ROBOTS IN DEVELOPMENT BY JET PROPULSION LABORATORY

Tomáš Thér

Faculty of Mechanical Engineering, Brno University of Technology
Institute of Automation and Computer Science
Technicka 2896/2, Brno 616 69, Czech Republic
xthert00@vutbr.cz

Abstract: *This is a sample of the format of your full paper. For text in abstract and keywords, use Italics, 10pt. Leave one blank line after the Abstract.*

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1 Introduction

Space robotics has many different applications as of today and there are even more missions planned for the future. Space is an extremely hostile environment for humans, sending a robot to space is not only much safer but also cheaper than sending a human. There is no need for life support systems, the mission can take place over a long period of time and when it is done, the robot doesn't need to return to Earth. Robots are very useful for exploration and also for service and maintenance activities and in assisting astronauts in orbit.[8]

Jet Propulsion Laboratory (JPL) is a research and development centre for NASA, located in California. They are in close collaboration with the Caltech university. Their main field of operation is space exploration. Their past projects include satellites (like Explorer 1 which was the first American Earth-orbiting satellite), probes (for example Voyagers) and Mars rovers. This paper focuses on a few JPL's robotic projects in development, that use new ideas in the aim for further exploration of celestial bodies. The first section will be about new types of rovers for surface exploration and the second section will focus on concepts of underwater robotic explorers that could be used on icy moons in our solar system. [2]

2 Rovers

The most well-known use of robots in space is exploration of planets and other celestial bodies carried out by robotic vehicles called rovers. In current missions, rovers are used for exploration and scientific experiments that take place in easily accessible areas and most of the time not far from the landing site because the distances covered by these rovers are usually just a few tens of meters per day. Since it takes a signal to travel from Earth to Mars over 5 hours, the speed of these missions is dependent or rover's autonomy. A few of JPL's designs focus on the ability of rovers to traverse difficult terrain that current rovers can't reach. These places, that are interesting for planetary exploration, include craters, vents or caves. [8]

2.1 Axel and DuAxel

The main idea for exploring difficult terrain is the use of tethered robots. JPL and Caltech developed a robot called Axel (figure 1). It is a two wheeled robot that is connected by a tether to a landing craft that would be located on the edge of a crater. Axel would then drive down, collect samples and return to the lander. [5]

It uses three actuators - two for its wheels and third for control of its trailing link that keeps the robots body from turning around with the wheels and is vital for generating any forward momentum. The third can adjust the pitch for pointing cameras and in a so called tumbling mode, when the wheels aren't moving, reels an unreels the tether by spinning the rover's body around. The rover is symmetrical so it can drive upside-down. Due to it's two wheeled design it can also turn in place. The other benefit of this design is that it is simple, light and it doesn't require a lot of power to operate. Field tests already demonstrated that it can traverse sloped rocky terrain and even 90º vertical cliffs thanks to the tether attachment which can reel the rover. It can collect samples on slopes with maximum of angle of 40º. [5]

One big disadvantage of the original Axel rover is that it is limited by its tether how far it can go. It is capable of exploring a circle with 300 meter radius around the landing craft, which can be enough for some landing sites, but other times it would be desirable for the rover to be able to traverse several kilometers. Also since Mars has a very thin atmosphere, it is difficult to land the craft near the edge of a crater. To work

Figure 1: Testing of Axel on steep, rocky terrain [5]

around these issues, JPL is now designing a rover that is based on Axel called DuAxel (figure 2). It basically consists of two Axel robots connected by a central module. In driving mode DuAxel acts as a four wheeled rover with steering. Then there will the so called sit/stand mode that is still being integrated, when one of the Axels and the central module would stay stationary and anchor themselves while the other remaining Axel would go on to explore on tether. The docking procedure when the rover returns back to it's four wheeled driving configuration was successfully tested by manual operation, which was said to be quite difficult because of the need of synchronization of wheels, trailing link and tether spool. Future research will include methods for automated docking procedure which will probably be vision-based. [4]

Figure 2: Prototype of DuAxel [4]

