Levitation of Dust Particles in Lunar Environment Compared with Different Case Studies

[1] Zarana D. Gandhi, [2] Hiral P. chaudhary, [3] Nabila Shaikh
[1]Masters of engineering student, [2] Masters of engineering student, [3]Assistant professor
[1]Electronics and Communication,
[1] L.J Institute of Technology ,Ahmedabad, India

***Abstract*— Moon is natural satellite of the earth as well as closest object. Surface of the moon is charged due to several mechanisms and dust grains may be levitated from the surface. Particle-in-Cell method is used to simulate the various results presented in the paper. Different case studies are formed for study of various parameters like electric field, velocity, position of the dust. This paper explains how the different levitation parameters changes with the various case studies and on lander. Similar concepts can be applied to find the lunar landing site.**

Keywords: *landing; levitation; lunar; Particle-in-Cell; satellite*

I. Introduction

Surface of the moon is formed about 4.6 billion years ago [1]. Lunar surface topography is not plain and it is littered with craters and boulders. Craters on the moon are formed due to continuous bombardment of the meteorites and asteroids. The craters could be in the range of 1-100 kilometers of diameter. Some of the craters were formed due to volcanic action inside the moon [2]. Lunar surface is continuously exposed to solar UV rays and plasma. Due to this, the surface of the moon gets electrostatically charged. Dust particles on the lunar surface continuously get charged and repel each other. The charged dust grains levitate from the lunar surface up to several kilometers [3]. Dust clouds suspended above the lunar surface and first observed by the surveyor spacecraft and later by Apollo astronauts. The charged dust which levitates from the lunar surface can cause several problems like clogging of equipment, puncture of space suits, breathing problems of astronauts etc. [4]. In this paper, Particle-In-Cell (PIC) method is studied and code is developed for simulation of the several case studies which can be compared to lunar environment [5]. For all the case studies simulation is done for micron sized particles Levitation condition of the dust is given by following equation [4]

$$\boldsymbol{F_d} \geq \boldsymbol{F_g} + \boldsymbol{F_c} \quad (1)$$

Here, $\mathbf{F_d}$ is value of the electrostatic force on the dust grains, $\mathbf{F_g}$ is gravitational force and $\mathbf{F_c}$ is adhesive force between the surface and the dust grains. For the levitation of the dust grains force on the dust grains should exceed the gravitational force. The value of adhesive force $\mathbf{F_c}$ is very small so it can be ignored.

II. FORMATION AND APPROACH

Initially we assumed that particles are rested on the lunar surface. For simulation, we entered some number of particles in the environment or in created sample space. It may be considered as solar wind ions in for the lunar surface charging case.

A. Model of Lunar Surface and Charging

For formation of model, we inserted 100 particles at each time step. The particles are distributed as Maxwellian distribution. All the particles are levitated up to several hundreds of kilometers. The particles will go in upward direction up to certain length and then they will follow ballistic trajectory [3]. Value of the De-bye length can be given by the equation as following [6],

$$\lambda_D = \sqrt{\frac{\epsilon_0 \, k_B T}{e^2 n_0}} \quad (2)$$

Here, ε_0 is permittivity of the free space, 8.85×10^{-12}, $k_B T$ is product of Boltzmann's constant and plasma electron temperature, e is charge of electron and n_o is ambient plasma density. For simulation parameter, values are taken from the lunar prospector data which is given in following table [3]

TABLE I: Parameter and values for simulation [3]

Parameters	Value
Lunar gravity	1.62 m s^{-2}
Dust grain mass density	1.6 gm/cm^{-3}
Surface potential	+4.1 V
Plasma electron temperature	12.064 eV

Different case studies are developed in this paper to express the charging of the lunar surface and to justify how the topography of the lunar surface affects to the levitation of the dust.

B. Dust Levitation Modeling

(a) Case Study 1: Plain surface without any object:

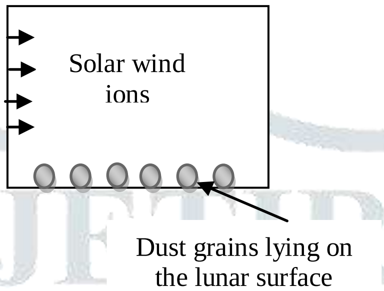

Fig.1: Basic model of lunar surface charging

The basic ideal model without any object on the surface is shown in Figure 1. Here, the sources of particles are inserted from the left side which may be compared with solar wind plasma and UV light. Due to the solar wind ions and plasma condition, one side of the lunar surface is positively charged and other side is negatively charged. Charging of the lunar dust may levitate up to several kilometers.

