# *LAMAlice* : A nanorover for planetary exploration

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## ABSTRACT

**Over the last years considerable efforts in miniaturisation have been made in autonomous robotics, especially in the domain of space missions in order to reduce costs and increase chances of success if using several robots. This has led us to imagine and realise a prototype of a nanorover which shows an example of what planetary exploration could look like in the future.**

**The robot is a four-wheel drive rover which is composed of two separate parts linked together with a flexible passive coupling (figure 1). This configuration allows a "push-pull" effect improving the overcoming of an obstacle and offers good gripping. The wheels are made of flexible blades radially fixed on the axis. On the one hand this permits the wheels to be rolled up for transport, on the other hand a smooth movement of the gravity centre is reached, which increases power efficiency of the obstacle overcome. The robot also presents a simple structure and it is possible to equip it with a passive sensor like a very low-power camera as well as with active sensors.**

**The power consumption is less than 50 mW which allows an operating time of roughly 20 hours with on-board batteries. *LAMAlice* is 11 cm long, 6 cm wide and 4 cm high and has a weight of 30 grams. The maximum speed is 1 cm/s and it overcomes steps of its own height.**

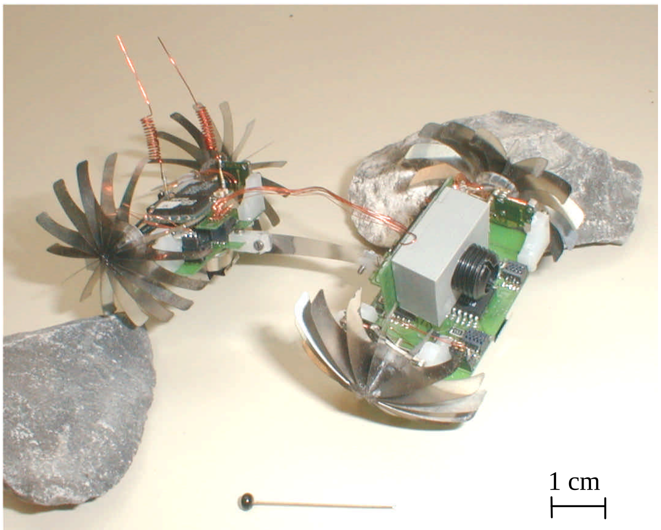



Figure 1: Nanorover *LAMAlice*

## 1. INTRODUCTION

Since more than one quarter century scientists and engineers occupied themselves with the design and improvement of robots used for planetary exploration. As space mission costs are extremely bound to the weight and volume of the payload, particular efforts have been made in miniaturisation [1], [6], [8]. This miniaturisation has taken advantage of recent developments in micro-technology and mobile robotics, and it is now possible to build tiny mobile robots, so called nanorovers, measuring only few centimetres and weighing less than a hundred grams.

Planetary exploration mainly consists in measuring chemical and physical data, classifying minerals, gathering of samples, searching for ice or microfossils on the surface. To achieve this, the robot has to be able to move around on the planetary surface which is not an easy task for the following reasons :
First, the environment contains plenty of obstacles which must either be avoided or overcome. The ability of moving straight until meeting an insurmountable obstacle is expressed by the mean free path, which depends on the dimension of the surrounding obstacles, their distribution, the robot's dimensions and its capability of overcoming obstacles [5]. Second, energy consumption for locomotion as well as for sensing, control, actuating and communication, has to be minimal, because of the very limited quantity of energy being able to be stored, carried or produced on the robot.
Finally, sensing and computing become difficult in these dimensions, therefore passive overcoming of obstacles is preferred.

Reliability is fundamental in space missions because of the impossibility of human intervention on the spot. Given the possibility of deploying several robots simultaneously, nanorovers increase the success rate of a mission because it is not terminated by the failure of one among them. It is conceivable to have many of these nanorovers cooperate and/or assist other robots by tracking them and so create a network of robots with a limited global control system. Moreover, nanorovers represent an almost negligible payload compared to the payloads planned for the Mars-missions of the next years and could be embarked as a secondary payload using whatever mass margin is left over at launch time.

It is also possible to use nanorovers as primary payload of a space probe for the exploration of Mars, the moons of gas giant planets, asteroids etc.
The development of a nanorover can take only a few months, much less than for a traditional rover. This permits to save development costs and space missions could be established in a shorter time.

At this point we want to briefly discuss some interesting examples of nanorovers. In the year 2001, the Japanese will send a spacecraft to an asteroid. On board, the MUSES-CN nanorover from JPL [1], will be the smallest rover ever used in a space mission. It is 20 cm long, weighs 1 kg and has a four-wheel drive articulated chassis, driven by small gear motors. Another nanorover, "Solette" [7], has been developed at the MIT Artificial Intelligence Laboratory. It has a mass of 30 g and is completely autonomous with its solar power system. Nevertheless, off-road behaviour is very limited.

