Embedded Control in Architecture: An Implementation in Furniture

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Everyone attending this conference is familiar with the myriad ways in which electronic networks and computer programs are changing our daily lives, our architectural imagination, and the very nature of urbanity. These changes are widely heralded, and therefore our perceptions about them are forthright, if incomplete.

The way in which embedded control devices are changing our daily lives is less often spoken about. That is because these devices have spread through the industrial design marketplace in stealthy ways. Today, rather than aiding us in the in conscious control and accomplishment of the tasks we set ourselves, these little devices normally help us in ways that are subconscious. They more often function like the movement of our diaphragm, which is un-noticed until it needs to be over-ridden, for whatever reason we might decide.

Over the last decade, embedded micro control devices have become very common in vehicles and appliances. The microwave oven was introduced before the integrated circuit became ubiquitous, but the advent of IC's has allowed a huge number of industrial design products like that to become easier to use, and safer than ever, often with an extended functionality.

Originally, many micro controllers were designed to aid the user's conscious control of these host products, as they were in the key-pad of the redesigned second generation microwave. Today, in addition to taking better care of those operational aspects that we aren't always paying adequate attention to. The auto-pilot and the Automatic Braking System are important examples of this design approach. In an ABS system, rapid micro-pulses are applied to the wheels differentially, in a rapid computed response to individual wheel rotation. This is not data that is normally available to the person who is braking, who could not in any event think through and apply the braking pattern fast enough for it to be effective, especially given the normal single brake pedal.

In architecture, the modern thermostat is a common example of a similar extended functionality. We tend to set it, and forget it; no matter how convoluted the energy use profile of the building is. What previously was accomplished with a simple physical thermocouple, is now done with the aid of a microcontroller that holds several different functional patterns for a typical week, and deploys them independently of the inhabitants. "Did you remember to turn down the temperature?" is no longer a part of the pillow talk of average U.S. citizens. "Do you know how to set this thing?" is a more common question today, and the answer has to do with careful interaction design as an adjunct to industrial design.

Small servo motors have also become very common in vehicles and appliances, adding precise control and extended functionality to features that human power once managed without much help. The power window and power door lock are obvious examples. Remember also that the starter motor has been engaged to the crankshaft of your car by an electric solenoid for many decades.

These dynamic power actuators are used less frequently in architectural applications, but the HVAC and security systems in most modern buildings are studded with examples that work so well we forget to think about them when we design a building. As designers we are only too happy to think that someone else, probably not a design architect, will take care of that stuff. But neglecting to think about these dynamic possibilities when designing a building is a mistake that has kept architectural design a step behind industrial design, and it is an omission that should be corrected. Embedded intelligence in architecture will ultimately deal with more than issues of access and temperature management. It is likely to deal with issues that bear on form and function, just as various degrees of naturally embedded intelligence have had an impact on natural growth and form, or biomorphology.

BIOMORPHIC AND BIOLOGICAL EXAMPLES

Examining how the biological world has always dealt with these possibilities can be very instructive. Ideas about alertness and response, consciousness and motor control, and the Darwinian selection that refined these skills, are worthy subjects for the extension of an architectural education into this century. Under the influence of this kind of investigation, design and technology will soon begin to intersect in architecture in much in the same way they have always intersected in the natural world. When form is seem as part and parcel of a more dynamically conceived functionality, it can begin to extricate itself finally from the grasp of a more purely sculptural or representational sensibility.

What are the most useful concepts to draw from biology? To begin with, we should look at those concepts which have been used to clarify the function and taxonomy of plants and single celled animals. These can guide us as we begin to think about an architecture that should be as responsive as a plant, if not yet quite as smart. I say responsive and smart because we all hope for an architecture that has the accommodating energy profile of a plant, suited beautifully for its environment, and taking its part in a balanced ecosystem.

A short glossary would include the following concepts.

The *trope* is the most basic meta-concept. As an etymological root, a trope can mean a logical turning, or a geometrically reciprocated node. In biology, it refers to movements with respect to external stimuli. These movements can either be simple directional growth, or the more animated turgor, which in biology is a movement actuated by something like changes in internal water pressure. A sunflower growing to track the primary direction of the sun is called helio-tropic. In architecture, a security camera which has been given the kind of limited intelligence that is needed to track blobs of any sort, can be designed to rotate and track using this kind of limited intelligence as a trope. A morning glory blossom opens daily with a bit of heliotrope and turgor, among other mechanisms.