Initially, the dust particles are lying on the lunar surface and we are entering electrons in the model through solar wind ions. The density of lunar dust particles in this region is 1.6 gm/cm^3. Moreover the potential of the surface is +4.1 V and it is updated by user with every time step. Simulation is done for total 1000 iterations and finally the value of potential is obtained through Poisson's equation. Value of the electric field is gradient of potential. The velocity of the dust particles is obtained from the Equation of leap frog method [5]

$$\boldsymbol{v} = \boldsymbol{v_0} + \boldsymbol{at} \quad (3)$$

Here v is the final value of velocity which updated at each time step, v_0 is initial velocity of dust grains. Here **a** is acceleration which is obtained through

$$\boldsymbol{a} = \boldsymbol{F}/m \quad (4)$$

Here m is mass of the dust particles which can be calculated by following equation:

$$m = V \times \rho \quad (5)$$

where, V is volume of dust particle and ρ is density of dust grains. If we assume that particles are of spherical shape then we can take volume as $4/3\pi r_d^3$, where r_d is radius of dust particles which is in range of nanometers to micrometers. In equation (4) **F** is the electrostatic force experienced on the dust particles. Force $\mathbf{F_d}$ is given by following equation [4]

$$\boldsymbol{F_d} = q\boldsymbol{E} \quad (6)$$

Here q is the charge of electron which is 1.6×10^{-19}.

(b) Case study 2: Surface with strip object:

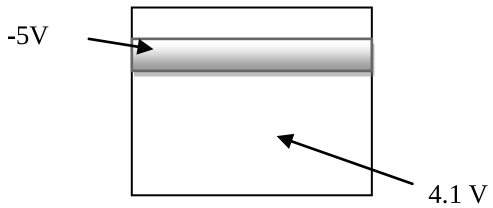

Fig.2: Model for surface with a strip type object

(c) Case study 3: Surface with circular crater:

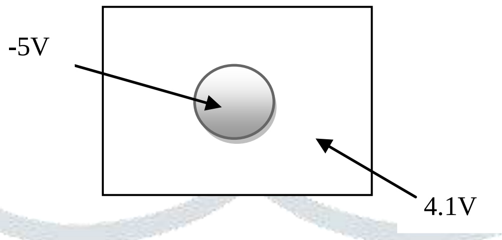

Fig 3: Model for surface with circular crater

As shown in Figure (2) and Figure (3) two case studies with different objects on the surface is created to identify the changes in the result compared with the blank surface. The problem can be compared with the lunar surface which has 4.1V potential and craters or boulders on it. The parameters which are taken for these two models are same as the model 1 plain surface.

III. RESULTS AND DISCUSSIONS

This section explains simulation results for above models. Simulation is done based on the particle-in-cell method. The parameters and values used for the simulation are given in table I.

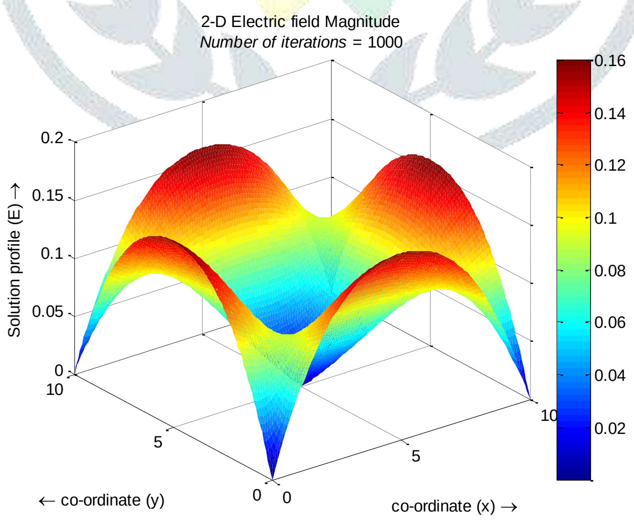

Fig 4: Magnitude of electric field for plain surface

Electric field is gradient of potential. So, magnitude of the field is calculated from the slope of the value of potential. But due to negative sign in the Poisson's equation the direction of the field will downward.

For case study 2, strip object it can considered as shadowed region. In this portion there is absence of the sunlight so the potential is negative. Here we assumed that it is charged with -5 V potential and rest of the surface is charged with +4.1 V potential. Velocity and positions for these two models is simulated using equation (3).

