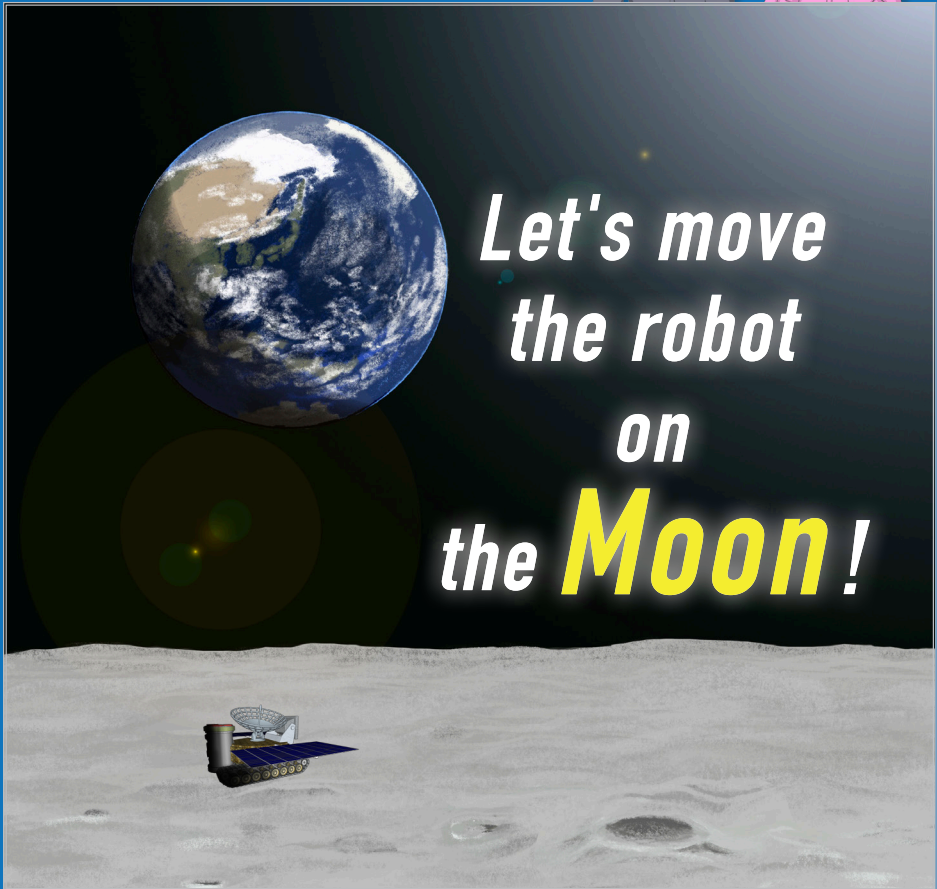


# SPACE ROBOTS

HANDBOOK

Let's get ready!



In the 1960s, the Moon was a major player in space exploration.

In 1961, John F. Kennedy, the 35th President of the United States, promoted the manned lunar landing program, known as the "Apollo Program," with the famous words, "**We choose to go to the Moon.**"

Eight years later, Captain Neil Armstrong and three other astronauts finally reached the Moon aboard the Apollo 11 spacecraft. They left their mark.

Since then, five more lunar landings have taken place, with a total of 12 astronauts landing on the Moon.

In the 1970s, however, space exploration moved beyond the Moon to Earth orbit and planetary exploration, and after Apollo 17 in 1972, there were no more manned flights to the Moon.

Now, more than 50 years later, the Moon is once again poised to play a leading role in space exploration.

Lunar exploration has penetrated to the private sector level, and lunar exploration robots are being launched. In addition, the development of Gateway,

a manned space station in lunar orbit, is underway. Furthermore, the construction of a lunar base is planned, and a space program centered on the Moon is about to be promoted.

You may feel that this is not yet relevant to us. However, space is getting closer than you think.

We seem to be moving from an age in which only a limited number of people are involved in space development to an age in which more and more people are getting involved in space related activities.

Perhaps the day is not far off when you will move to the Moon.

Now, this story is about the not-so-distant future. Twin siblings think about a "cleaning robot that runs on the Moon".

If you take a robot from Earth to the Moon, will it work as is?

