ure 2. Here, the hinge has two wire-shaped strips of shape-memory alloy across its length; one strip of alloy remembers a bent position (like the letter "V") and the other remembers a straight position (like the letter "I"). When a current is passed across the first alloy strip, that strip heats up and bends the hinge into a V-shape; when the current across this strip ceases and a current is now sent across the other alloy strip, that second strip returns to its straightened position, opening the hinge.

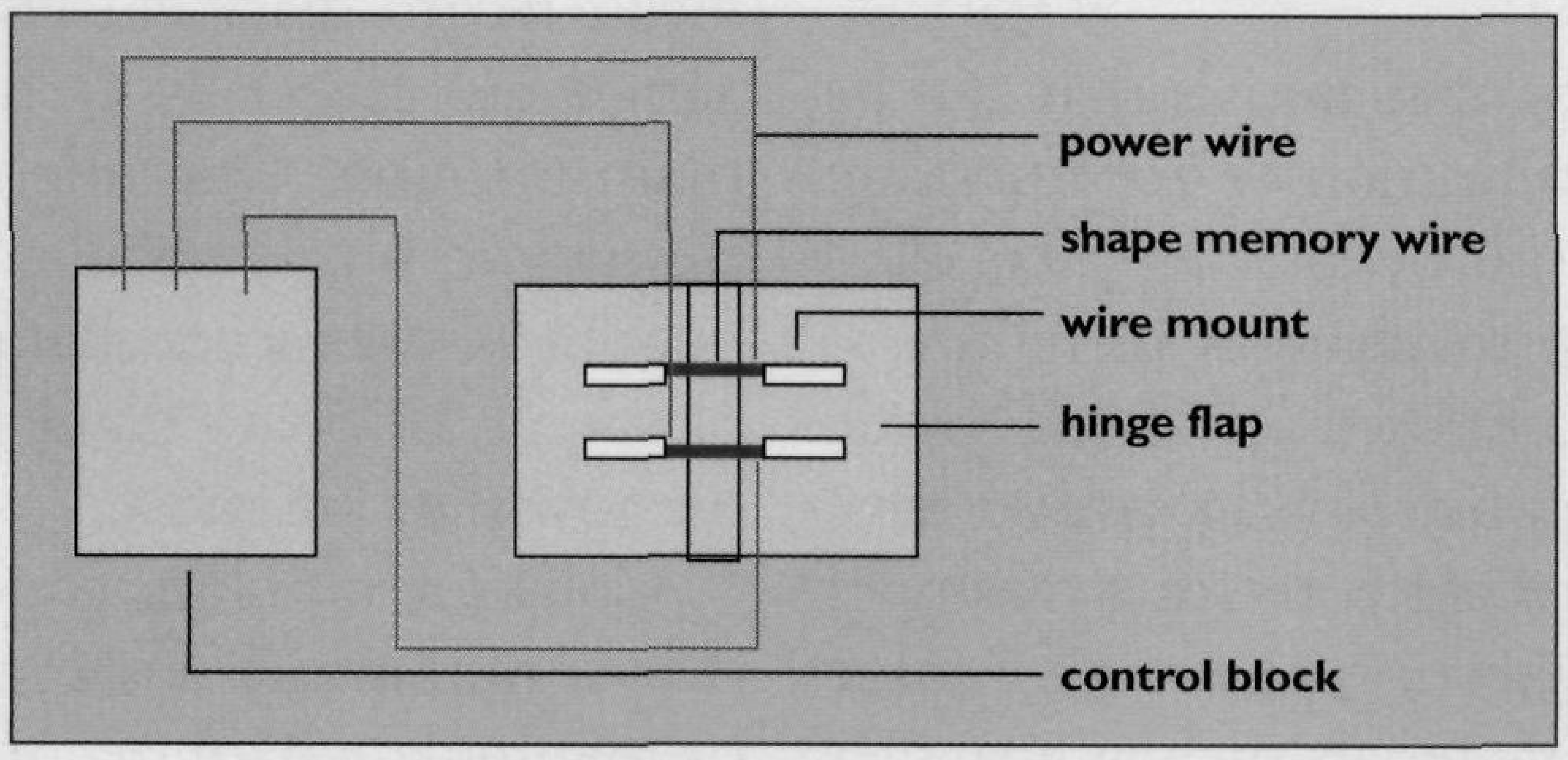

Figure 2. A schematic view of T. Wrensch's programmable hinge showing the control block (including a small computer) at left and the hinge with two strips of shape memory alloy at right.

There are still other materials that behave along similar lines. *Electroluminescent materials* light up in response to an electrical current; *electrorheological fluids* can change their viscosity in response to an electric field; some varieties of glass can change their degree of transparency in response to an applied field; novel types of programmable paper [6] act, in effect, as flexible computer display screens that can be used to present patterns of pixels on a variety of surfaces. For all these materials, a typical pattern of usage would be to have some artifact respond to its user (by changing color, shape) in accordance with a program from a desktop or embedded computer.

Input, sensing, or communicative materials. The materials described earlier can be naturally imagined in the "output" role; in contrast, several other major classes of materials may be plausibly imagined as input or communicative substances.

Piezoelectric materials [9] denote a collection of (mostly inorganic) materials that deform (by expanding or contracting along specific axes) in response to an applied electric field, and that conversely can produce an electric field in response to a mechanical deformation. Many types of sensors employ piezoelectric materials of some sort [5]; a simple, commercially available product is a small disc of piezoelectric material that can respond to the press of a finger. (That is, by pressing the disc, one causes a mechanical deformation in the material, which can in turn produce an electric signal; the overall result is the disc acts as a button that can be positioned onto arbitrary surfaces and connected via wires to computers or other electrical devices.) In more sophisticated scenarios, it is possible to coat a surface with an array of piezoelectric sensors that respond to the mechanical stress caused by, for example, the human hand; thus, one could make an artifact that responds to the position and orientation of the user's touch.

