Beyond Traditional Energy Planning: The Weight of Computations in Planetary Exploration

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Context

Past Mars rovers have had extremely limited computational resources due to large temperature changes and high radiation levels [1]. Yet, future space robots are expected to automatically learn features of the terrain to predict future actions.

The increasing demand for autonomy challenges the traditional energy planning model for planetary exploration robots–each mission to Mars uses more control software than all the ones before it combined [2].

Approach

The proposed approach–a **mission-aware energy planning strategy** that highlights **computations**–addresses increasing demands for autonomy and their implications to the energy planning for planetary exploration robots.

It focuses on aspects of a space mission such as its periodicity and uncertainty, splits the energy into the energy due to the trajectory traveled and the computations performed, and potentially extends mission time by changing the trajectory and computation specific parameters.

Energy due to computations

The energy cost of the computations in a hypothetical future scenario–a **space robot** that **detects patterns on Mars using a convolutional neural network**–can be evaluated using a modeling tool [3], that measures the energy cost difference $d(\mathbf{s}_k)$ of some computations $\mathbf{s}_k$ and uses a linear regression for the remaining.

The approach varies such an energy cost using quality of service within given boundaries–one can vary the frames-per-second rate of the detection algorithm.

Trajectory and computation parameters account for the change in energy, caused by variations in control $\mathbf{u}_k$.

Energy due to trajectory

The energy cost of the motion can be evaluated using trajectory explicit equations $\varphi : \mathbb{R}^2 \to \mathbb{R}$, an abstraction of the path to follow of a mission.

Given $\mathbf{p} \in \mathbb{R}^2$, the set $\mathcal{P} := \{\mathbf{p} : \underline{c} \leq \varphi(\mathbf{p}) \leq \overline{c}\}$ discloses all the possible paths within the boundaries.

A concept used to select c s.t. $\varphi(\mathbf{p}) + c$, $\mathbf{p} \in \mathcal{P}$ with the highest energy value under the energy budget constraints.

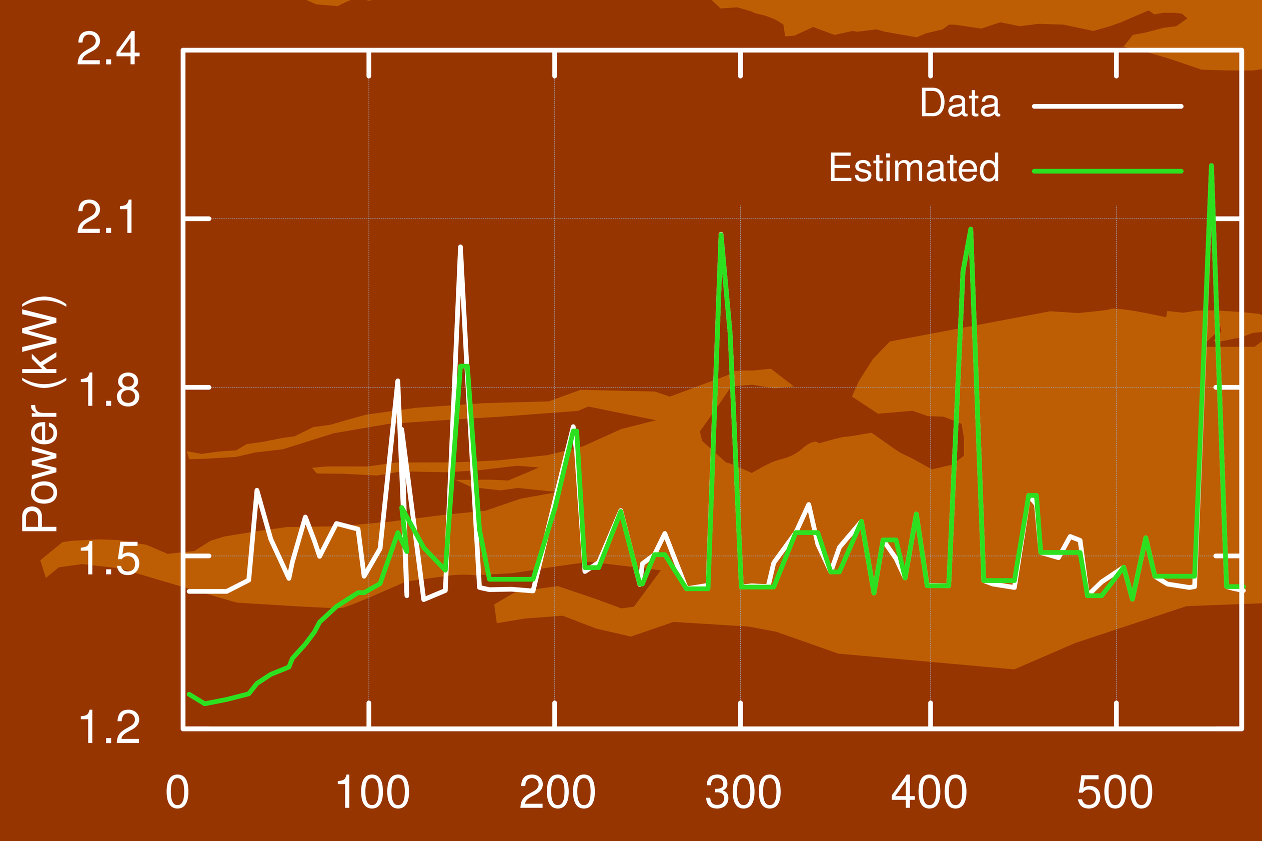
The direction to follow is derived using vector field [6]

