Intelligent structures for the future

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This paper provides an overview of the main potentials and limits of smart/intelligent/adaptronic structures for the future. The concept of smart materials/structures based on inspiration from biological systems is highlighted. Smart structures have adaptive features and capabilities to respond to stimuli and environmental changes and then to activate their functions according to changes. Their basic components i.e. actuating, sensing and processing (control) are reported. Smart structures can provide continuous health and integrity monitoring, damage detection, and intelligent operational management system. Several applications of smart structures in both the architectural and civil engineering fields, are demonstrated. They can be used for cost effective, innovative repair/retrofitting methods, high-performance infrastructure systems and actuating elements for active structures. In addition their implications on design are illustrated. Furthermore human perception to such technology is discussed. Smart structures design will reduce the mass and energy needs of the system to enable it to perform its adaptive functions. As the properties of smart materials could be tailored, the material is designed for the desired application instead of designing an application around fixed material properties. Integrating smart technology with traditional forms of architecture seems a matter of fit rather than creative design, and there is no visible evidence of a changed architecture, at least from a materialistic point of view.

يعرض هذا البحث لأهم مميزات وحدود المنشآت الذكية/الموائمة. كما يتناول مبدأ المنشآت/المواد الذكية المعتمد علي محاكاة النظم الطبيعية البيولوجية. وللمنشآت/المواد الذكية خصائص موائمة ومتجاوبة وقابلية للاستجابة للمؤثرات والتغيرات المحيطة وتفعيل لوظائفها بحسب هذه المتغيرات. كما يعرض البحث للمكونات الأساسية للمنشآت الذكية من إمكانية الاستشعار والتفاعل والاستجابة والتحكم. ويمكن للمنشآت الذكية توفير مراقبة مستمرة ورصد لحالة المنشأ وكشف لعيوبه وأماكن التدهور وتوفير نظام إدارة وتشغيل ذكي. وتم عرض العديد من التطبيقات في مجالي الهندسة المدنية والمعمارية. إذ يمكن استخدام المواد الذكية في توفير طرق حديثة للترميم والتدعيم ونظم فعالة للبنية التحتية وكذا في المنازل والمباني فضلا عن المنشآت في المناطق السيزمية. كما تم يتناول أثر المنشآت والمواد الذكية علي التصميم الهندسي وفلسفته والتفاعل البشري مع هذه التقنيات المتقدمة. وتصميم المنشآت الذكية يوفر خفضا للكتلة ومتطلبات الطاقة للمنشآت لتمكينها من أداء وظائفها الموائمة. وحيث أن خصائص المواد الذكية يمكن التحكم فيها بحسب الحاجة فعليه يمكن تصميم المواد لغرض وتطبيق معين بدلا من تصميم تطبيق معين محكوم بخصائص مواد ثابتة. والتكامل ما بين تكنولوجيا النظم الذكية والأشكال التقليدية للعمارة والتصميم يبدو كمسألة موائمة بين نظامين أكثر من كونه تصميم وعمارة متغيرة مستجدة كما وأنه ليس هناك دلائل علي حدوث تغير في العمارة والتصميم علي الأقل من وجهة النظر المادية.

Keywords: Architecture, Adaptronic, Building, Infrastructure, Intelligent

1. Introduction

The elegance, beauty, functionality and integrity of God creation, e.g. nature and living systems, have always fascinated and continue to fascinate mankind, especially engineers and architects. Designers have always dreamed of designing more natural objects and to make structures behave like nature's systems, i.e. to make structures that are soft, livable, and interactive, rather than "silent and solid structures" [1], whereas current available materials are hard, dry and inert. The concept of smart or intelligent or active materials and structures is of structures capable of continuously adapting to the changing environment. The vision of smart structures is that of learning from nature and living systems and to attempt to apply such knowledge to enable man-made artifacts to have some adaptive features of some systems seen throughout nature [2]. The central design analogy of smart structures is to living systems especially biologically inspired materials. However these are designed by human beings to achieve human purposes.

Smart materials are sometimes referred to as "adaptronic" materials or structures. On a technology basis they are defined as" the integration of actuators, sensors, and controls with a material or structural component". On a scientific basis they may be defined as "material systems with intelligence and life features integrated in the microstructure of the material system to reduce mass and energy and produce adaptive functionality" [2].

