

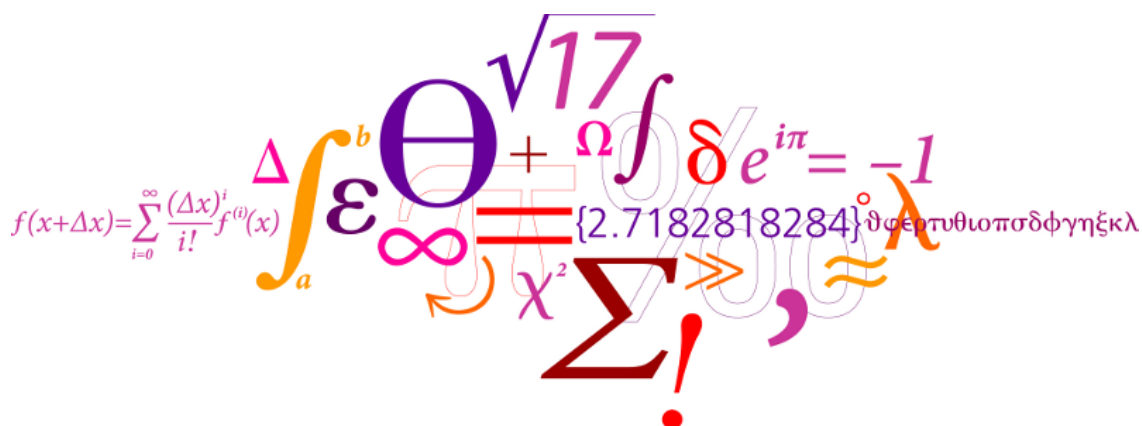
30330 IMAGE ANALYSIS WITH MICROCOMPUTER

PROJECT REPORT

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Introduction

Part 1

Problem formulation and delimitation

1.1 Problem formulation

In this report, we assume that we would like to send a rover on Mars, capable of communicating with Earth. Self-powered by solar panels, it will land at latitude 50° where it could get enough sunlight to recharge its lithium batteries. It is provided with an arm whose hand is replaced with a camera (see figure 1.1). The latter will be used by scientists to observe relevant rocks to study. In order to accomplish this mission, once a stone is designed, the camera must be able to keep it in focus, despite the wind, the movement of the robot or any other perturbation. This implies a real time image analysis to be able to rectify the position of the camera. As a robust method is needed to maintain the stone in front of the arm, the identification of patterns should be completed by carrying out a 3D map of the surface. A luminous source should then be added to the rover to be projected on the surface containing the rock and detected by the camera.

This luminous source must be powerful enough to outshine the sunlight during the day, notwithstanding that the energy needed to make it work has to be negligible compared to the amount provided to the rover. Moreover, the characteristics of the camera need to be perfectly adapted to Mars, as once the rover has landed on the red planet, it would be impossible to adjust it.

Will it be feasible to design such an embedded system, composed of a camera, a luminous source and algorithms, capable of keeping a rock in focus thanks to a 3D map, for an application on Mars soil?

