Robotic rovers on Mars

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Abstract: *This seminar paper briefly discuss about two robotic rovers exploring Mars.*

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1 Introduction

On August 6, 2012, a robotic vehicle Curiosity was successfully landed on Mars, which was transported to the planet by a spacecraft Atlas V launched from the Kennedy Space Center in Florida. After more than eight years, on February 18, 2021, another robotic vehicle - Perseverance - reached the planet Mars too. As of March 2021, there are two active and movable robotic rovers on Mars. This seminar paper briefly discuss about these two robots: Curiosity and Perseverance.[1]

2 Curiosity

Rover is about 3 meters long (not including the arm), 2.7 meters wide, and 2.2 meters tall. Arm reach is about 2.2 meters. Weight of the rover is 899 kg in Earth gravity and 337 kg in Mars gravity. Mission of the rover is to search areas of Mars for past or present conditions favorable for life, and conditions capable of preserving a record of life.[1]

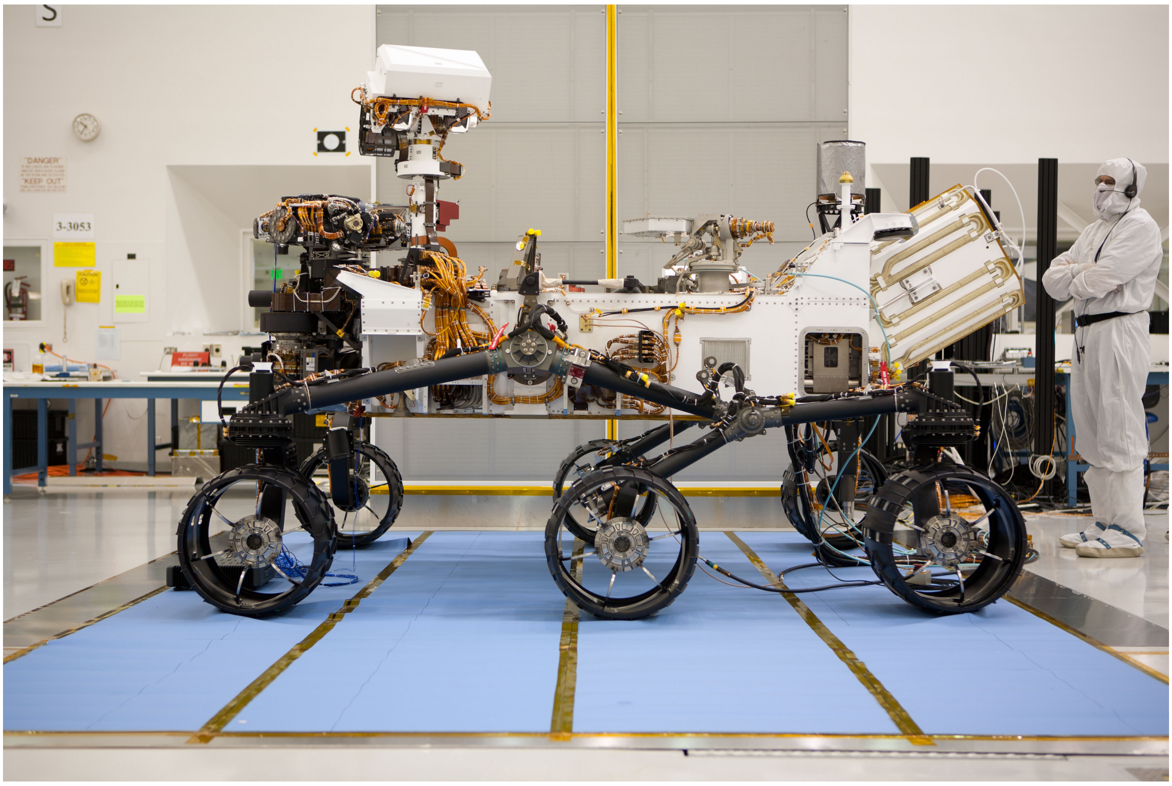

Figure 1: Curiosity rover in science lab [2]