In the context of this paper, the terms adaptronic, intelligent and smart structures will be used interchangeably. Likewise, there will be no distinction between material systems and structures as such distinction is supposed to be only superficially defined in terms of the scale of their microstructures, on the suggestion [2] that the microstructure of any natural system governs its behaviour regardless of its size. Adaprtonic structures are designed for a given purpose and to be able to modify their behaviour to create an envelope of utility. Their design attempts to mimic biological structural systems, i.e. the structure actual life experience; and accounts for aging, overload, and damage; and to determine the structure current state of health. They include actuators or motors that behave like muscles; sensors that have the architecture and processing features of nerves and memory; and communication and computational networks that represent the motor control system i.e. brain of biological systems [1]. Smart structures can sense changes in their environment and respond accordingly. They can autonomously modify their shape to perform the desired task regardless of the particular environmental disturbance. Besides, they are capable of monitoring their condition, detecting impeding failure, controlling damage and adapting to a changing environment.

Designers attempt to learn from nature the way by which natural systems adapt to their environment and the aging process and how the natural systems of muscles, nerves, and motor control are architected to produce adaptive life functions in engineered artifacts. The utility of adaptronic structures [2] is not simply to perform functions programmed a priori by the designer but to learn what the appropriate responses are to a wide range of situations. Smart structures should have adaptive features to interact with the environment besides the means with which to convey this information to the designer and user. The material that can be considered as a host e.g., skeletal form of the adaptronic structure, can range from biomaterials to polymers to electronic materials to structural composites to large architectural and civil engineering construction. There is need to develop methodology by which material systems, components and structures will be designed to reduce mass and energy by incorporating adaptive features and intelligence. New muscle–like materials or nerve-like sensors will enhance the concept and capabilities and the concept can be commercialized with existing materials and devices [1,2]. In such high tech systems, sensors and actuators made of smart materials are integrated together with structural materials in order to control actively the deformations, vibrations and fracture of composite structures. Multi field coupling is present in these structural devices involving elastic, temperature, electric, magnetic, and light interaction [3].

2. Significance of intelligent structures

The intelligent renewal of our on going buildings, and civil infrastructure systems includes efficient use of smart materials and structures. Enhancing functionality, serviceability, and enhanced life span of infrastructure systems will contribute to the improvement of productivity and quality of life. A world that tracks records and monitors credit card transactions and temperature in most cities every hour should be monitoring the health of its bridges and buildings to detect signs of deterioration [4]. Smart materials can reduce weight; eliminate sound; reflect more light; dampen vibrations; and handle more heat leading to enhanced quality of life [3]. Smart materials can be used for cost effective, innovative repair/retrofitting methods; novel high-performance homes and infrastructure systems; and actuating elements for active structures. New, long lasting and cost effective high performance construction materials and systems may be developed. Smart structures design will reduce the mass and energy needs of the system to enable it to perform its adaptive functions. As the properties of smart materials could be tailored, hence designers could for the first time design the material for the desired application instead of designing an application around fixed material properties [1].

3. Aim

The aim of this paper is to provide an overview of the main potentials and limits of smart/intelligent structures for the future. Also, to highlight their design concept based on inspiration from biological systems, their basic components and to highlight some applications of smart structures in both the architectural and civil engineering fields. This is to increase the awareness of engineers and architects about the concept and applications of smart materials/structures for the future and how do they fit into homes, buildings, and projects; and assess their performance; and the impact of intelligent structures on the design.

4. Constituents of smart materials

Smart structures attempt to mimic human muscular and nervous system. Smart materials [2,5] are hybrid composite systems whether fluids, gel or solids, e.g. shape memory alloys (SMA), piezoelectric materials and polymers, magnetostrictive materials, electrorhelogical and magnetorheological fluids. They can change the shape, stiffness, position, natural frequency, damping, friction, fluid flow rate, and other mechanical characteristics in response to changes in temperature, electric and/or magnetic fields. The structure must share this information with the users and designers throughout the life of the system. The basic components of smart elements are [4]: data acquisition (tactile sensing); data transmission (sensory nerves); command and control units (brain); data instructions (motor nerves); and action devices (muscles), i.e. actuating, sensing and processing (control), fig. 1. In the biological world there are tremendous number of efficient actuators, sensors and control systems. The human body is the ideal or ultimate smart system [3].

