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# Simulation of an on-the-fly measuring system of a descent module under uncertainty of the lunar-surface composition

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**Abstract**

The measurement method for determining the motion parameters of the module de-orbiting upon the lunar surface has been suggested. The surface-scattered gammas emitted by a radioactive source are detected using four receptors under uncertainty of the lunar soil's elemental composition. The radar-tracking system in the module allows adapting the gamma-ray altimeter to the lunar-soil composition. A mathematical model of the measuring system has been put forward, and dependences of the gamma flux level on the module altitude and the angle of the slanted surface were obtained. The model makes it possible to analyze the relative position of the radioactive source and the receptors and the composition effect of the substrate. The measurement algorithm uses a recursive neural network, which is proposed to be trained in advance and adapted during the module landing.



*Keywords:* Descent module; Scattered gamma radiation; Adaptation; Lunar-soil composition.

## Introduction

Precise control actions are required on soft-landing engines for successfully landing a descent module on the lunar surface. For this purpose, the parameters of the descent module such as its speed, its height above the surface and the angle of inclination of the underlying surface have to be measured with the highest accuracy.

The altitude above the surface is measured by means of electromagnetic radiation of various types and frequencies. This includes laser, radio wave, infrared, gamma-ray and X-ray radiation; photo and video cameras are used [1,2].

Laser systems are employed, for example, in the BepiColombo joint mission of the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) to Mercury, in the NASA program for mapping the surfaces of the Moon and Mercury, in sampling soils from the surface of Phobos (a satellite of Mars) and delivering them to Earth.

The Opportunity Mars Rover, designed by NASA to explore the surface of Mars, was landed with the help of a radar-tracking system that carried out altitude measurements up to one and a half meters, after which a signal was sent to the DIMES (Descent Image

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Motion Estimation Subsystem) camera for determining the horizontal velocity.

It was planned to measure the heights of the Phobos 1 and Phobos 2 unmanned spacecraft via an X-ray altimeter with a vertical stabilization control system that operated in the nanosecond wavelength range. The angular coordinates were measured by the time-pulse method by the difference in the reception times of the signals by two pairs of detectors spaced apart. However, both missions to explore the satellite of Mars have been unsuccessful.

Despite the fact that all of the above-mentioned devices based on different physical principles have been actively used in aerospace engineering, there are some factors hindering accurate measurements of the landing parameters.

First, due to sharp focusing of laser radiation, surface roughness can lead to significant measurement errors.

Second, one factor limiting the use of radio altimeters is that electromagnetic waves cannot propagate through the plasma of working soft-landing engines; an increase in measurement errors with decreasing altitude is another.

Third, dust rises over the lunar surface as the jet engines operate, and this limits the use of systems sensitive to the transparency of the environment.

Fourth, the use of X-ray altimeters is limited by the need to cool the X-ray tube anode, since most of the kinetic electron energy is converted to heat and considerable energy is required for cooling.

Russian and foreign studies contain data indicating that integrated systems are preferable for measuring the parameters of spacecraft motion. Ref. [3] discussed a system consisting of a group of tools, each measuring certain parameters of the descent module. The angles of inclination of the descent module and its height above the underlying surface are measured, along with obstacle detection, by star sensors, gyroscopes, accelerometers, altimeters, solar radiation sensors and lunar sensors [4]. The landing system described in [5] is an example incorporating an optical navigation system and an inertial system. A combination of several devices based on different physical principles in one system makes it possible to reduce the measurement errors, allowing to use the system in different environmental conditions and expand the range of measured parameters.

In this study, we propose to combine the radar-tracking and gamma-ray systems (the latter is based on recording the intensity of scattered gamma radiation) for measuring the parameters of the descent module.

The measurements at heights from 500 to 10 m can be performed via the radar-tracking system, and via the gamma-ray system at heights from 15 to 0 m. The latter system allows to perform measurements through the shell of the descent module in the plasma of soft-landing engines. This system is almost insensitive to the dust layer on a planet's surface and to occasional obstacles; it provides sufficiently high accuracy of measurements at low altitudes, since it depends only on the activity of the radiation source.

## Experimental goal

The gamma-ray system for providing soft landing of a descent module, developed at the Russian State Scientific Center of Robotics and Technical Cybernetics (RTC) [6], has proved successful in modern systems for landing on Earth. Adjustments should be made to the existing system to develop a landing system for the lunar surface, in view of other landing conditions.

For example, parachutes are unsuitable for lunar landings due to the lack of atmosphere, which is also the reason why motion becomes less uniform than on Earth. Additionally, solar wind causes a high radiation background. Furthermore, landing sites on Earth, unlike those on the Moon, have been thoroughly studied, with ground characteristics determining the properties of gamma scattering obtained [7]. The uncertain composition of the soil at the landing site leads to a decrease in the accuracy with which the position of the descent module is determined relative to the surface; for this reason, additional adaptation of the gamma-ray system to the soil type is required. Radar-tracking and gamma-ray systems can work simultaneously at heights from 15 to 10 m, which makes it possible to adapt the gamma-ray system to the composition of the lunar soil at the landing site.

The goal of this study is to develop a method and an algorithm for measuring the motion parameters of the descent module using the principle of soft transition from measurements with a radar-tracking system to measurements with a gamma-ray system adapted to the composition of the soil at the landing site.

## Simulation of a system for measuring low altitudes

### *Factor of soil composition of the underlying surface*

The physical quantities characterizing the scattering of gamma photons depend on the structural and chemical composition of the underlying surface. Soil

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