Title: Moon-sighting satellite "Otsukimi"

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Organization: Kyushu Institute of Technology

(x) We apply for Student Prize.

1. Need

In Muslim countries, religious feasts depend on the Arabic monthly (Hijri) calendar that is related to lunar phases as seen from the Earth, i.e. the Islamic calendar is a lunar calendar and used by Muslims all over the world to determine the proper days on which to start the annual fast (Ramadan), to attend Hajj, and to celebrate other Islamic events.

Current methods for Moon-sighting typically employ the naked eye or telescopes, but clouds, pollutants, and other natural factors frequently interfere with observations, leading to confusion or lack of knowledge regarding appearance of the lunar crescent. Establishment of a ground-based network of astronomical stations to observe the Moon would be costly project and would not solve disputes already existing between different Muslim countries, as Moon-sighting would still depend on the weather and pollution and there would be resulting arguments regarding the lunar crescent. Sighting moon phases (Fig. 1) throughout the year could be achieved by observing lunar phases using a dedicated satellite, and sending the data to all concerned users.

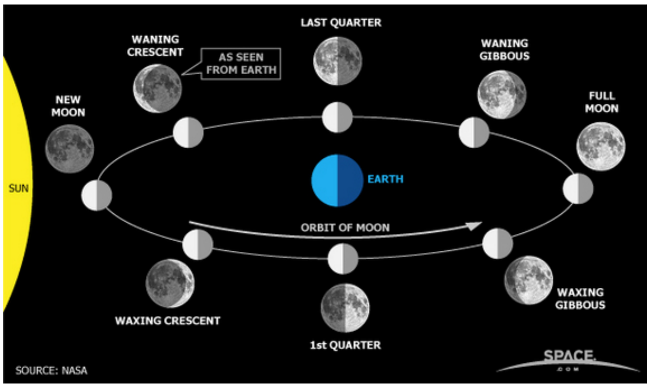

Figure 1: Lunar phases

2. Mission Objectives

The Otsukimi Mission Objectives are the following:

I. The primary mission objective will be achieved if Otsukimi can capture the lunar phase and image at sunset and transmit the data to users within approximately 2 hours.

II. A secondary mission objective will be achieved if the countries involved can develop and operate satellite ground stations in their respective countries to form a network.

III. A secondary mission objective will be achieved if a database of lunar images from the satellite can unify the starting of Arabic months for numerous Muslim countries.

IV. A secondary mission objective will be achieved if the project encourages developing countries involved in the project to embrace space technology in solving their developmental challenges (at least 4 countries).

V. A secondary mission objective will be achieved if the project encourages universities in the countries involved to develop nano-satellites projects, which will be based on successful missions in other countries (e.g. Japan).

3. Concept of Operations

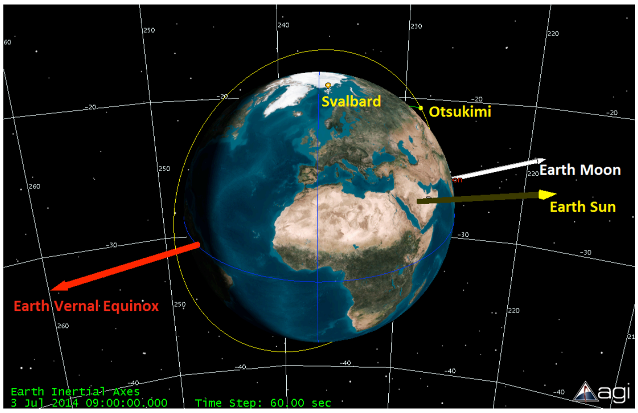

Figure 2: Otsukimi orbit and main ground station

The main satellite mission purpose is to supply data concerning the New Moon to Muslim communities as soon as possible and to regularly send lunar pictures to ground stations for various studies. Therefore, there will be two modes of downlink. One of these is normal downlink mode which will be active during every orbit and another one is the New Moon mode. In normal mode, there will be data downlink to the main ground station which will be Svalbard Satellite Station, in Norway, near the North Pole (Fig. 2). In the New Moon mode, the ground station should obtain the New Moon data/image as soon as possible. Consequently, a ground station network spread all over the world will be used to receive data of the New Moon. After the Moon images are downlinked to the ground stations, they will be immediately uploaded to the Internet for anyone to access.

