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# Identification of Magnetic and Gravitational Field Patterns for Localization in Space †

**Karina Abboud, Shalom Z. Carmona-Gallegos, Christian E. Duran-Bonilla and Rafaela Villalpando-Hernandez and Cesar Vargas-Rosales ***

Tecnológico de Monterrey, School of Engineering and Sciences, Monterrey 64849, Mexico
* Correspondence: cvargas@tec.mx
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**Abstract:** Establishing control over a mission to explore space is still one of the most difficult tasks. In order to achieve such mission control, we need communications into space through the transmission and reception of radio signals. To improve communication conditions, we propose a tracking system to locate space gadgets and transmit signals at minimum distances to reduce free space attenuation. We propose the case of a satellite sent off to the Moon or Mars, namely points where tracking devices can no longer reach them. In this paper, we discuss the methods and strategies to carry out this idea. The fingerprint of magnetic and gravitational fields can give us information to differentiate the quantity of electromagnetic waves that are received at a point in space in three dimensions. Each planet has specific characteristics, including a field around the planet, whether magnetic, electrical or otherwise, that protects its surface. The use of a spectrometer of masses allows us to identify the neighboring magnetic field as well as the compositions of celestial bodies and is a clear solution for the observation and monitoring of a planet. Additionally, the use of an oscillator is proposed to enhance the spectrometer. In conjunction with the use of a magnetometer, we can obtain an accurate measurement of the field of a celestial body, magnetic or not, and its composition. In addition, with the integration of an accelerometer, the altitude will be transformed into speed data, and to analyze its variation, we turn these data into gravitational force and define if the satellite is closer to the atmosphere of the celestial body. Attached to the sensing stage, a network of SatComs will be used to amplify the received signal and reach the ground station. Two SatComs per orbit will be positioned at specific Lagrange points of the celestial body.

**Keywords:** localization in space; magnetic field; gravitational field; magnetometer; spectrometer; space sensors

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## 1. Introduction

For a satellite to self-localize, it will take a combination of different sensors to detect the environment and relate it over sets of fingerprints for each feature measured. Magnetic fields can be found for almost any celestial body in the solar system and can be mapped through magnetometer measurements.

Every day now, society is looking up to space, trying to devise how to exploit new resources to meet the demand for services or to improve technological products. Given that Earth is currently running out of resources, exploration in space is becoming more of a necessity. In light of this situation, we find ourselves questioning the lack of communication with spacecraft in outer space that could make gathering data so much easier in order to determine new resources. Starting with innovative methods, we propose a localization system which would assist the satellites in space to send information on their localization using fingerprinting methods to a network of nodes in space and obtain a quick response for localization purposes.

### 1.1. Current Strategies

The implementation of constellations of cubesats has been life-changing in allowing scientists to apply research techniques that are cost-effective due to cheap and rapid manufacturing allowing designs to be tested in a reasonable time frame. An example of the evolution of those constellation is the 1990s version of the Magnetospheric Constellation (MagCon) missions and the changes applied in the early 2000s. The first versions included almost 100 mini satellites that eventually were reduced to 3 as a result of the revolution of satellites that started from prioritizing the reduction of connection nodes in the constellation without decreasing the coverage area [1].

#### 1.1.1. Magnetometer

Around our solar system, the magnetosphere of celestial bodies is shaped according to the pressure of the solar wind ejected outward through space. For the study of Earth's magnetosphere, NASA's Magnetospheric Constellation (MagCon) mission focused on a constellation of 36 small satellites with a weight of 30 kg each. With the magnetometer measurements, one can have a picture of the strength of the field and define its rotation, angle and direction and even locate particular objects within the coverage area. Recent years have shown that magnetic field variation measurements can give precise information about a location. Lockheed Martin works behind this idea with Dark Ice Technologies. They put on the market a quantum magnetometer that is proposed to serve as part of a GPS system on Earth capable of enabling location services in places where GPS signals cannot reach or get jammed. This proposal relies on the known unique variations of the Earth's magnetic field, which is defined by rock formations on the Earth's crust surface, although this method would require aerial surveys to have precise results.