Other examples of *turgor* would be movements that are powered by rapid changes in internal pressure, such as the energy-efficient pneumatic robots which populate most factories today. An elevating and rotating seat, which aids the in both the acceptance and ejection of the user, could be an example of this. The continuous thrust and parry of a knee-rest extension laptop computer on a workstation is an example I have been working on.

The workstation includes a powerful mechanical linkage which moves with internal mechanical and electrical position feedback.

Taxis is an even more motile movement toward or away from an external stimulus. Little robotic dust-busters rotating and then moving toward the sound of a dropped ashtray would be an example of taxis. Furniture which adjusts its overall orientation with respect to a subject, or groups of furniture pieces deploying into different work-group architectures, would be examples of taxis. These could be independent mechanisms communicating limited information about a goal, position, and proximity via an infrared or radio serial network. Bacteria using their cilia to navigate toward their food are a common biological example of taxis.

In contra-distinction to taxis. Nastic movements are more general and less directional in response to a stimulus. Examples of this would be the preparatory cycles an intelligent and robotic workspace makes with respect to overall illumination, the initial low-resulation blob-video recognition of the presence of an occupant, the calibration of blob-tracking video on the a user's size and initial posture, and an initial anticipatory elevation of desk-lip. Salivation comes to mind as an example in the natural world. Automatically bringing the temperature up or down also falls into the nastic category in architecture.

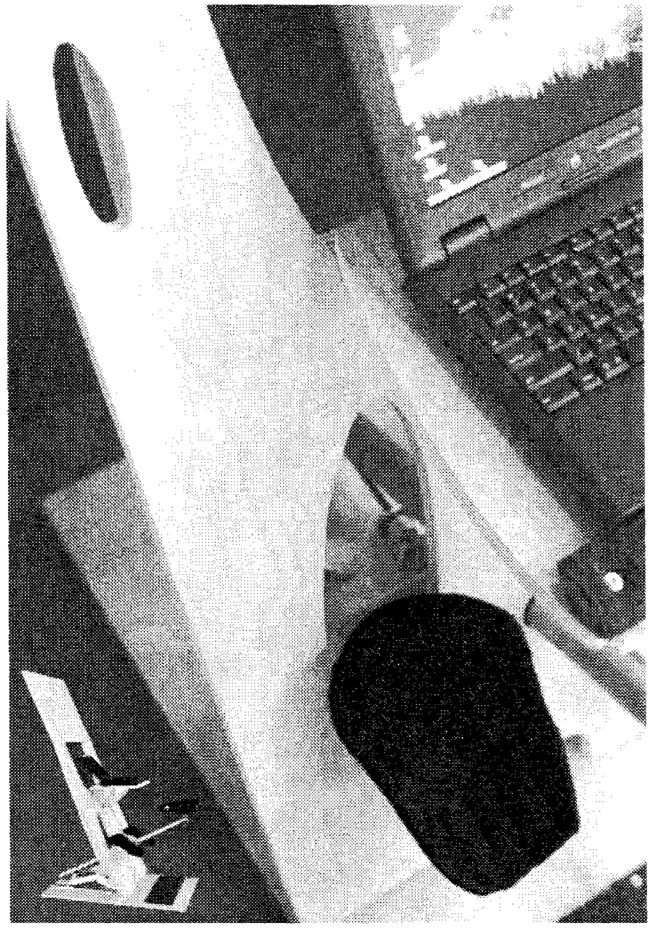

Fig. 1. The actuated knee-rest and tray of the Laptop Easel (patent pending)

Thigmotropism, or touch-based sensing and triggering, can be nastic, as in the mimosa plant: or it can use turgor, as in the Dionaea or Venus fly traps. This kind of sensing is simple[1] and has been useful in the robotic workstations I have designed and built.

AUTONOMIC (NERVOUS) SYSTEMS

What are the most useful concepts to draw from zoology? Some animals have a form of consciousness and attention which we can agree is, for the moment, beyond the degree of embedded intelligence we would want for our architecture. Underlying this is a kind of lesser functionality and some concepts which will be useful as we begin to think about an architecture that can do some things for us, without concentrating too hard on us.[2] We will need to keep HAL at bay.