4. Key Performance Parameters

Here we consider the following three key performance parameters:

- Resolution of the Moon images
- High accuracy attitude determination
- Communication rate

The minimum camera requirement is to capture lunar phase. The correlation between the theoretical value of the image sensor and the focal length of the camera must be determined. The angle of view θ is determined from the value of Y as the distance L (distance from Earth to the Moon) is fixed to about 350,000 km ~ 400,000 km. Focal length is chosen to be around 80 mm~260 mm and the desired resolution of the moon image is considered to be over 100 pixels.

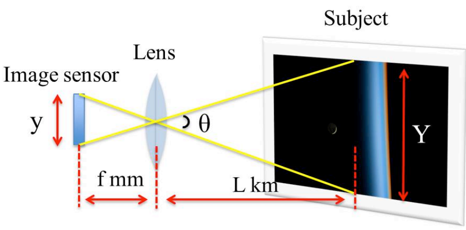

Figure 3: Camera focal length

Y : Vertical length of the photo [km]
y : Vertical length of the image sensor [mm]
L : Distance to the subject [km]
f : Focal length [mm]
θ : Angle of view [deg]

Due to the fact that the Otsukimi satellite must constantly track the Moon, to determine its own location and to be able to change its orientation (actuation), two ADCS modes shall be implemented:

- POWER mode: Power generation is the main objective (using sun sensors: FOV: 114°, Accuracy: <0.5°);

- MISSION mode: Taking the Moon picture is the main objective. A star tracker (accuracy: 18 arcsec (x,y axis) 122 arcsec (z axis)), reaction wheels (momentum Storage: 7.6 mNms at 1000 rpm, maximum Torque: 0.625 mNm) and magnetorquers (3 axes, actuation level 0.24 Am^2 max) will be used.

For downloading the mission data to the ground, for transmitting beacon and telemetry and for uplinking commands from the ground stations, the following drivers are chosen for the Communication subsystem:

- Visibility window for communication with ground segment: for orbit of altitude ~ 1000 km, the visibility window that makes the connection between the satellite downlink / uplink possible is around 10 minutes;
- Mission data size: mission data size is 10 MB maximum (as determined by the Camera system) and the data rate is 1Mbps which allow transmitting the mission data of 10MB in 80 Seconds;
- Frequencies: an S-band transmitter will send mission data. Telemetry shall be transmitted via UHF and commands uplinked from the ground station via VHF.

5. Space Segment Description

5.1 Camera: It was first necessary to determine the desired resolution of the Moon. The method to determine the desired resolution of the Moon (n [pxl], the image comparison of 25 [pxl] ~ 800 [pxl]) is shown in Fig. 4, where the desired resolution of the Moon is at least 100 [pxl]. To determine the vertical length of the photo as N[pxl], we used the ratio n/N from the graph shown in Fig. 5. Choosing the Moon image as 100 [pxl] ~ 300 [pxl], a 1/4 moon size and VGA resolution camera is adequate. Choosing the QXGA resolution camera is sharpest, but as there are constraints on image data size, a lower resolution is necessary. These calculations and constraints led to the choice of the camera model CV-M9 GE from JAI Camera Solutions.

