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Title: A NOVEL MICROSATELLITE CONTROL SYSTEM

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A Novel Microsatellite Control System

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Abstract – We are researching extremely simple yet quite capable analog pulse-coded neural networks for “smaller – faster – cheaper” spacecraft attitude and control systems. We will demonstrate a prototype microsatellite that uses our novel control method to autonomously stabilize itself in the ambient magnetic field and point itself at the brightest available light source. Though still in design infancy, the “Nervous Net” controllers described could allow for space missions not currently possible given conventional satellite hardware. Result, prospects and details are presented.

1 Introduction – Biomorphic Design

The current trend in spacecraft is "smaller - faster - cheaper" but it is not known just how small, fast, and cheap satellites can be built and still perform useful work. However, clearly a major engineering paradigm shift is required to move beyond the very highly evolved and optimized space systems that are currently available. In particular, the paradigm of anticipating every possible anomaly and engineering the appropriate mitigation has in recent years proven to be unfeasible - we just cannot anticipate everything that can go wrong, especially in space, and especially under the current cost-risk constraints that bind space programs. We need engineering solutions that respond to unanticipated events in non-catastrophic ways. In other words, rather than designing systems primarily to perform work and trust them to survive all anticipated circumstances, we must instead design systems that automatically attempt to survive all circumstances and then try to extract useful work.

The concept is bottom up rather than top down. Such satellites would not have fixed algorithmic behaviors, but rather be survivors "domesticated" by their sensors and control payloads into performing high-reliability tasks. The best analogy is a horse and rider matched pair -- the rider is the source of motivation and destination, the countryside the fractal environment, and the horse the sensory-actuator platform that allows for the transparent interface between both. If you have a good "horse", then you can have a bad (or even dead) rider and still expect advanced competency from the system.

Using this new paradigm, we have been developing extremely simple yet quite capable analog pulse-coded networks for a variety of advanced robotic applications that include spacecraft attitude and control systems. The basis of these control systems is a two-transistor "motor neuron" that produces control pulses proportional to the perceived load on its inductive actuator (Appendix A). These non-linear neurons can be configured in bounded, phase-locked ring structures so as to mimic the attributes of biological central pattern generators. Our experiences with over two-hundred robots have shown these simple systems are extremely reliable, robust to electrical and mechanical fault, and capable of surprising emergent behavior such as self assembly and synergistic collective behavior, especially when compared to conventional neural network implementations for equivalent control tasks. A hexagonal ring central pattern generator in a four legged crawling robot can, for instance, reproduce the walking and running motions observed in living quadrupeds, but can do so from a single battery source. The evidence is that these Nervous Net (Nv) controllers thrive on noise, and show a biological-like robustness in all areas of inductive actuator control.

Systems such as robots and spacecraft are immersed in their environment. Environmental feedback into these systems is unavoidable, even without sensors, but in conventional designs, such spurious feedback is always regulated or removed where possible. For Nv nets, the main advantage of their adaptive quality comes from the fact that the actuators themselves are effective environmental sensors. For example, an Nv equipped satellite that is oriented using magnetic torque coils will respond to the magnetic variations induced by geomagnetic storms, even if it has no magnetometer for sensing the ambient field. Instead of designing systems that oppose their environment, we attempt to engineer systems that depend on "flowing" within such environmental complexity. The actuators and sensors coupled to the environment feed back into the control system by augmenting Nv control pulse timing relationships. A further advantage here is that often the sensor and actuator can be combined into a single unit, simplifying and distributing the processing for the design.

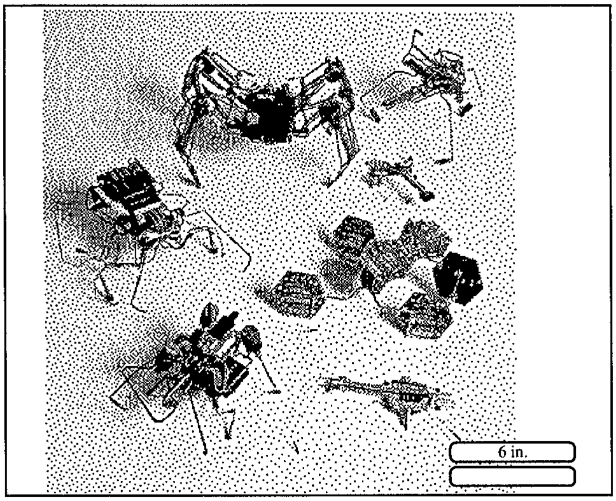

Figure 1: Some Biomech walkers, hoppers and solar rovers. Over two hundred Nv machines of thirty-five "species" have been built so far. Some have been in continuous operation for over seven years.