2.2 PUFFER

This design (figure 3) focuses on exploration of tight and hard to reach spaces like caves or lava tubes that are potentially very interesting for further research, but today's rovers are unable to go there. For this purpose JPL is designing a rover called PUFFER which is an acronym of Pop-Up Flat Folding Explorer Robot. It is a two wheeled robot that is very small in size and its main feature is that it has a collapsible chassis that can fold its wheels and make the rover's profile smaller. This function is made possible by an integration of a textile layer in the rover's printed circuit boards that can be bent without breaking. Other than being beneficial for moving in small caves and similar parts of terrain, it is also more compact in its folded form, so there could be multiple PUFFERs as a payload being carried by a bigger rover, without taking too much space. Another advantage is that it can lower its center of gravity, making it better for traversing steep slopes. The disadvantage of PUFFER is that unlike other rovers it isn't protected against extreme cold and radiation that is on Mars. It would instead have its components like electronics, batteries and motors tolerant to radiation and cold. Technologies that would enable that are currently under development. [3, 9]

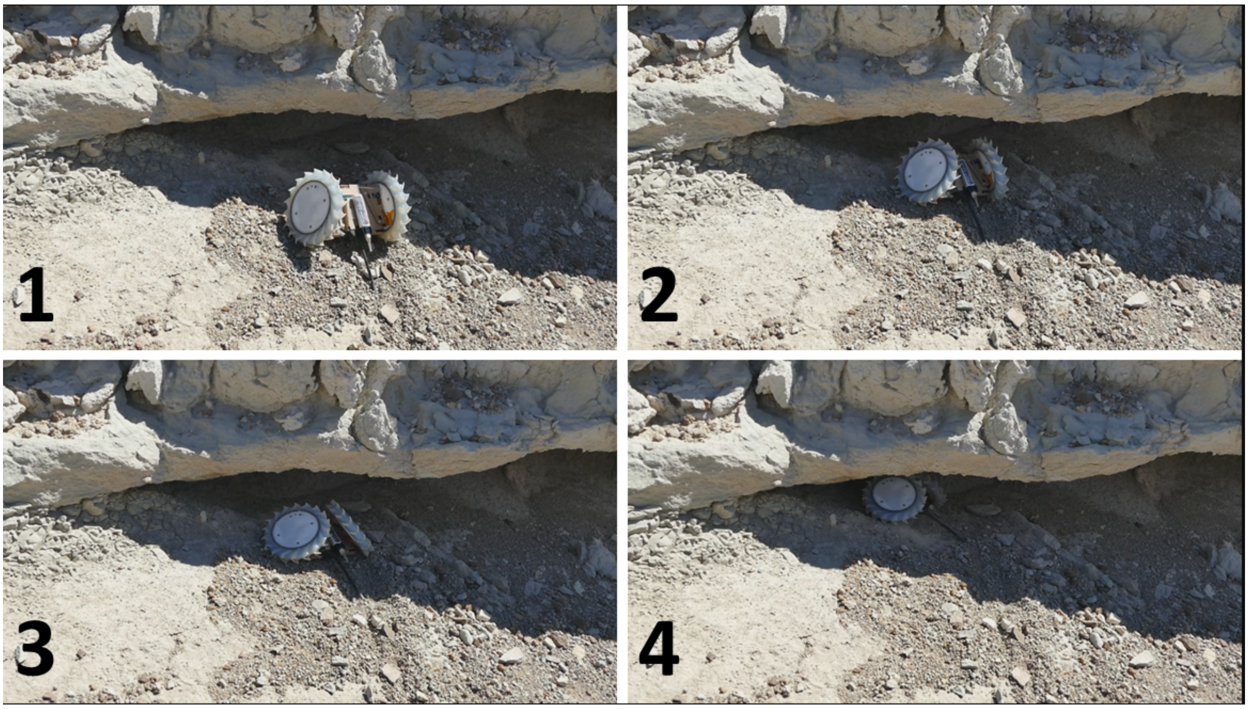

Figure 3: A-PUFFER folding to go under a rock [9]

3 Underwater exploration

Ice-covered moons in our solar system such as Europa, Titan or Enceladus all show evidence that there are subsurface oceans with liquid water which are perhaps the most probable places where microbiotic life could be found. One way of finding signs of life there is analyzing plumes that are erupting vapors and fluids to space from beneath the ice. These plumes are confirmed to be on Enceladus and thought to be on other icy moons as well. [11] Other way could be sending autonomous robots under the ice to collect data. There are a few proposed solutions for this application that are currently being developed.