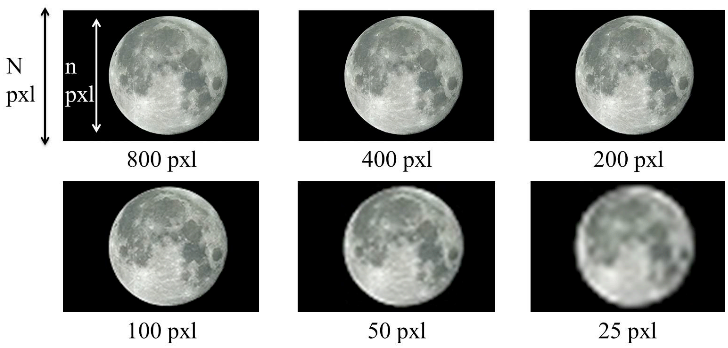

Figure 4: Moon images at pixel sizes

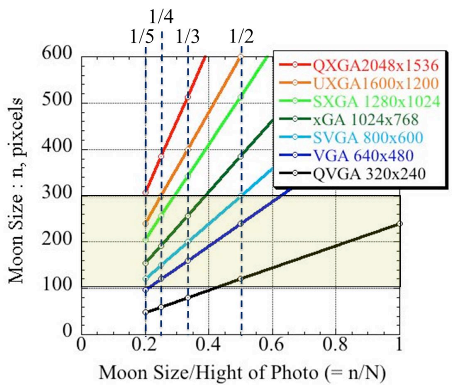

Figure 5: Moon size/Height of Photo

5.2 Attitude Determination and Control Sub-system (ADCS): The Otsukimi satellite will constantly track the Moon using a 3-axis controlled ADCS. The camera will be operated during 20% of any given orbit and the COM subsystem during 10% of the orbit. It is possible to determine the ratio between the angular velocity of the satellite and the angular velocity of the Moon around the Earth. This ratio will determine the angular velocity regarding the satellite inertial frame and this data will be provided by the Otsukimi inner actuator (reaction wheels, magnetorquers). In case the satellite direction is lost, it is possible to obtain an initial vector (i.e. Earth/Vernal Equinox vector) to reset the tracking process. Also, the Otsukimi camera shall not be flooded with sunlight during operation so it is necessary to find a trade-off between power generation and mission operation.

5.3 Communication subsystem (COM): The system has two operational modes: transmitting mode and normal mode. In the transmitting mode COM is transmitting mission data through the S-band transceiver or uplinking commands when communicating with the ground station. The normal mode is when the COM control unit is in standby mode and transmitting the beacon periodically and waiting for commands from the ground station.

5.4 Electrical Power subsystem (EPS): The satellite's subsystems need to operate at:

- Two regulated values: 3.3V ± 5% and 5V ± 5%.
- Unregulated value of 14.4V.

The solar arrays are the main power source and will deliver power during the sunlit part of the orbit and will cover five faces of the satellite, or two deployed paddles. In eclipse a rechargeable battery (NiMH cells) will provide power. EPS will exchange data and commands with CDHS through I2C interface, the data will include voltage, current and temperature measurements, and commands of switching ON/OFF for EPS will be received from CDHS.

5.5 Structure Design

The launch vehicle is assumed as H-IIA or H-IIB rocket, with payload adaptor PAF239M that requires the satellite mass to be less than 100 kg. The predicted satellite mass is approximately 30 kg, with a size of 30 cm cubic. An overall view of Otsukimi is shown in Fig. 6.

