Formation Flying Mission

Title: CubeSat Formation for monitoring and detecting plastic wastes in water bodies
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1. Mission Objective

Our proposed satellite mission in 8th Pre-MIC not only includes detecting plastic wastes and following their path but also tests and evaluates the efficiency of a new sensor (moon-sun sensor). Additionally, the mission background was mainly based on our research, so that the following missions have been carefully evaluated in scientific point of view.

Primary Objective

Establish a plastic waste detection and monitoring system providing medium resolution imagery (a minimum of 100m GSD is required) with a useful repeat time (maximum of one hour between availability of satellite images is considered acceptable) within target areas.

Secondary Objective

To provide an experimental testing for the moon-sun sensor by implementing it in some of the CubeSats in the mission and comparing the performance of these satellites with the performance of the other satellites.

2. How to realize the mission objectives

To perform our mission, we will use rosette Formation formation consisting of 12 3-U CubeSats, every 2 satellites will orbit in pairs parallel to each over to cover as much area as possible. To maintain daytime coverage, the satellites will orbit with a period of 92 minutes with an optimal operating altitude of 407km. And, to reduce repeat time without compromising coverage, the satellites will be deployed in different inclinations, as shown in **Table 1** with 2 satellites in each inclination and delay time between each satellite. Moreover, we tried making the direction of observation angle NADIR most of the time when the satellites are passing over large water bodies. The satellites will be equipped with a total of 36 cameras (3 in each CubeSat) which are able to capture images in both Nadir and Glint views ($\pm 26°, \pm 36°, \pm 45°, \pm 57°, \pm 63°, \pm 71°$) in three spectral bands (red, green & blue)

Our mission will aid in many fields and here are some examples:

1. A golden opportunity to test a new sensor and comparing its performance with other sensors performing the same mission.
2. Detecting the major sources of plastic wastes
3. Tracking the path of the wastes in oceans, seas and rivers
4. Getting a clearer picture of how huge the 8^{th} continent is (a great pacific garbage patch 3 times the size of France) [1]

Table 1 Initial parameters of the satellites

#	Sat -1	Sat -2	Sat -3	Sat -4	Sat -5	Sat -6	Sat -7	Sat -8	Sat -9	Sat -10	Sat -11	Sat -12
a(km)	410	410	410	410	410	410	410	410	410	410	410	410
e	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
I (°)	28	28	33	33	41	41	52	52	57	57	64	64
Ω (°)	0	0	72	72	114	114	216	216	288	288	360	360
TA (°)	0	180	0	180	0	180	0	180	0	180	0	180

3. Technological aspects

The technological aspect of our mission includes the integration between all the subsystems and the satellites with the ground station and they should have the accuracy of around 3 degrees. required for relative attitude and relative position of the satellites. The Image Resolution is 100 m and with image accuracy of the satellite will have an upper limit on the error of 5°. The swath width of 10km and is determined by the view angle of the imaging device and the orbit altitude, view angle is 4°. Size of the scene is equal to the swath width multiply by the length of the scene. Storage capacity of the imager is 2 Gb. Scene location accuracy will have an acceptable error of around 5%.

Each satellite will circle the Earth 16 times from North to South every 24 hours. And, the number of pixels in CCD unit in each satellite is 4000 (estimated from initial availability search).

The Ground station will cover 2500 km at the height of 670 km, consequently, each satellite will have contact with the ground station approximately 4 times per day and night. These are the times within which the operators of the satellite can contact the Telemetry and Command subsystem on the satellite and upload the command file and download the telemetry file.

The orbit will be in L.E.O in a height of around 407km and the satellites will be launched from the International Space Station. For the satellites to stay in orbit and keep the formation in shape they should be orbiting at a speed of around 7 km/s.

4. How to realize the required relative attitude and position control of satellites.

The Satellite's attitude is controlled using the attitude determination and control system (ADCS) which consists of the following components:

Attitude Determination: One of the missions of this satellite constellation is testing new attitude determination technologies which rely on image processing, compute vision and machine learning. Thus, the sensors used in attitude determination are a combination of traditional attitude sensors such as magnetometer and new sensors such as Moon-Sun sensor.