#### 1.1.2. Gravity

Gravity represents an important variable to be measured and used as a parameter for the location and orbiting of satellites and probe trajectories, as well as spacecraft. In this way, trajectories are implanted in periodic orbits in the solar system in order to put into orbit satellites for exploration and analysis of celestial bodies. This has happened with important space missions such as those related to the study of Venus, being extremely important both for sending data through space and for the study and monitoring of the solar system.

#### 1.1.3. Spectroscopy

Spectroscopy is commonly used in astronomy to know the properties of celestial bodies such as electromagnetic radiation, distance, age and composition through the Doppler effect. Edwind Hubble applied spectroscopy to the study of celestial bodies in 1920, discovering the expansion of the universe, a methodology currently used by space agencies, such as the European Space Agency (ESA) through the launch of LISA Pathfinder on 3 December 2015 around the first Sun–Earth Lagrange point at 1.5 million km from Earth and, more recently, the James Webb telescope with the use of a medium resolution spectrometer (MRS) MIRI creating data cubes in three dimensions, as well as a Near InfraRed Spectrograph (NIRSpec), which allows spectroscopies of 100 objects simultaneously, in order to study the composition and kinematics of astronomical objects, which we can use for localization in space [2].

#### 1.1.4. Interplanetary Connections

For seamless integration for the transmission of scientific data, satellite communications (SatComs) have implemented innovative forms of processing multicast capabilities through non-terrestrial network (NTN) groups. The localization method proposed for the connection with satellite nodes, bases and other systems is the time difference of arrival (TDOA) method, allowing an accurate, reliable and scalable approach in its infrastruc-

ture and considering a delay tolerance in the network (DTN) for the communication time between them, which makes possible a correlation with the signal and noise (SNR) [3].

## 2. Methods for Space Localization

In this section, we discuss further the technologies for those aspects highlighted in Section 1 that will make possible the localization.

### 2.1. Satellite Structure

MagCon missions of multiple satellites for a constellation demonstrated that the basis of a cost-efficient design and even availability for international collaborations is the modularity that facilitates the deployment. Reducing the number of orbiters with a different method of communication focused on Lagrange points helps address the problem of waiting for development and deployment dates through fewer satellites, a lower cost, less waiting time and fewer nodes to communicate with [1].

### 2.2. Magnetometers

Lockheed Martin is developing a prototype for a magnetometer, using a synthetic diamond to measure the direction and strength with extreme sensibility for magnetic field anomalies. The measurements taken are then compared with existing mappings of the fields to determine localization. The synthetic diamond is an important material in the instrument since it provides quantum-level properties through trapped particles in its material structure, which end up turning it into a hyper-sensitive detector of magnetic field waves [4]. The diamond has a nitrogen-vacancy (NV) center with a negative charge state that has a spin equal to one, which gives a path to controlled and coherent optical readings through microwaves. Magnetic field measurements are made by probing the NV spin levels split in the electronic Zeeman interactions. These kinds of interactions are best sensed by diamonds formed through a chemical vapor deposition due to its preferable morphology giving a more controllable environment for the NV center [5]. The quantum magnetometer is one foot long in size, making it a suitable tool for its application in spacecraft and promising to give better location measurements than actual methods [4].

#### 2.2.1. Gravity

In the case for the GOCE mission, a design was given which required six accelerometers along three orthogonal axes to take measurements of the gravity gradients. Limitations exist for accelerometers, not allowing them to take any measurements past a certain bandwidth. The longest wavelengths' harmonics are instead measured through orbital perturbations taken from the received GPS signals. Procedure takes 1 year of measurement phases with an alternating 6-month period for hibernation due to the not-so-optimal position of the Earth for solar cells at the time [6].