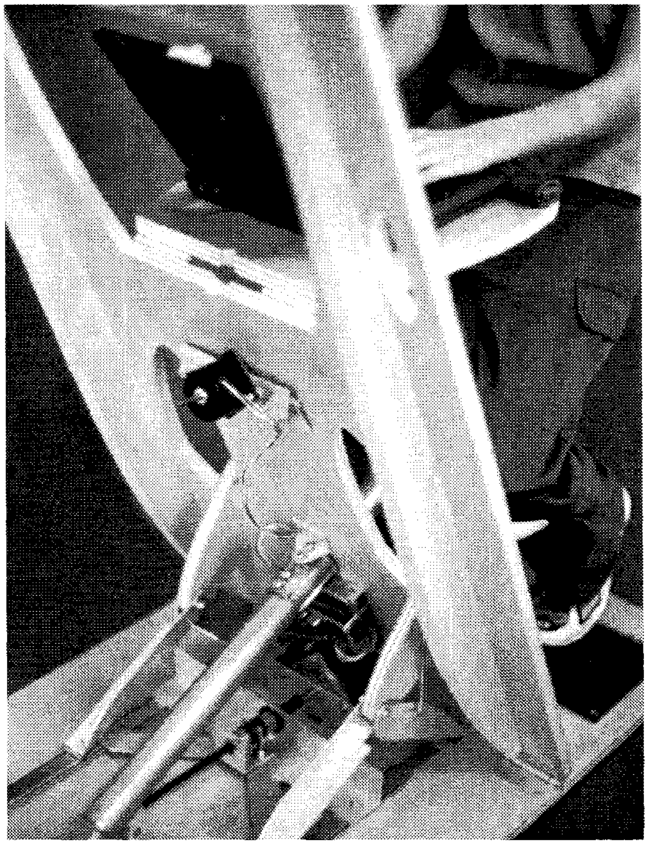

Fig. 2. The microcontroller and actuators of the Laptop Easel

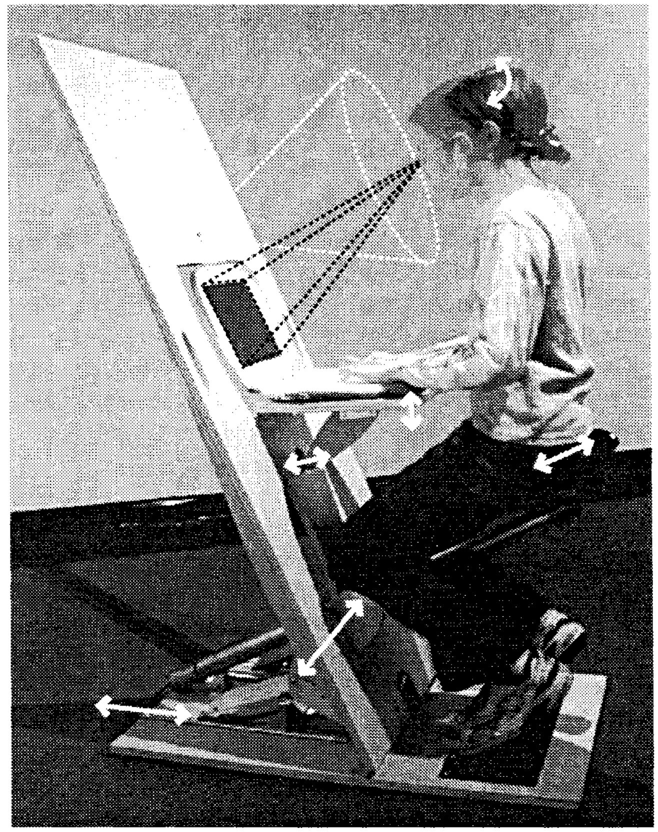

Fig. 3. Sensors and actuators watch and correct your posture while you concentrate on a different set of tasks.