In dimensions inferior to the MUSES-CN nanorover, off-road characteristics are difficult to maintain. It is a challenge to develop a passive locomotion system that keeps a high obstacle overcoming capacity in spite of reduced dimensions.

## 2. Description of the system

Our goal was the conception of a nanorover for Mars-exploration. The considerations made above have given us the main criteria to be respected :

- Very small dimensions (around 1 $dm^3$) and weight (less than 100 g)
- Simple and reliable design
- Passive overcoming of obstacles and adaptation to the terrain
- Extremely low power consumption allowing a high energy autonomy

The development of *LAMAlice* was inspired of Alice [2], a tiny robot also developed at EPFL. Its dimensions are of only 23mm x 21mm x 16mm for a weight of 6 g and a power consumption of less than 10 mW. However, Alice, in its actual version, is not suited to move on uneven grounds.

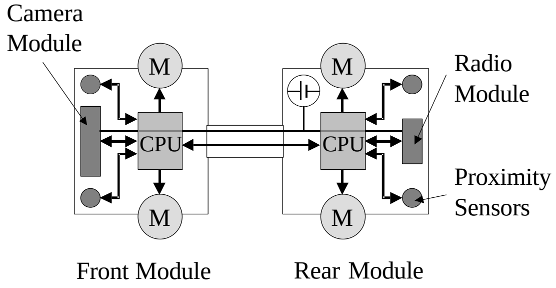



Figure 2: Bloc-scheme of *LAMAlice*

A total amount of roughly 600 hours was invested to realise a first prototype of the off-road nanorover: *LAMAlice* (figure 1 and figure 2).

*LAMAlice* is 11 cm long, 6 cm wide and 4 cm high, has a weight of about 30 grams and is powered by three button-batteries of 1.55 V (silver oxide) each.

### 2.1 Mechanical concept

*LAMAlice* is composed of two modules with two motorised wheels each. The modules are linked together with a passive coupling permitting torsion as well as horizontal flexion but avoiding vertical one. This configuration is advantageous as regards the adherence on the ground, due to the non hyper-static contact with the terrain. Another characteristic of such a system is the possibility of bending in place allowing almost a turning on the spot and so reducing the turning circle diameter to the minimum. During the surmounting of an obstacle the robot benefits from a "push-pull" effect :
first, the rear module helps the front module by pushing it, then, once the latter is on top of the obstacle, it helps by pulling the rear module up. The behaviour described above is strongly dependent on the type of the coupling. A simple solution is the use of a flexible blade as shown in figure 3.

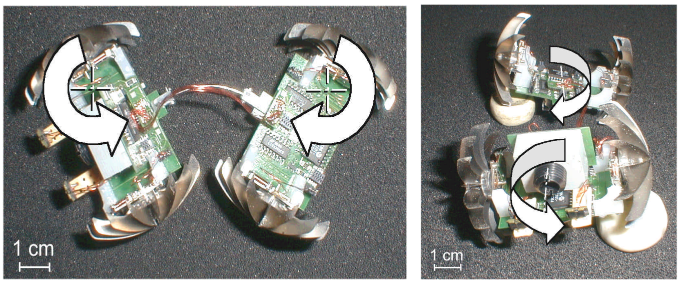



Figure 3: Horizontal flexion and torsion

Finally, the modularity of such a system permits to assemble more than two modules together and thus to realise a snake-like robot. It is evident that in such a case vertical flexion of the coupling is needed. By increasing the number of modules, the robot might be able to overcome higher obstacles, again benefiting from the "push-pull" effect. The number of modules used can be adjusted for specific environments. Furthermore, each module can execute individual tasks and carry out different measurements.

### 2.2 Wheels

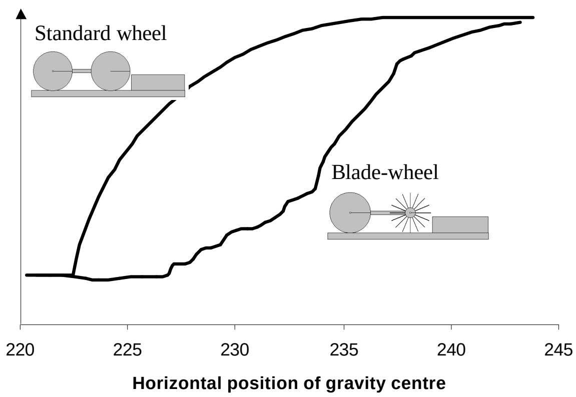
Space environments, presenting strong radiation and big temperature differences, impose severe constraints on the choice of materials. This is the main reason that tyres, commonly used on earth, are hardly suitable for space applications.

