The Lorpex Concept for Powerbursts

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ABSTRACT

A new concept is presented in high-technology which enables powerbursts to be generated in biomorphic robots and mobile platforms. A small, light-weight ISRU(In-Situ Resource Utilization) unit, carried on-board, generates a slow stream of fuel-oxidizer combination that can be rapidly consumed on demand. This powerburst can last ten to thirty seconds, and, can be ten thousand times the average power that is used to generate the ISRU stream. Typically, on the inner planets (up to Mars) and their moons (or asteroids), the steady, low power is supplied by a photovoltaic array that is required to generate a few watts only, and can thus be small in area and mass. The rapid consumption is in a mechanical device akin to the internal combustion (IC) engine. A powertrain transmits this power to the end-use device, which can be a drill, auger, crusher, wheels, scooper, or, other tools.

The basic design represents the efficient integration of the key components which include:

mobile platform chasis/structure, support and suspension
deployable PV array
the small ISRU unit
fuel and oxidizer storage bottles, and the associated plumbing
mobility control subsystem, which includes the attitude control devices
on-board sensors, which include a CCD camera
the end-use mechanical device.

A very detailed, scientifically accurate, computer animation has been developed for the entire operation sequence of LORPEX. Detailed engineering calculations are also performed on the mobility system which includes the attitude control system. Plots are generated that show the range and endurance while exploring a typical target planet such as Mars.

At the time of this workshop, the LORPEX hardware is at its third generation revision. [It will be recalled that the first generation LORPEX was displayed at the Planetfest97 in Pasadena.] The PV array deployment is through an efficient modern technological innovation, popularly known as *Muscle Wires*. The ISRU unit of choice is MIMOCE, which offers significant advantages over solid oxide electrolyzers (SOXE, or, popularly known simply as zirconia technology), Sabatier reactors and other variations; MIMOCE operates at temperatures below 450^{o}F, has no problematic seals, and handles thermal cycles with ease.

The most important aspect of LORPEX is its *scaleability*, which is accomplished through its simple modular design. Future modifications that promise the attainment of full-function under 1 kg (total) will be presented.

The LORPEX concept for powerbursts

(Locally Refueled Planetary Explorer)

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1st NASA/JPL WORKSHOP ON BIOMORPHIC EXPLORERS FOR FUTURE MISSIONS

Pasadena, California

19-20 August 1998

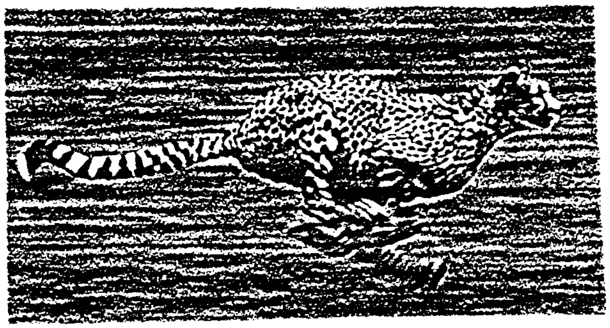
THE CONCEPT

- **Energy issues are straightforward**
  - PV, with back-up batteries
  - RTG, RHU,.....
  - Novel Concepts (lower TRL's)

- ***Power* is the real issue**
  - "power bursts" often necessary
  - not available from sources above
  - or, very heavy mass penalty,
  - or, (complex)multiple missions

INSPIRATION

- **Dolphins, which feed on small fish, convert the chemical energy of food into powerful bursts of muscular energy**
- **Powerful and highly coordinated skeletal muscles of the cheetah enable it to attain speeds over 70 MPH for short bursts**



ENERGETICS & POWER NEEDS

CO_2	=	CO	+	$\frac{1}{2}O_2$	
44		28		16	gm
-393.522		-110.53		0	KJ

16 gm O_2 needs 282.992 KJ

$$\frac{282992}{16} = 17687\frac{KJ}{kg} \Rightarrow \frac{17687000}{10 \times 3600} W = \boxed{491.3W} \quad \text{for 10 hrs}$$

FOR 10 Hrs OF OPERATION: 1200 ml/min⇒300A CURRENT AT 1.63 V
[UA DATA: 2V OR 78% EFFICIENCY]

