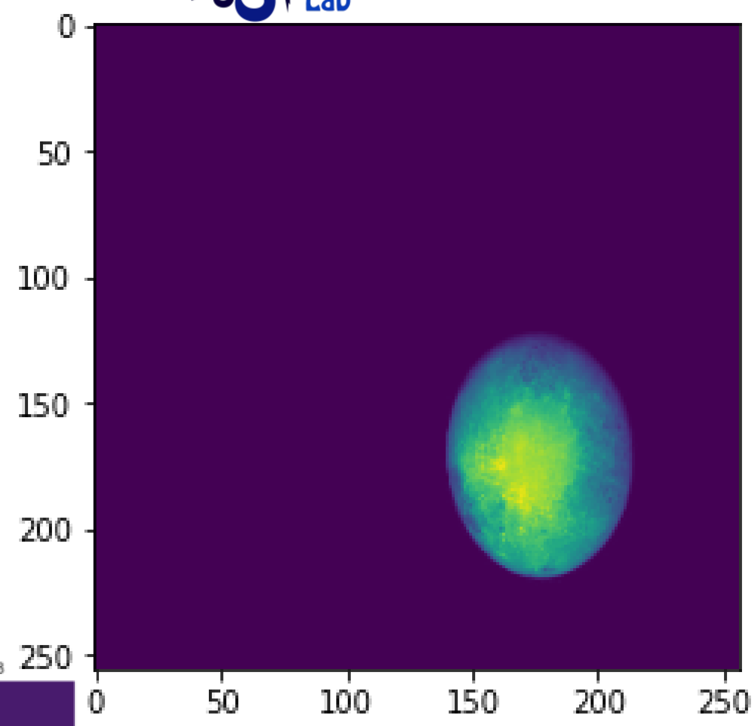
This image can be used later to get the value of the third rotation angle Ψ

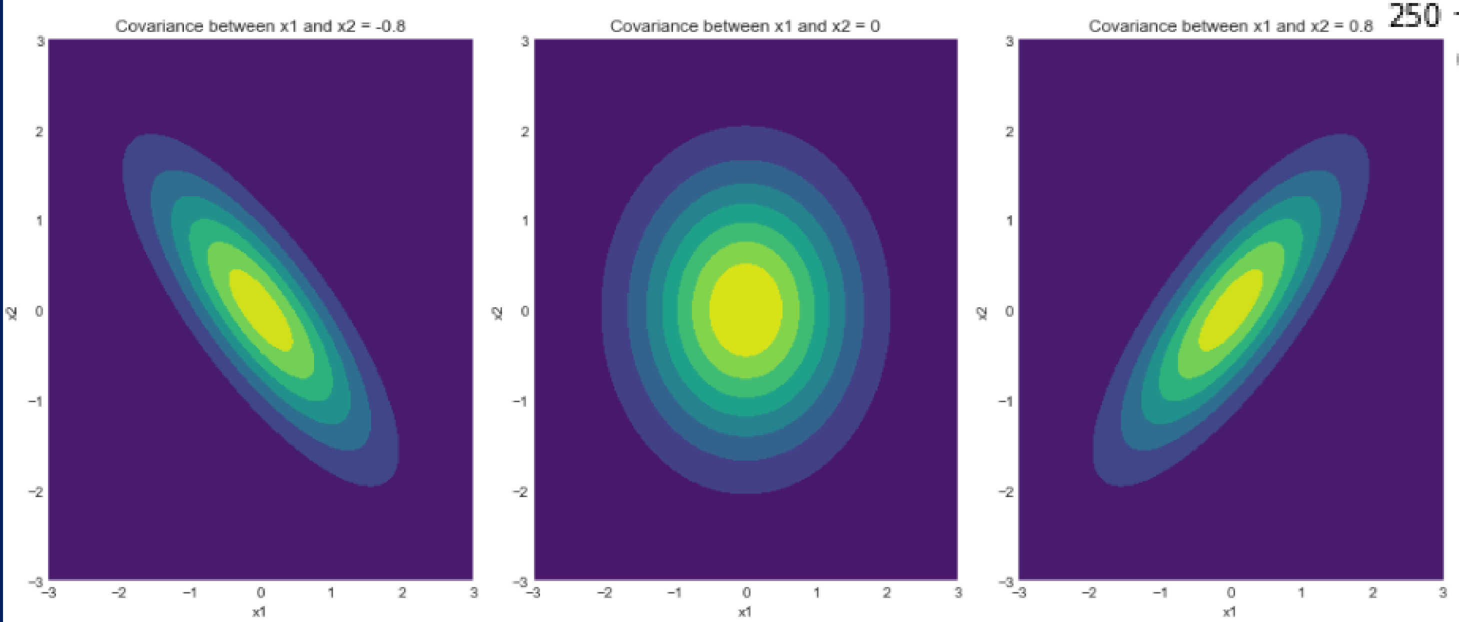
Psi Estimation (Sobel)

The angle can be estimated by averaging the hue values for the sobel phase filter, yet it requires additional manipulations to comply with angles >90

Estimating Psi (Moments)

We can treat the image as a 2-D gaussian distribution, treating its mean vector as the coordinates of the center of the moon.





Choosing Computing Board

Available options

- Implementing the algorithm on an FPGA and manufacturing it as an SOC for operation
- Implementing it on a low-power microcontroller
- Implementing it on a low-power general purpose computer running ARM or RISC-V architecture.

Choice: Raspberry pi

- Tested for space operation (GASPACS)
- Has enough computational power with low power consumption
- Good GNU/Linux support with RT Kernel

Deep Learning

Generated 10,000 imaged using MATLAB GL renderer (not best performance due to java backend but it has easy controls for programmatic rendering)

Processed the images using C++ code and labeled them

Trained a CNN on the data

Future Work

Future Work

- Optimizing and Manufacturing the moon-sun sensor to participating in the MIC 8.
- More detailed research on how can we detect plastic more efficiently.
- Optimized Satellites' configuration and their orbit's parameters.

THANK YOU