This approach has produced another unexpected result - the trivialization of the sensor fusion problem. Inputs from multiple sensors combine concurrently and without the need for "cycle-time" polling. There is no need for interpolation or decimation to handle temporal mismatches and relative importance is assigned directly by specifying the sensor voltage relationships. Our prototype spacecraft control system uses gradients in the magnetic field as sensed by the magnetic torque coils to stabilize itself and simultaneously uses light gradients from a photosensor pair to orient the spacecraft toward the brightest light source. The advantage is that as Nv controllers are asynchronous, the satellite can match the complexity of the environment at the rate its sensors can perceive. This has been shown in many Nv designs: the ability of the machine to automatically adapt to the stress of its condition. A biological feature that can sometimes produce more constructive behavior than just waiting in orbit like a rock.

2 Nv Control Competency

Initially it was thought these devices avoided the problems of an internal world representation by using a reactive or behavior-based approach. Recent work has shown that Nv controllers instead take a chaotic map of their surroundings onto their process control hierarchy (that is, they dynamically and efficiently mold their behavior to the difficulty of their surroundings). This is due to the analog-electronic nature of the devices, the adaptive hardware of their structure, and the topological orientation of their interconnections. The defining characteristic of this adaptation is continuously updated by the immediate fractal complexity of the environment. These devices are "soft" designs, in that the environmental dimension must be absorbed, modified, and acted on for the devices to make successful headway through a complex world. These devices do not use "feedback" in the standard sense, but rather "implex", as the driving forces are augmented by immediate load rather than from just separate "sensor" sources. The result is highly compliant, animal-like machine motions that "negotiate" rather than "bully" their way through an environment, and machines that both move and measure with the same actuators.

We talk about these devices in the general sense because the precepts of their existence and subsequent design are based upon environmental macros, such as fluidity, turgidity, gravity, scale, materials strength, and many others. Biomorphic designs must use this information as principles to shape appropriate response(s) for an environment, consequently the machines that emerge are vastly different from the conventional. We suspect, at least from the experimental evidence, that this technique embodies a novel control paradigm, and at least a new engineering discipline for the matching of competent machines to complex environments. Here, once the problems of existence are ratified, the devices can do unsupervised, long term work without human intervention.

The problems are that Nv technology is analog and currently a "Black Art". The potential for this control paradigm is vast, but it is far from linear, and requires concentrated design skills to pull a competent ability from the nets. Furthermore, though the systems do not require programming, there is the problem that emergent behaviors of the systems are still not understood at this time. Indeed, Nv systems show an incredible ability to do something "surprising" under severe duress, and this can result in massive unpredictability in the system behavior.

The solution to this is to build as many different Biomech robots of a certain "species" as possible, and study them for the best characteristics. To this end, the use of this technology to "evolve" satellite robots (Satbots) from a lesser to a higher operational state has resulted in not only a wide spectrum of devices, but even completely different "species" of creatures, all evolved from a crude primal "genotype". A further advantage is the speed at which this evolution occurred, indicating that real-world Lamarkian evolution may be far superior to computer models yet seen.

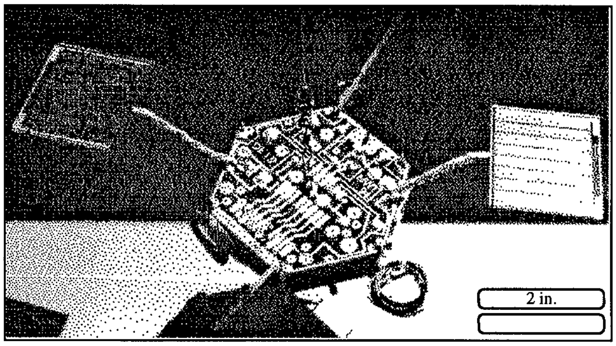

Figure 2: Satbot 2.1, a second-generation solar-powered Nv control Satbot prototype for autonomous magnetic field stabilization.

The conclusions from this "evolutionary" design technique is that there may be some universal megacepts that bind survivor oriented designs, allowing for the creation and optimization of devices that can do work for any specified environment, under many situations, using adaptive, bounded control techniques. Regarding the "Satbot" genus, the evolutionary goals have been to demonstrate a prototype microsatellite that uses an Nv control system to autonomously orient itself in the ambient earth's' magnetic field and point itself at the brightest available light source. This is a first step toward defining a minimum useful microsatellite design of the future and is relevant to all areas that use spacecraft platforms.

3 Basic Satbot Design

Given the nature of distributed control in these systems, the following shows the proposed design of the latest generation Nv Satbot using magnetic torque stabilization vanes, one for each magnetic axis. Such controllers have been known to be unreliable for large masses, so the Satbots used here have evolved between ten and fifty grams maximum. This weight not only reduces cost, but improves the accuracy and response of the satellites to minutes between targeting and orientation responses.