H_20	=	H_2	+	$\frac{1}{2}O_2$	
18		2		16	gm
-286.827(l)		0		0	KJ

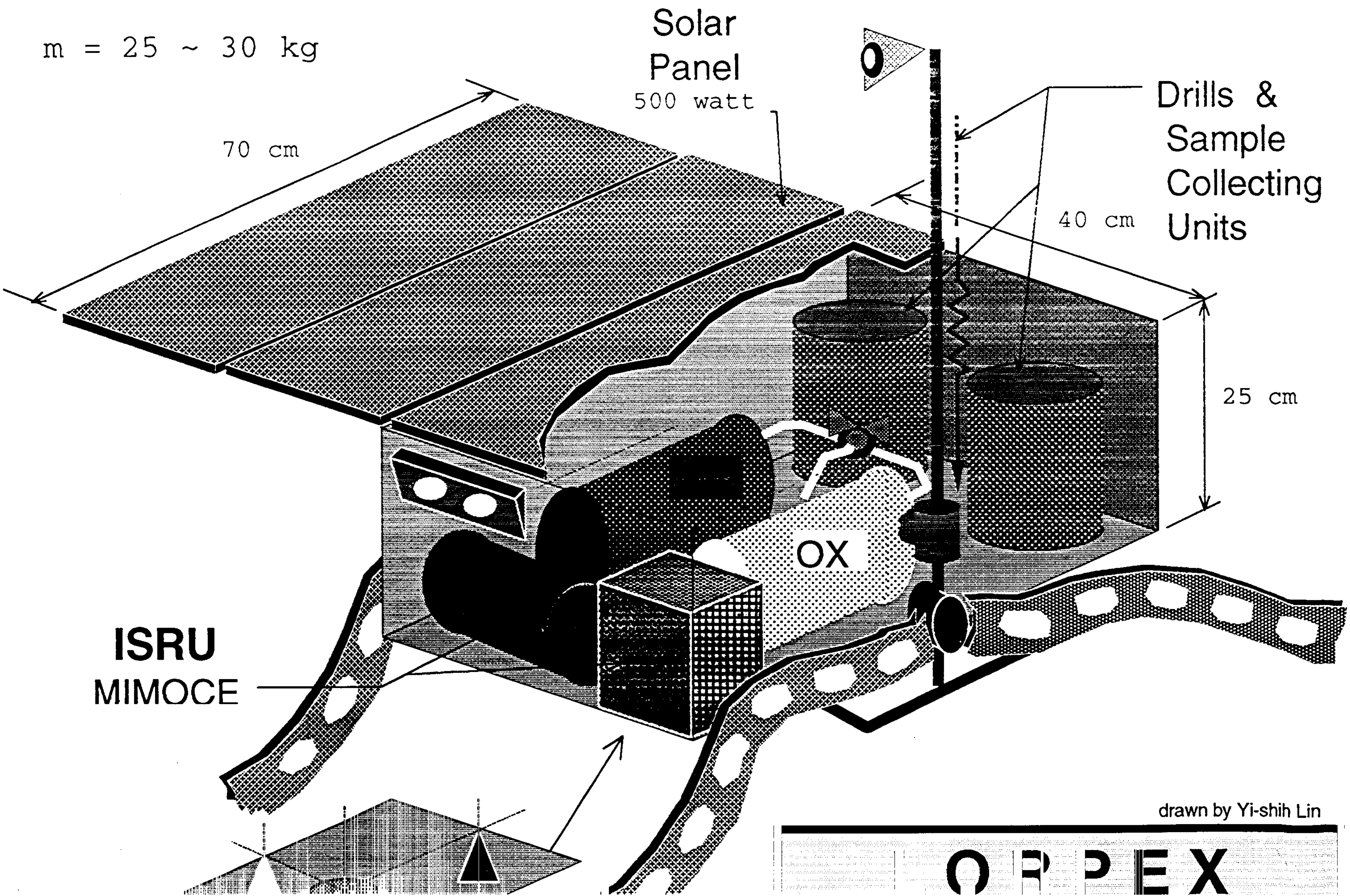
16 gm O_2 needs 286.827 KJ

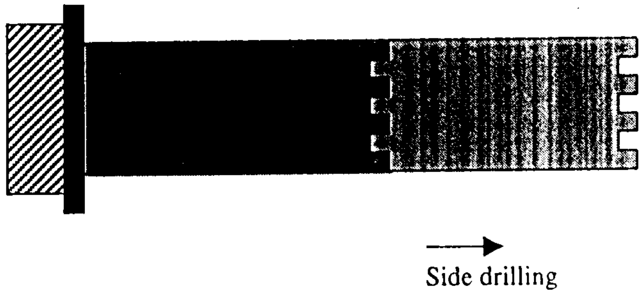
$$\frac{286827}{16} = 17926\frac{KJ}{kg} \Rightarrow \frac{17926000}{10 \times 3600} W = \boxed{497W} \quad \text{for 10 hrs}$$

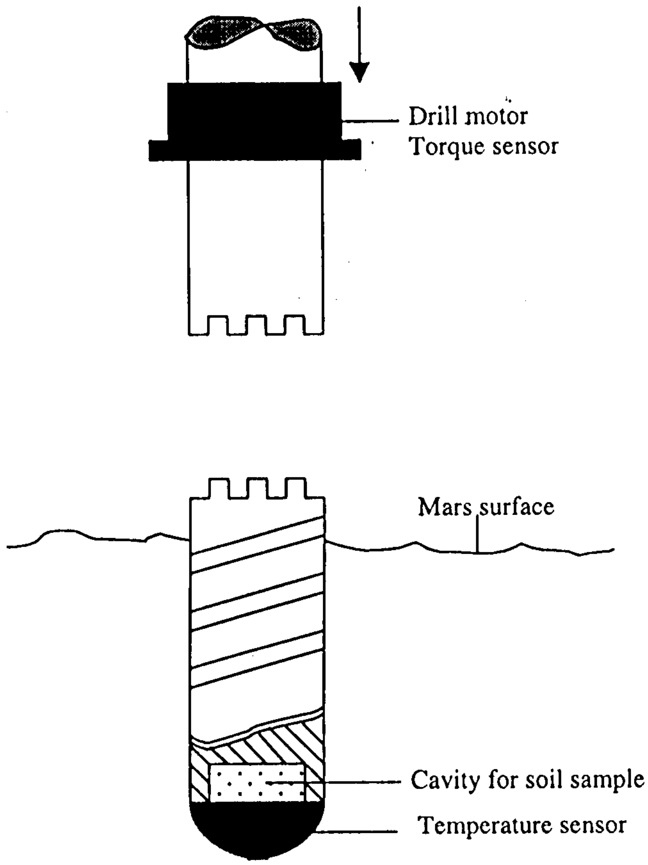
$$D\rho \frac{d^2}{dx^2}\left(\frac{a}{\rho}\right) - \dot{m}\frac{d}{dx}\left(\frac{a}{\rho}\right) + \dot{\omega} =$$