The autonomic nervous system provides a marvelous example of the kinds of behavior that do not need to rise to the level of consciousness. This is different from the "unconscious," in the Freudian sense of repressed thoughts that can come to the surface in certain circumstances. The autonomic system is not fraught with those connotations. These are activities and levels of control that do not, and probably should not, rise up to the level where they can become enmeshed in the idea of "will."

The most obvious biological example is breathing, which proceeds based on an unconscious monitoring of blood chemistry, and can only be over-ridden for short times before it falls back out of conscious control. An example of an artificial autonomic control system can be found in the Laptop Easel[a], which includes a system of sensors and actuators that watch and correct your posture while you perform much more complicated tasks with a separate networked intelligence system.

MOVEMENT

Outside the realm of biological nervous systems, there is the larger issue of what is being controlled. Muscles, which usually provide a longitudinal force through lateral expansion and contraction, are the prime motion actuators for most organisms which are anywhere near our human size. These muscles have to be approximated in construction just like artificial control systems do. The closest artificial mechanisms to muscles are linear actuators. These are powered by a variety of energy sources, including hydraulic fluid for heavy lifting (like an elevator); compressed air, which makes quicker, more animal-like motion possible; and previous centuries' old stand-by: electric linear actuators. Examples of these include the quick and reliable solenoid; the precise, but weak, slow, and finicky stepper motor; and the stronger but less precise gear-head linear actuator.

Electric linear actuators also have the advantage that they can be driven with a larger dose of the same medium—and indeed the same logic—that is used for the micro-controller: electricity. No extra layer of different technology is required, and therefore the designer's learning curve is quicker (note 3). Solenoids impart a sudden, noisy force over a short distance, and their use is generally limited to simple two-state valves and switches. They can be driven with one simple to design switch-like power stage downstream from the microcontroller.

Stepper motors are an integral part of CNC rapid prototyping machines and printers, so they carry an aura of precise control. If you give them careful instructions, they can find their way to exactly where you want them, without asking advice along the way. They would be a relatively good choice to get an ice cream cone to your mouth instead of hitting your forehead. They require two extra electronic layers beyond the microcontroller—one of differential phase control for the motor's various windings, and another to safely deliver the high amperage power needed to move things at a larger scale. Figure 2 above shows both medium and heavy-duty stepping motors.

Gear-head linear actuators can be several times stronger, and they also require two extra layers of electronic control. In this case the two layers of control include pulse-width modulation for varying the amount of power that is applied, and a power amplification stage to drive the large motor without overheating the logic-level electronics. In addition, they absolutely require an external set of simple sensors to tell you where they are. With the inclusion of these sensors, they make a good analog to biological musculature, which typically feeds back its condition and location through an integral nervous system. This provides the kind of redundant guarantee that is missing from a stepper motor alone, and makes it a sure bet that the ice cream cone will get to your mouth.

REDUNDANCY

Redundancy and parallel processing are among the concepts which have been shown to underly consciousness, and make a kind of foundation for it (note 4). They also give a robust stability to most biological systems, and they can lend the same stability to embedded control systems. This raises the design question of which sensing modes to use, and how to overlap them, spatially or over time (note 5). For instance, the non-directional stroking of a newborn baby's cheek will bring a strongly directional turning and nursing response toward that cheek's side. At this point, the baby's sight and sense of smell are not yet clearly developed, so the recognition of a primary care-giver is just beginning, yet pressure and touch are ready for use immediately. At this crucial stage, any functioning breast will do as far as the baby is concerned. Several month later, nursing is obviously just as important, but it is part of a personal relationship, and is triggered by a different set of stimuli including time of day, a need for closeness, and a sense of stomach hunger. A breast that doesn't smell familiar will be a cause for some confusion or alarm.

As an illustration of this last concept, redundancy, overlapping scales and modes of sensing can allow a seemingly more sophisticated response by an otherwise very simple piece of robotic furniture. In the workstation, shown above, which is designed to hold a laptop computer and provide a spine-friendly posture for long work sessions, I implemented a bend-sensor originally intended for a finger in a data glove, to index the presence of a working user.