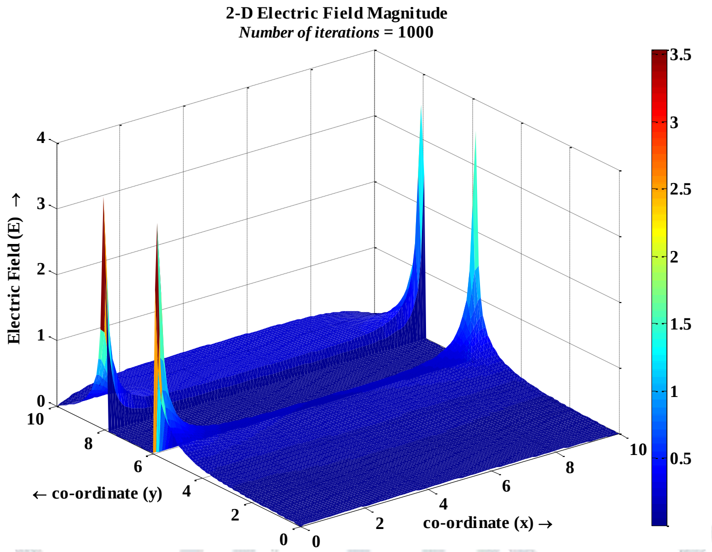

Fig.5: Magnitude of electric field for strip object

For case study 3, circular crater on the surface it can considered as shadowed region. In this portion there is absence of the sunlight so the potential is negative. Here we assumed that it has -5 V potential and rest of the surface has +4.1 V potential. Velocity and positions for these two models is simulated using equation (3).

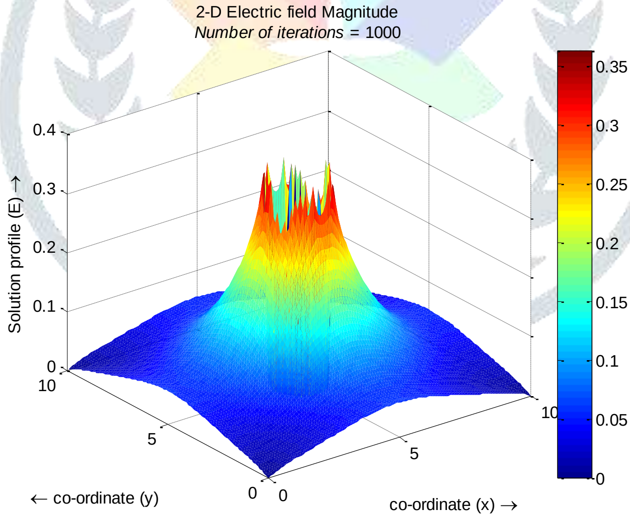

Fig.6: Magnitude of electric field for circular crater

TABLE II: Velocity and levitation height for different cases

No.	Type of 2-D Case Study Model	Velocity of Dust Grains (km/s)	Levitation Height of Dust Grains (km)
1	Plain Surface	0.19	1.2
2	Surface with strip object	1.23	1.57
3	Surface with circular crater	1.25	1.61

Here our goal is to find the electric field which can affect the lunar landing site and to observe the behavior of different case studies. At boundary of surfaces and at the object, we get zero electric field due to the constant value and gradient of the constant value is zero. At the border of objects we get complex electric field.

IV. SUMMARY AND CONCLUSION

From the simulation results of above three cases we can say that plain surface has fewer particles levitated and it increases as the craters on the surface increases.

For the strip object, it behave like a shadow of some boulder on surface and therefore negative potential is taken in that portion and other surface is charged positively. Due to this we get complex electric field at edges and dust particles in that region may be levitated more. Velocity and levitation height of particles in other cases are more than plain surface as given in Table II.

For circular crater we get the approximately same result as the strip object but at the edges of crater complex electric field is developed. Velocity and height up to which particles are lifted is more than above cases.

Craters could be in range of 1-100 km and due to shadowed region of crater negative charge is produced in that region. As the number of craters increases on the surface or topography becomes uneven, the particles in that region will have more velocity and levitates more. We can also say that the topography of the surface affects the lunar surface parameters like potential, electric field, force, velocity and position of particles and overall it will affect the landing of instrument. More sophisticated dust charging models with different elevation angles will needed to be developed in future studies and to understand the dust charging characteristics in the surface topography by referring [7,8].

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