Optical fibers are cables in which a glass "cladding" surrounds a glass core of a different refractive index; the net effect is the fiber can be used to conduct light signals along its path. Optical fibers are used extensively in telecommunications because of their high bandwidth and low cost; for the purposes of this discussion, though, the interesting thing about optical fibers is their wide utility as a means of conducting light signals within and between physical objects. That is, one can think of optical fibers as a means of wiring up an object so that by shining a light (or perhaps blocking a light) at a particular point, the object can send a signal over an optical fiber to a sensor (or computer) at some other location.

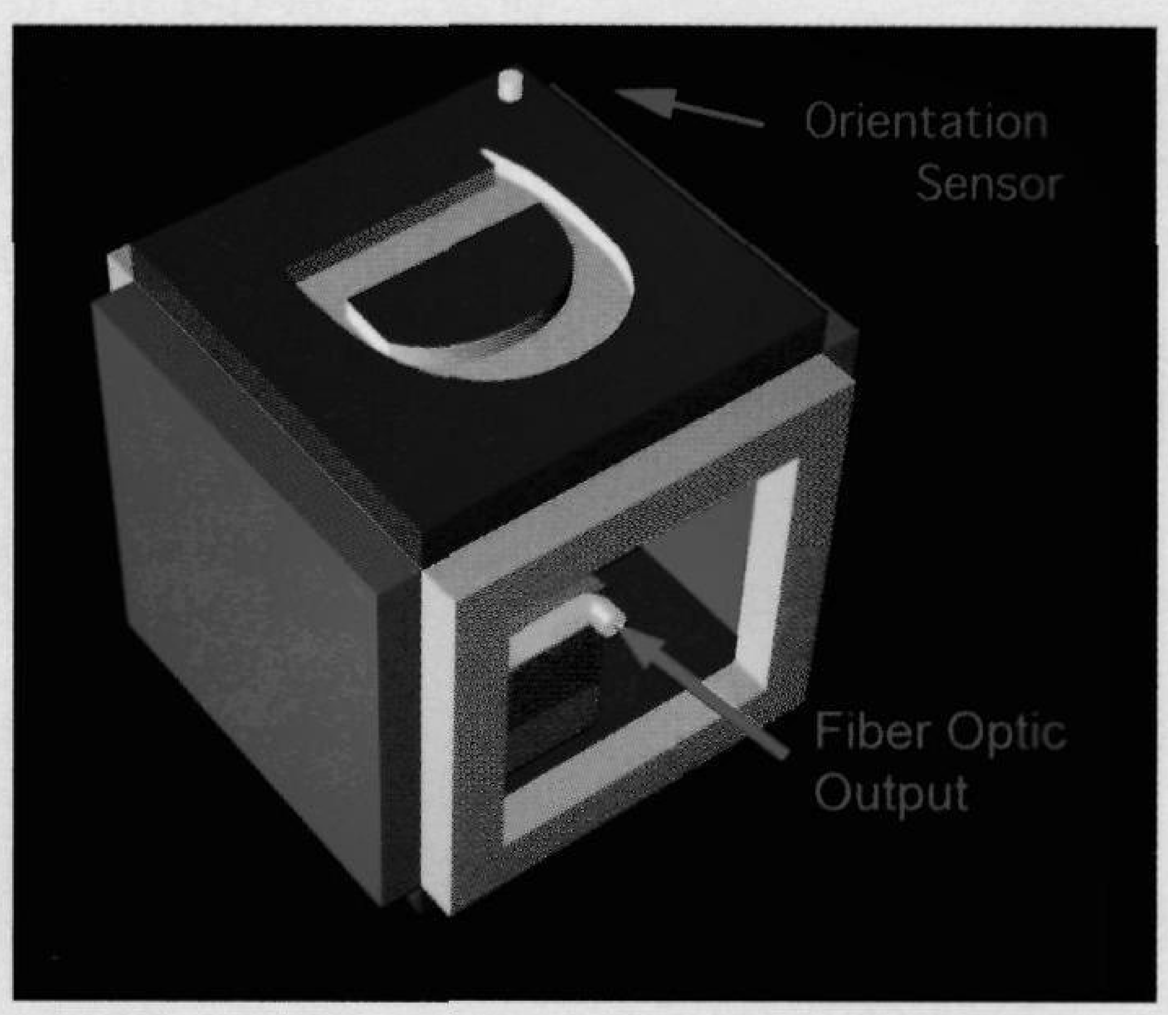

Figure 3. An open schematic view of a single talking alphabet block, showing the block's orientation sensor at its surface and the fiber optic cable used to communicate signals between the computers embedded within each block.

Figure 3 depicts a prototype of a talking alphabet block—one of a set developed in our lab by K. Kaowthumrong, N. Lee, and W. Lovett [3]. Each block includes an embedded computer (one of the MIT Media Lab "crickets" developed by Mitchel Resnick and colleagues [7, 8]). These computers are able to send and input an infrared light signal, which in most cases requires that the communicating computers be positioned so that they are in a direct line of sight. The talking alphabet blocks, however, employ fiber optics cables to communicate a light signal between neighboring blocks. In the Figure 3 schematic, an orientation sensor on the surface of the block determines which side is up or down, while the internal computer sends a signal (indicating which letter is visible in this particular block) to the next block in the sequence via the fiber optic cable. (In the complete block, the fiber optic cable emerges from a hole in the