What must be considered in order to run a robot on the Moon?

We hope that you will read it and think about it with us.



# 1.

## Cleaning Robot

One pleasant Sunday morning,

twin siblings in the fifth grade of elementary school, Sorao and Tsukiko, are watching TV together in the living room. Children's news programs have begun.

Narrator: *"In 2030, there will be a base on the Moon where people can live. Also, inside and outside of the base, robots will work freely and help people..."*

This raised a question for both of them.

What kind of robot would work on the Moon?



I'd like to see it!

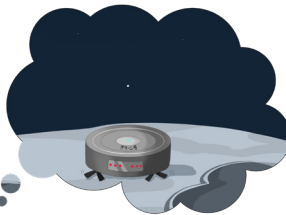
Sorao

Tsukiko

When they looked to the side, they saw that the cleaning robot that cleans the living room every day was charging at the charging station.

Their eyes lit up as they thought about that.

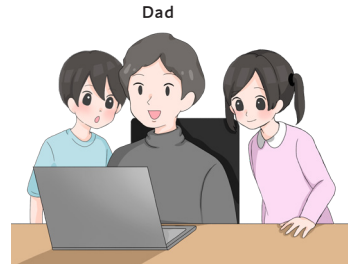
If we take this cleaning robot to the Moon, maybe it will move on the Moon!



As they were excited, their dad came downstairs to the living room. Their dad is an engineer at a company that makes robots. Immediately, they told their dad about taking the cleaning robot to the Moon.

Dad grinned. ✨

Then let's use the lunar simulation software I have on my computer. If we put the weight and shape information of the cleaning robot into this software, we can see how it will move on the Moon!



Immediately, dad used the lunar simulation software on his work computer to enter the cleaning robot's information and began the simulation.

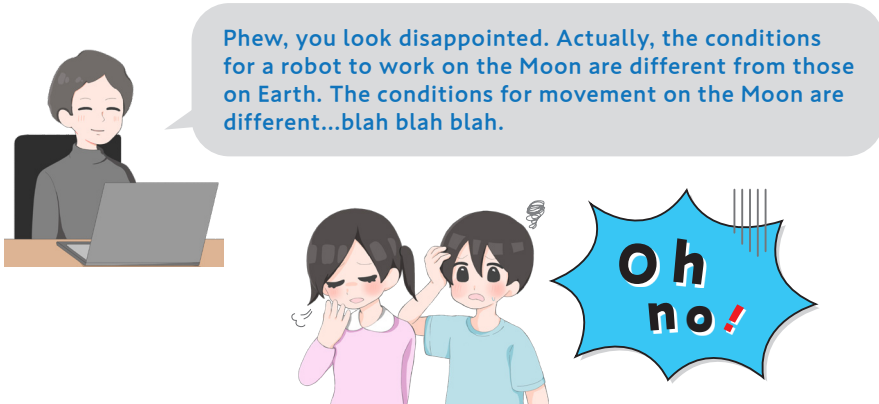
The condition assumes that the cleaning robot was taken as is from the Earth to the Moon and cleaned on the lunar surface.

They also stand beside their dad and watch the simulation. But unfortunately, the cleaning robot does not respond at all.



They were not convinced.

The battery was charged fully and the accumulated dust was removed to make it clean.



**They now understand that the environment on the Moon is completely different from that on Earth.**



## 2.

# Cleaning Robot Modification Project

Time passed, and Sorao and Tsukiko became sophomores in high school.

One night, they were watching TV in the living room when they saw a program about modifying ready-made products to make them work.

They remembered their elementary school days and decided to try again to develop a cleaning robot for the Moon.