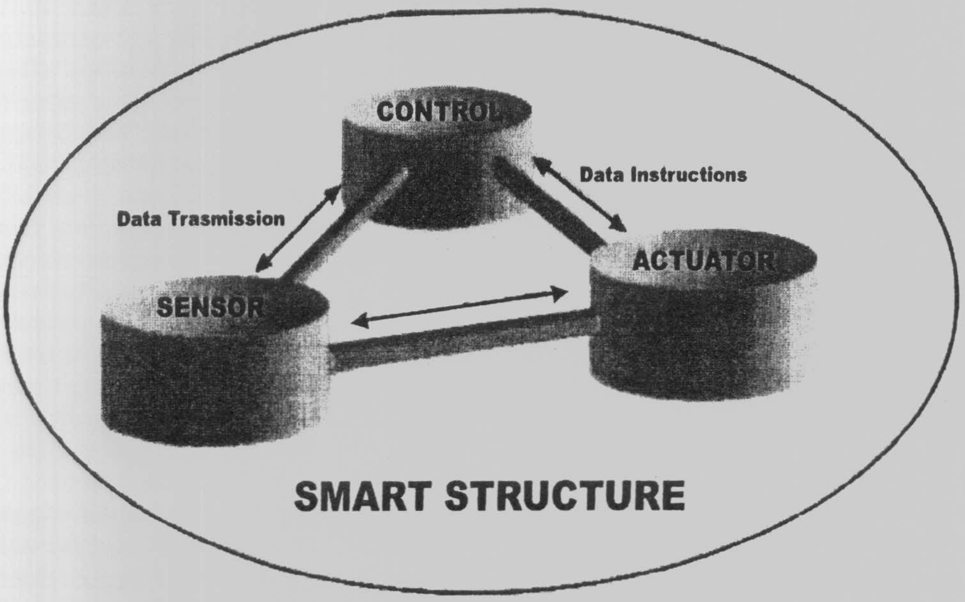


Fig. 1. The basic components of a smart structure [3].

4.1. Actuators

Actuators (artificial muscles) [2,3] are required to provide motion, mobility and change to allow an intelligent structure to adapt to its environment and changing needs. These may include shape memory alloys SMA; piezoelectric actuators, magnetostrictive actuators, and fluids.

4.1.1. Shape Memory Alloys (SMA) [2,5]

SMA can generate very large forces that are very useful for actuation. They are characterized by their ability to recover plastic deformation induced while the crystal structure is in the martensitic form. The recovery is triggered by temperature leading to crystalline phase change i.e., reversible thermoplastic, martensitic phase transformation. Below this temperature SMA will be martensitic while above this temperature they will be austenitic [5]. They undergo solid-to-solid martensitic phase transformation that allows them to exhibit large, recoverable strains. Strains up to 8% can be reversed [2] by heating the SMA above its phase transformation temperature, that is a temperature which can be altered by changing the composition of the alloy. SMAs suffer shape change then return to their remembered shape. Actuations depend on heating (e.g. for SMA with high electrical resistivity, heating by applying an electrical current) and cooling. Nickel-titanium alloys (Nitonil) are high performance shape memory alloys exhibiting high corrosion resistance, large recovery strains and excellent fatigue behavior. Less expensive are copper based SMA, e.g. copper-aluminum-nickel and copper-zinc-aluminum [2]. SMAs are capable of repeatedly absorbing large amounts of energy under loading without exhibiting permanent deformation. Their usable strain range can reach 70% that is it is substantially larger than with conventional metallic materials [5]. They possess unique properties of being able to be temporarily frozen in a particular state then with proper heat, electrical, or radiation treatment, go back to a prior equilibrium state. Two different types of deformations can occur, i.e. free recovery and constrained recovery. SMA may have either relative narrow or large temperature hysteresis [5]. In addition, SMAs have controlled shape recovery force, and can apply force or change shape of the structure and change the modal characteristics by changing the stiffness, state of stress and hence the natural frequency. SMAs have several applications including those in robotic actuators to mimic smooth motions of human muscles, and suspension systems that control vibration. Nitonil [2] wires may be embedded in composite materials to form adaptive composite structures with many similarities to muscles. In addition, they are used in civil engineering as energy dissipation devices in active smart base isolation (laminated rubber bearing combined with SMA) to shift the natural frequency of the structure and dissipate energy and in damping for buildings in earthquake areas. SMAs eliminate inertial forces generated when large actuators are used for counter acting dynamic excitations (self stabilizing seismic or impact resistance structures [5]). Active structural vibration control SMA wires are used to dampen the dynamic response of beams constrained by SMA wires. Polymeric composites with embedded Nitonil may display large bending deformation when activated. In addition SMA can reduce stress concentrations near holes and notches by creating localized compressive stresses. Furthermore SMA may be used as muscle fibers within self-stressing composites allowing the composite to change the pre-stressing force at any time after the composite matrix has hardened. Besides, they have the unique property of freezing part of the elastic deformation and then recovering it upon special treatment [5]. The SMA tags embedded in composites can be monitored externally through the life of the structure to relate the internal material conditions. Measurements such as stress, moisture, voids, cracks, and discontinuities may be interpreted via remote sensors.

4.1.2. Piezoelectric actuators

Piezoelectric actuators exert mechanical forces in respond to applied voltage and can change shape when their electrical dipoles spontaneously align in electric fields causing deformation of the crystal structure. They are useful when high precision or high speed actuation are necessary, e.g. optical tracing devices, active acoustic attenuation, adaptive optical systems, active structural damping for earthquake resistance, and active damage control [2].