The deflection of the workstation's flexible base, when it is loaded by someone sitting down, is converted to bending in the sensor, which changes its electrical resistance, which changes the time a capacitor takes to discharge, which information can be read and used very quickly by an embedded micro-processor. This data and processing take the form of

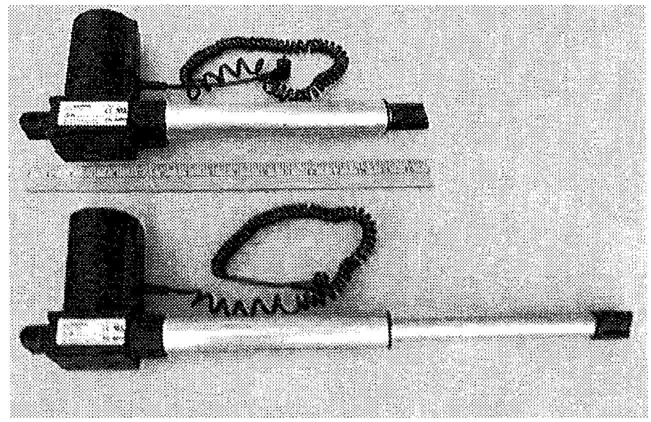

Fig. 4. A gear-head linear actuator with 1000 lbs. of thrust

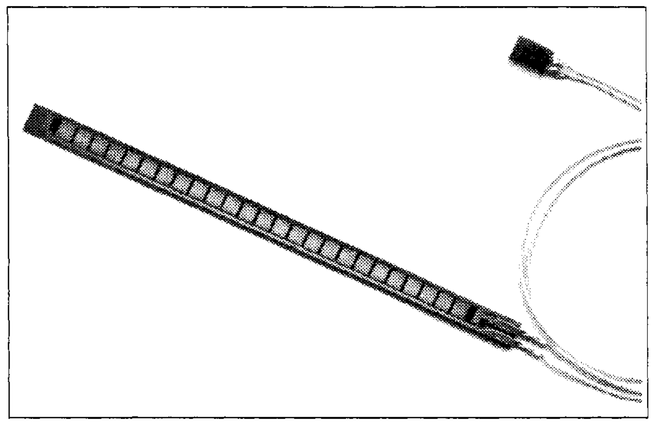

Fig. 5. A variable resistor which can be used as a bending sensor

thresholds in bending intensity and patterns of bending activity over time, both of which are remarkably simple to program once you decide to put your mind to it.

In addition to this gross sensing of the presence of a body on the furniture, a finer cognition of head and neck posture can be sensed and rapidly analyzed by a tiny blob-sensing video camera assembly, which is made by Decade Engineering in Oregon. This marvelous camera analyses the video stream and sends out the coordinate centers and size-extents of up to six perfectly anonymous blobs as a serial number stream which can be polled by the same embedded micro-processor which is watching the bend-sensor. The relationship of the head blob to the shoulder blob can be rapidly analyzed and used to send out corrective impulses for the various motors and pads to deliver to the careless body in question.

BETA TESTING LESSONS

As it turned out in the beta testing of this piece of furniture, the bending of the base alone was sending out a lot more useful information than we first assumed. By correctly analyzing this information for spatial and temporal patterns at a finer scale, the blob-tracking camera became less important, and its cost could be saved for another project

