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SPILL-SATCON, Satellite Constellation Mission Idea to Detect Oil Spills in Oceans

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Need

When freight ships carrying thousands of tons of fuel crash, malfunction, or encounter harsh weather, they spill enormous amounts of oil into the water. This causes oil slicks to float on oceans and seas, in forms of thick film of crude or refined petroleum oil. The problem gets magnified considering that thousands of oil leaks result from massive oil spills every year.

In addition, hurricane damage to oil production infrastructure in seas often causes oil spills and the resulting pollution of waters. Natural seepage from the ocean floor introduces a significant amount of oil to ocean environments as well. Once formed, an oil leak becomes an unpredictable phenomenon. It might end up spreading, migrating, thinning or thickening, moving towards land or further out to sea. An international community of activists, organizers, and technical developers has formed to identify, manage and eliminate the devastating oil leaks.

Because the ocean is never perfectly smooth or calm, the Sun's reflection gets blurred as the light is scattered in all directions by waves. The leaks become visible not because they change the color of the ocean, but because they dampen the surface waves. The smoothing of the waves can make the oil-covered parts of the sun glint area more or less reflective than surrounding waters, depending on the direction from which they are seen.

The usual technique for mapping oil leaks from space uses radar, which bounces pulses of radio waves off the wave-roughened surface of the water and detects the amount of backscattered energy. The disadvantage of using space-based radars to map oil spills is that they don't provide routine coverage of large areas, and oil leaks may evaporate or disperse significantly within a day. The researchers suggest that tracking oil leaks in the wide sun glint region of daily LEO satellites images will be a better avenue for comprehensive, near-real-time monitoring of large oil spills and natural seeps in marine ecosystems.

Morever, oil spills are difficult to identify in visible satellite images, especially in the open ocean. Because the ocean surface is so dark blue in these images, the additional darkening or slight color change that results from a spill is usually imperceptible.

Mission Objectives

1) The mission concept aims to place 3 remote sensing cameras in orbit in the 300 to 750nm bands (RGB), each with pixel resolution of 50 meters. Every camera will be located in a different LEO small satellite. And every satellite will share the orbit with a separation of 10^0 from each other based in the orbital radio with respect to the earth

center. The mission altitude will be of 650 Km with a polar inclination of 75^0.

2) Satellite stabilization and its pointing capabilities have to be successful to obtain images of the same location at ground level (sea and oceans).
3) Every satellite will share the orbit with a separation of 10^0 from each other based in the orbital radio with respect to the earth center. The mission altitude will be of 650 Km with a polar inclination of 75^0.
4) Generate the image processing software to be applied to satellite data from the 3 constellation spacecrafts in order to enhance information that will allow oil-spill detection.
5) Generate a data image center to acquire, store, process, generate and distribute worldwide data related to oil spills in oceans.

Concept of Operations

It was recently demonstrated that oil spills can be sensed in the sun glint region, figure 1. In this way, there are studies and results such as those obtained with the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite on May 13, 2006, of dozens of natural crude oil seeps over deep water in the central Gulf of Mexico, [1]. MODIS satellite renders 250 meters resolution images that can also be obtained with small satellite technology.

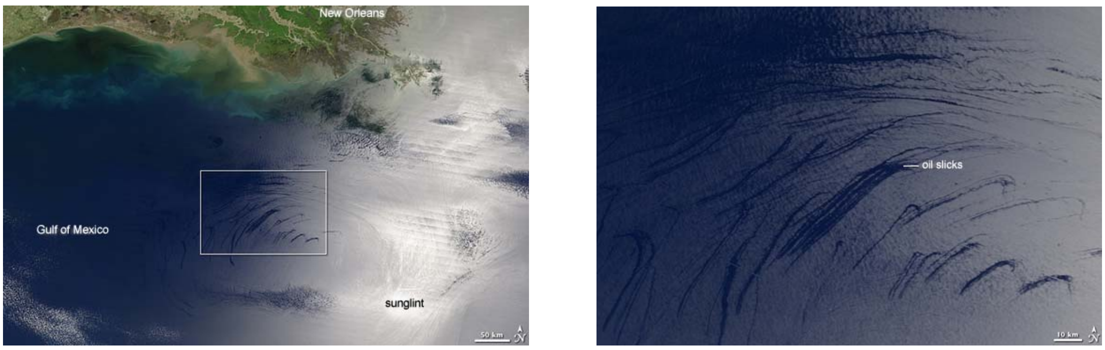

Figure 1. Satellite image of natural oil seeps in the Gulf of Mexico by Jesse Allen, NASA.