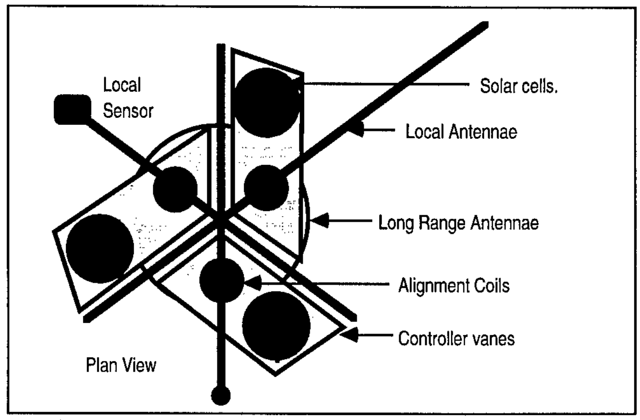

Figure 3: Rough Plan of a 10 gram "Gestalt Satbot".

Local antennae establish communication between other local Satbot "cells", whole long range antennae are for phase-array reception/transmission of distant signals. Coils use Biomorphic controllers to adjust altitude and attitude within any magnetic field. The result is emerging as capable, fast, small, and disposable a spacecraft as might be physically possible.

The idea is to launch these Satbots in huge stacks, shearing themselves in orbit as a vast array of sensory "pixels", giving a whole new spectrum on the potentials for data measurement. From space stations to earth to planets to asteroids, such collective Satbot nets would provide direct, inexpensive, non-filtered information.

4 Summary

We present an application of a technology that seems, in experiment, to withstand most of the problems normally present in space missions; complexity, reliability, redundancy, and cost.

The Nv control method could be adapted to most types of machine control, but it has been applied to autonomous robots because of the difficulty conventional control systems have solving the seemingly simple task of negotiating undefined complex environments. The two hundred robots built so far are not "workers" in the traditional sense, but "survivors", in that they fight to solve the immediate problems of existence rather than procedural condition. That is, Nv control architectures focus on adaptive survival rather than the performance of specific tasks. Once survivability is under control, goals can be superimposed and the machine used as a platform to carry sensors and conventional intelligence. It is believed that these machines, although now in an early stage of development, can within a few years be brought to the point that they can serve as inexpensive, robust, and versatile carriers for a variety of instruments. In the handling of undefined environments, Biomorphic designs might be a very efficient and cost-effective approach.

The basic, most encouraging conclusion is that there really are minimal elegant solutions to the problems of handling unspecified environments, even if those solutions are imbedded in complex dynamical control. The idea of clusters of inexpensive satellites that can withstand massive damage and automatically restore themselves to operation is an attractive one, but more research needs to be done on the integration of these "living machines" to the needs of future customers. The principal investigators will gladly demonstrate their prototypes on request.

Appendix A

Living machines have to run from solar power. The problem is that conventional solar cells are too weak, fragile, and inefficient to provide continuous energy to a motor system. A minimalist biomorph needs a robotic "digestive system" that takes what little energy solar cells put out, integrates it and delivers it to a motor at semi-regular intervals based upon light availability. The most effective circuit that can do this (as of the time of this writing) is detailed below:

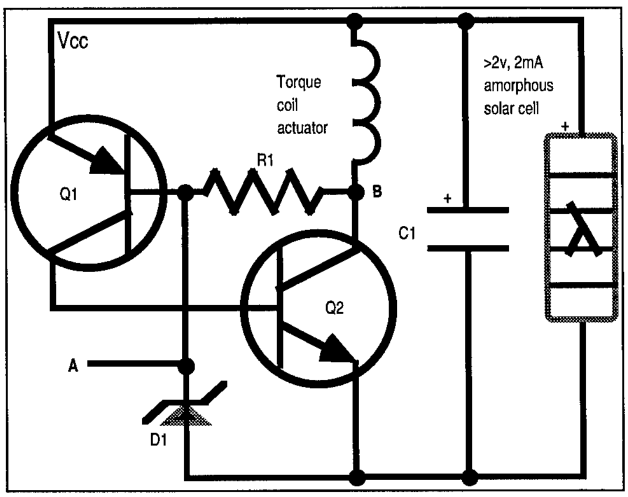

Figure 4: Solarengine Schematic (Nv-)

Transistors are typically a 3904 and 3906, but for higher power designs, Q2 must be replaced with something like cascaded 2N2222s, or high gain power transistors like a TIP 31. The optional zener should be rated at 1 volt below the solar-cells maximum voltage rating to get best motor efficiency. R1 should be between 1k and 18k, and gives more actuator torque at lower values with less energy efficiency. The value for C1 is dependent upon the magnetic "thrust" required, but is typically greater than 1000uF. The torque coil should be more than 100 turns in an ironless toroid form.

Essentially the Solarengine (held under international patent) is a modified SCR design with supercritical feedback. The advantages of this design are small component count and adjustability, but mostly its very high off-state impedance until tripped. This means that Biomorphic satellites can use very small solar cell arrays which are robust against damage.

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