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

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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 to points where tracking devices can no longer reach them. In the paper, we discuss the methods and strategies to carry on 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, 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 composition of celestial bodies, and is a clear solution for the observation and monitoring of the planet. Also, the use of an oscillator is proposed to enhance the spectrometer. In conjunction with the use of a magnetometer, we can get an accurate measurement of the field of celestial bodies, magnetic or not and its composition. Also, with the integration of an accelerometer the altitude will be transformed into speed data, and to analyze its variation, we turn this 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 to reach the ground station. Two SatComs per orbit will be positioned into 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 the 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.

Everyday 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 sight of this situation, we find ourselves questioning the lack of communication with spacecraft in outer-space that could make gathering of data so much easier in order to determine new resources. Starting up with innovative methods, we propose a localization system which would assist the satellites in space to send information of their localization using fingerprinting methods to a network of nodes in space to get 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 90's version of the MagCon (Magnetospheric Constellation) missions and the changes applied for the early 2000's. The first versions included almost 100 mini satellites that eventually were reduced to 3 as the 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 depending on the pressure of the solar wind ejected outwards through space. For the study of earth's magnetosphere NASA's MagCon (Magnetospheric Constellation) mission focused on a constellation of 36 small satellites with a weight of 30 kg each. With the magnetometer measurements you can have a picture of the strength of the field and define its rotation, angle, 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 on places where GPS signals can't reach or get jammed. This proposal relies on the known unique variations of the Earth magnetic field which is defined by rock formations on 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 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) that 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 are Satellite Communications (SatComs), implementing 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 infrastructure, 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 bases of a cost efficient design and even available 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. In this way with fewer satellites, less 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 on 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 with spin equal to one which gives 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. This kind of interactions are best sensed by diamonds formed through a chemical vapor deposition due to its preferable morphology giving a more controllable environment for NV, [5]. The quantum magnetometer is one-foot-long 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 of 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. For the longest wavelengths' harmonics are instead measured through orbital perturbations taken from the received GPS signals. Procedure takes 1 year of measurement phases with alternating 6-month period for hibernation due to the not so optimal Earth's position 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 goes from 4.9 to 28.8 $\mu$m, 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 of range of 0.6 to 5.3 $\mu$m, 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, visualize magnetic field lines, and locate a satellite or target with already known points in space, either defined patterns or celestial bodies, [2]. The use of a downscaled mass spectrometer is proposed for this type of exploratory satellites, allowing to analyze the chemical composition of the materials and particles adjacent to its structure, allowing in addition to mapping the composition of the nearby environment, self-localize in high concentrations or trained patterns over time.

#### 2.2.3. Interplanetary Connections

The development of the 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 to transmit scientific data, where it is capable of layered communication and communication nodes. In this way any agency, space program or space industry can make use of the IPN, analogically speaking 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 that we use a data fusion method that combines base stations (BS) 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) will help to calculate separation 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, $t_o$ is the time at which the signal is transmitted and it is not necessary to know its value, and $c$ is the speed of light. This calculation is deterministic for localization and computation subsystems, also a 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 and then fragmented into smaller packets, then decoded and 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 satellites 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 sensors are combined in each reference satellite in order to get 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 to locate by using the separation distance estimates from at least three different reference satellites. We place the reference satellites in the Lagrange points so that those reference satellites have known positions.

### *3.1. Satellite Structure*

For the final design proposal of the satellite structure, we consider that it is made up of the main body for sensing magnetospheres and gravitational fields. It also has 3 detachable nanosatellites that will function as orbitals for the transfer of data and signals located at specific Lagrange points. Likewise, it has 3 solar panels for power supply and the general hardware components for data storage, telemetry and tracking.

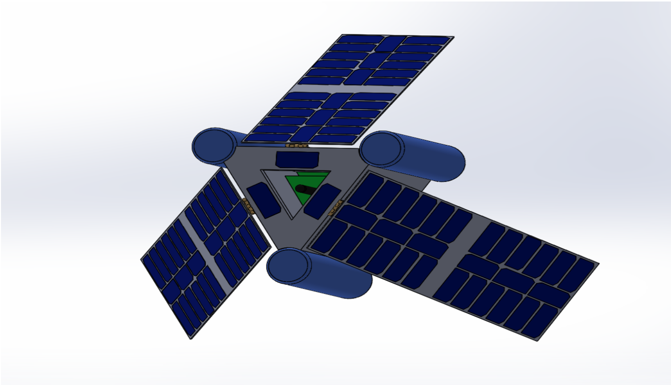

**Figure 1.** Deployment of satellite.

The final model of the satellite is based on the first 3-axis stabilized nanosatellite, the SNAP-1 and the MagCon missions, [7]. The 3-axis structure demostrated the feasibility of the power suministration trough the 3 principal solar panels and MagCon missions prove the efficiency of the detachable nanosatellites to work as orbiters.

### *3.2. Satellites Location*

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

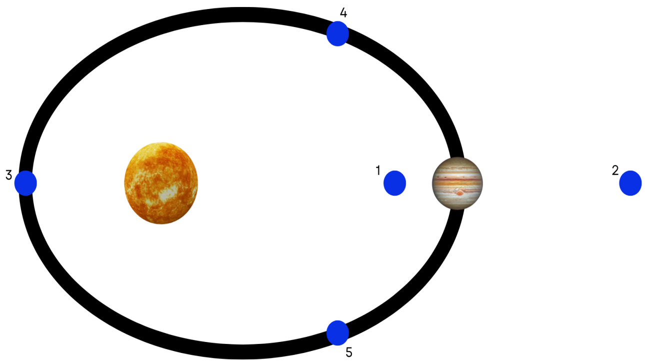


**Figure 2.** Nodes in Lagrangian Points.

### *3.3. Autonomy*

The autonomy of the satellite is essential to meet the objectives 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 that can be done 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 node 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 on the previous designs its possible to manipulate this data to offer new solutions in the localization of spacecraft environment. Comparing 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 into its results and taking no need to depend on radio frequency bands for it. Other sensor come in handy to help precise the parameters and conditions such as the accelerometers and optical spectrometers. A set of accelerometers will sense the gravitational field and its variations. Spectrometers will set parameters through NIR detections. All this factors can be helpful to take into account before searching for the most precise location comparing the sensed data with fingerprints of previous mappings calculations. Once the location is estimated, the satellite sends a signal to nodes set not so far away of the planet where it's established. This nodes are set orbiting in specific lagrangian points to facilitate and speed up the signal transmissions and help work out an interplanetary network with the same objective to communicate around the solar system.

Downsides might be the not so cheap instruments to use, or the fact that we need of high magnetic field interactions to get exact results. In 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 to expand the areas to work with thinking of different types of planets as Mars and Venus where magnetic field is weak, then spectrometer comes in to be main base of precise localization data.

Exploration to outer space is a very competitive area to work with, evolution and technology go hand in hand to achieve the best they can, new methods must be formed in order to not get behind. This proposal hopes to get closer to that revolutionary idea that could help facilitate missions into outer space.

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