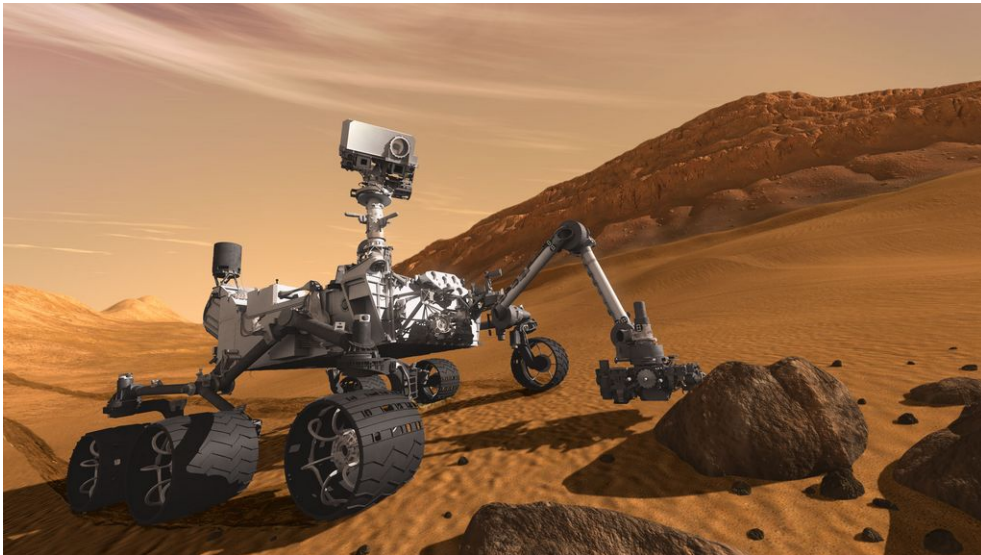


Figure 1.1: Curiosity Rover with an embedded camera on a arm [3]

Part 2

Theory Section

2.1 Scene Analysis

2.1.1 Albedo

Mars surface is covered by sand and volcanic rocks. The first purpose of this project is to allow scientists to examine these rocks through the camera. To achieve it, it is needed to know their characteristics, especially their albedo. As a reminder, the albedo is the fraction of incident light which is reflected from a surface. We can assume that the power reflection of Martian rocks is the same than on Earth. Then, to cover a wild range of rocks, the albedos of a black and of a white stone would be considered. Charcoal, as a dark rock, is a powerful absorber of the sun radiation, with an albedo around 0.05. On the contrary, chalks are poor absorbers and their albedo reach 0.45 according to [2]. In the following parts of the report, it will be taken for granted that Martian rocks have an albedo between 5 and 45%.

Part 3

Development

3.1 Mars Features

3.1.0.0.1 Irradiance

First of all, the irradiance F of the light from the sun falling at the top of the atmosphere of Mars can be calculated as following : Conservation of energy :

$$4\pi R_{\odot}^2 F_{\odot} = 4\pi R^2 F \quad (3.1)$$

with

$R_{\odot} = 6,956.10^8 \text{ m}$: solar radius

$F_{\odot} = 6,45.10^7 \text{ W.m}^{-2}$: energy flow of the surface of the sun

$R \in [2.06644, 2.49228].10^{11} \text{ m}$: distance Mars-Sun (Aphelion and Perihelion)

$$F = F_{\odot} \left(\frac{R_{\odot}}{R} \right)^2 \in [502, 730] \text{ W/m}^2 \quad (3.2)$$

In this report, we will consider that the rover is working on a specific date and we will chose the one when R corresponds to the semi-major axis. In this case $R = 2,27936.10^{11} \text{ km}$ and

$$F = 589 \text{ W/m}^2 \quad (3.3)$$

Moreover, we can assume that a part of the irradiance is absorbed by the atmosphere. Knowing that the atmosphere of Earth absorbs and scatters to space around 30% of the incident irradiance of the Sun[5], and knowing that the atmosphere of Mars is thinner than the one of the Earth, we will postulate that 10% of the incident irradiance is absorbed. Thus, using (3.3) the actual irradiance F_a of the light from

the sun falling on the surface of Mars is

$$F_a = \frac{90}{100} F = \frac{90 * 589}{100} = 530 \text{ W/m}^2 \quad (3.4)$$

However, this irradiance is the one of surface exposed perpendicular to the sun's beams. As Mars is a sphere, the projection need to be considered. Knowing that the weather is better into the northern hemisphere of Mars[4] and the fact that a latitude between 30 and 70 degrees is favored for a landing[1], we will assume that the rover has a latitude of 50° . This latitude corresponds to an angle of 40° between the surface of Mars and the sun's beams. Moreover, suppose that the rover stop working when this angle is inferior to 10° . Thus, the irradiance F_{50} at a latitude of 50° is

$$F_{50} = F_a \sin(\text{angleBeams}) \in [92, 341] \text{ W/m}^2 \quad (3.5)$$

with $\text{angleBeams} = [10, 90 - \text{latitude}] = [10, 40]^\circ$.