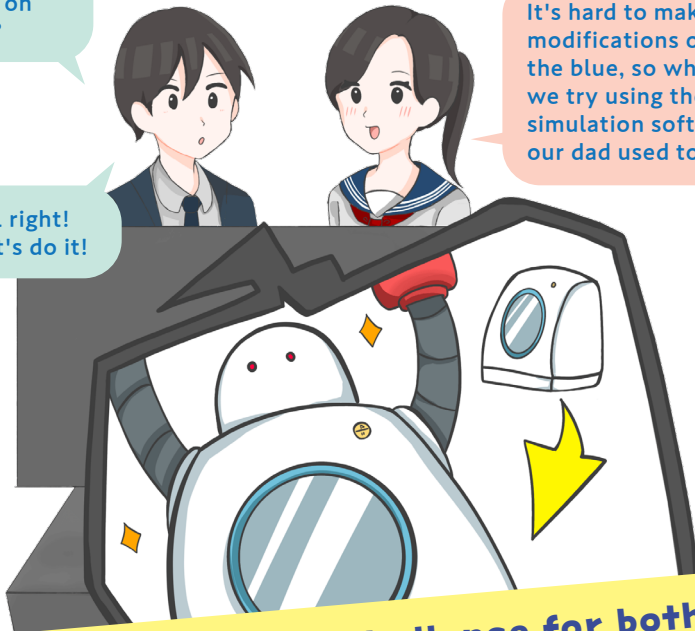
You know, when we were little, we used to say we wanted to operate a cleaning robot on the Moon. We were disappointed when we found out that it wouldn't work as is.

I didn't understand everything our dad was saying back then, but I want to think about it again properly. This time, let's modify the cleaning robot and make it into a robot that works on the Moon!

How can we get it to move on the Moon?

It's hard to make modifications out of the blue, so why don't we try using the lunar simulation software that our dad used to use?

All right! Let's do it!



**This is the beginning of a challenge for both of us!**

### 3.

## Environmental conditions of the Moon

In order for the cleaning robot to work, the challenges posed by the very different environments of the Earth and Moon must be solved.

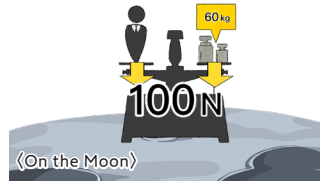
Sorao and Tsukiko summarized the following eight environmental conditions of the Moon that they found by using simulation software.



Let's look at each of these conditions in detail.

condition  
**01**

## Gravity is less than Earth's.



The gravity working on the Moon is 1/6 of that on Earth. This means that the weight will be much lighter.

I can't believe I can be lighter without dieting...!



Countermeasure

Design under the condition that the weight is lighter (analyze the motion and calculate the frictional force).

condition  
**02**

## There is no atmosphere and it is a vacuum.

Water and oil evaporate in a vacuum. Unlike the Earth, the Moon is a vacuum with no atmosphere, so if you use regular plastic, the oils in the plastic will evaporate as well. The gases produced at that time have a bad effect on the equipment.

I can't use regular plastic!



Furthermore, it is hard for heat to escape, so we have to think about heat dissipation.



Countermeasures

- Make materials and systems that can withstand a vacuum and do not release gases.
- Use cooling equipment to dissipate heat.



## Invisible atmospheric forces

The Earth and Moon gravitationally attract things around them. The Earth has an atmosphere because gravity attracts air. The attracted air presses down on us. This pressure caused by air is atmospheric pressure. Earth's atmospheric pressure is about 1013 hPa. This pressure is so great that water does not evaporate immediately on the Earth. This is because it is subjected to the atmospheric pressure. On the other hand, because the Moon's gravity is only about 1/6 that of the Earth, it cannot draw air around or to keep it in place. Therefore, the Moon has no atmosphere. Also, because there is no atmosphere, there is no atmospheric pressure, so substances that would not normally evaporate on the Earth will evaporate on the lunar surface.

## Meteorites rain down in large quantities.



There will be a lot of meteorites raining down on the Moon at high speed.



Really!? What if it hits the cleaning robot...  
There is insurance for cars but is there insurance in space?



Countermeasure

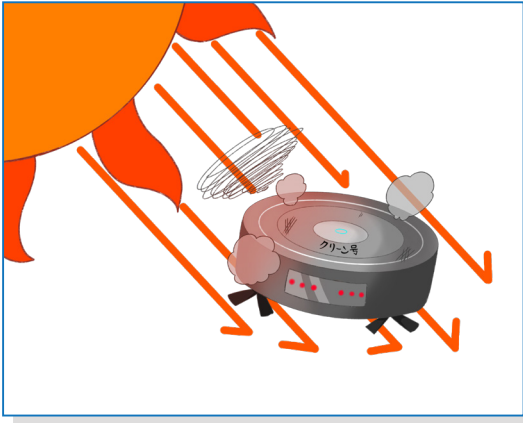
Purchase insurance?



