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Article

The Interplanetary Internet for Observation and Monitoring of the Solar System †

Shalom Z. Carmona-Gallegos ‡, Christian E. Duran-Bonilla ‡, Karina Abboud ‡, Juan Misael Gongora-Torres ‡ and Cesar Vargas-Rosales *,‡

Tecnológico de Monterrey, School of Engineering and Sciences, Sacramento, CA 95831, USA; A01620374@tec.mx (S.Z.C.-G.); A01369955@tec.mx (C.E.D.B.); A01704136@tec.mx (K.A.); A005516153@tec.mx (J.M.G.-T.); cvargas@tec.mx (C.V.-R.)

* Correspondence: cvargas@tec.mx

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‡ These authors contributed equally to this work.

Abstract: The solar system is still uncommunicated and unknown for humankind. To acquire more knowledge about the solar system, we send satellites and rovers to explore those planets, however it is costly and takes a lot of effort. Soil retains information about the environment of celestial bodies, and we can process that information to make decisions about future infrastructure settlements that could provide advantages for the interplanetary Internet. The interplanetary internet communications must be scalable, interoperable, secure, and easy for data transmission. But before thinking about carrying out soil analysis through surface exploration, we can see that the first step is to analyze it using sensing satellites studying the structure of their data collection orbits through intelligent vision. In this paper we propose the use of cameras mounted on sensing satellites for the soil analysis during orbit (high-resolution, infrared, spectral, optical) for general scanning of surface elements with AI post- processing, and mass spectrometer for spectroscopy. This equipment will analyze the chemical composition of the surfaces, the magnetic field lines, the material radiation, detecting rocks and gas elements, and identify the surface characteristics, among others. In this paper, we discuss how to develop the architecture of an interplanetary internet physical platform with space-to-ground observations and measurements. A satellite orbiting a celestial body will become a sensor node with physical layers designed with relays and a modular setup, as well as a data transport method and location estimation sensing system, as a basis for the interplanetary Internet system. The design of the interplanetary Internet must consider the information from analysis and observation of celestial bodies variables and parameters, as a fundamental flow of information that must be transported through the network to be further analyzed and used.

Keywords: soil; interplanetary internet; Solar System Observation; mapping; navigation

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1. Introduction

The practice of collecting, analyzing and storing resources from other astronomical objects in order to seek for substitute materials in outer space is known as In Situ Resource Utilization (ISRU). ISRU is the posibility of setting bases in the future in other celestial bodies for humankind. Despite of the great range of opportunities that ISRU could bring us, it is necessary to start with the compositions of those materials withouth the need of landing on the surface. Throughout this paper we intend to give first a state of the art analysis to set in context the previous ideas and applications of similar ideas, then we'll write the methods used in the studies to later give a comparison and complement with a proposal to apply this technology on space.

1.1. Motivation

A planet slowly dying in the hands of men. Humankind keeps growing and increasing the need for resources that soon the Earth won't be able to provide. When exploring new potential sources becomes a need, technological innovations must come to aid. Investigation and recognition of new environments will be a hard work which will implement the different use of multiple satellites and rovers until the unknown becomes the known. We set a proposal to form a map that in the future could be used as a navigation system, where spacecraft's locations won't be a matter of pure late estimations.

1.2. Background

1.2.1. Case I

Being limited to the analysis of only visible physical properties, it is necessary to resort to characteristics such as color whose information can provide a deeper description of the soil profile. An analysis of 136 soil samples carried out by the University of Moscow was based on the colorimetry of images using a digital camera to define the perception of the captured image. A high resolution camera is necessary for topographic maps and photogrammetry, in addition an infrared camera have the purpose of provide information about soil's composition throughout spectral analysis of the light coming from the materials. The use of an optical camera is mainly related to infrared technology.

