

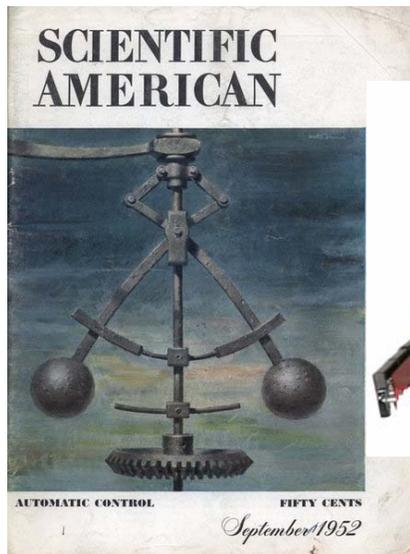
What is Control?
How does it make machines smart?
Where do we get ideas for control?

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Here is a story about a central principle in modern science and technology, **the principle of feedback**. In the era of increasing power of computation, a key interest is to make machines/systems smart. A combination of sources, ranging from examples in nature, to human ingenuity in exploiting physical principles, to patient mathematical analysis, is needed to devise smart machines.

Icons of their times



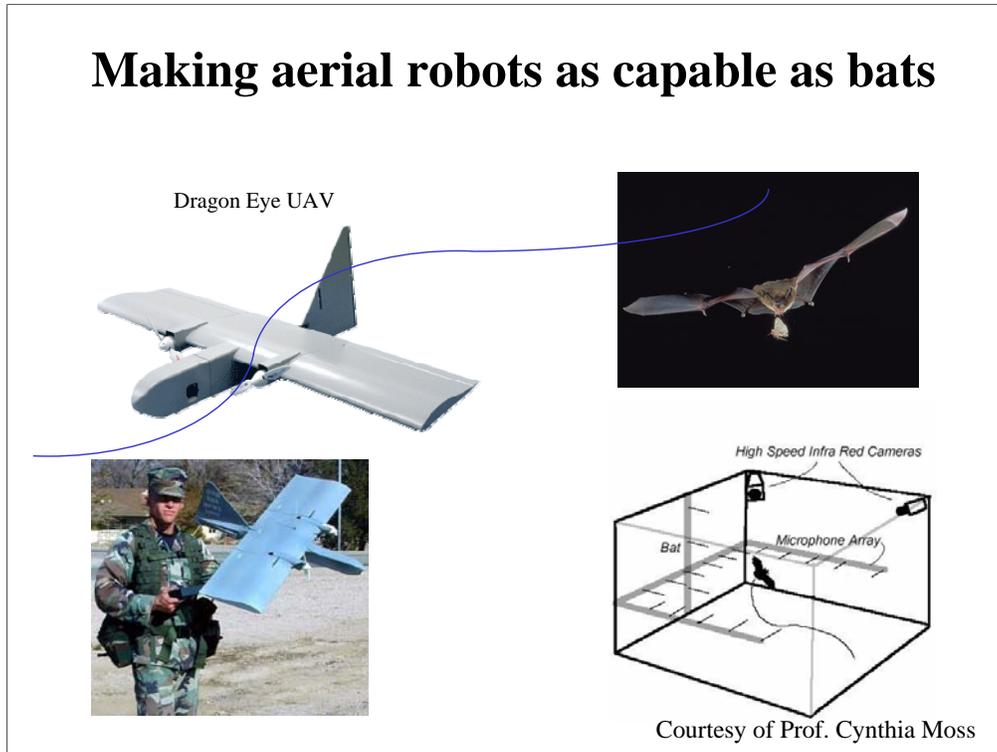
Feedback is the principle that governs these systems

The roots of the field of control are ancient, but in the era beginning with the industrial revolution (18th century), Automatic Control has made the difference in every generation of technology.

Without the **flyball governor** of James Watt (1788) there would not have been the dependable use of the energy in steam for a whole new world of industrial technology. The feedback control of steam engines was realized through the use of the Watt governor connected to the intake of steam into the cylinder by a mechanical linkage. Information-bearing signals were thus transmitted by mechanical linkage and used to maintain engine state.

The mathematical feedback control laws (algorithms) embedded in the on-board computer of a robot enable it to find its location, steer to a goal, avoid obstacles on the way, map an environment etc., all in the service of humans.

Making aerial robots as capable as bats



The echolocating bat is a magnificent mammal. Using sonar pulses it finds food, mates, roosts, while navigating in the dark. It has solved control problems through evolution. We would like to build small flying machines capable as bats are. To this end, we need to make machines smart (design feedback control).

Engineers study mathematical principles and algorithms for design of control systems that may be as capable, robust and adaptable as the ones we encounter in nature.

Sound following behavior



Here you see a robot seeking to zero in on a source of broad-band sound in an environment strewn with obstacles. The “head” on the robot carries two sensitive microphones and circuits to distinguish the sound patterns arriving at them, to infer desired direction of movement. This inference is passed onto the robot control system. The necessary computations are carried out with a high rate of repetition to make use of the most current inference. A key element of smarts is accomplishing the goal without collisions.

Control for balance



Dean Kamen's Segway



Ralph Hollis' Ballbot

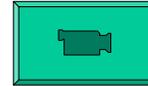
<http://www.youtube.com/watch?v=7KPOOU5NR4>

Control is the hidden and essential technology that underlies the world of robotic machines.

The examples above show the integration of algorithms of feedback control, using a variety of sensors (such as gyroscopes, accelerometers, inclinometers, shaft encoders) in real time, managed by power-efficient computers.

The **delicate balance** on display is the result of theory and technology working with fundamental physical principles. The Segway is a product for a human to use without worrying about balance, while the Ballbot is a research tool at Carnegie Mellon University. One day we might find machines built on the example of the Ballbot all around us.

Control for propulsion



Sean -straight line motion

Roller Racer

The roller racer is a ride (sit and skate) patented by William Hendricks in 1972. In his patent, he wrote:

“While the manner in which the rider can operate and cause the vehicle to be self-propelling can be and is hereinafter described in detail, the actual mechanism or theory of operation may be only partially understood and may even be erroneous, and while such theory is set forth, it is not desired to be bound by such theory of operation, **as it is possible to make, use, and enjoy the vehicle of this invention without knowledge of or understanding the correct theory of operation whatever it may be.**” - US Patent 3,663,038.

In the movie on the right Sean Andersson demonstrates how **controlled oscillations** lead to propulsion. The movie on the left is of a very simple robotic version of the roller racer.

Feedback

Feedback control is the principle that **regulates** self-organized systems

Feedback operates on sensory information, creating a **loop**

Making feedback loops **smart** is the task of engineers

Understanding feedback is of interest to:

- (a) biologists who study the behavior of animals in a world of scarce food resources;
- (b) engineers who design and build self-regulating machines and write software for them;
- (c) economists and financial engineers who move capital and information around to create and manage wealth.

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