### Cosmic material that also rains down on the Earth

In fact, as much as 100 tons of cosmic material rains down on the Earth every day. We do not notice them because the Earth is protected by the atmosphere. Friction with the atmosphere ignites the cosmic material that rains down on the Earth, and most of it burns up, leaving only small dust particles. Shooting stars in the night sky are ignited cosmic materials. However, on the Moon, which has no atmosphere, cosmic material directly impacts the lunar surface. The lunar surface is covered with numerous craters, which are the remains of meteorite impacts. And the reason there are so many is that craters hundreds or thousands of years old remain because weathering and erosion do not occur on the Moon, where there is no atmosphere or water.

## Radiation (cosmic rays) rains down.



On the Moon, radiation (cosmic rays) mercilessly rains down directly on you.



Oh, no!  
That's scary!

What should I do?



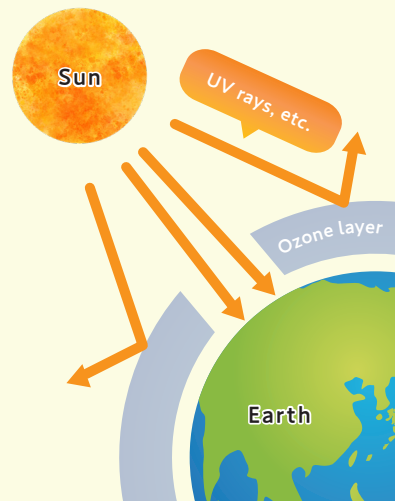
### Countermeasure

Use materials that protect against radiation (cosmic rays).

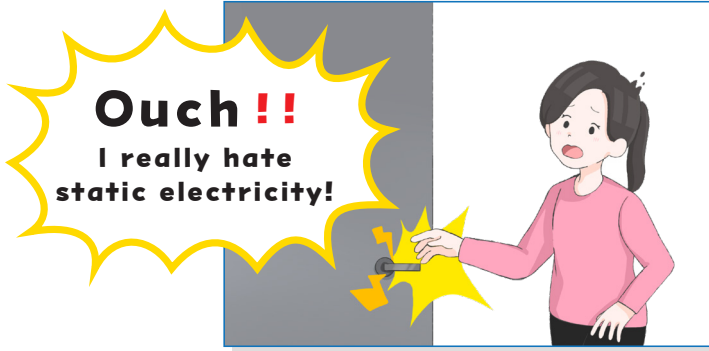


### Cosmic rays and living organisms

We benefit a lot from the Sun. However, the Sun's energy is so great that cosmic rays such as ultraviolet rays are rather harmful to living organisms. The ozone layer in the atmosphere blocks these effects. Since prehistoric Earth did not have an ozone layer, living organisms could not survive on land. However, the formation of the ozone layer blocked ultraviolet rays and allowed many living organisms to expand to the land, including plants, insects, and our ancestors, the amphibians. By the way, you may have wondered if aliens live on the Moon. The possibility is not zero, but it seems unlikely that life forms would be found on the Moon, which has no atmosphere and would be directly affected by cosmic rays.



## Covered with "regolith," the sands of the Moon.



Static electricity is going to cause regolith to cling to the cleaning robot, so we'll have to figure out a way to prevent regolith.

Well, it seems that the "regolith" sand that covers the lunar surface also tends to accumulate static electricity.

I wonder if we need something like a cover.

And regolith can be as deep as 0.3m to 20m.

It looks like it would be hard for a cleaning robot to move, assuming it moves on regolith, stones, rocks, and craters.



### Countermeasures

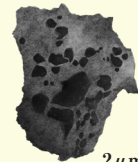
- Cover to prevent regolith
- Use caterpillar mechanism for the drive system.



### Angular sand, regolith

Regolith is angular and prone to static electricity. This is because the absence of air and water prevents the surface from being shaved off by weathering and erosion. On the Earth, particles of sandstone and mudstone deposited with erosion are rounded, while those of tuff (type of volcanic ash) deposited without erosion are angular.