1.2.2. Case II

In 2021, the Institute of Earth Sciences of the Belgorod State National Research University in Russia conducted a research applying colorimetry to the detection of soil color coordinates, in order to evaluate the cultivable soil and its consequences on ancient structures, using analysis of variance, permutations and corrections in the sample data, being helpful in determining the complexity of the soil composition and deciphering photographic images relating color. Spectrometers allow to determine the elements beneath the surface. Through generating reflectance of certain wavelengths spectrophotometers help to identify mineral materials depending on spectral signatures. A recent archaeological analysis on the Crimean Peninsula, maps its land formations through multi-spectral satellite pictures. Pictures were taken by the CORONA series of satellites receiving panchromatic images from which measuring brightness, contrast and texture was the key to recognize boundary ramparts and obtaining coloring data. Results were given through laboratory previous spectrometric and colorimetric studies comparing the results with the implementation of deciphering images. The study carried out with success obtaining results of morphology of the land and chemical composition through the use of colorimetry and satellital image, therefore we intend to place this idea on a spatial context to map lands in other planets in order to help achieve a navigation system. All this is directly related to the classification of the different terrains according to their physical characteristics, allowing a mapping of the surface, which is possible thanks to the use of combined technologies such as cameras and the use of a spectroscope analyzing the luminosity of the materials, [1].

1.2.3. Case III

Agronomers in the need to know the nitrogen contents of the soil developed a system through multispectral imaging and AI. Information over nitrogen levels help them make decisions over how to treat crops in each area to bring major profits. They started the idea with satellital images of the land which was functional but costly. Then images were taken with drones and compared with an AI trained with machine learning to recognize the results of multispectral analysis done on ground level samples and apply them on images taken from the sky. Using the correlation of Nitrogen levels with chlorophyll meter measurements a computer is capable to determine on the multispectral images the percentage for each element. The data used from the aerial sensing was red, near infra-red, green spectral bands, vegetation indices, air temperature and humidity. For this kind of analysis many factors have to be taken into consideration such as: clouds interference, wind and humidity. This alterations can send images with low quality that won't give precise results with the machine learning. Applying this methods to the detection of elements in soils of another planet would allow to work with more information without taking hundreds of samples back to Earth, [2].

1.2.4. Case IV

After the launch of the Hubble Space Telescope (HST), it was discovered that star formation in faint galaxies had small and compact physically high redshifts. Since then, the near-infrared has been optimized with larger aperture to more accurately determine the photometric redshift by fitting the template spectra to broadband colors. The James Webb Space Telescope (JWST) employs a near-infrared spectrograph (NIRSpec) having a capacity of more than 100 simultaneous multi-objects in a field of view of several arcminutes, with the aim of improving studies in astronomical observations of celestial bodies, with greater possibilities of finding hidden exoplanets and solving other astronomical problems that were limited by the operating range. In this paper, the same technique will be used for the detection of celestial bodies, their composition and surface evaluation of materials, [3].

1.2.5. Case V

In surface exploration missions like rovers, antennas play an important role for ground control. Space exploration vehicles like Curiosity or Perseverance are equipped with three antennas, an ultra-high frequency (UHF) that is in charge to transmit data to earth trough independent orbiters, a high-gain antenna to transmit data directly to earth and low-gain antenna to receive data, [4].

2. Methods for Observation and Monitoring

2.1. Case I

Within the study at the University of Moscow, the digital camera used was a 21.1-megapixel Sony DSC-HX50 with an Exmor R CMOS sensor that improves the quality of images in low-light environments by working as a noise filter. An RGB color technique is used to map the surface according to the brightness of the object with the help of a spectrometer. A normalization standard is applied to subsequently convert the plane values in XYZ to RGB color coordinates in order to adjust them and make corrections for their categorization, also taking into account the calibration in the camera. Another use for the digital camera is to map the surface by altitude, depending on the change in distribution of materials, patterns and geometries, [5].

2.2. Case II

In the case of the analysis of land in the Crimean Península two types of spectrometer were used. The first, a wavelength-dispersion X-ray fluorescence spectrometer (Spectroscan Max-GV) which served to determine the chemical composition of soils. The coloring was described using the Munsell system. color measurements were taken in laboratory conditions using an AvaSpec-2048 optical spectrometer, a standard light source AvaLight-DHc, a bifurcation fiber optic cable, standard white WS-2 and a computer with AvaSoft8.10 installed. Each sample was measured three times to take the mean value of color coordinates. The data obtained was then processed in Rstudio programming, applying statistical methods to visualize analysis of variance and comparisons, [1].