2.1 Body

The rover body is called the warm electronics box, or "WEB" for short. Like a car body, the rover body is a strong, outer layer that protects the rover's computer and electronics. The rover body keeps the rover's vital organs protected and temperature-controlled. Main job of the body is to protect the Computer, Electronic, and Instrument Systems.[3,4]

2.2 Brains

The rover computer (its "brains") is inside a module called "The Rover Compute Element" (RCE) inside the rover body. Radiation-hardened central processor with PowerPC 750 Architecture: a BAE RAD 750. Operates at up to 200 megahertz speed.

Computer has 8 gigabytes of flash memory, 256 megabytes of dynamic random access memory (DRAM). The computer contains special memory to tolerate the extreme radiation environment from space and to safeguard against power-off cycles so the programs and data will remain and will not accidentally erase when the rover shuts down at night. On-board memory includes 256MB of DRAM and 2 GB of Flash Memory both with error detection and correction and 256kB of EEPROM.

The rover carries an Inertial Measurement Unit (IMU) that provides 3-axis information on its position, which enables the rover to make precise vertical, horizontal, and side-to-side (yaw) movements. Main control loop keeps the rover "alive" by constantly checking itself to ensure that it is both able to communicate throughout the surface mission and that it remains thermally stable at all times. It does so by periodically checking temperatures, particularly in the rover body, and responding to potential overheating conditions, recording power generation and power storage data throughout the Mars sol (a martian day), and scheduling and preparing for communication sessions.[4]

2.3 Cameras

The rover has seventeen cameras. Each camera has an application-specific set of optics: Engineering Cameras, Science Cameras, Descent Imaging Camera.

Four Pairs of Engineering **Hazard Avoidance Cameras** (Hazcams) are mounted on the lower portion of the front and rear of the rover, these black-and-white cameras use visible light to capture 3D imagery. The cameras each have a wide field of view of about 120 degrees. Two Pairs of Engineering **Navigation Cameras** (Navcams) are mounted on the mast, these black-and-white cameras use visible light to gather panoramic, three-dimensional (3D) imagery.

Four Science Cameras: Mastcam (one pair), ChemCam, MAHLI. The **Mast Camera** takes color images, three-dimensional stereo images, and color video footage of the martian terrain and has a powerful zoom lens. **ChemCam** fires a laser and analyzes the elemental composition of vaporized materials from areas smaller than 1 millimeter on the surface of Martian rocks and soils. The Mars Hand Lens Imager is the equivalent of a geologist's hand lens and provides close-up views of the minerals, textures and structures in martian rocks and the surface layer of rocky debris and dust.

Mars Science Laboratory features an even more capable visual system. **Mars Descent Imager** (MARDI) provided four frame-per-second video at a high resolution during Curiosity's landing. The images are "true color," or as the human eye would see.[3]

2.4 Arm

The Robotic Arm holds and maneuvers the instruments that help scientists get up-close and personal with martian rocks and soil. At the end of the arm is a turret, shaped like a cross. This turret, a hand-like structure, holds various tools that can spin through a 350-degree turning range. At the tip of the arm is the turret structure on which five devices are mounted. Two of these devices are in-situ or contact instruments known as the **Alpha Particle X-ray Spectrometer** (APXS) and the **Mars Hand Lens Imager** (MAHLI). The remaining three devices are associated with sample acquisition and sample preparation functions: Collection and Handling for In-situ Martian Rock Analysis (CHIMRA), Drill System, Dust Removal Tool (DRT).[8]

2.5 Wheels

The Mars Science Laboratory has six wheels, each with its own individual motor. The two front and two rear wheels also have individual steering motors (one each). This steering capability allows the vehicle to turn in place, a full 360 degrees. The four-wheel steering also allows the rover to swerve and curve, making arching turns. Wheels are made of aluminum, with cleats for traction and curved titanium springs for springy support. Size is 0.5 meters in diameter. The rover has a top speed on flat hard ground of 4 centimeters per second.[4]