The referred studies detected natural seeps for a total coverage of 1900 Km^2 with individual leaks varying in surface area (11.7± 14.8 km^2) and length (19.2 ± 12.4 km^2). While concurrent SAR imagery showed similar area estimates within 30%. This estimate, based on a single image, was higher than earlier estimates from a database of multi-date SAR images for the same region. Additional inspection of more than 200 images for the month of may between 2000 and 2008 revealed similar leaks.

Under this scenario, we propose a constellation mission of 15 Kg small satellites that can offer a sustainable way to sense and follow world wide natural seeps as well as to improve estimates of seepage rates, [2].

Moreover, the creation of an international university center that will process the information of

this constellation to offer updated information about oil spills around the world is suggested. The information obtained through this type of satellite missions will help diverse associations around the world to contribute to mitigate this ecological problem.
In addition it is suggested to apply the first generation of this mission constellation to explore new applications oriented to solve worldwide issues related to the quality of water resources that influences several types of epidemiology issues in many countries.

Key Performance Parameters

1) Camera image resolution for satellites has to be of 50 meters by pixel. It has to fit in to a 15 Kgs nanosatellite.
2) Detection of sun-glints will be important to start image acquisition.
3) Satellite stabilization and pointing will be important for every satellite to obtain images from the same ocean location.
4) Ground station network will be important for constellation image acquisition.

Space Segment Description

Available studies about the roughness of surface water in oceans show that oil spills induce the reflection of electromagnetic waves in the visible light band, in L band (from 1.5 to 2.7 GHz) as well as in the infrared band. We propose the use of remote sensor cameras in the visible light from 300 to 750 nm. This approach lowers the mission cost and decreases the system power consumption as well.
The mission concept aims to place 3 remote sensing cameras in orbit in the 300 to 750nm bands (RGB), each with pixel resolution of 50 meters. Every camera will be located in a different LEO small satellite. And every satellite will share the orbit with a separation of 10^0 from each other based in the orbital radio with respect to the earth center. The mission altitude will be of 650 Km with a polar inclination of 75^0.
Every satellite camera will point to the same place within a solar-glint follow-up regimen. There will be a second regimen where an image acquisition will be performed independently of the solar-glint. This approach will allow the observation and analysis of solar-glints in oceans and seas. Allowing to sense for water roughness changes within 3 different angles when solar-glints takes place. This approach will render relevant information regarding the presence or absence of oil in oceans and seas.
As mentioned, the satellite constellation configuration in orbit will sense and acquire the reflections of sun-glints from three different angles. Under this approach the required statistical image processing will be performed to decrease the false alarm detection of sun-glints. The availability of satellite images from any place in the planet, from three different angles, will allow the correlation of images to avoid sensing mistakes.
Once acquired the images from every satellite and after being captured at Earth a data processing has to be achieved in order to perform the oil presence recognition. This will be completed by means of software algorithms that will include the analysis by principal components as well as by independent components. Data processing will include a digital

method developed at the Moscow State University for satellite telemetry signal treatment which considers data scattering applied to oil recognition in oceans.
The technical specifications of satellite cameras will be the followings. Resolution of 50 meters, average required power of 1 W, [3], data transmission of 5 Mbps, 12 bits quantization (8 bits can be acceptable). However, enhancing the camera resolution will render better results.
Each satellite will require three axis stabilization capabilities because every satellite will be required to acquire images from the same location in the oceans. Stabilization maneuvers will be accomplished by reaction wheels and magnetic torquer coils (MTC). However, there exists the possibility to employ just MTCs. In a next level of proposal the detailed information regarding stabilization and pointing sensors would be provided. The next level of proposal would be based on a deep satellite analysis regarding stabilization and bus capabilities and details. Among that information the power subsystem will be fully detailed.
For payload communications, it would be used S band equipment in the Mbps data transference. Further data would be exposed in a next level of proposal.
Regarding the satellite structure, shape and satellite dimensions would depend on the camera characteristics. In a next level of proposal those requirements would be treated with more detail.