2.3. Case III

A *Sentera* high-precision NDVI single sensor. The sensor used was 1.2 MP CMOS with a 60° horizontal FOV and a 47° vertical FOV that works with two spectral bands: red and NIR with a pixel count of 1248 horizontal/950 vertical. The sensor weights 30 g and was attached to an unmanned aerial vehicle such as the Mavic 2 Pro that was used for the study. 865 multiespectral images were analyzed and compared with 54 soil samples that were taken with a hydraulic probe. Then the spectrometer measures the intensity reflected through the material for each wavelength to search for the nitrogen concentration in each patch of land. A band separation for each spectrum (near-infrared, red and green) is realized and measured with colored pixels to obtain parameters to work with in machine learning. Once parameters are set, they are put through a neural network to optimize the processing of images. Errors were measured with RMSE (root-mean-square deviation) to machine learning methods multilayer perceptron regression and support vector regression, [2].

2.4. Case IV

The near-infrared spectrograph (NIRSpec) used by the James Webb Space Telescope (JWST) has an infrared wavelength range of 0.6 to 5.3 µm with three modes of spectral resolutions of R'100 for redshifts, R'1000 for measuring nebular emission lines and R'2700 for kinematic studies with emission lines. It contains 7 main components: front optics, filter wheel, slit plane, collimator optics, grating wheel, Era Optics cam and detector array. The light path arrives along the plane of the orthogonal dispersion optical bench, which is made of Silicon Carbide (SiC), maintaining the stability of the instrument in orbit due to its high thermal conductivity and very low thermal expansion. Its cooling is provided by passive refrigeration, with a radiator and an insulating layer to be light-tight. In conjunction with the above, a high fidelity software model has been developed that allows tracking the light path with an accuracy of a fraction of a pixel, while containing a data reduction and observation planning software. The task of the Pick-Off Mirrors and Foreoptics is to create an image of a demagnified section of the local sphere to ensure the best possible image quality, whereby the Foreoptics refocuses the image telecentrically which also makes the image scale in the slit plane insensitive to changes in viewing focus. The latter module contains an eight-position filter wheel with five long-pass order separation filters, two finite-band target acquisition filters and an eighth shutter position. Multi-object spectroscopy employs a Micro-Shutter Array (MSA) for multi-positioning of the light. It is a purely interesting concept, which can be realized on a smaller scale than in the original hardware, if the use of several panels used in the MSA is reduced, and only if only one alignment with a much smaller aperture is focused on, considerably reducing size, weight and cost, while retaining functionality, adapting to the needs of a medium range, [3].

2.5. Case V

For the communications, the three antennas system could be adapted on the satellite for the soil analysis. The ultra-high frequency antenna of 400 MHz could be in charge of the transmission of data to earth but just with the help of other orbiters around the celestial body under study. These orbiters could make an extension of the information route instead of use long-range telecommunications and depending completely to the antennas on earth. Also, using a steerable high-gain antenna of a radio frequency that goes from 7 o 8 GHz is an advantage in order to save energy by moving only the antenna in the direction to the earth position instead of changing the position of the whole satellite. Finally in the three antenna system there's a low-gain antenna of 7 to 8 GHz focused on the reception of signals, its main distinctive characteristic is that it is omni-directional so it does not need to be pointed at earth in order to establish communication with the satellite, [4].

3. Discussion

3.1. Satellite Structure

Based on the principles of the satellite architecture, the proposal is based on a satellite that compacts the 4 cameras, three antennas and the whole communications system and basic hardware components. Figures 1 and 3 show this. Among the main hardware components:

- RGB Digital Camera, and Photospectrometry Camera
- Multispectral Camera, and Infrared Camera
- Ultra-High Frequency and High/Low-Gain Antenna
- Communications Module (COM)
- Power Module and Propulsion Module (PROP)

- Altitude and Orbit Control Sytem (AOCS)
- Data-Handling System (DHS)

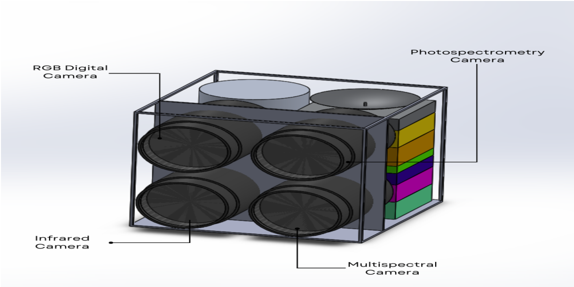

Figure 1. System camera deployment.

