Automated Design of Robots for Exploring Extreme Environments

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Motivation

This work is inspired by the principles of natural evolution as rules for optimum seeking procedures. The process of natural evolution is used as a role model for a strategy to find optimal or near optimal solutions for a given problem. Just like natural evolution (Figure 1 and 2) that evolves a population of individuals over millions of years to optimally adapt to an environment using principles of 'selection', 'recombination', and 'mutation', artificial evolutionary approaches are used that rely upon the collective learning paradigm gleaned from natural evolution to find optimal solutions for a given problem [1].

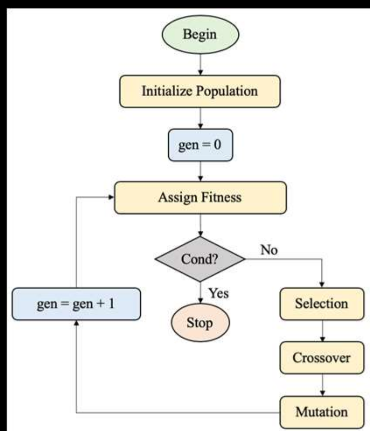

Figure 1: Evolutionary Algorithm Structure.

Knapsack Problem in System Design

Considering a system composed of n subsystems with each subsystem consisting of o options (Figure 3 and 4). Each option has a particular value and requires m resources. The objective is to pick exactly one option from each subsystem maximizing the total value subject to m resource constraints. This problem is termed as Multidimensional Multiple-choice Knapsack Problem (MMKP) [2].

Structure	OBC	Antenna	Transceiver	Battery	PMB	ADCS	Solar Panel	Camera
sID	cID	aID	tID	bID	pID	adID	spID	caID
Integers [0 l_i]: $l_i \rightarrow$ no. of options available								

No. of Batteries	No. of Body Panels				No. of Deployable Panels (Side)				No. of Deployable Panels (Top)			
n_b	b1	b2	b3	b4	ds1	ds2	ds3	ds4	dt1	dt2	dt3	dt4
Integers [1 10]	Integers [0 1]				Integers [0 3]							

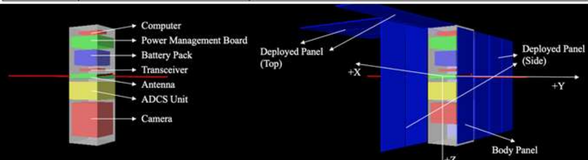

Figure 3: Genotype and Phenotype expression of a CubeSat design.

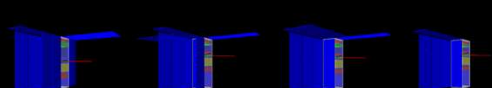

Figure 4: Evolution of CubeSat design over generations modeled as MMKP.

Natural Evolution v/s Artificial Evolution

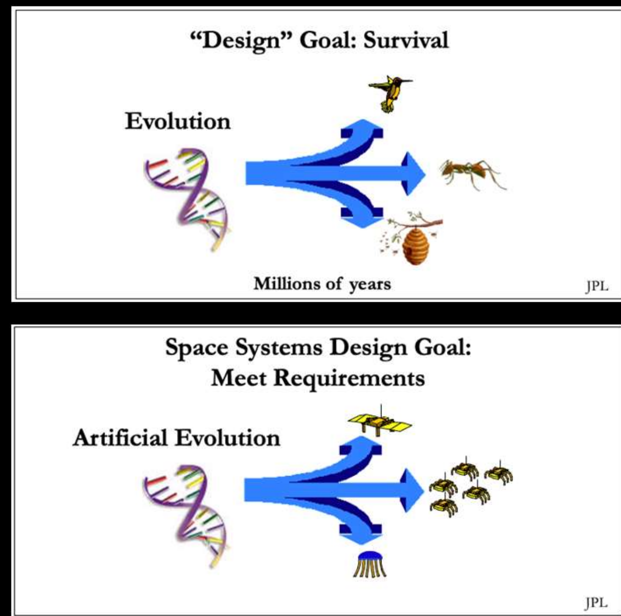

Figure 2: Illustration of (Top) Natural evolution for survival of the fittest, (Bottom) Artificial evolution for system design.

Unconventional Robots

The principles of artificial evolution was also used to design spherical robots that achieves mobility through hopping and rolling (Figure 10 and 11). The objective was to design multiple pareto optimal robots such that their mass, volume and power is minimized while maximizing the available payload mass, volume and power.

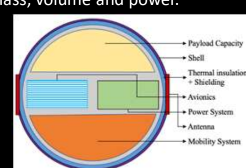

Figure 10: Nominal design of Spherical robot.

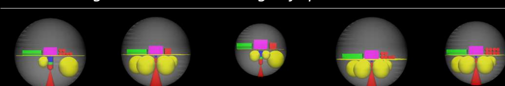

Figure 11: Pareto optimal design found through the application of artificial evolution.

Conclusion

This work presented the use of machine learning methods to design robotic platforms for different environments. Current design methods use engineering experience and judgement of a team of experts and lack a systematic approach to fully evaluate the whole design space. Machine learning methods can overcome human team limitations and can result in creative designs that may not have been thought by human designers.

Rover Design

This section provides an optimization technique to design rover mechanisms using the concept of artificial evolution. The rover considered for analysis is a 6-wheeled rover similar to the Shrimp architecture (Figure 5, 6, and 7). The rover design is expressed by 9 design variables in the form of a gene and a dynamics model is developed as a function of the design variables. The performance of the rover is measured in the form of a fitness function such that it maximizes the distance traveled while minimizing the total mass.

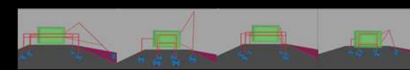

Figure 5: Evolution of rover design over generations.

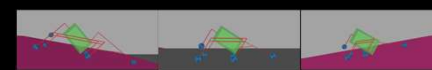

Figure 6: Snapshots of failed designs.

Figure 7: Snapshots of the fittest design.

Legged Robot Controller Design

This section provides an optimization technique to design walking and hopping gaits for a bipedal robot in low-gravity environments using the concept of artificial evolution (Figure 8 and 9). The system is modeled with 7 links and the design variables are the gait period and joint trajectories of the hip, knee, and ankle joints [3].

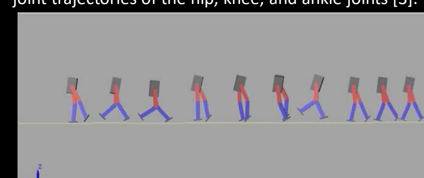

Figure 8: Low-gravity bipedal walking gait generated through evolutionary process..

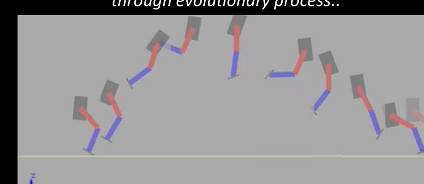

Figure 9: Low-gravity bipedal hopping gait generated through evolutionary process..

References

[1] Holland J. H. "Adaptation in Natural and Artificial Systems" University of Michigal Press, 1975.
[2] Kalita H., Thangavelautham J. "Automated Design of CubeSats using Evolutionary Algorithms for Trade Space Selection" Aerospace, 2020.
[3] Kalita H., et. al. "Advancing Asteroid Surface Mobility using Machine Learning and the Spike Spacecraft Concept" Advances in the Astronautical Sciences, 2021.