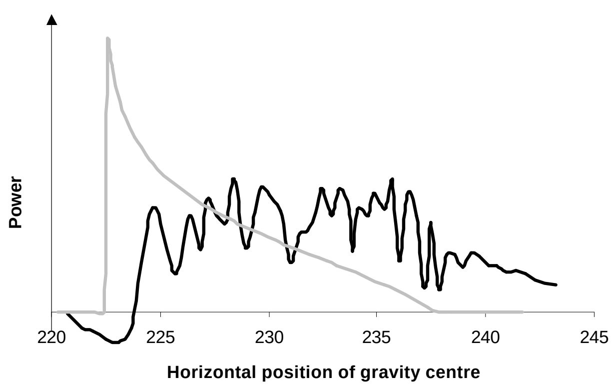
On our robot we introduced a novel concept, consisting in the use of wheels made of flexible stainless steel blades (figure 6). In comparison to a traditional wheel, this system has numerous advantages :

It has a low mass and presents a certain deformation possibility that increases adherence and thus improves terrain adaptation.

As a biologic inspiration, one may imagine a blade wheel as a multitude of arms and legs. Over a flat terrain this wheel has a walking behaviour and against obstacles it is a kind of climbing.

The elasticity provided by the blades can significantly enhance the overcoming of high obstacles and also offers better capability of surmounting overhanging obstacles than a traditional wheel. Additionally, the flexion of the blades adds a damping effect and also causes a smoother surmounting of the obstacle. Figures 4 and 5 show a simulation calculated with *Working Model®2D*. Two two-wheel-drive vehicles roll at constant speed towards a step. The first of them has standard wheels, the second a standard wheel at rear and a blade-wheel in front. Four rigid segments linked together by a rotational spring model a blade. Weight, wheel diameter and speed of both vehicles are identical. Figure 4 displays the position of gravity centre during the front wheel step overcome and figure 5 the matching total power consumption.




Figures 4 and 5: Step-overcoming : Standard wheel vs blade-wheel

We notice a smoother progression for the blade vehicle even if there are some oscillations which also appear in the power graph. The negative consumption at the beginning is the result of the polygon-shape of the blade-wheel on flat terrain. Compared to a standard wheel, the maximum power consumption is approximately reduced to the half. This is particularly important in the case of a power limited system (motor torque and supply current).

Another advantage of blade-wheels is that they can be folded for transportation of the robot and thus its volume can be even more reduced (figure 6).

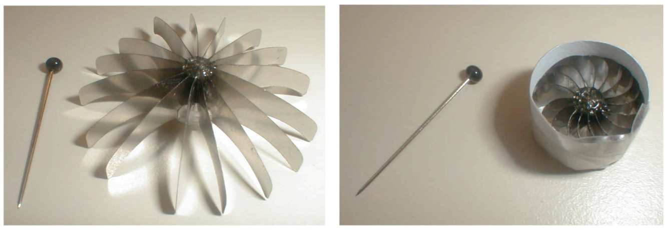


Figure 6: Opened and folded configuration of the blade-wheel

For the design of the blade-wheel, one has to consider the mass of the robot, the type of environment, the required stability and robustness. With an adapted shape of the blades the risk of flipping over can be reduced effectively. The number of blades fixed on the wheel depends on the terrain : The bigger the mean obstacle height (taking in account only obstacles smaller than the wheel diameter), the smaller the number of blades should be and vice versa. This is because a wheel with a high number of blades tends towards the behaviour of a traditional wheel, having good performance on flat ground (little sinking and reduced driving resistance). In the other case a low number of blades presents a better obstacle contact.

*LAMAlice*'s wheels, only weighing 0.9 g for a diameter of 4 cm, are equipped with 16 stainless steel blades having a thickness of 50 µm.

The motors used on *LAMAlice* are swatch® watch-motors. They present very low power consumption (less than 10 mW) for a maximum torque of about 3 mNm at 3 rpm. The motor's weight is 1 g and its design allows a simple mounting onto the chassis.

### 2.3 Sensors

In order to permit autonomy of navigation and data gathering, it is necessary to equip the robot with sensors. Given the strongly restricted amount of available power for space applications, it is advantageous to use passive sensors. An example of a very low power sensor is the CMOS-camera (APS256D from the CSEM [3], [4]) mounted on the front

module, which has a power consumption of only a few milliwatts. The optics were chosen to have an opening angle of 50° and permit a focussed image for distances over 4 centimetres.
Four SIEMENS SFH 900 IR-proximity sensors, two on each module, were used for obstacle detection. Their range is of a few millimetres (at low power consumption), which is sufficient given the low speed of the rover.

