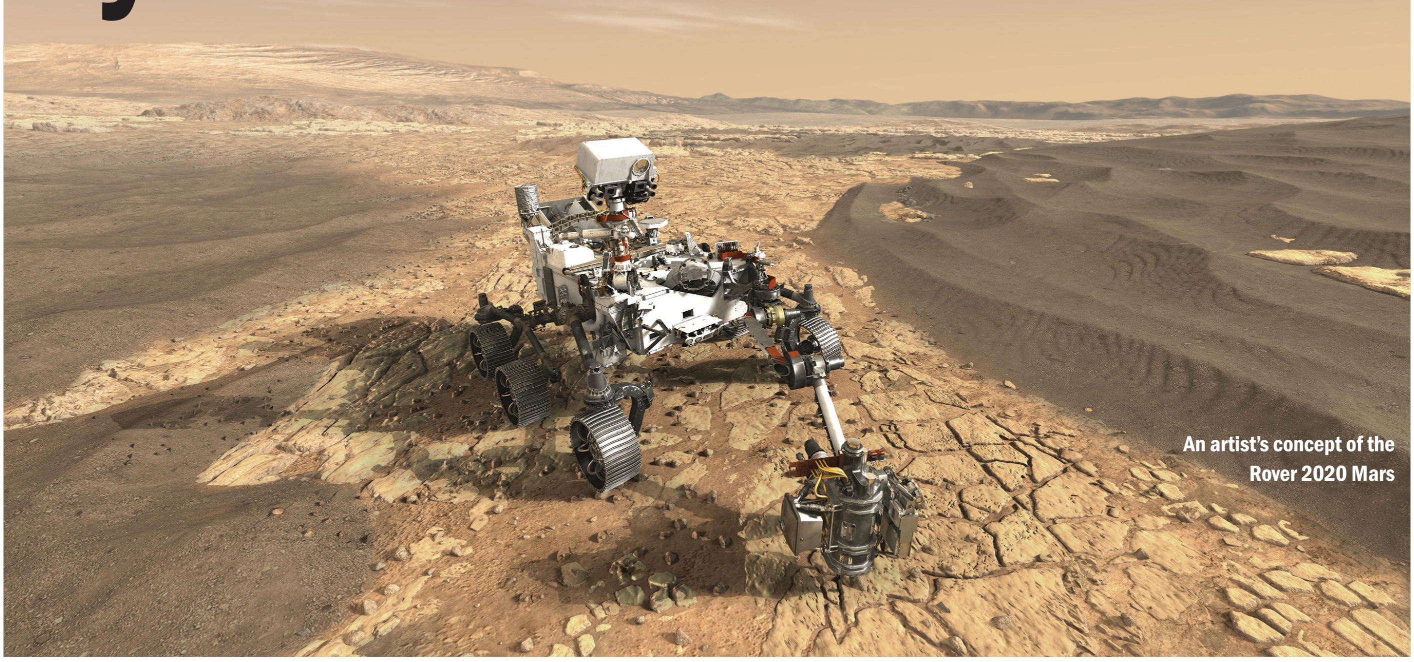
Eyes on Mars



An artist's concept of the Rover 2020 Mars

In the wake of Nasa's recent 'eye test' of the Mars 2020 Rover, **David Wilson** explores the technology underpinning its visual systems

Charles Darwin described human eyes as 'organs of extreme perfection'. While robotic vision has far to go before it matches the human eye's natural guile, it is growing increasingly sophisticated, thanks to the power of cameras and other sensors that help robots see and interact with their surroundings. The leading cybernetic 'eye' belongs to the 2020 rover – a Nasa contraption slated to launch on July 17, 2020 and touch down in Jezero crater on Mars on February 18, 2021.

Armed with visionary science instruments, the rover recently had an 'eye test' in an Icelandic lava field after several cameras were fitted to it. The visionary vehicle with 20/20 vision boasts imaging capabilities ranging from narrow-angle, high-resolution zoom lens cameras to wide-angle landscape cameras.

To gauge the cameras' effectiveness, members of the 2020 team functioning as optometrists used target boards featuring grids of dots spaced between one and 40 metres away. The results proved the rover's cameras fulfilled requirements for resolution and accuracy.

'This measurement is critical for accurate stereo vision,' says Nasa Jet Propulsion Laboratory engineer Justin Maki.

While one report claimed Nasa's optics were influenced by jumping spider vision, the technology is actually old-school, says James Bell: an Arizona State University astronomy professor and Planetary Society president, who has played a key part in Nasa missions involving the Mars rovers Spirit, Opportunity and Curiosity.

'We're actually pretty far behind the times. The sensors are one-to-two megapixel sensors – computational powers comparable to the early 2000s. Nasa's extremely conservative with its technology – especially technology that has to work in deep space,' Bell tells *Optician* and explains why.