This angular structure affects the human body. For example, astronaut Harrison Schmitt and his crewmates who went to the Moon on Apollo 17 brought regolith aboard their space suits during their work. They experienced hay fever-like symptoms such as sneezing and itching. Astronaut Schmitt and his crew named this symptom "lunar hay fever". In addition, it has been pointed out that inhaling regolith can damage the lungs and other organs, so care must be taken when living on the Moon.



2 μm

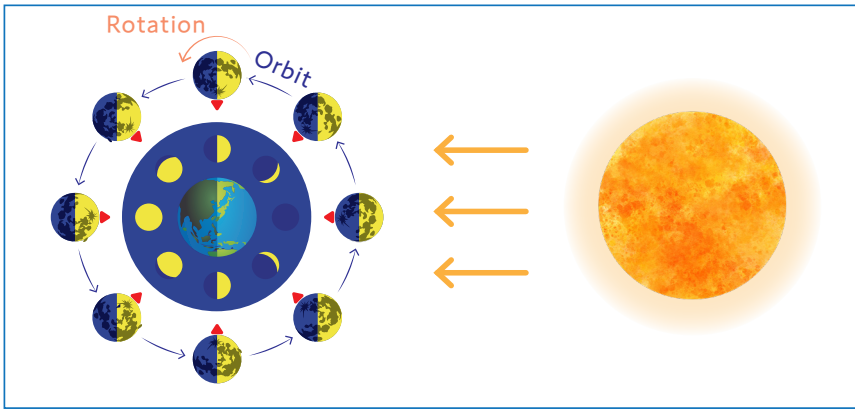
※ 1 μm=0.001mm

## Day and night each last for 14 days.



I would like to run the cleaning robot by solar cells.  
But the Moon has a 14-day cycle of day and night.  
The cleaning robot needs to be charged a lot so that it can work during the night.

A day on the Moon is roughly a month long?  
A day is very long...!



### Countermeasure

Incorporate a charging system capable of storing sunlight during the daytime.



### Is one day and night really a 14-day cycle on the Moon?

When a celestial body "rotates," there is "rotation," in which it spins around like a ballerina, and "orbit," in which it revolves around another celestial body that is not itself. These cause day and night, the phases of the Moon, and many other phenomena. For example, day and night are caused by "rotation". The Earth rotates once over a 24-hour period, resulting in a 12-hour cycle of day and night. On the other hand, the phases of the Moon are caused by its "orbit". Since the Moon takes about 28 days to make a full circle around the Earth, the full Moon also comes in a cycle of about 28 days.

Well, if the Moon's day and night really have a 14-day cycle, then the Moon "rotates" once over a period of 28 days. Let's check this from the way the Moon looks. The pattern of the Moon as seen from the Earth is always the same and never changes. The "unchanging pattern" means that "the Moon always faces the same plane (the red dot in the figure) toward the Earth. For the Moon to appear as shown in the above figure, the Moon itself must rotate once during one orbit around the Earth.

This means that the time for the Moon to make one orbit around the Earth and the time for the Moon itself to make one rotation are equal, about 28 days. Thus, we see that the Moon takes 28 days to rotate on its axis and that day and night make up a 14-day cycle.