4.1.3. Magnetostrictive actuators

Magnetostrictive actuators respond to magnetic rather than electric fields as in piezoelectric actuators. When in a magnetic field the magnetic domain in a magnetostrictor rotate until they are aligned with the field resulting in expansion of the material, e.g. Terfenol-D [2]. They may be used for example in high force linear motors and hydraulic actuators and active damping systems.

Solid-state actuators are also implemented in the aerospace industry, e.g. aircraft wings implementing the displacement amplification principle. Fluids can also act as actuators in adaptronic structure. Electrorheological (ER) and magneto rheological (MR) fluids experience reversible changes in rheological properties (viscoelasticity, plasticity and elasticity) when subjected to electric and magnetic fields [2]. Applications include vibration isolation systems and tunable dampers.

4.2. Sensors

Sensing (Artificial Nerves) [2,3] is a critical function. Damage control, vibration damping and intelligent processing require accurate information provided by sensors describing the state of the material system. Sensing of the structure may be by externally attaching sensors or by incorporating them within the structure during manufacturing. Examples of sensors include optical fibers; piezoelectric materials; and tagging particles. Passive peak strain sensors can remember the peak strain to which they have been subject to. When undergoing strain the material instantly and irreversibly transforms from a nonmagnetic state to a magnetic state [4]. Transformation-induced plasticity (TRIP) steels used in intelligent sensing can change from an austenitic nonmagnetic state to a martensitic, ferromagnetic state as they undergo axial strain. The key to the technology is the correspondence between the peak amount of strain and the percentage of ferromagnetism in the TRIP alloy [4]. Alarm can be triggered on the basis of either the magnitude of displacement or the percentage changes. Real time structural data (data collection system) may be made available on line for maintenance engineers to assess the structural integrity from their offices.

4.2.1. Fiber Optic (FO)

Fiber Optic (FO) technology [2,6] includes developing practical and cost effective applications for FO sensor systems (crash and vibration sensing, embedding sensor systems into infrastructure, e.g. to reduce the vulnerability of vital infrastructure to seismic events). Although surface mounted strain gauges can monitor stress and strain in a structure, however, they are limited in their ability to detect subtle changes over time. Optical fiber time–domain (OFTD) [6] sensors that use multiple in line sensor segments along a single strand of optical fiber allow spatially distributed sensor interrogation. Strain mapping of an entire structure may be provided, e.g. fig. 2. It will enable engineers to capture localized damage such as cracking or stress concentration before it reaches an advanced and hazardous state. FO can provide better monitoring of the actual behavior characteristics than traditional strain gauging. Besides they can be used extrinsically (transmit light, light beam security systems) or intrinsically (change in the light transmission characteristics of the optical fibers in sensing, e.g. measure strain in low temperature composite materials) for damage detection; and evaluation [6]. They have resistance to adverse environments and immunity to noise from electrical or magnetic disturbances. However their disadvantages include lose of signals, faulty adjustment, signal interference, kniking of the optical fibers, measurements errors, and disruption of the light path.

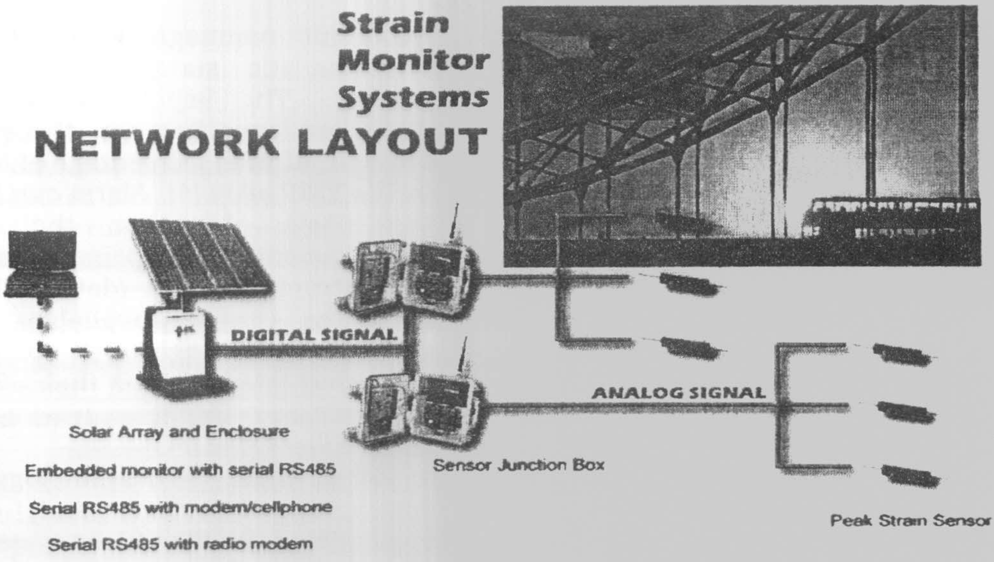


Fig .2. System for strain monitoring [4].

