Design and Testing of Clustered Components for Modular Spacecraft Architectures

Admission to third year

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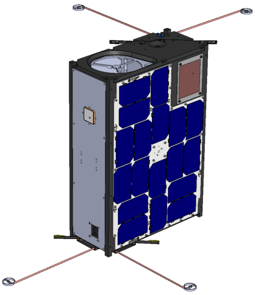
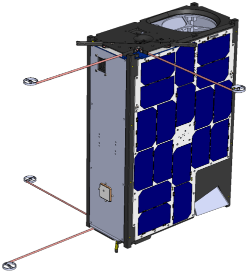
6 Months at Tyvak Int.



(a) FSS Cat 5A



(b) FSS Cat 5B

Payloads:

1. Soil moisture and sea ice mapping
2. Optical Inter Satellite Link
3. RF federation experiment

1. Hyper-spectral earth imaging
2. Optical Inter Satellite Link
3. RF federation experiment

Immediate benefits of Redundancy

Cluster ≈ Redundancy ⇒ Degrees of freedom for optimization.

Maximize Reliability

- Component failure is masked by redundancy.
- It assumes **independent** failures.
- **Required** for safety critical missions.

Figure: Iperdrone; a 6U cubesat sponsored by ASI to assess the ISS

Maximize Performance

- Components are coordinated to maximize some function.
- Can reduce cost at fixed performance.

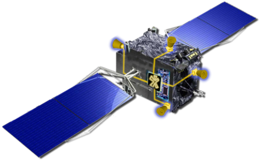


Figure: The Argo concept, based on redundant COTS start trackers.

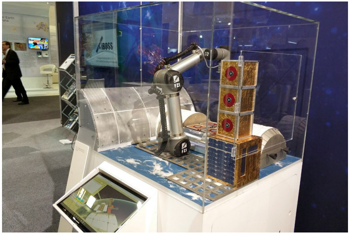
Drivers that may lead to clusters

Modular designs:

- Design with basic independent units
- Re configurable and versatile
- The core function of each block will be redundant.

Simple Scaling proprieties:

- Hardware development is expensive
- Hardware testing is **more expensive**
- $\Rightarrow$ Develop once, then copy-paste for scale.

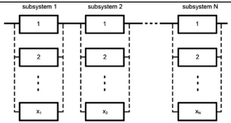
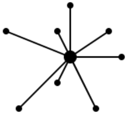


(a) iBoss demo at IAC 2017

(b) Multiple Merlin engines in the FH

Reliability Vs Performance

Assuming the spacecraft has some redundancy, the classical architectures revolve around the ideas of parallelization or central control

Architecture	Reliability	Performance
	Good	As good as the individual component
	Failure modes **not independent**, very hard to characterize (worst case: single point of failure)	Good

Can we have **both reliability and performance**?

Overview

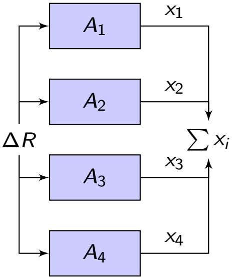


Figure: Cluster of 4 agents

Assumption and nomenclature

- Assume Single Input - Single Output Agents
- No communication allowed
- All agent behave *nominally* in the same way
- The agent i proposes a output x_i and updates it according to a specific rule

Algorithm:

1. Starting from $x_i(t = t_j)$
2. Measure the global propriety ΔR
3. Compute $x_i(t_j + \mathrm{d}t)$ according to Eq. 1
4. Repeat from step 2

$$\frac{\partial x_i}{\partial t} = k \cdot \Delta R + \eta \cdot \frac{\partial \mathcal{C}}{\partial x_i} \tag{1}$$