	Rotate	Orbit
Earth	24 hours	1 year
Moon	28 days	28 days

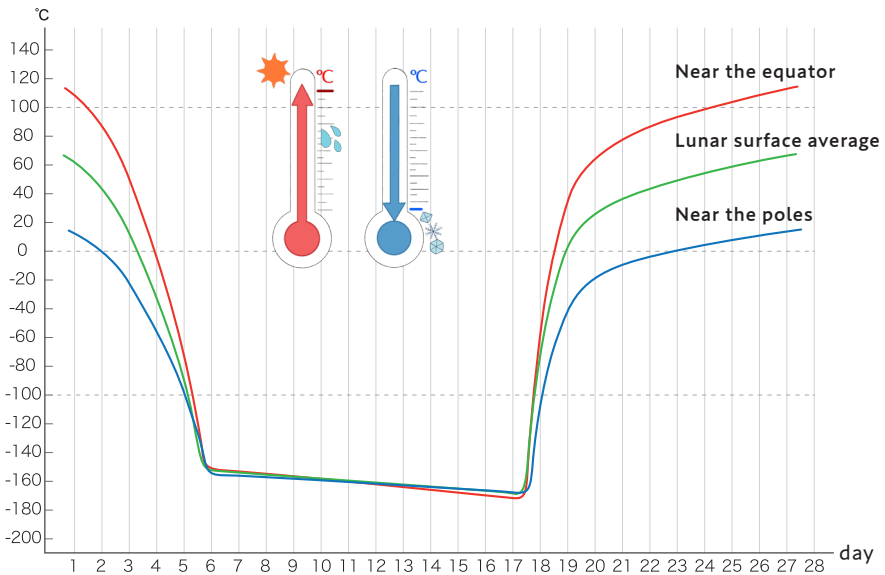


## It is scorching hot and extremely cold.



The surface temperature of the Moon is about  $120^{\circ}\text{C}$  during the day and  $-180^{\circ}\text{C}$  at night in some places! It seems to be very different at the North Pole, South Pole, and the equator. Just like on Earth, the temperature changes with latitude.

What? It's hotter than a sauna and colder than a freezer!



### Countermeasure

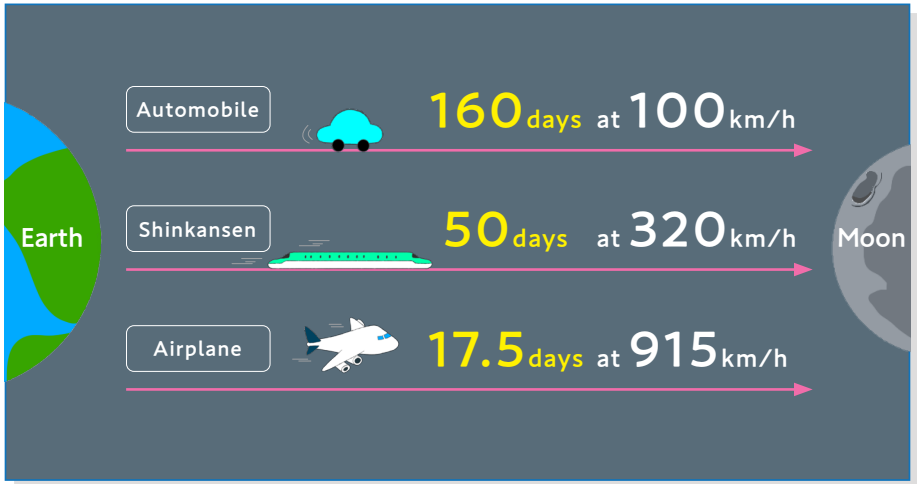
Make the system work both day and night by cooling during the day and heating at night.



### Atmosphere is like a thermal barrier

Even on Earth, it is warm during the day and cold at night. However, the temperature difference is not as great as that of the Moon. Why is this? There are several reasons, one of which is the effect of the atmosphere. Gases such as water vapor and carbon dioxide maintain temperature by storing heat and preventing it from escaping. This is called the "greenhouse effect". Thanks to this greenhouse effect, the temperature difference between day and night is reduced. However, on the Earth as well, when water vapor in the atmosphere is reduced, heat escapes more easily and the temperature drops. The reason why sunny, dry winter mornings are colder than usual is because this greenhouse effect is weakened. This phenomenon is called "radiative cooling".

## Distance from the Earth is far.



It's 380,000 kilometers from the Earth to the Moon.

The Moon is so far away..!  
Then we have to think of a way to communicate.



Countermeasure

Consider means of communication and incorporate a communication system (e.g., large antenna).



### Near and far, the Earth and the Moon

Suppose we put the non-Earth planets in order between the Earth and the Moon, starting with Mercury. How many planets do you think you can fit in that space?

Probably Mercury and Venus? Would Mars also fit in? Is Jupiter too big to fit in? Or, do you think Jupiter could just barely fit in? ...Actually, we can line up all the planets up to Neptune. And that's almost exactly perfect.

You may find that the 380,000 km distance from the Moon that you usually see is much farther than you imagine.

Based on these eight items,  
Sorao and Tsukiko tried to modify the cleaning robot.