4.2.2. Piezoelectric materials

Piezoelectric materials [2,3] are used for structure health monitoring and nondestructive evaluation (damage identification). These include piezoelectric ceramics and polymers and may produce measurable electrical charges in response to mechanical stress. For example polyvinylidene can measure stresses along one axis or in a plane (skin like sensors). Polymers containing piezoelectric powders are used as sensing matérials. Piezoelectric paints and coatings may provide information about the state of stress and health of the underlying structure.

4.2.3. Passive and active tagging

Passive and active tagging embedded piezoelectric and electrostrictive materials, e.g. distributed in situ sensing, may be used to provide information about the in process or in service state of adhesives and polymers, characterization of adhesive bonds, cure monitoring intelligent processing nondestructive materials evaluation, damage detection, and in service health monitoring.

4.3. Signal processing, communication and controls

Control systems (intelligence) for example neural works/networks are modeled after biological systems, e.g. the brain neurons, God complex architectural scheme for processing the information from these neurons to allow complex tasks to be performed with amazing speed. The available computational hardware and processing algorithms will determine how complex and fast the system can be [3].

Smart materials do not serve a single function but can be interacted with to provide a wide assortment of functions, however economical, simple and cost effective for man-made systems to replicate the adaptive self-preserving features of natural systems. They are hybrid material systems like silicon electronics, e.g., silicon microchips used as a structural ply of a composite laminate. The sensors, actuators, and silicon intelligence are reduced to the microstructure, micron level for advanced fiber reinforced composites or meter level for architectural and civil engineering constructions [2]. Smart materials may look like fluids, or can look hard then change their shape to jelly like just long enough to deflect and absorb energy.

5. Applications

Applications of smart materials/structures are common [1,2,3,5,6] in automated houses, buildings, infrastructure, aerospace industry, electronics industry...etc. Smart materials are implemented in the aerospace industry, e.g. space ships and structures, airplanes (smart wings that shape themselves to fly). Also, in helicopter blades, shape control propellers, and aircraft wings to provide flight and marine adventure with increased efficiency and maneuverability reduced vibration and noise and longer life by reducing vibrations that can cause structural fatigue. Other applications include precautionary signal lights in vehicles to signal faults; and automatic open doors in lifts, entrances, and airports.

Intelligent materials are found in many infrastructure applications where sensors are embedded in bridges and road surfaces for detecting vehicles and monitoring material performance; variable lighting to study road visibility, and in experimental concrete and asphalt pavements e.g. the smart Virginia Road, USA. In addition, smart materials are found in home/building automation systems where almost every aspect in the building is automated e.g. regulate lighting, energy, and temperature (e.g. TRON Hyper Intelligent Building, USA; and the advanced measurement laboratory at the National Institute of Standards and Technology, USA [7,8]); operate internal systems, ventilation, air conditioning, power, access systems, and vertical transportation, fire and life safety, and security; control utilities and services; computer aided identification cards; voice recognition systems; and voice activated lights. For example curtains may glide open automatically to admit light and windows sheds that can change their reflectivity to control room temperature or light level, or even close automatically when it begins to rain (e.g. covering sheds in ElHaram El Nabawy, in El-Medina Saudi Arabia (sensitive to level of sunlight and rain). Besides, yards may be watered depending on weather conditions.

Intelligent transportation systems (ITS) help planning and traffic engineers in their efficient management [7,8]. ITS can tell patrons waiting at a bus stop exactly when the next bus will arrive; inform drivers where delays are occurring; detect accidents by using video cameras and sensors; and track travel times by using transponders affixed to vehicles and collect tolls electronically, fig. 3. Closed circuit television; video cameras; detectors (sensors); and fiber optics can detect the changes in the traffic flow and respond to incidents. Traffic pulse [7] collects data via a series of sun-operated sensors that use microwave radar detectors to determine traffic speeds, volume, and point to point travel time leading to more safe and efficient traffic systems.

In addition, smart materials may be used in buckling controlled active members. Sensors may be embedded in composite materials, stressed area in buildings, bridges (fig. 4), dams, tunnels, and pipelines.