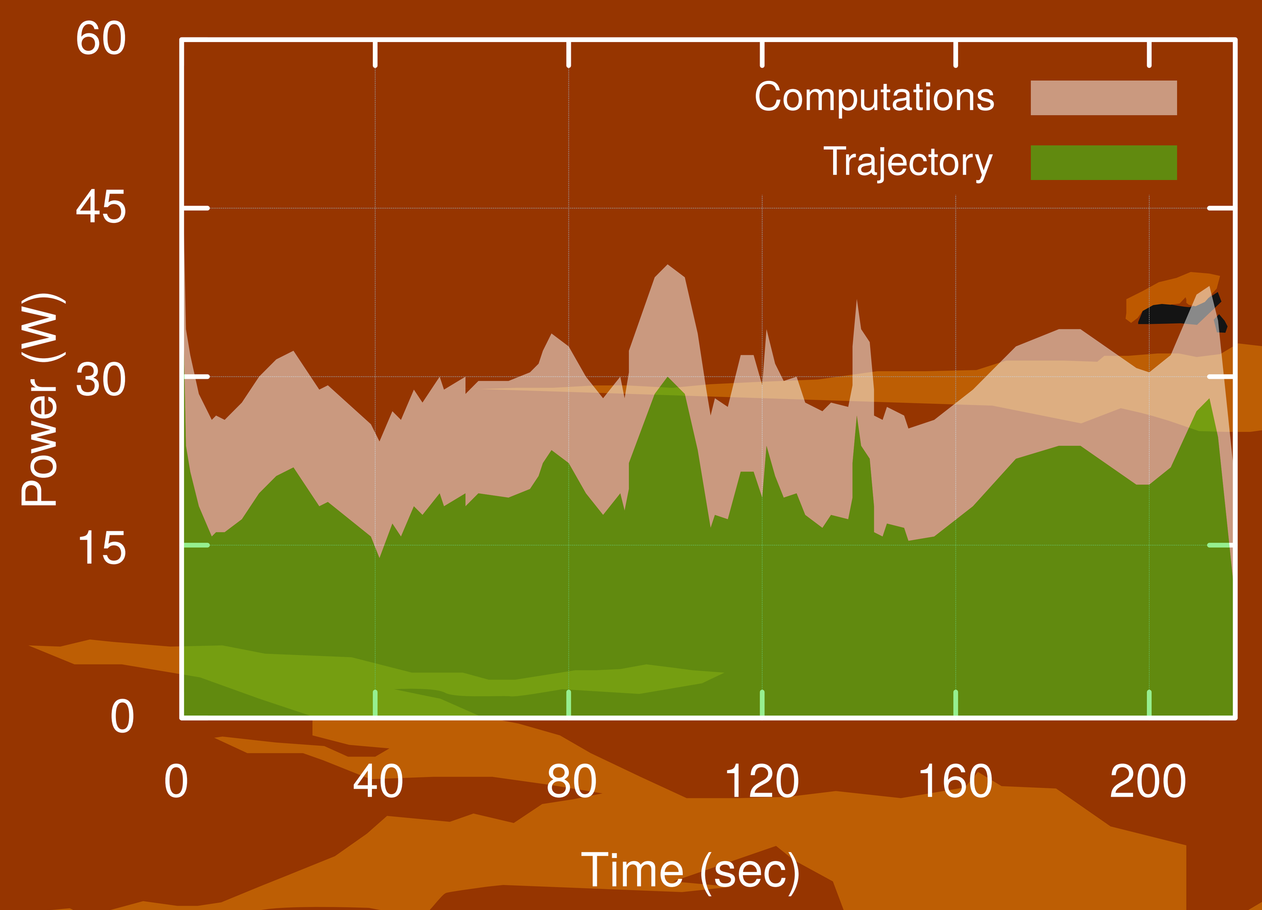
$$\dot{\mathbf{p}}_d(\mathbf{p}) := \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \nabla(\varphi(\mathbf{p}) + c) - k_e(\varphi(\mathbf{p}) + c)\nabla(\varphi(\mathbf{p}) + c).$$

The total energy is derived using a harmonic oscillator–an equivalent representation of a Fourier series of order r–and a state observer for the estimation of the energy state $\mathbf{q}$

$$\begin{cases} \mathbf{q}_{k+1} &= \begin{bmatrix} 1 & & & \\ & A_1 & & \\ & & \ddots & \\ & & & A_r \end{bmatrix} \mathbf{q}_k + \begin{bmatrix} 1 & & \\ & 0 & \\ & & \ddots \\ & & & 0 \end{bmatrix} \mathbf{u}_k + \mathbf{w}_k \\ y_k &= \begin{bmatrix} 1 & 1 & 0 & \cdots & 1 & 0 \end{bmatrix} \mathbf{q}_k + v_k \end{cases},$$

$$\mathbf{q}_k = \begin{bmatrix} a_0 & a_1 & b_1 & \cdots & a_r & b_r \end{bmatrix}, \ \mathbf{u}_k = \begin{bmatrix} d(\mathbf{s}_k) & c_0 & \cdots & c_{\rho-1} \end{bmatrix}, \ A_n = \begin{bmatrix} 0 & \frac{n}{\xi} \\ -\frac{n^2}{\xi^2} & 0 \end{bmatrix}.$$





Six-legged and rover planetary robots. Above, the power evolution simulation of the Ambler [4]–a six-legged robot for autonomous traversal of Mars-like terrain–along with the estimate of its energy. Below, the hypothetical cost of computations of a tiny rover [5].

Acknowledgments

This work is supported and partly funded by the European Union's Horizon2020 research and innovation program under grant agreement No. 779882 (TeamPlay).

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