#### 2.2.2. Spectroscopy and Lagrange

The Medium-Resolution Infrared Instrument (MIRI) used on the James Webb Space Telescope (JSWT) divides the wavelength spectrum into four channels, with channel one for short wavelengths and channel four for long wavelengths. Its range is from 4.9 to 28.8 μm, together with a spectrograph and a coronagraph, whose function is to explore the origin of many of the galaxies in the infrared optical range at the beginning of the universe. Together, the Near InfraRed Spectrograph (NIRSpec) has an infrared wavelength range from 0.6 to 5.3 μm, with a multi-object capability of more than 100 simultaneous celestial objects, making use of a light diffraction technique to image its field. In conjunction with the two previous technologies, we can make a combination in the measurement of variables such as spectrum luminosity and visualize magnetic field lines and locate a satellite or target with already known points in space, being either defined patterns or celestial bodies [2]. The use of a downscaled mass spectrometer is proposed for this type of exploratory satellite, allowing one to analyze the chemical composition of the materials and particles adjacent to

its structure, allowing mapping of the composition of the nearby environment in addition to self-localization in high concentrations or trained patterns over time.

#### 2.2.3. Interplanetary Connections

The development of interconnection for the Interplanetary Internet (IPN) requires a series of transmission protocols, as well as an organization in the structural conformation of the nodes. The characteristics of the IPN require it to be interoperable, reliable, scalable and easy for transmitting scientific data, as well as capable of layered communication and communication nodes. In this way, any agency, space program or space industry can make use of the IPN, speaking analogically of the conventional Internet. Although there are several ways to organize the nodes, this proposal is structured as an incremental constellation in each of the nodes, so we use a data fusion method that combines base stations (BSs), taking as reference new iterative nodes to obtain an estimate of the location of the new mobile station (MS). For this, the time difference of arrival (TDOA) helps to calculate the distance between reference nodes $i$ and $k$ and the node to locate as follows:

$$r_{ik} = (t_i - t_o)c - (t_k - t_o)c = (t_i - t_k)c, \quad (1)$$

where $t_i$ and $t_1$ are the times at which the signal is received at nodes $i$ and 1, respectively, $t_o$ is the time at which the signal is transmitted (it is not necessary to know its value) and $c$ is the speed of light. This calculation is deterministic for localization and computation subsystems. In addition, DTN SmartSSR routers are necessary for node connection in order to achieve autonomous routing and multipoint communications, allowing delays in sending and arriving signals. A frequency range in the Ka band is recommended, avoiding the oversaturation of radio frequency systems in nearby years, while a signal segmentation system is proposed where for intercommunication, the consolidated signal is sent in a single packet, fragmented into smaller packets and then decoded before Kalman filters are applied to finally combine the fragmented signals, reducing noise and interference for the communication [3].

## 3. Discussion

In this section, we briefly discuss the localization method proposed based on the satellite structure and autonomy. Localization can be seen as a process with three stages. The first stage is where sensors are used to measure variables and estimate parameters for the calculation of separation distances. The second stage is when those measurements from the sensors are combined in each reference satellite in order to obtain a value of the separation distance estimate and communicate this to a fusion center. The third stage is when those estimates are received by a fusion center, and this calculates the coordinates of the node for location by using the separation distance estimates from at least three different reference satellites. We placed the reference satellites at the Lagrange points so that those reference satellites had known positions.

### *3.1. Satellite Structure*

For the final design proposal of the satellite structure, we considered that it was made up of the main body for sensing magnetospheres and gravitational fields. It also had three detachable nanosatellites that would function as orbitals for the transfer of data and signals located at specific Lagrange points. Likewise, it had three solar panels (as shown in Figure 1) for the power supply and the general hardware components for data storage, telemetry and tracking.

The final model of the satellite was based on the first three-axis stabilized nanosatellite, the SNAP-1 and the MagCon missions [7]. The three-axis structure demostrated the feasibility of power suministration through the three principal solar panels, and the MagCon missions proved the efficiency of the detachable nanosatellites for working as orbiters.