Let's start making modifications based on this and come up with a robot that works on the Moon.



Let's attach a camera to the cleaning robot and film it cleaning and watch it together.

Dreams  
are  
swelling...

After cleaning, I would like  
to bring the full dust box  
back to the Earth.



# 4.

## A modified cleaning robot is born!

They considered the inherent need for a mechanism to suck up trash, but realized that it takes air to suck up trash.

What should we do about the trash intake?  
It's better to be able to suck up a lot of debris anyway, right?



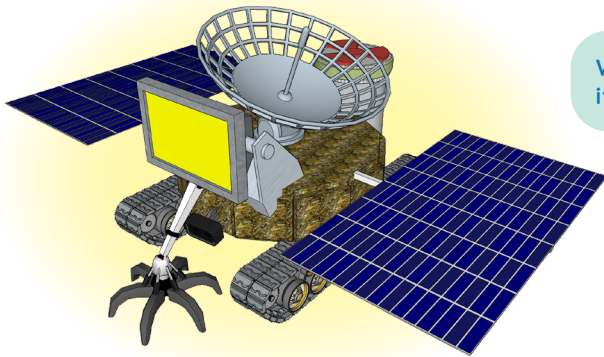
Oh, wait. The Moon has no air, right?  
Then, cleaning robot can't suck up trash on the Moon, can it?



If it can't suck up trash, it should either sweep it up or pick it up by hand...

They forgot the important stuff, and eventually came up with a cleaning robot that picks up trash by hand.

After much trial and error, a modified version of the cleaning robot was completed.



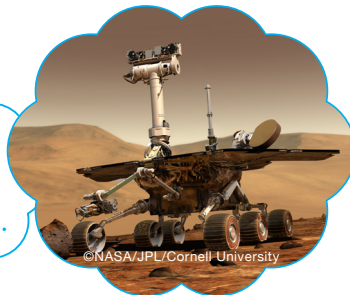
We had to modify it so much.



It's no longer a vacuum cleaner.



It kind of looks like a probe that went to Mars.



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# A MODIFIED CLEANING ROBOT

CLEANING ROBOT  
for  
THE MOON



✓ FEATURE

## Antenna

To communicate with the distant Earth, make it larger.

✓ FEATURE

## Large solar panels

Produce electricity from the sunlight during the day.

✓ FEATURE

## Large light

Use when traveling at night. It is also equipped with a camera.

✓ FEATURE

## Nuclear power battery

The solar panels cannot produce electricity at night, so the electricity is obtained from nuclear power batteries.

✓ FEATURE

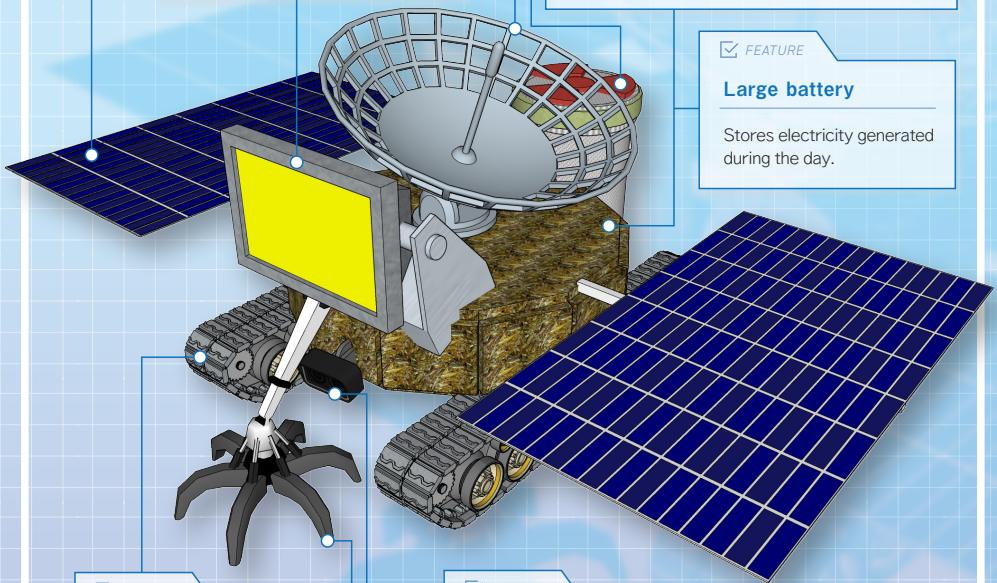
## Robust body

Make it thick so that it will not break even if it is hit by a meteorite. If the body is thicker, cosmic rays will be reduced.