Visual Idea of behavior

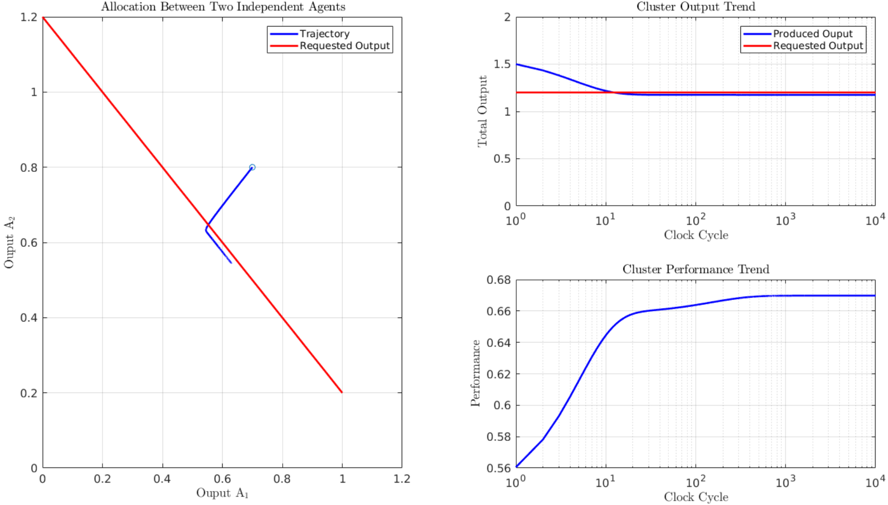


Figure: Numerical simulation with two arbitrary actuators

Visual idea of Stability

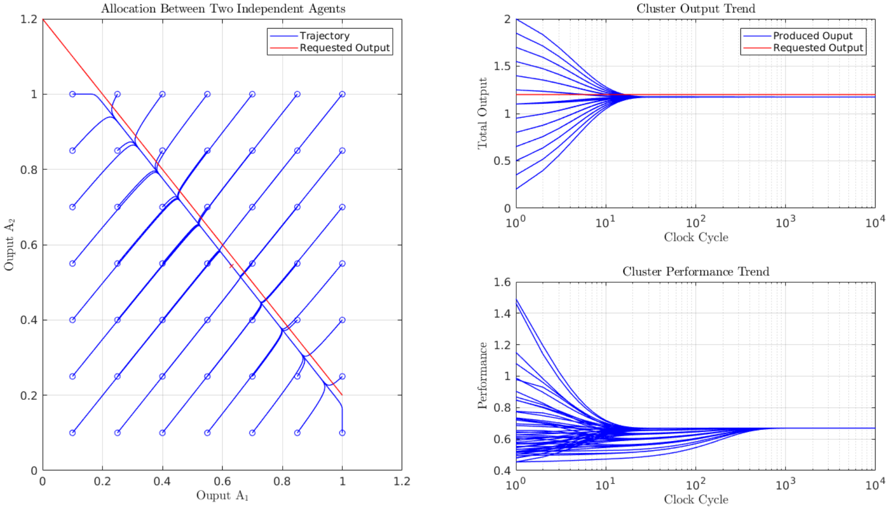


Figure: Intuition for stability with two arbitrary actuators

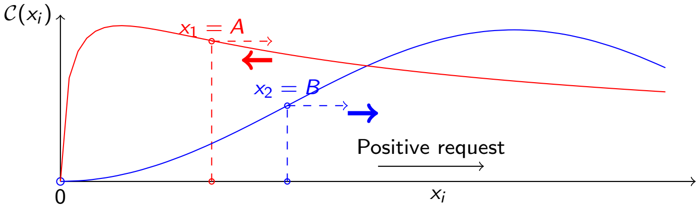
Intuitive Explanation

$$\frac{\partial x_i}{\partial t} = k \cdot \Delta R + \eta \cdot \frac{\partial \mathcal{C}}{\partial x_i}$$

- ΔR is a global propriety of the system
- $\mathcal{C}$ is a performance function, *estimated* internally by each agent
- k and η are positive constants that need to be tuned

Example:

- Starting condition $x_1 = A$, $x_2 = B$
- The system is not producing enough $\Delta R = R - A - B > 0$
- Both agent increase production, but in different ways



Implementation details,measuring $\mathcal{C}$

The curve Watt-Torque, $\mathcal{C}$ depends on

- Engine *constants* (k_v, k_c, R etc)
- Rotor angular velocity ω

By measuring both power consumption and torque output, it is possible to update the estimates for the system constant using standard statistical tools.