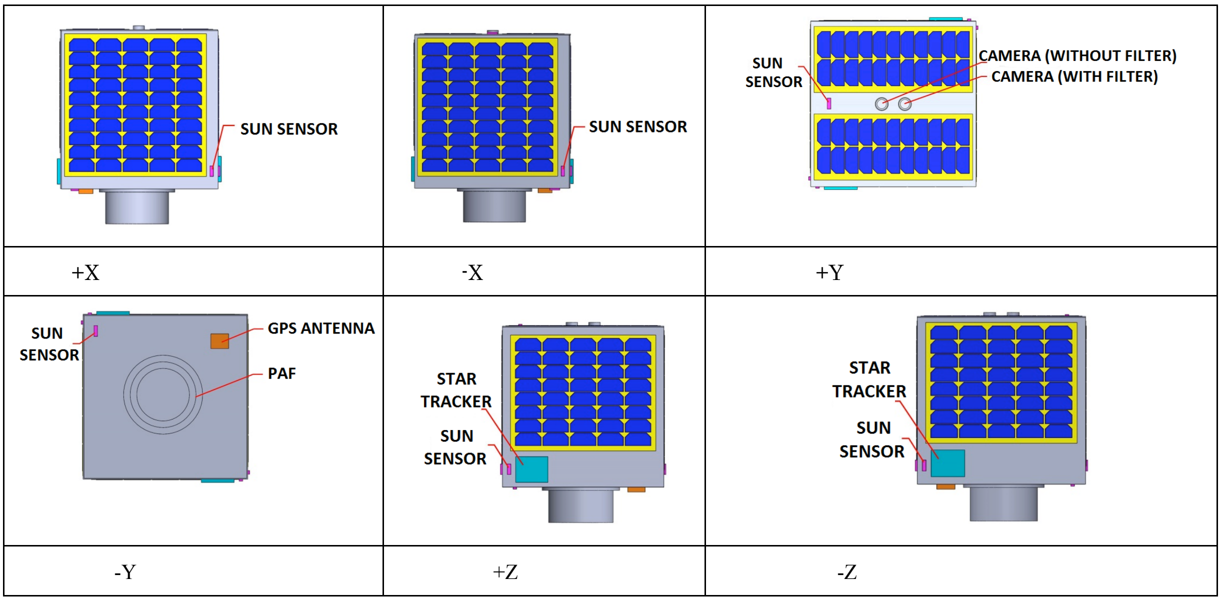

Figure 6: External configuration

6. Orbit/Constellation Description

In order to image the Moon at sunset from the standpoint of a user on the ground at approximately the sub-satellite point, and to provide the user with a clear image of the Moon and its phase, the orbit will be a dawn-dusk sun-synchronous orbit, with an inclination of 99.5°. The orbit selection is motivated by the trade-off between the mission operation mode which needs relative shadow to get an unsaturated sun light picture of the Moon and the power generation operation mode. The orbit must also give Otsukimi multiple passes over the Middle East (Fig. 7). Therefore, Otsukimi will have the following orbital parameters:

- Circular Orbit Altitude: 1000 km
- Angle of Inclination: 99.5 deg
- Eccentricity: 0 – 0.001
- Local time at ascending/descending node: 7:00 p.m. and 7:00 a.m

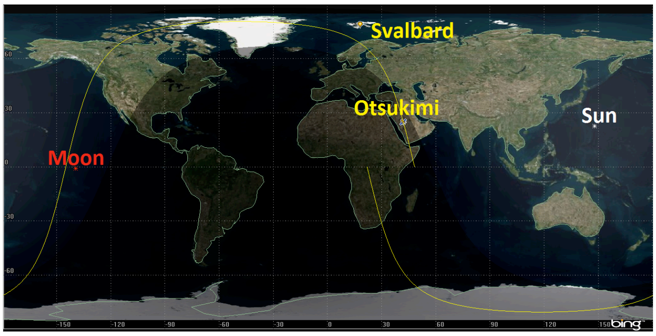

Figure 7: Ground track

7. Implementation Plan

Otsukimi will be a low-cost satellite devleoped in maximum two years (Fig. 8). The satellite developer (represented by the Kyushu Institute of Technology) is well equipped with infrastructure which will minimize the cost and hence the risk.

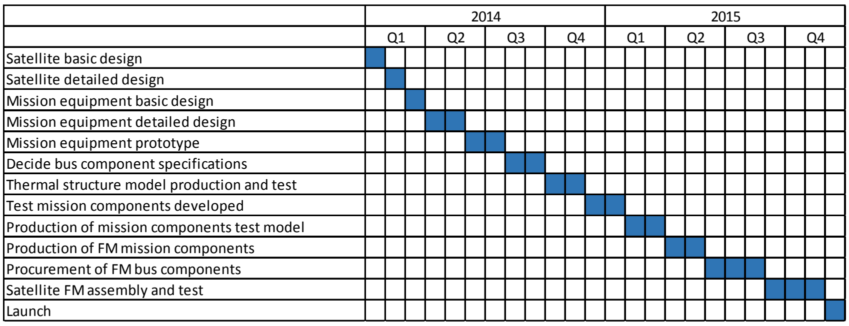

Figure 8: Project schedule

Potential investors and collaborating partners from Arabic countries are private companies or government agencies from Arabic countries: National Authority for Remote Sensing and Space Sciences (Egypt) (NARSS), Space Research Institute of Saudi Arabia (KAC ST-SRI), Algerian Space Agency (ASAL) and SGAC Sudan.

The mission requires the lunar image to identify the phase in the first day of New Moon. Project and technical risk events include the following:

a. Single point of failure:
   1. Mission failure due to ADCS failure
   2. Mission failure due to Power system fault
   3. Mission failure due to Transmission fault

b. Other risks
   1. Imprecise camera image
   2. Radiation damage
   3. Project over budget

8. References

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