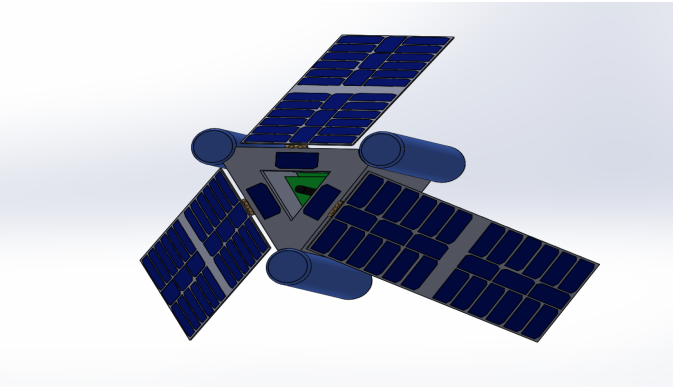


**Figure 1.** Deployment of satellite.

### *3.2. Satellites Location*

For this task, it was proposed that they be located at Lagrangian points, particularly based on the 2015 mission with LISA Pathfinder around the first Sun–Earth Lagrange point 1.5 million km from Earth. These satellites would have more powerful features to help with the localization by calculating the distances between the points of interest once they had the information. A conceptual diagram can be seen in Figure 2.

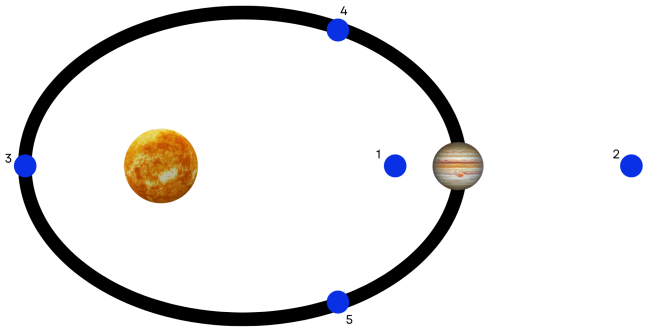



**Figure 2.** Nodes in Lagrangian points.

### *3.3. Autonomy*

The autonomy of the satellite is essential to meet the objective set, which is considered a satellite for self-localization, which will help establish the basis for a future interplanetary Internet with solar energy and sensors that require minimal maintenance, which can be performed remotely, and that have already been tested in other satellites and observation telescopes, such as Hubble, James Webb or exploratory missions such as Venus Express. It represents an innovative solution that can be scaled over time, even more so because it does not require an operator and contains everything necessary for exploration, measurement of variables, analysis of the chemical composition of its environment, spectral visualizations and nodes in the IPN.

## 4. Conclusions

In order to bring new technologies, we must look to exploit our main resources at hand. Magnetic and gravitational fields form a big part on the characterization of a planet and the solar system that surrounds Earth. As shown in the previous designs, it is possible to manipulate these data to offer new solutions in the localization of a spacecraft's environment. Comparing the state-of-the-art methods and uses of sensors inspired us to set a proposal that could benefit the management of localization as well as data transmission. The idea of using a quantum magnetometer might not be an economic aid, but it certainly certifies that localization through magnetic fields can be achieved, giving much precision

to its results and with no need to depend on radio frequency bands for it. Other sensors come in handy to help make precise the parameters and conditions, such as accelerometers and optical spectrometers. A set of accelerometers will sense the gravitational field and its variations. Spectrometers will set parameters through NIR detections. All these factors can be taken into account before searching for the most precise location and comparing the sensed data with the fingerprints of previous mapping calculations. Once the location is estimated, the satellite sends a signal to nodes set not so far away from the planet where it is established. These nodes are set to orbit in specific Lagrangian points to facilitate and speed up the signal transmissions and help work out an interplanetary network with the same objective of communicating around the solar system.

The downsides might be the not-so-cheap instruments used or the fact that we need high magnetic field interactions to obtain exact results. On the other hand, the idea was based on a hybrid sensor of multiple sensors that can make up for the lack information of one another, allowing it to expand the areas to work with for thinking of different types of planets such as Mars and Venus, where magnetic fields are weak. Then, the spectrometer comes in to be main base of precise localization data. Exploration of outer space is a very competitive area to work in. Evolution and technology go hand in hand to achieve the best results possible, and new methods must be formed in order to not fall behind. This proposal hopes to get closer to that revolutionary idea that could help facilitate missions into outer space.

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