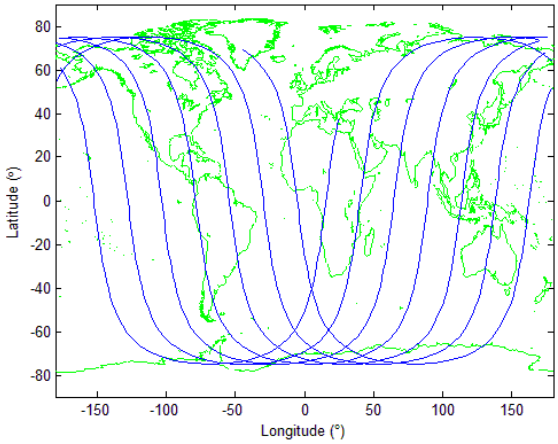

Figure 2. Ground tracking of the SPILL – SATCON constellation.

Orbit/Constellation Description

Every constellation satellite will follow the same orbit with a height about 650 Km, this altitude was chosen for several raisons. First, at this height acquired images have a good resolution of big ocean areas. Second, at this height, the 3 satellites will be capable of taking pictures of the selected area in presence of a sun glint. Third, at this height, the satellites will avoid the harmful effects from the Ionosphere phenomena. Other orbital satellite characteristics are: semi major axis of 7016.47, eccentricity of 0, inclination of 1.309 radians, right ascension of the ascending node of 3.14 radians, argument of perigee of 4.97 radians and true anomaly of 3.24. The angular velocity of satellites will be 14.75 rev/day. The satellites speed will be 7.53 Km/s. While the satellites ground tracking will have the appearance shown in figure 2.

Implementation Plan

The time difference between each satellite of the constellation will be 3 minutes approximately. Within this time is very difficult to receive the information of 3 satellites with only one ground station. For this reason a complete system of ground stations is required. The GENSO network of ground stations will be an optimal solution for this mission. In this way, image transmission from every satellite could be realized from different places along the Earth. In addition, the GENSO network would help to obtain the necessary images to perform subsequent analysis.

The satellite constellation mission feasibility depends on the cost reduction of the satellite constellation. This involves the cost of the satellite bus, which is affected by the image storage capabilities of each satellite. Therefore, in order to significantly reduce the needs of a high volume mass storage memory for the satellites it will be required to employ the worldwide network of ground stations called GENSO that can interact via an internet software standard. This network will increase the level of access to the satellite constellation.

GENSO will allow for a near global coverage in communication for every satellite, increasing the return of satellite images and the opportunities for sending commands to the constellation spacecrafts.

Data Processing for the Satellite Constellation

The satellite constellation for oil spills in oceans will render plenty of imagery data around the world. Those images will be gathered by ground stations of many countries through the GENSO system. In addition, there will be an international university center that will be responsible to process, to generate and to distribute the products generated by the Spill-Satcon mission. The characteristics as well as the operative logistic of this center will be generated in team with University of Tokyo.

Further applications of the Spill-Satcon mission

It is suggested to apply the first generation of this mission constellation to explore new applications oriented to solve worldwide issues related to the quality of drinking water resources that influences several types of epidemiology risks issues in many countries.

Identifying the risk factors for stomach diseases related with water resources can enhance preventive practices and preventive medicine.

Of course, there are will be other applications for this satellite constellation. Particularly for land areas, where many applications can be found, all of them related to remote sensing. One of them would be the generation of 3D-images of land.

References

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[3] E.A. Baker, The Design of a CMOS Sensor Camera System for a Nanosatellite, Master Thesis, University of Stellenbosh, South Africa, 2006.