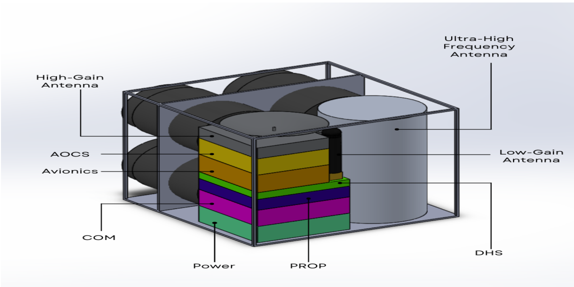

Figure 2. Deployment of satellite system.

3.2. Orbit Architecture

The objective of this proposal is merely strategic in the placement of this type of satellites for the monitoring of celestial bodies in the cosmos, primarily the sensors we propose would be sent to orbit in the low orbits where it is possible to measure the variables and determine the characteristics of the celestial bodies. We expect to receive interference due to unknown elements, and some inaccurate data. Thus, we propose to realize multiple measurements in the same patch for at least 1 week to get an average value for the color coordinates, elements found by spectrometers and environment factors. The more measurements the better.

3.3. Interplanetary Internet Node

The satellite structure, besides having the objective of analyzing and monitoring celestial bodies, is a node for the interplanetary internet structure. The production and putting into orbit of more than one of these satellites represents the possibility of building one of the pillars for communication in space without the need for a terrestrial base (NTN), as well as contributing to the acquisition of scientific data of interest for the future establishment of bases on other planets, [6].

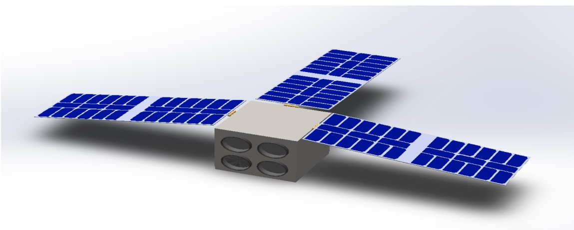

Figure 3. Satellite Model.

3.4. Expectations

The idea of detecting soils through images from another planet, would require of numerous previous studies of the soil to work on AI and machine learning tools to recognize the components. Its a process that would also take much power of image processing ans storage to keep track of the results in order to form a map and use similar results to speed up the process. Also taking into account that since environment conditions has factors we may know nothing about, pictures per patch of land to obtain a single color coordinate must increase to ensure the best estimations in case that storms or clouds could be interfering the camera certain days. Another problem would the fact that the best images will be obtained closer to the surface so satellites can only work aligned to the lower orbits for the method to show good results. In the other hand, position and angle of the satellite is crucial for the mission in plan. Cameras must get an accurate visual aid from the satellite infrastructure and position. The satellite establishing on a low orbit would travel at higher speeds which would complicate the taking picture process.

4. Conclusions

Our proposal turns out to be very feasible due to the cost-benefits involved in its development, production and construction as well as its implementation to monitor the cosmos, at the same time that it becomes one more node for an interplanetary internet infrastructure. Developing plans to map a celestial body can be very expensive and complicated. In this paper we propose a method to facilitate the exploration and detection of soils while mapping landforms and establishing coordinates for positioning new machinery. Instead of producing soil sample after soil sample and then dealing with the cost and effort of shipping it to Earth, our method of colorimetry and image processing would reduce the need for samples and maintain samples for larger land areas. With this proposal, launch costs are reduced, due to the compact size of the satellite, as well as landing missions on celestial bodies for analysis on their chemical composition. This method recognizes larger ground arrays with nanosatellites that are much lighter and cheaper to produce and work with. In addition, we know the importance of preserving the nature of the cosmos, being aware that the techniques used in this proposal do not represent a risk or do not involve damage to the study surface. A long work that will allow future missions to localize with much ease.

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