2.6 Power

Curiosity carries a radioisotope power system that generates electricity from the heat of plutonium's radioactive decay. Power Source uses 4.8 kilograms of plutonium dioxide as the source of the steady supply of heat. Electrical power produced over 100 watts. Two lithium ion rechargeable batteries to meet peak demands of rover activities.[7]

2.7 Communications

Rover has three antennas that are located on the rover equipment deck. Curiosity sends waves through its **ultra-high frequency antenna** (UHF) (about 400 Megahertz) to communicate with Earth through NASA's Mars Odyssey and Mars Reconnaissance Orbiters. Transmission rates are up to 2 megabits per second on the rover-to-orbiter relay link. Curiosity uses its **high-gain antenna** to receive commands for the mission team back on Earth. The high-gain antenna can send a "beam" of information in a specific direction, and it is steerable, so the antenna can move to point itself directly to any antenna on Earth. Curiosity uses its **low-gain antenna** primarily for receiving signals. This antenna can send and receive information in every direction.[4]

3 Perseverance

The Mars 2020 rover, Perseverance, is based on the Mars Science Laboratory's Curiosity rover configuration. It is car-sized, about 3 meters long, 2.7 meters wide, and 2.2 meters tall. Weight of the rover is about 1,025 kilograms.[14]

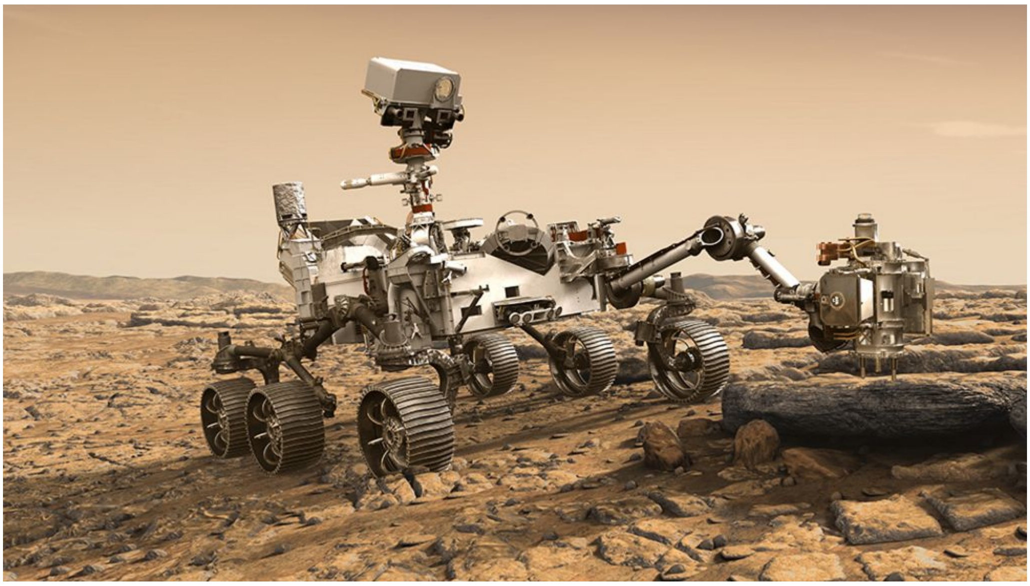

Figure 2: Model of Perseverance rover [5]

3.1 Body

The Perseverance rover relies on the successful design of the Mars Science Laboratory rover, Curiosity. However, Perseverance has a new science and technology toolbox. An important difference is that this rover can sample and cache minerals. To do so, Perseverance has a new coring drill to collect samples. The samples are then sealed in tubes and placed on the surface of Mars. In the future, another space mission could potentially pick up the samples and bring them to Earth for detailed analysis.[14]

3.2 Brains

Tech specs of processor and memories are the same as in Curiosity rover. However the perseverance rover has two "computer brains," one of which is normally asleep. In case of problems the other computer brain can be awakened to take over control and continue the mission.[12]