'Because it has to work. A lot of the cutting edge, brand-new sensors and electronics, etc, have not been tested in the environments of a very high-shock, high-vibration rocket launch or the vacuum of deep space – or the extreme cold of space, or the shocks and vibrations of a Mars landing.'

Many modern high-tech sensors – iPhones for instance – could not survive, he says.

'But what will survive are technologies that have been there before. So they tend to be technological advancements in space – very incremental.'

Further, consumer innovations like cameras that pack tens-of-megapixels would be wasted in space, because it provides no bandwidth for returning recorded data, he says.

'So there's nothing like high-speed internet to Mars or other planets. And so we're really trying to get the data back down a very narrow straw.'

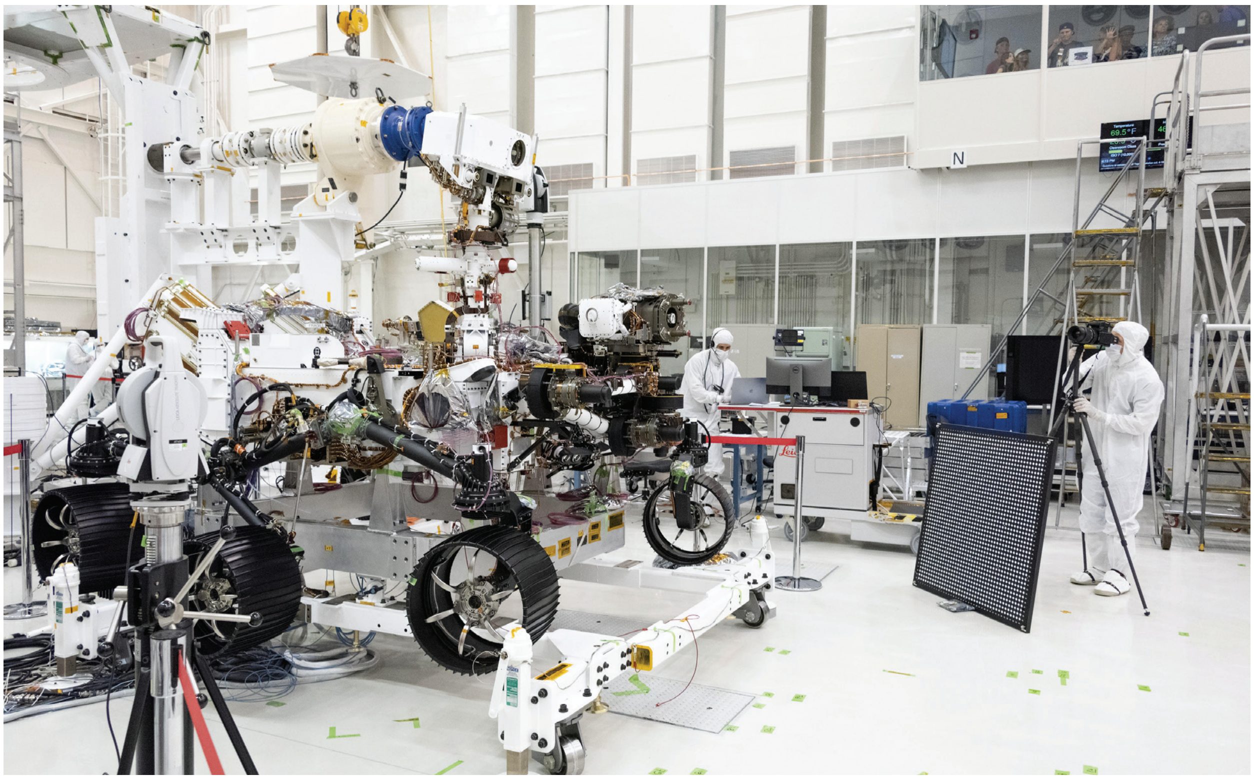
For data retrieval, small numbers of pixels and image compression are a must, contrary to expectations Bell acknowledges.

'It's somewhat non-intuitive. One would imagine that the Nasa technology would be cutting-edge, that there would be wizardry involved in the deep space world.

'It's really not. It's tried and true, very conservative. Very much lagging consumer technology,' he says.

On how the 2020 Rover's vision compares with ours, he says the vehicle is just an inanimate machine. It cannot think for itself.

The cameras it counts on see the visible spectrum: red, blue and green, for instance, which give an accurate picture of the world. The cameras are also sensitive to ultraviolet and infrared. →



Engineers test cameras on the top of the Mars 2020 rover's mast and front chassis at the Spacecraft Assembly Facility's High Bay 1 at NASA's Jet Propulsion Laboratory in Pasadena, California

The idea is to extend the range of human vision using 'semi-modern' sensors like those in cell phones and digital cameras.