Moon-Sun sensor:
The Moon-Sun sensor is a new three-axis attitude determination sensor which works by analyzing real-time images of the moon and extracting three attitude vectors from it. Then the attitude matrix can be estimated using the Triads method. The sensor is proposed for the first time in a paper in the Journal of Spacecraft and Rockets - AIAA - Vo. 34 No.3 May-June 1997 by Dr. Daniele Mortari. [2]
The sensor was developed as a project in the Aerospace Engineering department at Cairo University using a simple camera and raspberry pi 3 computer board. The angles are determined using the following algorithms:
- The first two angles are estimated using Hough transform by approximating the position of the Moon center in the image given the FOV and the camera's resolution the angle can be calculated using a ratio of the Moon's center to the resolution and the resolution to the FOV.
- The last angle is estimated using the mean vector of the lit area of the Moon. The image is treated as a 2-D Gaussian distribution in the moments form which makes the calculations clearer. The mean vector represents the

center coordinates of the lit area. Subtracting it from the center of the moon gives us the Sun-Moon Vector component normal to the Satellite-Moon Vector.
Magnetometer:
Two magnetometers are used to estimate two deviation angles between the measured vector of the Earth's magnetic field and the reference vector at the current orbital position.

Inertial Measurement Unit:
- One inertial measurement unit (IMU) is used to estimate the deviation angles between the measured Earth gravity vector and the reference Earth gravity vector. This can estimate two deviation angles.
- The gyroscope is used to measure the angular rates which is integrated in the predication step in the Unscented Kalman Filter (UKF).

Attitude Control: The attitude is controlled using a combination of one reaction wheel with two magnetic torquers to achieve both cheap and expensive control action in a three-axis configuration with minimal weight and power consumption.

5. Rough image of satellites

Table 2 CubeSat Specifications

Item	**Specification**
Size	$0.10 \times 0.10 \times 0.3405\ m^3$
Weight	$\approx 4\ kg$
Power generation	20 Wat
Uplink speed	$1.25\ M\ bits$
Downlink speed	$1{,}5\ M\ bits$
Upload frequency	$7.2\ Ghz$
Download frequency	$8.4\ Ghz$
Mission data downlink	$9600\ bps$
Satellite lifetime	$5\ years$

Table 3 Mass and Power Budget

Subsystem		**Mass (g)**	**Peak Power (Watt)**
ADCS		980	5
Structure	CubeSat Structure	340	..
	Solar Panels & Lens Shade	850	..
OBC	CPU	150	1
Communication	S-Band Transceiver	80	6
	Antennas	150	
Electric Power		300	20 (Maximum supply)
Payload	Sensors	400	9
	Lens	550	
	Imaging structure	250	
Total		4050	22W required

From the Power budget we found that it will be impossible for image capturing and downlink to happen at the same time. Consequently, the CubeSat will have different operation modes. Image capture mode while taking the images, Data transmission mode while sending and receiving the data. Charging mode will heading to the scene location in the sun. And finally, low power mode when orbiting the dark side of the Earth.