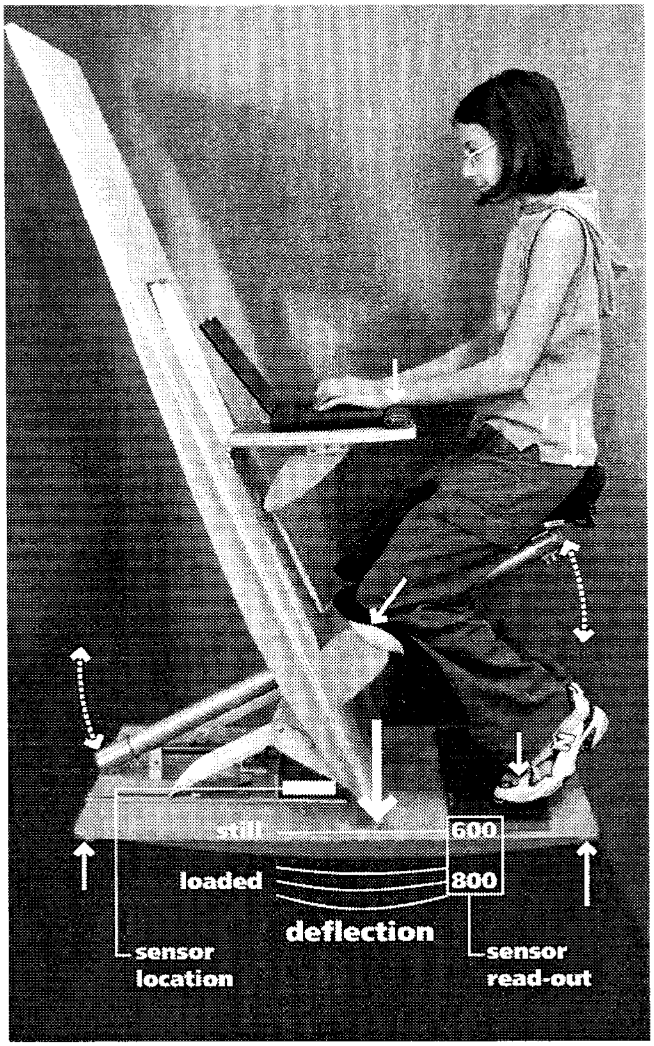

Fig. 6. Bending and actuation vectors of the Laptop Easel

where its use may be imperative. The logic of our data analysis began to follow the famous labor efficiency experiment of fifty years ago, whereby any perceived change will typically increase efficiency in the office environment. It almost doesn't matter what kind of change is instituted. For example, If this piece of furniture is loaded, but very active, it gives evidence of generally healthy movement and posture, because of the five carefully designed points of support the furniture offers— two wrists, two knees, and the seat. If it is loaded but quiescent for more than a few minutes, it is probably holding someone who is getting stiff, hunching up, and doing a lot of small repetitive movements. This information can be measured, compared to thresholds and patterns over time, and then used by the microprocessor as a basis to physically suggest a kind of movement that breaks a period of relative inactivity.

In another related beta testing surprise, the designed-in precision of the furniture's stepper-motor-driven, posture-balancing response, and the aimed-for skeletal adjustment, were not as important as the subject's own triggered body

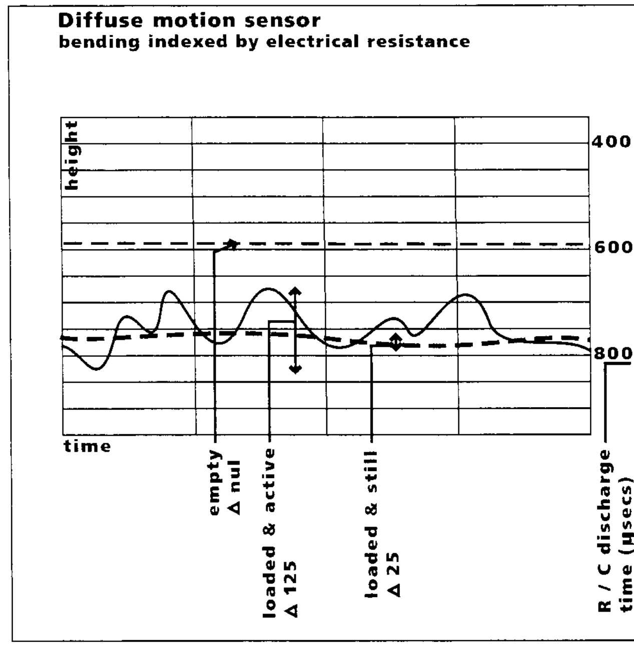

Fig. 7. Degrees and patterns of electrical activity due to bending.

realignments. Making appropriate suggestions for the several different sizes of users was computationally intensive, and ultimately we realized it was beside the point. After a simple initial adjustment for each different body size, each user could be encouraged to re-align his or her own skeleton by a series of simple motions triggered by a period of suspicious inactivity. This amounts to encouraging the body to heal itself, rather than aiming at ever more precise and problematic prescriptions. Imagine that—a robot which does less, and thus does it better. I like to think of this piece of furniture as out-sourcing something I have proven I can't be bothered with—my posture—while I am working at a computer for long periods of time. On the other hand, I don't think this kind of integrated computational, electronic, and mechanical design should be outsourced from architecture schools.