3.3 Cameras

The rover has 23 cameras: 9 engineering cameras, 7 science cameras, 7 entry, descent and landing cameras. For the Mars 2020 Perseverance rover, the engineering team added several cameras. The cameras capture full-color video throughout the vehicle's final descent to the Martian surface. Some of what the cameras see on the way down helped mission planners decide on the rover's first drives.The enhanced engineering cameras for driving help human operators on Earth drive the rover more precisely, and better target the movements of the arm, drill and other tools that get close to their targets. A much wider field-of-view gives the cameras a much better view of the rover itself.Image Size: 5120 x 3840 pixels and Image Resolution: 20 megapixel.Perseverance carries six newly developed **Hazard Detection Cameras** (HazCams): four on the front and two on the rear of the rover body. HazCams detect hazards to the front and back pathways of the rover, such as large rocks, trenches, or sand dunes. Engineers also use the front HazCams to see where to move the robotic arm to take measurements, photos, and collect rock and soil samples.Two color stereo **Navigation Cameras**, called Navcams, help engineers navigate Perseverance safely, particularly when the rover operates autonomously, making its own navigation decisions without consulting controllers on Earth.The **CacheCam** is a single camera that looks down at the top of the sample cache. It takes pictures of sampled materials and the sample tubes as they are being prepared for sealing and caching.

The Science Cameras: Mastcam-Z, SuperCam, PIXL, SHERLOC, WATSON. **Mastcam-Z** is a pair of cameras that takes color images and video, three-dimensional stereo images, and has a powerful zoom lens. Like the Mastcam cameras on the Curiosity rover, Mastcam-Z on Mars 2020 consists of two duplicate camera systems mounted on the mast that stands up from the rover deck. **SuperCam** fires a laser at mineral targets that are beyond the reach of the rover's robotic arm, and then analyzes the vaporized rock to reveal its elemental composition. Like the ChemCam on rover Curiosity, SuperCam fires laser pulses at pinpoint areas smaller than 1 millimeter from more than 7 meters away. Its camera and spectrometers then examine the rock's chemistry. **PIXL** uses X-ray fluorescence to identify chemical elements in target spots as small as a grain of table salt. **SHERLOC's** main tools are spectrometers and a laser, but it also uses an integrated "context" macro camera to take extreme close-ups of the areas that are studied. The **WATSON** (Wide Angle Topographic Sensor for Operations and eNgineering) camera is one of the tools on the "hand" or turret at the end of Perseverance's robotic arm. It is almost identical to the MAHLI hand-lens camera on the Curiosity rover. WATSON captures the images that bridge the scale from the very detailed images and maps that SHERLOC collects of Martian minerals and organics to the broader scales that SuperCam and Mastcam-Z observe from the mast.[12,13,14]