3.1 BRUIE

BRUIE is an acronym for Buoyant Rover for Under-Ice Exploration (figure 4) and is currently being developed by JPL. The rover would go under the ice and then due to it's low overall density it would drive beneath the ice. This form of motion has quite a few benefits. Unlike other submersible crafts it isn't susceptible to currents that could cause it to crash into ice. It also doesn't need much energy to operate and can even safely shut down, so the mission could span over several months because the rover could be turned on for just a brief periods of time when it would take measurements. On Earth life often exists around the water-ice interface, so it is a good place to look for potential life. It would carry lights, cameras and instruments necessary for measuring parameters that are relevant to life as we know it, like dissolved oxygen, water pressure, temperature or salinity. [10]

It's movement was already tested under the ices of Alaska, Arctic and Antarctic. It was controlled via a tether, future versions would be operated without it. Other development goals are making the rover able to operate for months at a time and surviving greater depths. While this design seems promising, there would have to be a way to get BRUIE under the thick layer of ice. [10]

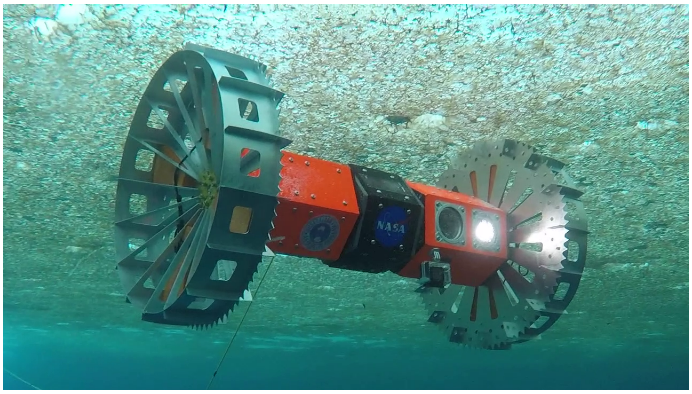

Figure 4: BRUIE traversing under the ice [10]

3.2 EELS

Exobiology Extant Life Surveyor (figure 5) is another robot that JPL is developing. The main idea is to use the plumes mentioned above as a pathway to the ocean below. Designing a robot capable of traversing these plumes is quite a unique challenge. It has to be able to traverse steep ice slopes and also propel underwater. For this purpose the concept has a screw propulsion configuration which works as tracks on surface and propellers under water. The robot has to fit into channels that are just over 20 cm thick, hence a snake-like design was chosen. Another problem is that gravity on Enceladus is 87 times weaker than on Earth so the robot would have to propel itself even downwards against the erupting vapors and liquids because it couldn't rely just on its weight to pull it down. It is also proposed that EELS would return back to the surface after collecting data and samples. A prototype has been built and went through some experimental testing. [1, 6]

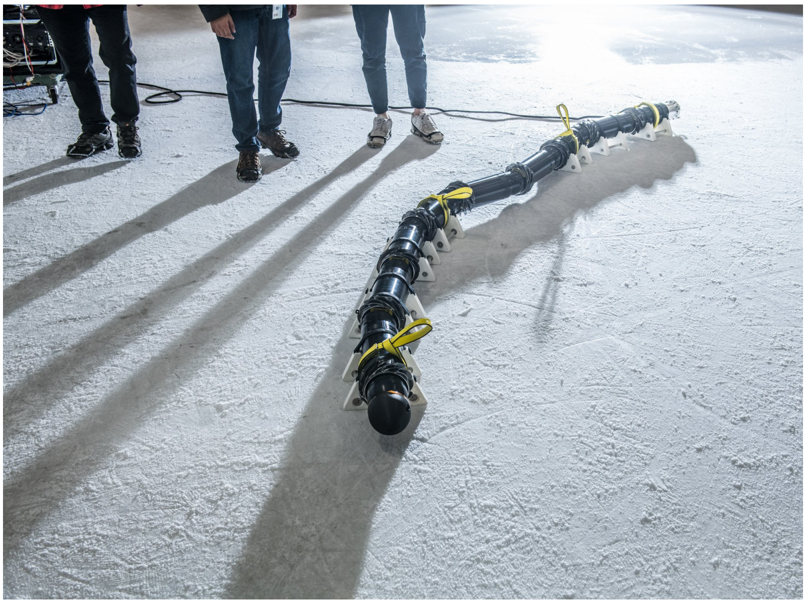

Figure 5: Testing of EELS prototype [6]