✓ FEATURE

## Large battery

Stores electricity generated during the day.



✓ FEATURE

## Caterpillar

To enable movement over craggy rocks and regolith.

✓ FEATURE

## Trash inlet

The robot hand grabs the trash and puts it in here.

✓ FEATURE

## Robot hand

Since it cannot vacuum the trash, it grabs it with its hand.

Looking at the modified cleaning robot, it needs to be changed significantly from its Earthly form.

Thus, we can see that life on the Moon is not quite the same as on Earth.

Researchers and engineers around the world face these challenges on a daily basis while enjoying space development.

You may think that space development is impossible or irrelevant to you. However, you are just like these amazing researchers and engineers.

Because researchers and engineers, like Sorao and Tsukiko, have opened up a new world by conducting research with the energy of "dreams" and "excitement" that sprouted from pure "questions," and by taking on "challenges" without giving up. We believe that everyone has such "questions," "dreams," "excitement," and the desire to "take on challenges".

Therefore, you too can contribute to space development.

We hope this booklet has piqued your interest in lunar development.

We are currently summarizing in a book the challenges that need to be considered when creating robots in space.

If you want to know more, read this book and let's work together to make a robot for use on the Moon.

See you on the Moon someday.

### ◆ Creation

Frontier Business Consortium, Space Robotics and Automation/Autonomy Study Working Group (ASTRO TECHNOLOGY SOHLA. Systems Engineering Consultants Co.,LTD. Dymon Co., Ltd. Japan Manned Space Systems Corporation)

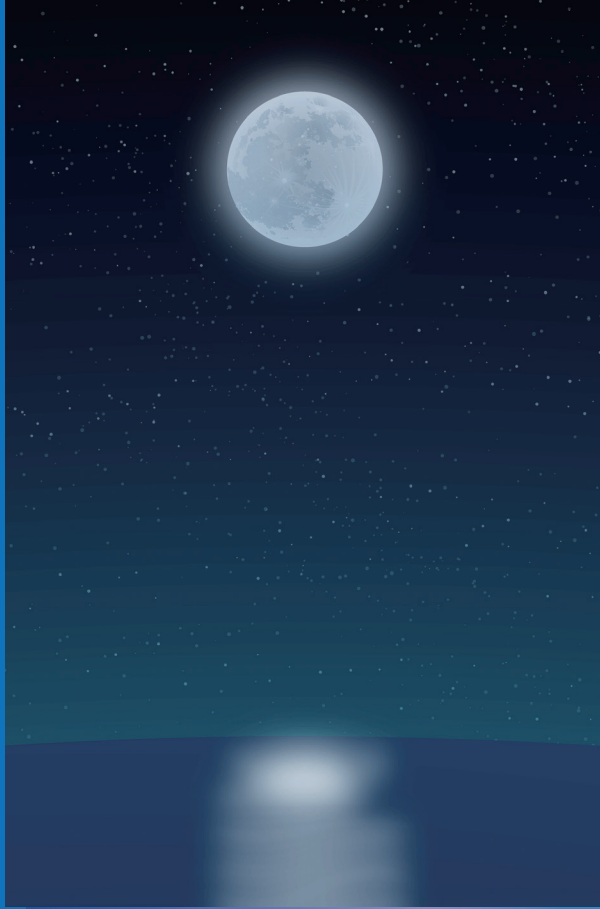
### ◆ Illustration

Daisuke Ishinabe, Associate Professor, Instruction Illustration, Department of Character Design, Kyoto University of the arts  
Makoto Mori, Creation Illustration, Department of Character Design, Kyoto University of the arts

### ◆ Supervising

Kensuke Sakai, Ichikawa Gakuen Ichikawa Junior and Senior High School





**SPACE  
ROBOTS**

HANDBOOK