3.1.0.0.2 Target's Radiance

Considering the trajectory of the Sun into the sky of Mars and knowing that the rock target is more or less vertical to the surface of Mars, the angle θ between the target's normal and the sun's beam is considered to be included in $[10, 50]^\circ$. In addition, in the optimal case (when all the optimal conditions are provided to have the maximal radiance), the BRDF of the surface of the target is assumed to be 90% Lambertian and 10% Glossy while in the worst case the BRDF will be only Lambertian. In this way, the radiance of the target R_T is

$$R_T = \begin{cases} \frac{F_{50}\alpha}{\pi} \cos \theta & \text{optimal case} \\ F_{50}\alpha(\frac{9}{10\pi} \cos \theta + \frac{1}{10}) & \text{worst case} \end{cases} \quad (3.6)$$

with

$\alpha \in [0.05, 0.45]$, the albedo of the target??

$\theta \in [10, 50]^\circ$, the angle between the target's normal and the sun's beam

Thus,

$$R_T \in [92, 340] \text{ W/m}^2 \quad (3.7)$$

3.1.0.0.3 Target's Irradiance

Now, the irradiance of the target I_T can be calculated with

$$I_T = R_T \frac{\pi}{4} \left(\frac{Dsr}{EFL} \right)^2 \cos(\alpha_{CT})^4 \quad (3.8)$$

with

α_{CT} the angle between the normal of the target and the axis of the camera

Dsr the effective lens entrance aperture

EFL the focal length

However, knowing that the camera is supposed to be right in front of the target, we have

$$\alpha_{CT} = 0$$

And according to (3.7), ?? and ??, we have

$$I_T \in [0.0271, 1.1000] \text{ W/m}^2 \quad (3.9)$$

Finally, the luminous power from the target to the camera W_{lum} is

$$W_{lum} = I_T A_T \quad (3.10)$$

with

A_T , the area of the target

According to (3.9) and ??

$$W_{lum} \in [0.0027, 1.1000] \text{ W} \quad (3.11)$$

3.1.0.0.4 Signal/Noise Ratio

Three different cases will be studied. In the first one, we examine the case of a target illuminated by the sun without the use of laser, the second one considers the use of lasers by night and the last one, which is the case that we need to consider for

our rover, study the use of lasers by daylight. In order to calculate the Signal/Noise ratio, the different noises need to be determined. Three will be taken into account: the readout noise, the dark current noise and the noise from the sun light.

The three different cases have the readout and the dark current noise in common which are given by the datasheet of the CCD ??.

$$\delta_{readout} = 25 \text{ el} \quad (3.12)$$

$$\delta_{dark} = ?? \text{ el} \quad (3.13)$$

First case

In this case, the signal that needs to be considered is the sun light reflected by the target. Therefore, the readout and the dark current noises are the only two which need to be considered and the noise is

$$N = \sqrt{\delta_{readout}^2 + \delta_{dark}^2} = ????? \quad (3.14)$$

Then, the number of photons per shutter time N_p corresponding o the radiance of the target is

$$N_p = \frac{1}{\lambda_{max} - \lambda_{min}} \int_{\lambda_{min}}^{\lambda_{max}} \frac{W_{lum} ts}{\frac{h.c}{\lambda}} d\lambda \in [1.4112, 573.10].10^{37} \text{ photons} \quad (3.15)$$

with

$ts = s$, shutter time

$h = 6,6263.10^{-34} \text{ J.s}$, Planck's constant

$c = 3.10^8 \text{ m/s}$, velocity of light

$\lambda \in [400, 800] \text{ nm}$, wavelength of the sunlight

The number of photons to the lens N_{CCD} is

$$N_{CCD} = \frac{\pi \left(\frac{D_{st}}{2}\right)^2}{2\pi(r)^2} N_p \in [1.5920, 646.53].10^{30} \text{ photons} \quad (3.16)$$

with $r = 2 \text{ m}$, the distance between the camera and the target

the number of photons to the lens registered by the CCD Nen_{CCD} is

$$Nen_{CCD} = N_{CCD} \int_{\lambda_{min}}^{\lambda_{max}} CCDqe(\lambda).alphaLens(\lambda) d\lambda \in [???, ?????].10^{30} \text{ photons} \quad (3.17)$$

with

$CCDqe$, the quantum efficiency of the CCD??

$alphaLens$, the pass band efficiency of the lens??

Finally, according to (3.14) and (3.17) we obtain the Signal/Noise ratio

$$\frac{S}{N} = \frac{Nen_{CCD}}{N} = ??? \quad (3.18)$$

Bibliography

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