3.3 SWIM

Sensing With Independent Micro-Swimmers (figure 6) is a concept of a swarm of small under water robots, proposed by Ethan Schaler. The first part of the concept is a so called cryobot - a probe powered by a nuclear battery that would melt ice around it so it can get to the ocean. It would carry a number of robots that would be released once the probe reaches the ocean. Cryobot would be connected via a communication tether to a surface lander which would be communicating with researchers back on Earth. Since the SWIM robots are proposed to be just 60 to 75 cubic centimeters of volume, they would take just 15% of the probe's payload. So the probe could carry more scientific instruments of greater volume. Cryobot would not have any means of its own propulsion so after descent through the ice it would remain stationary. [7]

The micro-swimmers would all have their own propulsion systems, computers, communication systems and a variety of sensors ranging from temperature and pressure to chemical sensors detecting signs of potential life. There are quite a few advantages of a robotic swarm for this application. It can cover a wider area of the ocean so chances of finding signs of life are greater. Also if a robot is damaged it wouldn't jeopardize the mission because there are still others left. This project is now in Phase II funding from NASA Innovative Advanced Concepts, in the near future some 3D printed prototypes should be made and tested. [7]

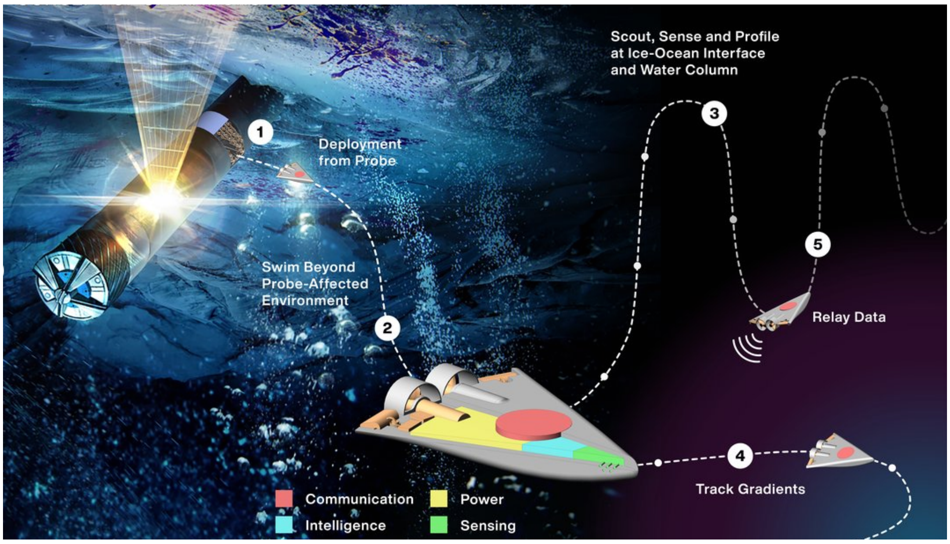

Figure 6: Illustration of the SWIM concept [7]

4 Conclusion

This seminar paper gave an overview a few of promising robotic concepts for space exploration being developed by NASA's Jet Propulsion Laboratory. When it comes to surface exploration, the focus is on rovers that would be able to pass difficult terrain because these places are often the most interesting and nowadays rovers are unable to do this task. The next area of interest is underwater exploration of icy moons in our solar system, that are the biggest candidates when it comes to potentially finding signs of microbiotic life. Unlike the developing rovers, proposed concepts that with this challenge would take place well into the future, because we need some more technological advancement and we are waiting for space probes to survey these moons more thoroughly.

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