Embedded memory materials may be used as muscular fibers in cementitious composites to develop self-inducing pre-stressing composites, capable of changing the level of pre-stressing throughout the life of the structure without using jacks or other mechanical devices [5]. SMAs may trigger self-stressing of composite plates. Memory polymers can be used to manufacture self-stressing composites. With prestressing the ultimate capacity of materials can be increased and the structure becomes more impervious to penetration by liquids and gases, and cracking can be avoided. In SMAs force is generated through the change in material crystal structure and not through the use of mechanical devices, eliminating the need to maintain mechanical devices [5]. SMAs are deformed at temperatures below the ambient temperature and stored at ambient temperatures without experiencing shape recovery. They may be factory produced, stored, shelved and then are placed in the composite and triggered to recover its deformation including pre-stressing at any appropriate time. They may be fabricated into rods, mats, or cages, and used as special self-stressing elements. Besides, the concept allows shifting from prestressing at a structural level to prestressing at a material level [5]. Examples of prestressing thin elements may include cladding elements and composite tile flooring. Moreover, active lateral confinement of beams and columns, self-stressing jackets can be manufactured for rehabilitation of existing infrastructure or for new construction as self-stressing stay-in-place formwork elements. The active

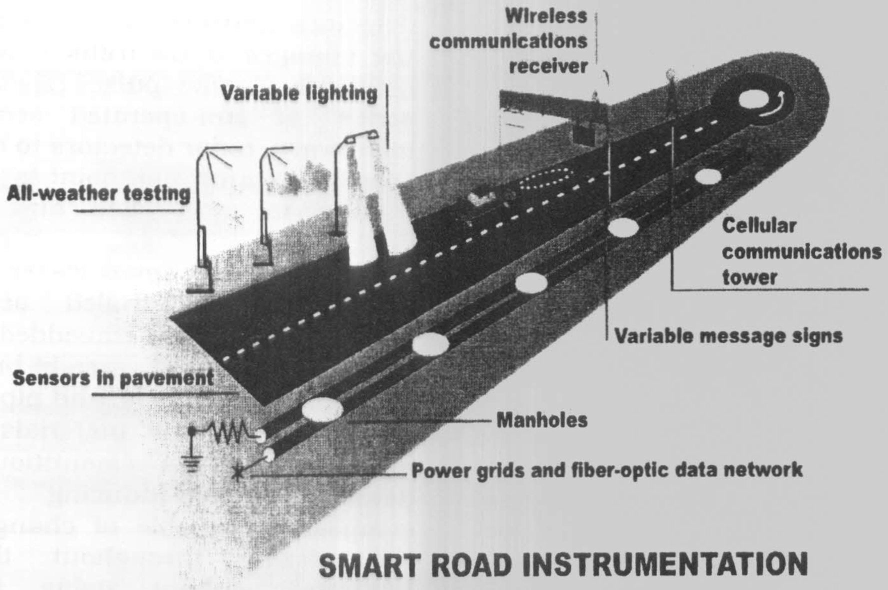


Fig. 3. Smart road instrumentation [8].