The infrared and ultraviolet capabilities mean some minor landmarks reflect differently. 'So we get a little bit of sensitivity and discovery potential for the rocks and minerals that are there,' he says.

The challenge is the settings the cameras have to navigate. Even the Moon is difficult.

'It's close-by. You'd think it wouldn't be that hard.'

'But of course,' he says, referring to a travelling camera, 'it has to survive a pretty violent rocket launch. There's a lot of shaking and a lot of shocks during a rocket launch. Somehow it has to survive a landing.'

A landing is shocking, too, he stresses, also highlighting the challenge posed by the vacuum of space and the Moon's temperature: plus hundreds of degrees Celsius during daytime and minus hundreds at night.

'So a huge range of thermal environments. Same for Mars.'

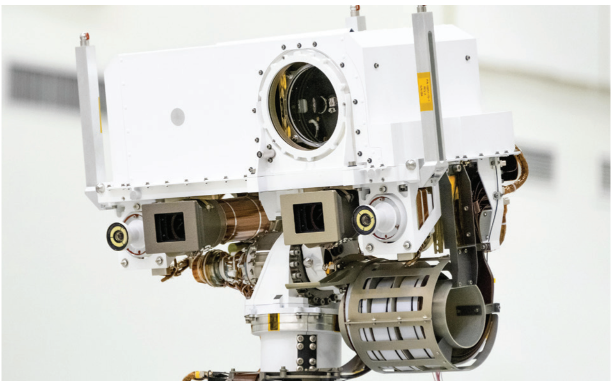
The Red Planet soars to 10° Celsius during daytime, and dips as low as -100° degrees at night, every day.

Handling a dusty atmosphere full of particles trying to enter every little optic mechanism is tricky, too.

'So they're harsh environments. You know, it's not a walk in the park to get this kind of equipment out there,' he says, adding that equipment and vacuum chambers must be stress-tested in the laboratory.

'We put them on shake tables and simulate the rocket launch and the vibrations and the violence of that. And so a lot of testing and a lot of ruggedizing has to happen, to get the machine vision out into deep space.'

For maximum realism, the whole Rover goes into a vacuumised giant tank and its temperature is lowered to Mars' night-time level. A bunch of conservative engineers goes even further, inducing extreme conditions beyond what Nasa expects.



The head of Mars 2020's remote sensing mast which contains the SuperCam instrument (its lens is in the large circular opening). In the gray boxes beneath mast head are the two Mastcam-Z imagers. On the exterior sides of those imagers are the rover's two navigation cameras

'And then we take pictures in that chamber. And, lo and behold, they work!' he says, referring to the ocular cameras. The results mean he is confident they will function properly when faced with actual working conditions.

'So those tests are optimised for wherever these robots are going to be going. It's the Moon. It's Mars. It's our deep outer solar system.'

More than up to the job of scouring the cosmos, Nasa's 3D zoom cameras operate beautifully, he says. Landscape shots will deliver telephoto-style high-resolution, it seems.

'So we've done some of that work in the laboratory, demonstrated the resolution and the fidelity of the images, and it's just looking great. So I'm looking forward to having a bunch of 3D data to send back from Mars,' he says.

The site to be rendered in 3D is a delta: an ancient lake from way back in the history of Mars, when it was young, three to four billion years ago.

'And it was an environment that had liquid water flowing across the surface: rivers and lakes, delta deposits, kind of like the Mississippi River, the Mekong River. These beautiful delta deposits.'

Those deposits pan out as more than just red. Additionally, the host dark rock, volcanic rock and light-toned, whitish sedimentary rock. Thanks to dust storms, much of the ground will be covered with a fine particulate layer, which is where the rover's special removal tool comes in. It will brush the dust off samples before Nasa analyses them.

As for the air, visibility should be good, in sharp contrast to earlier Nasa missions dogged by dust storms 'knocking the sunlight down'. The delta is not susceptible to storms during the season that the rover will land, at the start of northern hemisphere spring. 'We don't expect much of a problem,' he says.

He summarises the quality of the images that the rover should yield as 'very sharp'.

The microscope attached to the camera will drill down – deliver the kind of millimetre-scale detail produced by a geologist's hand lens.

'We'll get that kind of very, very fine-scale resolution,' Bell says.

Ophthalmologist Dr Ming Wang, the director of Wang Vision 3D Cataract & LASIK Center in Nashville, Tennessee, describes the rover's array of visionary cameras and sensors as 'incredible'.

'This allows it to collect panoramic data from many sources including ahead and below. In this way, the vision in some ways significantly surpasses that of human vision, which is limited to a fairly narrow field left and right and up and down,' says Dr Wang, who holds a doctoral degree in laser physics.

The 2020 vision system performed well in the test, he notes, adding that its robotic vision is designed to gather 'gross information for navigation'. The system focuses more on volume and data integration than exact resolution, because navigation does not require total exactitude.

