Subsurface investigation and interaction by self-burying bio-inspired probes

Type of activity: Standard study

1 Background and Study Motivation

A thick layer of dust covers the surface of the terrestrial planets of the Solar Systems, of moons, and some asteroids, hiding the ground underneath and its mysteries. This regolith has been formed over billions of years by the impact of large and small meteoroids breaking down surface rocks. On Moon, nearly the entire surface is covered with regolith, bedrock being exposed only on very steep-sided crater walls and the occasional lava channel, and also on Mars, regolith covers vast expanses of surface. When in December 2007, the rover Spirit's dead wheel scraped off the upper layer of the Martian soil, it uncovered a patch of ground that thrilled scientists, showing evidence of a past environment that would have been perfect for microbial life.

Growing interest in extraterrestrial subsurface prompts an examination of advanced technologies for its exploration to obtain geophysical data. One of the major limitations of sampling in relatively low gravity environments (such as asteroids, moons, comets and small planets) is the need for high axial force when using conventional drills.

The self-burial strategies of some seeds (such as the *Erodium cicutarium*) address this limitation by applying a motion that requires no additional steady coupling with the surface.

Providing probes and sensors with this unconventional behaviour would facilitate the exploration of the surface underneath regolith, as well as of asteroids, especially rubble-piles.

Such sensors could self-bury to give information related to the geology of the soil or to the temperature or simply dig themselves to find shelter from the space environment. Chemo-sensors could be spread on selected areas of interest and used as a sensor web, for long term monitoring of specific targets of the environment. A large number of antennas could be used to form a sensor mesh for the autonomous navigation of rovers. They could also find other applications such as anchoring (on asteroids or other small bodies).

The aim of the study is to provide concrete basis for the biomimetic transfer of the self-burial strategy of the *Erodium cicutarium*, addressing some important question related to its digging strategy.

1.1 The seed

Erodium cicutarium L. plants are characterized by explosive dispersal, in the sense that seeds are discharged by the rupture of the fruit, produced by the elastic contraction of its tissues. The distance reached by seeds is usually quite short compared with the distance reached by other means (Bullock and Primack, 1977; Willson, 1993). For this reason, this explosive dispersal is coupled with the additional strategy of the self-planting that increases the chances of success (Westoby and Rice, 1981; Andersen, 1988; Stamp and Lucas, 1990). Each fruit consists of five seeds joined together and forming a spine like structure. As the fruits dry, they increase their tension, and stresses developed in the structure cause them to separate abruptly and fly the spinning seeds up to half-a-meter away (Stamp 1989).

Each seed is equipped with a special dispersal unit (botanically called “awn”) that give the seed the ability of self-burial. This is possible thanks to movements achieved by changes of external humidity (Stamp 1984). The long awn has two preferred shapes: the dry awn is helical while the wet one is linear. Once on the ground the humidity changes cause the awns to unwind straight when wet, and rewind back to their helical shape when dry. The resulting motor action, combined with hairs on the seed and along the length of the awn, moves the seed across the surface, eventually lodging it into crevice and causing it to bury itself into the ground.

Each seed is equipped with 4 main structures: (1) the twisting awn, (2) long hairs along the awn, that are perpendicular to the awn when wet, and parallel to it when dry, (3) short stiff spines on the seeds (barbs) and (4) a sharp tip. In the ’80 some experiments were done to provide information on the role of each of the listed structures for the efficiency of the self-bury but the explosive launch was not taken into account (Stamp 1984). Also the impact of the soil textures was assessed, but tested substrates were characterized by very coarse textures that are very far to be comparable with regolith or asteroid composition. Anyway, the aforementioned results shed light on some very important aspects of this feature and should be considered in the study.

Fig. 1: The seeds of Erodium cicutarium.
Photo courtesy of Steve Hurst @ USDA-NRCS PLANTS Database

2 Study Objective

The objective of this study is to evaluate the performance of self-planting seeds (in particular of the *Erodium cicutarium)* as subsurface penetrators for different soil textures, understanding the role of the launch phase as well as of the above mentioned four main structures. The final goal is to lay the bases for the biomimetic transfer of the self-burial strategy for applications to space exploration needs.

3 Proposed Methodology

Two main research themes form the study.

The first is more experimental and includes a full characterization of the single components of the self-burial strategy; the following questions will be addressed:

1. How does the self-burial performance vary among soil textures that are of space relevance (i.e. finely structured)? Stamp, N. E. 1984 did this test, but the soil particles he considered were even bigger than the seeds.

2. How do the seed accessory structures affect seed burial performance?
3. Is the initial launch mechanism and resultant landing important for the self-burial performance?

The results shall then serve for the second part of the study, which will be performed concurrently and mainly by the ACT, based on the results of the experimental part. The following questions will be addressed:

1. Which are the key parameters that characterize the performance?
2. How do gravity and substrate affect the performance of the strategy?
3. Evaluation of the scalability of such strategy for the future biomimetic transfer

In addition, the proposing research team / University is encouraged to propose a computer model of the seed behaviour including all the relevant parameters that characterize the performance. The model should be validated with additional experiments and final consideration on the feasibility and scalability of the biomimetic transfer should be done.

3.1 Quantification of the self-burial performance of the biological level:

The experimental part will be performed mainly by the proposing research team / University. It aims at getting a deeper insight into the strategies of the model seed. In order to do so, the seed will be confronted with different experimental situations where they have to dig themselves. By changing soil texture and seed accessory structures, the properties of the strategy in question will be assessed.

The seeds should face at least these situations:

- Different substrate textures, ranging from clay (grain size less then 2 μm) to coarse sand (up to 1 mm), plus three mixtures simulating the granulometry of Martian and Lunar regolith and a more coarse mixture simulating the 'rubble piles' type of asteroids (loose collections of 'pieces', held together by the force of their gravity).
- Seed alterations (shortening the awn, the lateral hairs, removing the spines, smoothing the sharp tip) to determine the contribution of seed accessory structure in the strategy.
- The importance of the launch in the self-burial strategy: the trajectory of the launch, the initial launch speed, the terminal velocity, the initial and terminal angular velocity and the way the seed impacts the ground (i.e. speed and angle of contact) should be determined. The use of a high speed recording camera is strongly recommended to assess the contribution of the launch to the digging strategy.

In the proposal, applicants are asked to describe how they plan to perform the experiments; the techniques and equipments used; substrate tested; availability of plants and seeds; timeline of the planned experiments.

3.2 Evaluation of the self-burial performance as a basis for a biomimetic transfer:

The second part will be mainly done by the ACT in close collaboration with the university, and will consist of:

- Analysis of the results and quantification of the self-burial behaviour;
- Selection of the key parameters that contribute to the performance in view of the modelling;

- Study of the mechanical properties of the seed and its structures;
- Quantification of the contribution of the mass of the seed and consequently of gravity to the strategy;
- Evaluation of how the efficiency changes depending on the depth of penetration.

In this phase some additional experiments might become necessary and universities will be asked to perform them in order to give a description of the strategy as complete as possible.
This study is mainly addressed to research laboratories in the fields of plant biology, botany or ecology.

4 ACT Contributions

The project will be conducted in close scientific collaboration with ACT-researchers who will work together with the university in the evaluation of the performance and definition of the key parameters. ACT-researchers will also provide expertise in the characterization of the physical processes, in the modelling and in space related issues. Based on the outcome of the study, the team will also evaluate and propose material and structures that could be used to successfully mimic the self-burying strategy of the seed in order to conclude the biomimetic process of the study.

5 Bibliography

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