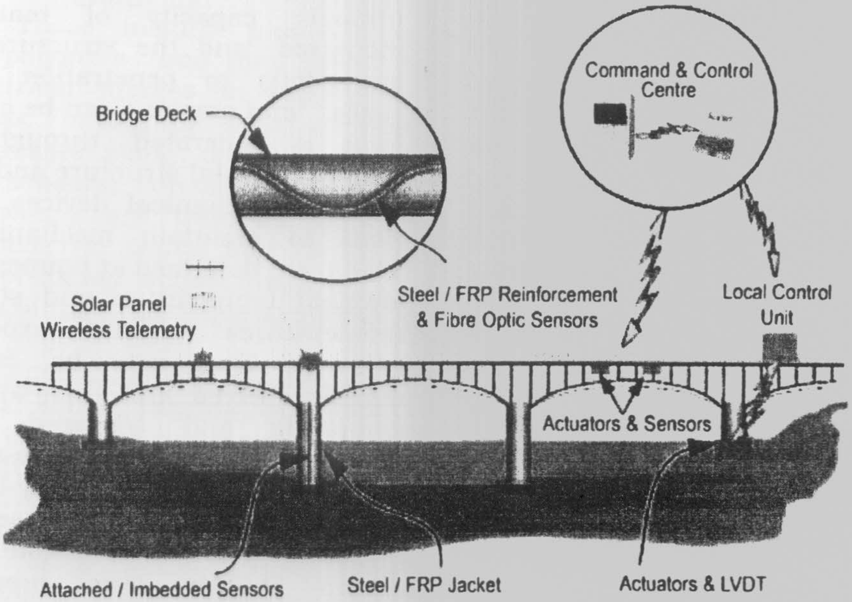


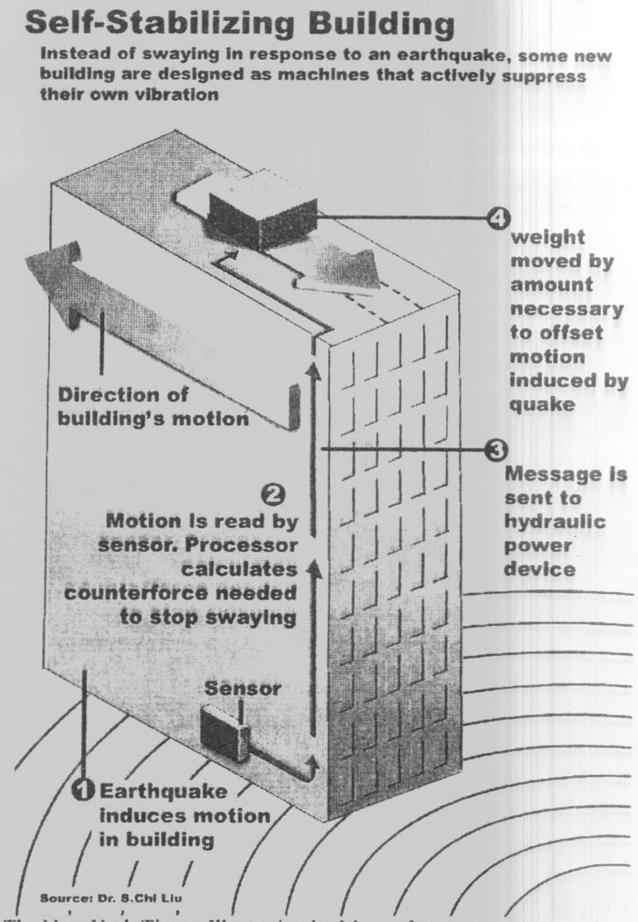
Fig. 4. A schematic view of a smart bridge [7].

confinement of highly stressed regions (anchorage zones of conventional prestressing tendons, bearing areas, corbels, concrete hinges at bridge supports, and critical zones within the compressive force path) leads to improved overall structural performance [5].

Variable geometry trusses (VGT) with elements that can change their length in a controlled fashion can be used to change the impedance of portions of a structure and thus control vibration efficiently. Space truss elements with low volume and low mass that can be actively controlled to change their length, behave much like a mechanical muscle. Induced strain indicators such as shape memory alloy fibers and piezoelectric ceramics can actively reduce strain concentrations from transverse cracks, near holes and notches and other forms of damage or strain concentrations. Actuators may be used in a structure and sensors can determine the state of health in real-time, look for signs of weakened materials or damaged structure around these portions of the structure until remedial action and repair can occur.

Control of structural impedance (fig. 5) is one of the most fundamental and powerful concepts of adaptronic structures, i.e., changing the structural impedance can alter the vibration and acoustic behavior as well as changing its resistance to damage [2]. In large structures, smart materials can control the transmission of motion and the flow of energy into the structure by adaptively controlling the impedance of the structure at its base. Magneto and electrorheological fluids can be used to change and control the friction of thrust bearings used to support large buildings in areas of high seismic activity. Incorporating sensors and actuators into thin flexible surfaces with active control algorithms can reduce weight and volume as compared to passive counterpart structures by using electrical energy to assure that a desired shape is maintained. The concept of using mass to support load, to add stiffness or to increase strength will allow mass to be replaced with energy. Earthquake resistant structures in Japan, i.e. self-stabilized buildings, use smart materials to adaptively control the impedance of the structure at its base, to counteract the effects of earthquakes.

Acoustic applications of smart materials range from speakers and noise control devices that are parts of curtains or walls to quiet commuter aircraft, and to reduce sound radiated from vibrating structures. Biomedical applications include new artificial organs such as pancreas and artificial limbs [2] that not only provide basis motor control but tactile responses as well. As electro active ceramic materials can adaptively change shape, they are used in mirror surfaces e,g. Hubbell telescope, to mimic the change of eye lens curvature with light and distance from objects.



The New York Times; Illustration by Megan Jaegerman

Fig. 5. Active self-stabilizing building.

Future homes may utilize sophisticated user-friendly design tools; manufactured wall systems with integrated super-insulation and super-windows optimized for orientation, external temperature and future needs; photovoltaic roof shingles with reflective roofing; low cost solar water heaters and fuel cells providing low carbon energy; lighting systems actively operated with an array day lighting and site/task strategies to optimize luminosity and reduce energy consumption; improved sensors and controls, zoning and variable loading of the heating and cooling; smart technology to closely match energy and water supply for multifunction and integrated appliances and automatic load modulation of heating and cooling systems in response to varying weather, environment and occupants demands. Smart systems can also be employed in homes for the elderly [9].