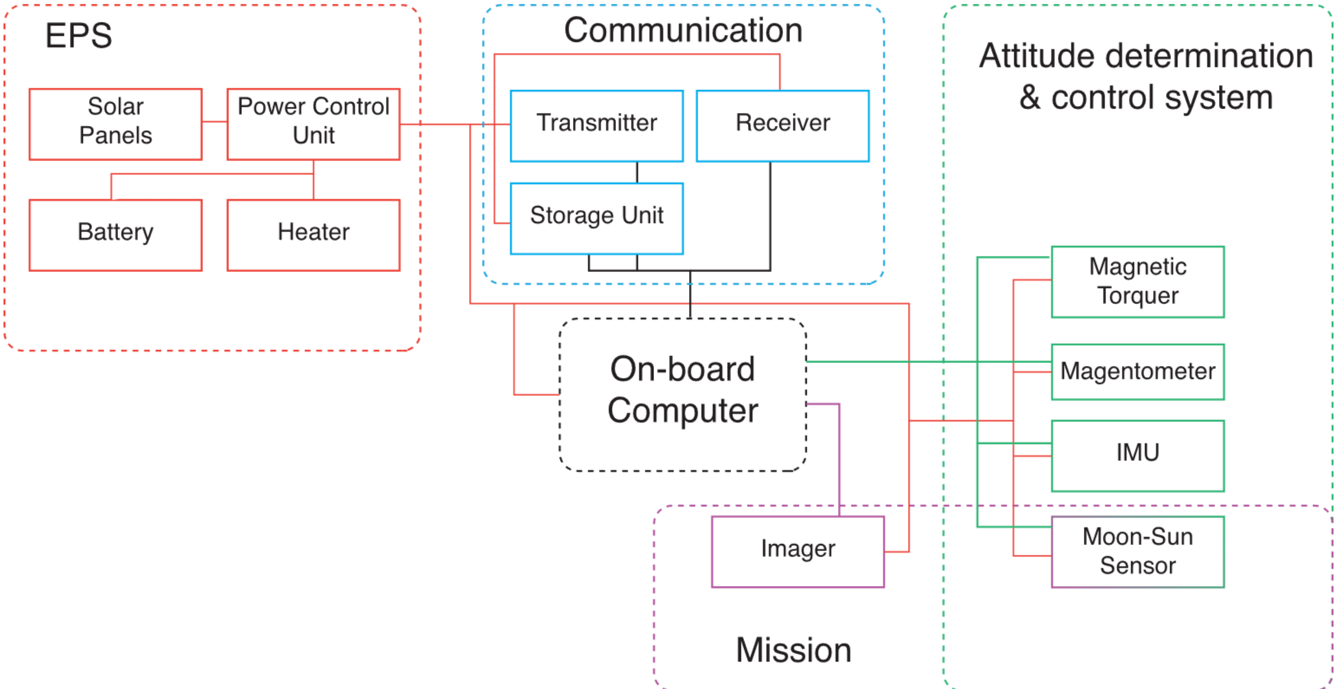

Figure 1 Satellite Schematic

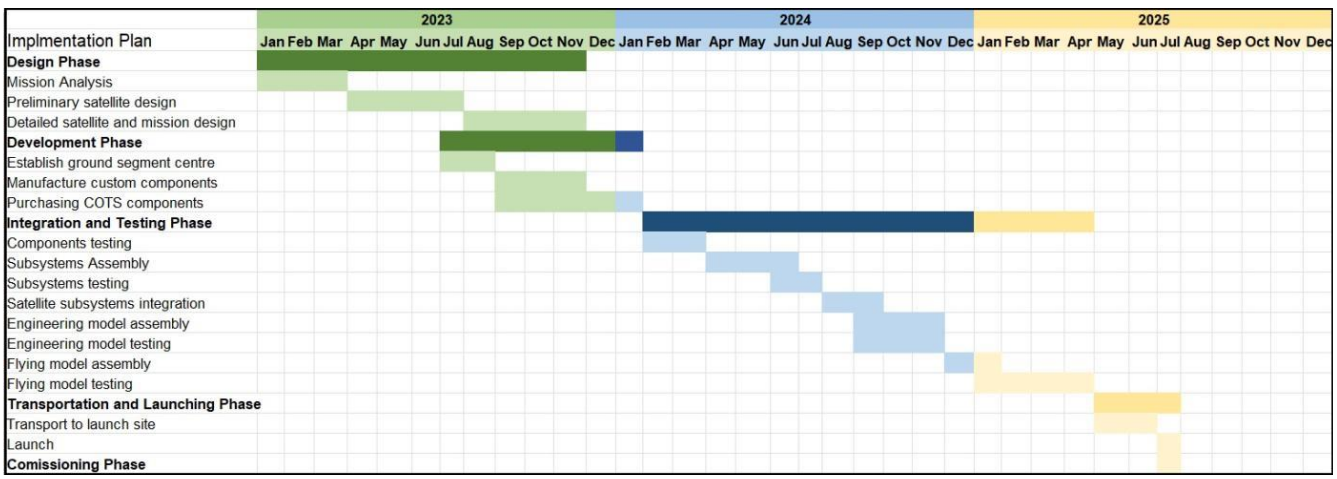

Figure 2 Gantt Chart

Table 4 Mission Cost

Components	$ 753,233.00
Testing	$ 960,000.00
Launching (12 Satellites)	$ 50,000 × 12
Ground Station	$ 1,200,000.00
Operation Cost	$ 75,000.00 × 5
Total	**$ 3,888,233.00**

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