$$k\frac{d^2T}{dx^2} - \frac{\dot{m}c_p}{A}\frac{dT}{dx} + \dot{\omega}Q' = 0$$

$$\dot{\omega} = B[a]e^{\frac{-B}{RT}}\left(\frac{moles\,CO_2}{m^3 s}\right)$$


m = 25 ~ 30 kg
Solar Panel
500 watt
70 cm
40 cm
25 cm
Drills & Sample Collecting Units
OX
ISRU
MIMOCE
drawn by Yi-shih Lin





Down drilling

Additional tools:
- Grabber
- Scoop
- Saw
- Claw

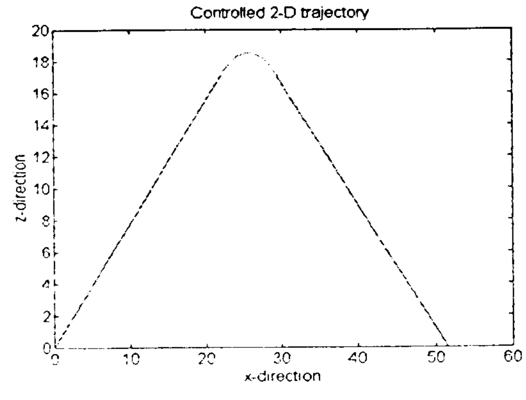
ATTITUDE CONTROL\TRAJECTORY

-ATTITUDE CONTROL:

- Pitch and roll: Bang-off -bang logic control.Limit cycle with two powered phases and two inertial phases.Accuracy: 5 degrees
- Yaw:On-off control.Only powered phases because related to the control trajectory Accuracy: < 1 degree.
- Propulsion system for attitude:Cold gas CO2/O2

-TRAJECTORY AND CONTROL: Thrust-coast-thrust

- On-off with the main thruster in vertical direction (to close the “loop”)
- On-off in x direction using 4 thrusters (both for yaw and x-control)
- No control in y-direction



A Brief Digression

- Need a Figure-of-Merit (FoM)
- Screening competing components, and ranking the overall mission architectures
- Must recognize changing/evolving technologies, and priorities
- Must be rational and quantitative

New Technologies

- ***Muscle Wires**: force/weight ratios of tens of thousands*
- ***LORPEX:** enables powerbursts (million times average, for seconds)*
- ***PV-Aerobots:** controlled coverage of large terrains*
- ***Hybrids:** safe, reliable, compact ascent vehicles*
- ***Hybrisols:** two-stage motor advantages in a single motor*
- ***MIMOCE:** extracts fuel+oxidizer from CO_2, operating at $<650^\circ$ C*

- ***FoM Software:** ties it all together, and includes risk factors*

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JPL TU OFFICE

Making Fuels Onboard for Power Bursts in Explorator Robots

Products of solar-powered electrolysis would be slowly accumulated for occasional rapi consumption.

NASA's Jet Propulsion Laboratory, Pasadena, California

In-situ resource utilization (ISRU) equipment would be incorporated into remotely controlled exploratory robots, according to a proposal, to generate fuels and oxidizers to extend operational ranges and to provide occasional bursts of power for actions like drilling into the ground, hopping over obstacles, flying, or transmitting data on high-power radio signals. In its original form, the proposal is directed toward the development of a locally refueled planetary explorer (LORPEX) -- an exploratory robot that could function on a remote planet, without need for fuel transported from Earth and without need for heavy, bulky power-generating equipment that would be utilized to full capacity only occasionally. The proposal might also be applicable to remotely located scientific instruments (e.g., meteorological instruments) on Earth, or even to automobiles.

The basic idea is that instead of using heavy source that would consume transported fuel to generate high power, one would use a lightweight ISRU unit that would slowly generate a fuel and oxidizer from natural material in its vicinity. The fuel and oxidizer would be stored in lightweight containers (e.g. balloons). The stored fuel could then be consumed rapidly in a lightweight engine or fuel cell to satisfy the occasional demand for high power.

Typically, a LORPEX and its ISRU unit would be powered by solar photovoltaic cells (see figure). The ISRU unit would generate a fuel and oxidizer through electrolysis. On Earth, Venus, or Mars, for example, one could use a solid-oxide electrolyzer with platinum electrodes to split atmospheric carbon dioxide into carbon monoxide (the fuel in this case) and oxygen. Alternative ISRU units might include Sabatier reactors that would produce hydrocarbon fuels from locally available natural materials; such units might prove useful for enhancing the performances of automobiles.

Two proposals that depart somewhat from the basic ISRU/LORPEX concept offer important potential benefits in terrestrial applications. One of these proposals calls for the use of ISRU units to partly detoxify automotive exhaust by converting CO and CO_2 to O_2 and C. The other proposal calls for sending LORPEX-like robots to hazardous waste sites to detoxify dangerous substances.

This work was done by Kumar Ramohalli and Massimiliano Marcozzi of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, write in .. on the TSP Request Card.*
NPO-20269

figure caption:
(1 column)
Solar Energy Collected by Photovoltaic Cells would be converted to chemical energy — typically by electrolysis of an oxide to produce a fuel and oxygen.