CONCLUSION

Learning how to design for interactivity in other fields has lead to an explosion of new and successful educational programs. The technical classes in architectural education, which now deal primarily with statics, material explorations, and some mechanical issues, are still predicated on a motionless, relatively unconscious architecture. At some point it will become obvious that this static existence will not define the architecture of the future. Architectural curricula would definitely benefit from the inclusion of some simple programming and electronic control projects. I am still using today the basic programming skills I learned as a required part of my architectural education almost thirty years ago.

Unfortunately for other students, that lucky Fortran class I took was long ago replaced by a required class in AutoCAD. But now it is high time to take computer visualization skills

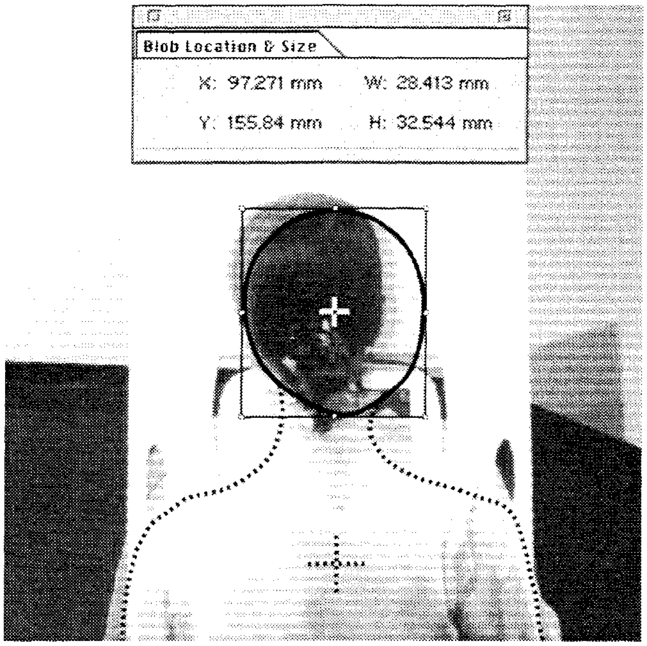

Fig. 8. Numerical data representing blob centers and blob extents is derived in hardware from the video stream, and sent to the microprocessor for the interpretation of posture.

out of the specialized ghetto of classes where they have been bred, and put them back into the studio, where manual drafting and rendering used to be taught. We should also bring back basic programming skills, which are as applicable for designing the information architecture of an interactive web site, as they are for designing interactive architecture. A modern design class which fails to ask questions about the degree of interactivity and response required for a given situation, is missing a very big boat which has already taken aboard the rest of the design disciplines.

So how is an adjustable easy chair like the LazyBoy different from the functionality of the Laptop Easel? The LazyBoy is used while searching for relaxation; wanting to relax and then adjusting the chair to allow it.

Relaxation is a part of the subject matter, so one's attention is on getting comfortable. Therefore a conscious adjustment is close to the point. Semi-intelligent automation isn't needed for that. On the other hand, the Laptop Easel is used while focusing on something other than correct work posture, namely work. Anyone who has spent 12 straight hours at a computer has been torn between getting up to stretch, and thus breaking concentration, or staying put and paying the price in disks and ligaments. An embedded intelligent control system can encourage the correct posture without infringing on the actual work focus.

So what are the benefits of robotic attention systems and movement in architecture? For the moment, and for this audience, I simply want to reiterate that the attentiveness and insight of architectural designers into these issues will pay the same huge dividends that have already been paid in industrial design. We just need to begin thinking about it and incorporating it deeply into the architectural design process.

The attitude of "it's done, what more can you do," or "it's set in stone," is made possible by a history of inanimate architecture. That will ultimately fade away, answered by the new set of architectural characteristics which will benefit from a real-time responsive circuitry. Architecture can ultimately even begin to learn recursively, just like a handheld electronic organizer learning the peculiarities of handwriting recognition.

The still-born metaphor of an always-already responsive architecture, enlivened only by those things passing around and through it, will give way to an actual interactive responsiveness, with a genuine difference. While the word "interactivity" currently carries with it the tincture of gaming, the time will soon come when new architectural graduates don't need to go to work for the gaming and entertainment industry to apply this kind of knowledge. It will be in our regular architecture.

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