Self-Reconfigurable Robots for Space Exploration

Effect of compliance in modular robots’ structures on the locomotion

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Motivation

- **Final Goal**: Modular robots for space exploration
- **Target environment**: Mars
- **Means**: Improve locomotion using compliant elements inside the structure
Project Design Choices

- **Structure**: Choice between Snake, Tripod, **Quadruped**
- **Simulation platform**: Webots
- **Hardware**: Bioloids kit
Project Design Choices

- Fixed structure, only stiffness varied
- Compliant element between every two joints
- Effect of compliance on the stability of the structure
Main steps

Step 1: Modelling in simulation
Step 2: Gait parameters optimization
Step 3: Robustness to external disturbances
Step 4: Rough terrain with compliant elements
  a) Systematic searches and PSO
  b) Analysis
Step 1: Modelling in simulation

Modular model

- Multiple “Robot” nodes
- Each module is one servo motor and one compliant element
- Compliant elements modeled as ball joints
- “Connector” nodes
- Modules snap together
- Each module is controlled by a controller, plus a supervisor
Step 1: Modelling in simulation

Compliant element

Servo motor
Step 1: Modelling in simulation

Terrain modelling

- Combine 13° slope with random roughness
- Max height: 5%, 10% of leg length
Step 1: Modelling in simulation
Step 2: Gait Parameters optimization

- Optimize controller parameters for speed and stability
- Stiff structure
- Motors are controlled with CPG
- Three parameters per motor (Amplitude, offset and phase)
- Symmetry between pair of legs
- 13 open parameters
Step 2: Gait Parameters optimization

- Optimization using PSO
- Each run takes 30 seconds, on 5% rough terrain
- Maximizing Fitness function

\[ F = \frac{D}{1 + d} \]

\[ R = \sum_{timestep} (|\text{roll}| + |\text{pitch}|) \]

- D - Advance in the direction of movement
- d - Deviation from a straight line
- R - Stability evaluation
Step 2: Gait Parameters optimization
Step 3: Robustness to external disturbances

- Flat terrain, previously found gait parameters
- Test robustness to external forces
- Three forces at random times
- Norms of 3, 4, and 5N
- 100 repetitions
Step 4: Rough terrain with compliant elements

- Using compliant elements
- 7 Systematic searches (All units are Nm/rad)
  - 5% and 10% roughness:
    - \((10, 100, 1000)\), \((1, 10, 100)\), \((1, 10^{0.5}, 10)\)
    - Only 5%: \((1, 10^{1/3}, 10^{2/3}, 10)\)
- 2 PSO: 5% and 10% roughness
  - Stiffness:
    - 1 - 50
- Above 100Nm/rad practically rigid
Step 4: Rough terrain with compliant elements

After examining the data, two hypotheses:

1. The inner compliant elements of the structure should have higher stiffness

2. The outer compliant elements of the structure should have lower stiffness

Both hypotheses exclude the front leg
Dataset 1: Systematic search, 5% Roughness, 1-10-100 Nm/rad

Clustering by threshold

Threshold: median = 0.213 \times 10^{-3}
Dataset 1: Systematic search, 5% Roughness, 1-10-100 Nm/rad
Dataset 1: Systematic search, 5% Roughness, 1-10-100 Nm/rad

Grouping compliant elements by position in the structure
Different clustering to explore the inner-outer patterns

Dataset 1: Systematic search, 5% Roughness, 1-10-100 Nm/rad
Clusters are significantly different

p-value = 4.09 \times 10^{-57}

Dataset 1: Systematic search, 5% Roughness, 1-10-100 Nm/rad
Dataset 3: PSO, 5% Roughness, 1 - 50 Nm/rad

Best five solutions

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Videos

PSO
Videos

Worst case (Database 1)
Conclusions

Hypothesis 1: Supported by all the tests

Hypothesis 2: Present in many tests
Not as clear

Structure should not be too soft
Physical interpretation

Stiff inner modules for efficient transfer of the motors’ energy

Soft outer modules for shock absorbing and improving traction by adjusting hold

Structure too soft can lose its grip in the terrain

Front leg has contradictory roles - No conclusive patterns
Conclusion and Future work

Optimal stiffness value depends on position in the structure

Improving the symmetry of the quadruped

More dynamical gaits and structures

Get closer to Martian terrain
Thank you for your attention