### 2.4 Control and communication

Each module has a simple microcontroller (PIC16F84) permitting basic navigation, like detecting and avoiding obstacles as well as communication with a control unit. This communication consists in data transmission and command reception and is done by a radio transceiver.
The four motors being individually controlled, provide maximum liberty of action. Since the coupling between the two modules of the robot is passive, a differential drive of the motors will indirectly determine the bending of the coupling blade.
The navigation algorithm is limited by the processing capability and the sensors and allows a certain autonomous behaviour such as obstacle avoidance. To enhance the navigation abilities, radio communication permits assistance from the control unit which could be the lander.

## 3. Characteristics and Results

One might believe that a larger vehicle will always be able to surmount bigger obstacles than a smaller one, and so it is natural to believe that a larger vehicle is always better than a smaller one. However, for the rock distributions observed on Viking landing sites on Mars, this is not the case, since a smaller vehicle can fit between obstacles which a larger vehicle would have to overcome.

To check if our miniaturisation efforts for *LAMAlice* are justified we computed the mean free path (MFP) relative to the vehicle's turning circle diameter, using the calculation described in [5]. The results are shown in table 1 :

| | Sojourner | *LAMAlice* |
|---|---|---|
| MFP of Viking landing site 1 | 9.6 | 15.1 |
| MFP of Viking landing site 2 | 2 | 6.6 |
| Mass of the robot [kg] | 11.5 | 0.03 |
| Volume of the folded robot [$dm^3$] | ~45 | ~0.2 |

Table 1: Mean free path of Sojourner and *LAMAlice*

We notice that in comparison to Sojourner, *LAMAlice* is able to move further, relative to its turning circle diameter and therefore relative to its dimensions. Another interesting point is the fact that we could have packed more than 200 *LAMAlice* nanorovers instead of Sojourner in the Pathfinder lander !

A table with the main characteristics of *LAMAlice* is given below :

| | |
|---|---|
| Dimensions [cm] | 11x6x4 |
| Front module weight [g] | 15 |
| Rear module weight [g] | 14 |
| Power consumption [mW] | ~40 |
| Autonomy [h] | ~20 |
| Maximum speed [cm/s] | 1 |
| Minimal Turning Circle Diameter [cm] | 15 |
| Maximum obstacle height [cm] | 4 |
| Maximum slope [°] | 37 |

Table 2: Main characteristics of *LAMAlice*

## 4. Future developments

Different improvements are presently under development and test phase. These concern essentially the coupling between the two modules as well as the blade-wheels :

With the current blade coupling, it is difficult to determine the relative positions of the modules and also to limit the horizontal flexion to a maximum value. A more sophisticated possibility solving these problems is represented in figure 7.

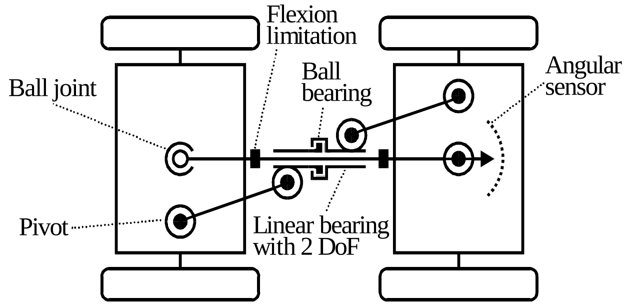



Figure 7 : Cinematic scheme of improved coupling

The blades provide excellent gripping, but there is an increased risk of sinking into the ground and therefore we have thought of another system (figure 8), which is supposed to keep the advantages of the current solution and additionally enhance soft ground performance.

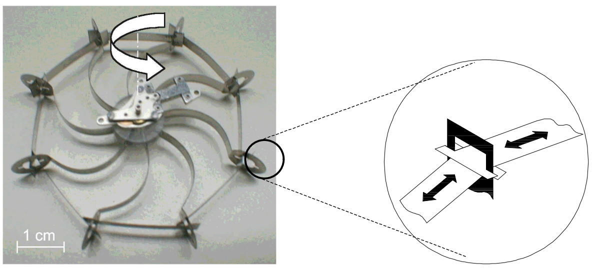



Figure 8: Alternative wheel design

## 5. CONCLUSIONS

We have seen the growing importance of nanorovers in space applications with their severe limitations concerning dimension and weight. In this paper, we have presented a simple two-module structure (upgradeable to even more modules) offering advantageous off-road characteristics. A novel concept was also the use of flexible blade-wheels providing high obstacle overcoming with torque limited low power systems. An interesting feature is the substantial volume reduction achieved by folding these wheels for transportation.

The work presented here is a step towards a new, simple and passive locomotion concept, which might be interesting for planetary exploration. Future work will have to confirm the performance of this concept.

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