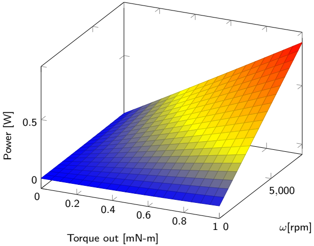
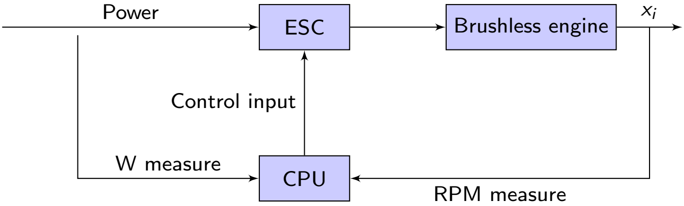


Figure: Electrical power required given T and ω



Benefits of insulation

Due to the constraints of independence, we have that

- The $\mathcal{C}$ function is computed locally
- The $\mathcal{C}$ is used, in real time, only locally

There is no need for these information to leave the subsystem.

- A lot of data can be gathered and processed locally, without added complexity for the system.
- Real time characterization of the agent performance, thus eliminating slow drift errors.
- Capability to autonomously adapt the behavior of agent to better suite environmental conditions.
- Real time monitoring the agents health and deterioration.

High level scheme for the individual agent

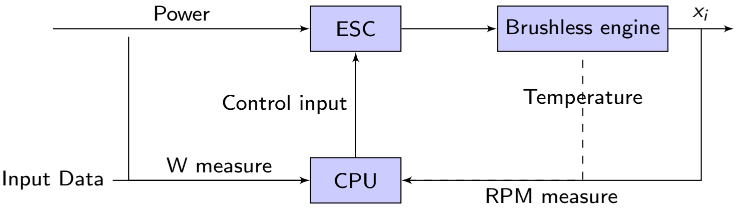


Figure: High level scheme for the Hardware demonstrator

The temperature monitor on the engine will be used to validate the concept of statistically enriched regression model.

Conclusions

- Redundancy is pervasive in the space industry, either as a requirement or as a consequence of best practices.
- There exist at least one class of decentralized control algorithms able to maximize both reliability and a target performance function.
- A simple hardware demonstrator is under development to validate the implementation of the control schemes above.

List of Conference Papers and Presentations

- IAC 2017, Adelaide. Presentation: Multibody tether concept for asteroids capture. **Francesco Feltrin**, Laura Bettiol , Lorenzo Olivieri , Alessandro Francesconi.
- IAC 2017, Adelaide. Presentation: Economic Value Proposition of Modular Assemblies. **Francesco Feltrin**,Lorenzo Olivieri, Francesco Sansone, Alessandro Francesconi.
- 4S Symposium 2018, Sorrento. Presentation: Enabling ENVISAT deorbiting: a multi-spacecraft mission for inspection, capture, and detumbling. Lorenzo Olivieri, **Francesco Feltrin**, Andrea Valmorbida , Riccardo Mantellato, Enrico C. Lorenzini, Alessandro Francesconi.

Thanks for the attention!

Questions?

Broader Applications

In some cases, the benefit of redundancy might still not outweigh the costs of increasing system mass and volume.

Generalization:

- For some subsystem it is possible use the secondary effects of the actuators to perform an opportunistic thermal control.
- All subsystem produce heat.
- They could be coordinated to support an thermal control system.
- Using the framework of MIMO system, similar results can be achieved **without explicit coordination**.

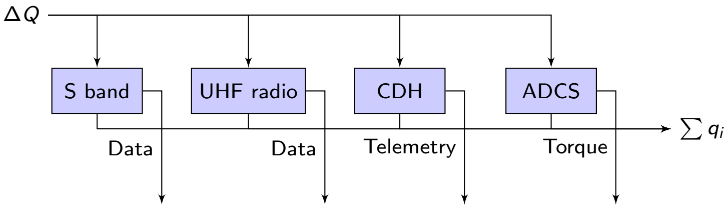


Figure: Redundancy in the thermal control system due to inefficiencies