Professor, students study self-fueling planetary exploration possibilities

by Jeff Harrison
News Services

There is one thing all space projects, from the Soviet Union's Sputnik to the recent Mars Lander and the upcoming Cassini mission to Saturn have in common.

All of them depend on fuel and other energy sources brought with them from Earth. Run out of gas away from terra firma and the lights go out.

And stay out.

The only exceptions are if you happen to have solar panels and are within squinting distance of the sun, or you can find enough fuel at hand to keep things going.

The latter is what Kumar Ramohalli and his students have been working on for several years. Ramohalli, a professor of aerospace and mechanical engineering, have put together a prototype unmanned rover called LORPEX, or Locally Refueled Planetary Explorer, which is designed to extract the raw materials of other planetary bodies and manufacture fuel from them.

The problem with exploring outer-space, says Ramohalli, is that a very significant portion of any spacecraft is the fuel needed to lift it out of Earth's gravitational pull. In the case of exploratory vehicles, like the Mars Pathfinder, extra fuel is also needed to power their movement on the surface of a planet, and to conduct experiments. It's an idea that has been around for some time, but is only recently being considered seriously.

Ramohalli, who was just recently elected to the Engineering Sciences section of the International Academy of Astronautics, has been investigating the use of *in-situ* resources at the UA Space Engineering Research Center (SERC), looking at everything from "cooking" lunar soils to tapping into carbonates on asteroids and other planetesimals. The likelihood that a self-fueling vehicle will be used for exploration is improving. The latest generation of oxygen/fuel production robots, for instance, have increased 10-fold improvement in production rates and energy use compared to units built a decade ago.

"Far more important," says Ramohalli, "is the demonstration of its thermal and mechanical robustness, so that mission planners can seriously consider it for inclusion in future spacecraft."

He says the important basic issues of energy, power, thermal insulation and electrochemical performance have been clarified through sound theory. The entire Lorpex robot weighs 21 kg. (46 pounds), and generates enough propellant (fuel and oxidizer) in one year for both planetary exploration and to return to Earth with 100 grams of Martian soil or rocks.

In theory it sound pretty simple. The solid oxide ISRU (In-Situ Resource Utilization) unit extracts oxygen and a simple fuel, like carbon monoxide (CO), from the Martian atmosphere using solar energy harnessed through on-board photovoltaic cells.

By storing this simple propellant, a robot could generate bursts of energy sufficient enough to march around or over rocks and other obstacles, or drill into Mars' surface for samples, bring them back and return them to Earth for further examination.

Displaying the Lorpex is Professor Kumar N. Ramohalli with Christopher Green, graduate student; Tyler Strankik, undergraduate student; Vanessa Duke, undergrad; and graduate students Ji Qi, Massimiliano Marcozzi and Yishih Lin.

The Lorpex design is a[…] enough, says Ramohalli, t[…] incorporate future advanc[…] technology, such as altern[…] ISRU units, such as a Sab[…] reactor that produces hydr[…] bon fuels for higher perfor[…]mance.

Ramohalli credits the […] lineage of past rovers pion[…] at the NASA Jet Propulsio[…] Laboratory (JPL) in the de[…]opment of Lorpex. In fact, Ramohalli and his student[…] displayed Lorpex at the Planetfest, held last July i[…] downtown Pasadena, Calif[…] near JPL, during the Mars Pathfinder landing. Many stopped by, including curr[…] and former astronauts, sci[…]tists and NASA administr[…] signed a poster Ramohalli intends to keep as a souve[…] the visit.

Lorpex will be on disp[…] Sunday, Oct. 5, noon-5 p.m[…] the Pima Air and Space M[…]seum, located at 6000 East Valencia Road. The museu[…] holding a technology fair […] from Hughes and other ma[…] as well as the UA Imager f[…] Pathfinder (IMP) and Lorp[…]

This article first appeared i[…] in LQP On Line Sep[…]

SUMMARY

- powerbursts are necessary
- difficult to provide with SoA technologies
- the concept of LORPEX can help
  - accumulate energy *slowly* with SoA (PV,...)
  - consume energy *rapidly* in distributed "limbs"
  - similar to ATP-ADP conversion in bio systems
  - millionfold power....over.....average
  - hardware demonstrated; need support

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