MATHEMATICS MATTERS

# ExoMars: Autonomous Vehicles for the Red Planet

A new Mars rover is being prepared for launch in 2020 that will carry equipment capable of searching for life on the Red Planet. Mathematics is ensuring the rover can scour as much of the Martian surface as possible.

The question of whether life exists elsewhere in the universe is an age old one, but recent advances in technology have allowed us to scour the skies like never before. New telescopes have enabled astronomers to hunt out planets orbiting around other stars; and planets similar to our own have even been found.

But by no means have we given up the search in our own backyard – a fleet of probes and landers has been sent throughout the solar system to explore potentially habitable environments. One of the most studied worlds is Mars – a rocky planet like ours which sits slightly further away from the Sun. That distance means that today it is a cold, dry world with no liquid water on the surface, yet previous missions to the 'Red Planet' have revealed that this hasn't always been the case – it is likely that three billion years ago Mars had a vast ocean covering more than a third of its surface. The presence of water on another planet at roughly the same time as life was beginning on Earth is an intriguing prospect. Despite this potential, very few robots have been sent to Mars to look directly for signs of biology. Instead, rovers like Spirit, Opportunity and Curiosity have trawled the surface looking for evidence that Mars may have had suitable conditions for life, but not looking for life itself. That's about to change.

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The European Space Agency (ESA) is currently preparing for the launch of the ExoMars rover in 2020. The 310 kilogram machine should arrive at Mars in March 2021 and will be equipped with a two metre drill capable of digging down into the Martian soil and returning samples to the surface for biological analysis. However, unlike Curiosity, it won't be carrying a nuclear power source - it will rely on solar panels instead. It will have six months to explore before Martian winter descends and sunlight becomes a scarce commodity. It is hoped that the rover will "wake up" once the harshest season passes, but that can't be guaranteed. So ExoMars needs to explore as much of Mars as it can in the time available. And that means using mathematics to change the way the rover navigates.

To navigate across the Martian terrain, ExoMars will need to receive instructions from Earth via a satellite in orbit around Mars. However, the satellite only flies overhead twice a day. One of these passes is used to download instructions to the rover, the other to upload its data including images of the surface. Researchers could examine these images for potential dangers, before plotting the next day's path and sending it on ready for the next pass. But engineers can only plot a path of 20-30 metres. Any further and they

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can't be confident of safe passage around dangerous obstacles such as high boulders which could beach the rover and scupper the mission. What if the rover could drive itself without the need for human steering? All that would need to be downloaded on the first pass is a required destination for the rover to reach by the time the satellite comes round again. Such autonomous driving is exactly what ExoMars is designed to do, and mathematics plays a crucial role.

Two cameras are mounted on the 'head' of the rover, spaced 15 centimetres apart, which effectively allow it to 'see' in a similar way to humans. Each camera is capable of snapping a 1000 x 1000 pixel image of what's in front of it. Features such as rocks will appear in slightly different positions in each image. To see this for yourself, hold one finger in front of your face and close one eye at a time and you'll see your finger jump around. The first task for the rover's systems is to identify the pixel in the second image that corresponds to the same feature – say the middle of the top of the rock – in the first image. This 'stereo correlation' is done using a mathematical tool known as the sum of absolute differences (SAD) algorithm.

The bigger the gap between the corresponding pixels in each image, the closer the object is to the rover. This is an effect known as parallax, and again your finger is a useful way to picture it. Hold up one finger at an arm's length and close your left eye. Now line your finger up with something in the distance. Keeping your finger where it is, open your left eye and close your right eye. As before, you'll see your finger jump to the right. Get a rough sense of how far your finger moved with respect to the background object. Now repeat the procedure again but start with your finger much closer to your face. You should see that your finger jumps more when it starts closer to you. The mathematics of trigonometry can be used to turn the amount of 'jump' into an exact distance to the rock. This procedure is done for all one million pixels in ExoMars's field of view to build up a 3D map of its surroundings.

The rover's computers can then plot and drive a safe two metre path ensuring that it doesn't beach on a rock, get stuck on a slope or crash into an obstacle. The rover then takes two minutes to construct another map of its new surroundings before setting off on another two metre journey. This means the rover will be able to cover seventy metres in one day, compared to the thirty metres if it were driven via remote control. All that's required from the engineers is to download a desired destination on the first pass and by the time the satellite arches overhead again the rover should be there.

The performance of this system is currently being tested at the 'Mars Yard' in Stevenage. Part of Airbus Defence and Space, it takes the form of a sandpit the size of a basketball court that has been made to mimic Mars. A model of the rover is being put through its paces and made to drive itself across the room.

It is this autonomous navigation, rooted in mathematics, that will greatly increase the amount of Martian terrain that ExoMars can explore. Perhaps it will even help throw up something remarkable: evidence that there's more to the universe than just us.

A rover prototype pictured in the Mars Yard at Stevenage, UK.

**Credit:** Airbus Defence and Space 2014

# TECHNICAL SUPPLEMENT

## Stereo correlation and SAD algorithm

Due to having two cameras, ExoMars has stereo vision of a feature in front of it – say a rock. The pixels in the images that correspond to the rock will have a different brightness compared to the surrounding terrain. The ExoMars software is able to use this to identify which pixel in the first image corresponds to the same pixel in the second image. This is done by drawing a 'correlation window' around a fixed point in image one – say the top of the rock. The system then scans the second image, trying to find the same window there. The Sum of Absolute Difference algorithm is used to calculate a correlation criterion, C. The lower this number, the more the correlation windows match. Multiple windows are drawn, and a correlation function is obtained which describes how C varies over position in the image. The minimum of this function is the best approximation to where the top of the rock is in both images.

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