Anyway, robotic vision is 'an evolving field', he says, adding that it is exciting to see how much progress has been made. In future, robot vision just might exceed human vision, he says.

'Multiple cameras can provide more information on depth than humans can gather with our two fixed eyes. Laser displacement systems can use reflected light to more precisely measure distances than humans can with our naked eyes.'

The resulting phenomenal resolution may exceed what we naturally experience – an impressive 576 megapixels, according to Curiosity.com.

Even so, he says, while humans tie visual input to experience and read data 'seamlessly', a robot has limited ability to interpret and use it.

'I feel that the chief challenge is not the acquisition of the data, but the interpretation of the data.' Whereas gathering it is easy, it is hard to arm a robot with the programming needed to exploit the data and guide its interaction, he says.

He frames the outlook for the future of robot vision as 'very interesting to see'. 'There is such potential for incredible advances, as input sources can be almost limitless.'

Dorian Tsai, a PhD researcher at the Australian Centre for Robotic Vision, argues the artificial visual future belongs to 'light-field cameras' which give the long view.

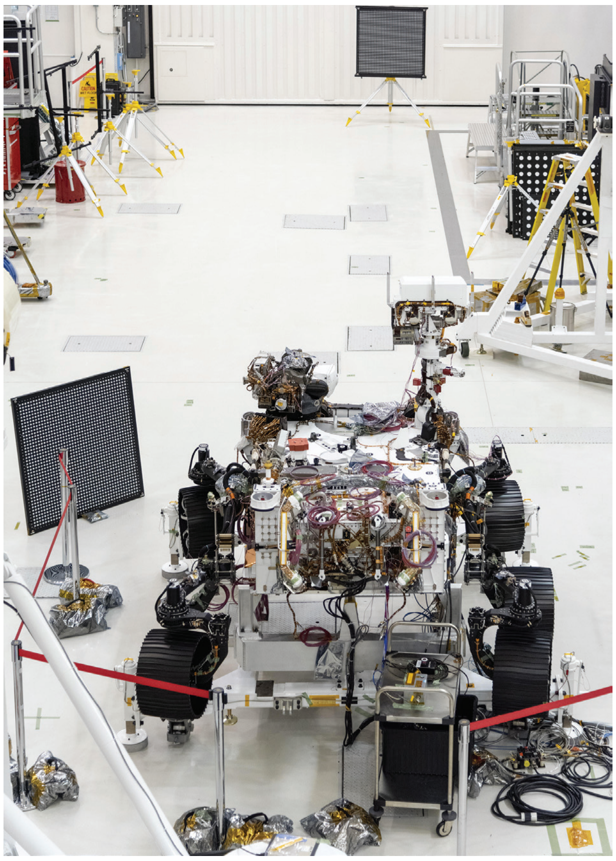
While a regular monocular camera just uses a single aperture to image a scene from one viewpoint, a light-field camera uses multiple apertures to simultaneously capture multiple views.

'Loosely speaking, it's like having a densely packed array of cameras. But with an array of cameras, we can leverage a lot of the development that we have done for monocular or single-lens cameras. This puts light-field cameras at a huge advantage over unconventional camera designs,' Tsai says, citing octopus eye mimicry.

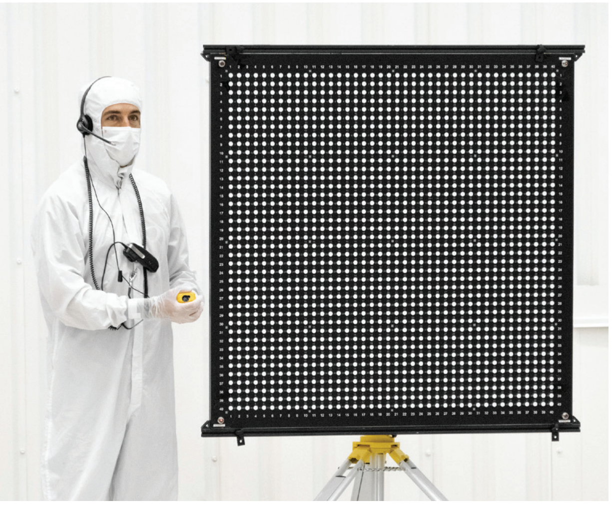
'What these multiple views afford you is depth,' he says. Regular cameras cannot measure depth directly, according to him.

'From my perspective, light-field cameras are going to be playing major roles in a variety of technologies,' he says, citing robot cars, among other fields.

Just don't expect Darwinian visual perfection any time soon.



The Mars 2020 rover undergoes an 'eye' exam after several cameras were installed. The rover carries everything from wide-angle landscape cameras to narrow-angle high-resolution zoom lens cameras



Nasa engineer Chris Chatellier stands next to a target board with 1,600 dots