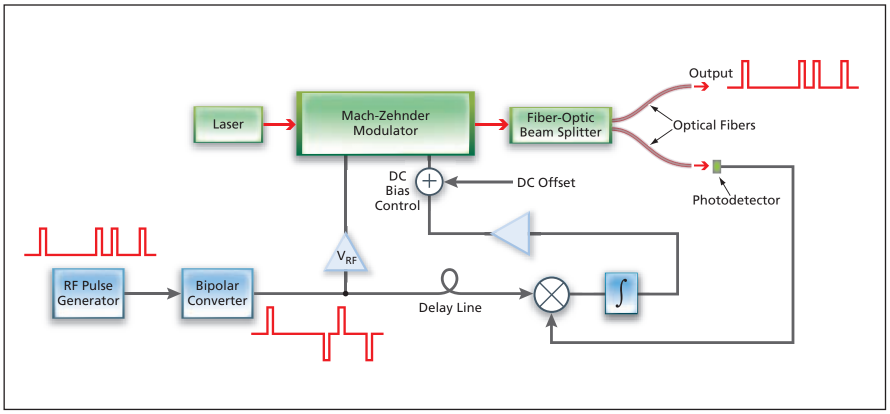

Figure 2. This **Modulation System** for PPM optical communication includes a bias control loop that corrects for electrical and thermal drifts to maintain a maximum extinction ratio.

The upper part of Figure 1 schematically depicts a Mach-Zehnder modulator. The signal applied to the electro-optical crystal consists of a radio-frequency modulating pulse signal, V_{RF}, superimposed on a DC bias V_{bias}. Maximum extinction occurs during the "off" ($V_{RF} = 0$) period if V_{bias} is set at a value that makes the two optical paths differ by an odd integer multiple of a half wavelength so that the beams traveling along the two paths interfere destructively at the output beam splitter. Assuming that the modulating pulse signal V_{RF} has a rectangular waveform, maximum transmission occurs during the "on" period if the amplitude of V_{RF} is set to a value, V_{π}, that shifts the length of the affected optical path by a half wavelength so that now the two beams interfere constructively at the output beam splitter.

The modulating pulse signal is AC-coupled from an amplifier to the electro-optical crystal. Sometimes, two successive pulses occur so close in time that the operating point of the amplifier drifts, one result being that there is not enough time for the signal level to return to ground between pulses. Also, the difference between the optical-path lengths can drift with changes in temperature and other spurious effects. The effects of both types of drift are suppressed in the present method, in which one takes advantage of the fact that when V_{bias} is set at the value for maximum extinction, equal-magnitude positive and negative pulses applied to the electro-optical crystal produce equal output light pulses.

In a modulation system designed and operated according to this method (see Figure 2), the modulating pulses are converted to alternating polarity, a small portion of optical output power is sampled by a photodetector, the photodetector output is multiplied by a sample of the alternating-polarity modulating signal, and the product is integrated over time to obtain an error signal. When V_{bias} is not at the optimum, maximum-extinction value, there is either an overshoot or an undershoot in the output light pulse, such that the integral signal amounts to an error signal that is proportional, in both magnitude and sign, to the difference between the actual and optimum values of V_{bias}. The integral signal is amplified and added to a DC offset voltage, and the sum fed to a bias control input terminal to drive the modulator toward optimum bias. Normally, the DC offset voltage would be set initially at a maximum-extinction point.

This work was done by William Farr and Joseph Kovalik of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).
NPO-41301

Generative Representations for Automated Design of Robots

Compact representations circumvent the computational obstacle to complexity.

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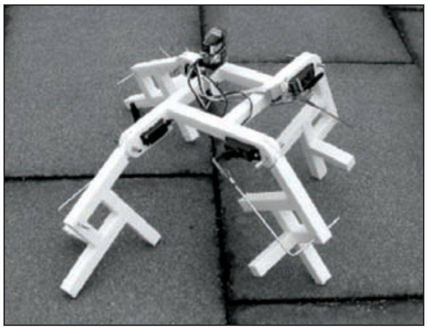
A method of automated design of complex, modular robots involves an evolutionary process in which generative representations of designs are used. The term "generative representations" as used here signifies, loosely, representations that consist of or include algorithms, computer programs, and the like, wherein encoded designs can reuse elements of their encoding and thereby evolve toward greater complexity.



The **"Quatrobot" Is a Walking Robot** that was designed by automated evolutionary synthesis, using a generative representation. The robot was built after 13 iterations.

Automated design of robots through synthetic evolutionary processes has already been demonstrated, but it is not clear whether genetically inspired search algorithms can yield designs that are sufficiently complex for practical engineering. The ultimate success of such algorithms as tools for automation of design depends on the scaling properties of representations of designs. A non-generative representation (one in which each element of the encoded design is used at most once in translating to the design) scales linearly with the number of elements. Search algorithms that use non-generative representations quickly become intractable (search times vary approximately exponentially with numbers of design elements), and thus are not amenable to scaling to complex designs.

Generative representations are compact representations and were devised as means to circumvent the above-mentioned fundamental restriction on scalability. In the present method, a robot is defined by a compact programmatic form (its generative representation) and the evolutionary variation takes place on this form. The evolutionary process is an iterative one, wherein each cycle consists of the following steps:

1. Generative representations are generated in an evolutionary subprocess.
2. Each generative representation is a program that, when compiled, produces an assembly procedure.
3. In a computational simulation, a constructor executes an assembly procedure to generate a robot.
4. A physical-simulation program tests

the performance of a simulated constructed robot, evaluating the performance according to a fitness criterion to yield a figure of merit that is fed back into the evolutionary subprocess of the next iteration.

In comparison with prior approaches to automated evolutionary design of robots, the use of generative representations offers two advantages: First, a generative representation enables the reuse of components in regular and hierarchical ways and thereby serves a systematic means of creating more complex modules out of simpler ones. Second, the evolved generative representation may capture intrinsic properties of the design problem, so that variations in the representations move through the design space more effectively than do equivalent variations in a nongenerative representation.

This method has been demonstrated by using it to design some robots that move, variously, by walking, rolling, or sliding. Some of the robots were built (see figure). Although these robots are very simple, in comparison with robots designed by humans, their structures are more regular, modular, hierarchical, and complex than are those of evolved designs of comparable functionality synthesized by use of nongenerative representations.

This work was done by Gregory S. Hornby of Ames Research Center, Hod Lipson of Cornell University, and Jordan B. Pollack of Brandeis University. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to the Technology Partnerships Division, Ames Research Center, (650) 604-2954. Refer to ARC-15334-1