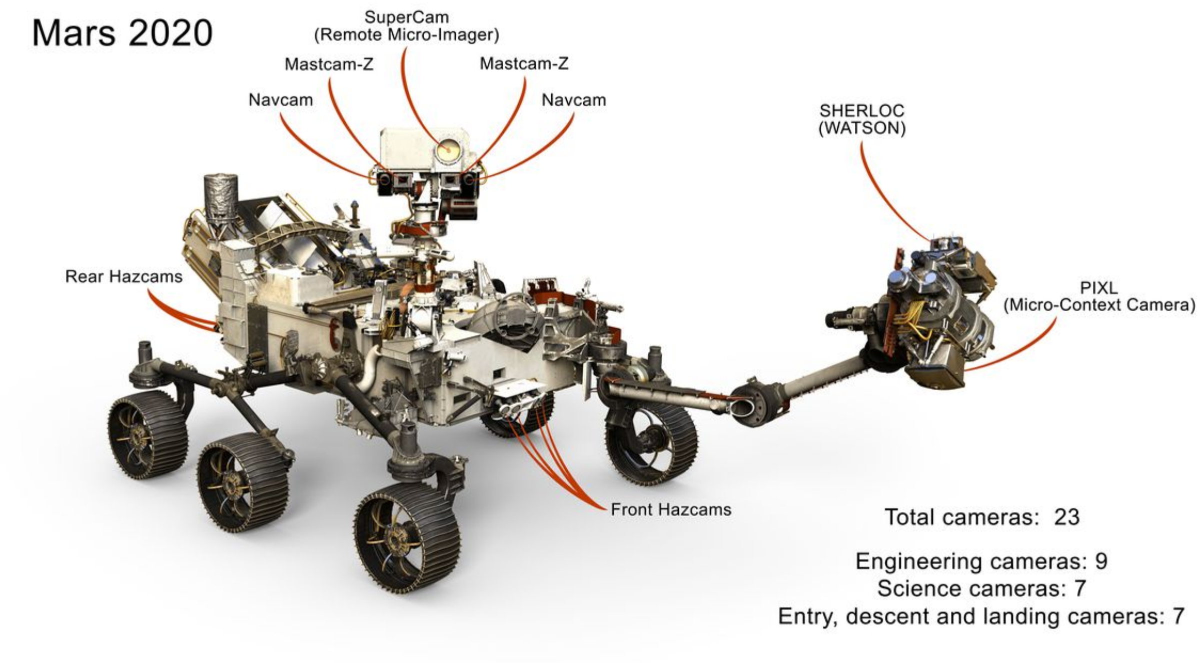

Figure 3: Cameras on Perseverance rover [6]

3.4 Microphones

Rover has Entry **Descent and Landing** (EDL) microphones that recorded the sounds of landing. SuperCam's toolkit also consists of a microphone that helps study Mars rocks and soil.The microphone also records sounds of Perseverance using its arm, coring rocks, and the wheels crunching against the surface. The rover may hear the other instruments, internal mechanisms, and hear when we drop off the sample tubes. In some cases, sound can help the team diagnose the health of the rover's internal mechanisms or instruments.[13]

3.5 Arm

The 2.1 meters long robotic arm has 5 degrees of freedom. The five degrees of freedom are known as the shoulder azimuth joint, shoulder elevation joint, elbow joint, wrist joint and turret joint. At the end of the arm is the "turret." It's like a hand that carries scientific cameras, mineral and chemical analyzers for studying the past habitability of Mars, and choosing the most scientifically valuable sample to cache. Tools on the Turret: SHERLOC and WATSON, PIXL, GDRT (Gaseous Dust Removal Tool), Ground Contact Sensor and Drill. Diameter of drilled holes is 27 mm.[9,14]

3.6 Wheels and legs

Legs enable the rover to drive over knee-high rocks as tall as 40-centimeters. They are made of titanium tubing formed with the same process used to make high-end mountain bike frames. Wheels are made of aluminum, with cleats for traction and curved titanium spokes for springy support. The suspension system has three main components: Differential, Rocker and Bogie. The rover has a top speed on flat, hard ground of 4.2-centimeters per second, or 152 meters per hour. As you can see in figure 4, the aluminum wheels of NASA's Curiosity (left) are slightly larger in diameter and narrower, 52.6 centimeters versus 50.8 centimeters, Perseverance's wheels have twice as many treads, and are gently curved instead of chevron-patterned.[12,15]

Figure 4: Curiosity's and Perseverance's wheels [11]

3.7 Power

The power source is called a **Multi-Mission Radioisotope Thermoelectric Generator** or MMRTG for short. The MMRTG converts heat from the natural radioactive decay of plutonium into electricity. This power system charges the rover's two primary batteries. It´s size is 64 centimeters in diameter by 66 centimeters long. It weights about 45 kilograms, uses 4.8 kilograms of plutonium dioxide as the source of the steady supply of heat and produces about 110 watts at launch, declining a few percent per year.

Rover includes two lithium-ion rechargeable batteries to meet peak demands of rover activities when the demand temporarily exceeds the MMRTG's steady electrical output levels.[14]

3.8 Communications

The Mars 2020 rover, Perseverance, has three antennas on rover deck: Ultra-High Frequency Antenna, X-band High-Gain Antenna, X-band Low-Gain Antenna. Their purpose and tech specs are very similar as antenas in Curiosity rover.[10]

4 Conclusion

This work briefly describes two robotic rovers operating on Mars - Mars Science Laboratory Curiosity Rover and Perseverance Rover. Main differences between these two robots: The large robotic arm on the front of the rover differs from Curiosity's for two main reasons: Perseverance collects rock cores and it has a larger turret, that has the coring drill and two science instruments. Perseverance will operate very differently than Curiosity. The new rover will gather 20 sealed samples of Martian rocks and soil. The samples will be set aside in a "cache" on Mars. Software will be updated with improvements throughout the mission. Engineers redesigned the Mars 2020 Perseverance rover's wheels to be more robust due to the wear and tear the Curiosity rover wheels endured while driving over sharp, pointy rocks.

References

[1] CROUCH, Alex. *Perseverance VS Curiosity – What's New?* [online]. 25 July 2020 [cit. 2021-03-25]. https://everydayastronaut.com/perseverance-vs-curiosity/

[2] NASA's Curiosity Rover in Profile[online]. In: *nasa.gov.* [cit. 2021-03-16]. https://mars.nasa.gov/system/downloadable_items/35610_PIA15181.jpg

[3] HOWELL, Elizabeth. *Curiosity Rover: Facts and Information* [online]. 17 July 2018 [cit. 2021-03-16]. https://www.space.com/17963-mars-curiosity.html

[4] Mars Curiosity Rover [online]. In: *mars.nasa.gov* [cit. 2021-03-16]. https://mars.nasa.gov/msl/spacecraft/rover/summary/

[5] Nasa Mars rover: How Perseverance will hunt for signs of past life [online]. In: *bbc.com* [cit. 2021-03-16]. https://ichef.bbci.co.uk/news/976/cpsprodpb/4CC6/production/_110945691_5.jpg

[6] Mars 2020 [online]. In: *nasa.gov.* [cit. 2021-03-16]. https://www.nasa.gov/sites/default/files/thumbnails/image/pia22103-16.jpg

[7] GREGERSEN, Erik. *Curiosity: United States robotic vehicle* [online]. [cit. 2021-03-16]. https://www.britannica.com/topic/Curiosity-United-States-robotic-vehicle

[8] M. Robinson et al., "Test and validation of the Mars Science Laboratory Robotic Arm," 2013 8th International Conference on System of Systems Engineering, Maui, HI, USA, 2013, pp. 184-189, doi: 10.1109/SYSoSE.2013.6575264.

[9] Perseverance, NASA's Newest Mars Rover. *Planetary.org* [online]. [cit. 2021-03-16]. https://www.planetary.org/space-missions/perseverance

[10] Byrne C.J. (2020) Mars 2020: In the Tracks of Giants. In: Travels with Curiosity. Springer, Cham. https://doi.org/10.1007/978-3-030-53805-7_12

[11] Curiosity's and Perseverance's Wheels. In: *Mars.nasa.gov* [online]. [cit. 2021-03-18]. https://mars.nasa.gov/system/resources/detail_files/24910_Rover-Wheel-Comparison-800w.jpg

[12] MARS: 2020 Mission Perseverance Rover [online]. In: *mars.nasa.gov* [cit. 2021-03-16]. https://mars.nasa.gov/mars2020/spacecraft/rover/

[13] MAKI, J. N., D. GRUEL, C. MCKINNEY, et al. The Mars 2020 Engineering Cameras and Microphone on the Perseverance Rover: A Next-Generation Imaging System for Mars Exploration. *Space Science Reviews* [online]. 2020, 216(8) [cit. 2021-03-16]. ISSN 0038-6308. doi:10.1007/s11214-020-00765-9

[14] RED, Nora Taylor a Mike WALL. *Perseverance rover: NASA's Mars car to seek signs of ancient life* [online]. 02 March 2021 [cit. 2021-03-16]. https://www.space.com/perseverance-rover-mars-2020-mission