6. Impact on design

The core of smart structures design lies in developing a system with the ability to interface and interact with a network of sensors, actuators and controls that allow the user/designer to architect a system to perform the functions desired within the host material, i.e. adaptive architecture. An adaptive, interactive, and responsive architecture (sometimes termed "heterotic architecture") may be developed by the incorporation of biological materials in bulk as functioning devices [1]. For example skin as a biological material possess characteristics that are desirable in an architectural cladding, including protection from the environment and active role in maintaining internal conditions such as thermal and humidity levels, regeneration or self repair, sensory perception and biodegradation. It is flexible, complaint and responsive, and may be man largest and most robust organ [1]. Smart materials have the intrinsic and extrinsic capabilities to respond to stimuli and environmental changes and then to activate their functions according to changes. They have variable resistance [3] and are highly anisotropic. Smart structures will create possibilities never before open to the construction industry. As the properties of smart materials could be tailored, hence designers could design the material for the desired application instead of designing an application around fixed material properties, adapting technologies invented by other professional areas. Integrating smart technology with traditional forms of architecture seems a matter of fit rather than creative design. The smart technology will be hidden in the floors [10], walls, and ceilings so there seems no visible evidence of a changed architecture, at least from a materialistic point of view. The real change is in the process. In addition, smart structures design will reduce the mass and energy needs of the system to enable it to perform its adaptive functions. Although the structural implications of smart materials are just now beginning, intelligent materials may have developed another structural revolution. However, the technology of smart materials and structures is still in its infancy and the scientific community is just beginning to scratch the surface of its potential [3]. With some imagination one can see enormous benefits to the society. In the near future intelligent materials and structures will be produced commercially. They will impact the philosophy of engineering design. Architects and engineers will learn to use energy as a structural component instead of mass, and to make structures behave like nature's systems [2], and to make structures that are soft, adaptive, more natural, and livable instead of silent, hard, dry and inert, and to utilize materials around us. As stated in ref. 2 the concept of mimicking nature and instilling some life functions, inspired from biological materials, in objects and articrafts is the modern day alchemy. This seems to be a vision more akin to science fiction than present day realism. New visions of design and material functions and a renewed look at the natural world will develop. Adaptronic structures will be the manifestations of the next materials and engineering revolution, the dawn of a new materials age [2]. However, adaptronic structures will not and cannot replace the engineer/architect role. Engineers' personal judgment and decisions will always be needed and visual inspection is and will continue to be irreplaceable. A computer and sensor system can detect only what they have been set up to find. Hence engineers/architects must still design smart structures and determine where and how smart materials fit into buildings and projects and assess their performance. To make those decisions, architects and engineers must be aware and understand both the potential and limits of intelligent structures. However how warm, livable, suitable and humane is a smart dwelling or home to its occupants when its components are believed to have some sort of ears and brains and to be artificial. Besides one would wonder about the lost beauty, calm, peacefulness and tranquility of conventional buildings, materials, and natural environment. Smart technologies may also change the familiar conventions of comfort, cleanliness and convenience. A number of architects propose that increased comfort can and ought to be accommodated through intelligent design (i.e. natural lighting) rather than incorporation of more and more intelligent devices embedded in the design.

6. Human perception of technology

An important issue arises regarding the human perception of technology and human-technology interactions. It was proposed [9] that three kinds of relationships between humans and technology may be identified:

- Embodiment relations: Embodiment relations may describe the most intimate couplings between humans and technology. Embodied technology becomes part of us to the extent that we experience the world through them, i,e. non-intruding, non distracting (e.g. eye glasses, hearing aids). Although they may have some initial discomfort and self-consciousness, they are desirable because they allow us to forget about the technology and focus on the task in hand.
- Hermeneutic relations: Hermeneutic relations are those relations requiring some interpretative effort from human's part, to gain access to some property or aspect of the world that is normally unavailable or invisible to us. (e.g. speedometer in a car).
- Alterity relations: The term "alterity" refers to the "otherness" a technology not familiar and distinct from the normal realm of experience outside human experience (e.g. computer).

The three sets of relations are not separate but can be assumed to lie along a continuum and may overlap, fig. 6. For the vast majority many of the assisting intelligent/smart technology may form alterity relations with their users at least at the beginning. After some time, they as an object of concern withdraw and become part of our background awareness and are no longer a focal concern.

8. Conclusions

Biological systems have inspired engineers and architects to envision smart materials/structures. These are supposed to have adaptive and interactive features and capabilities to respond to stimuli and environmental changes and then to activate their functions according to changes. The structure then shares this information with the users and designers throughout the life of the system. The basic components of smart elements i.e. actuating, sensing and processing (control) have been demonstrated. Intelligent structures can provide continuous health and integrity monitoring, damage detection and intelligent operational management system. In addition they may have the ability of self-detection, self-diagnosis, self-correction, self-recovery and self-controlled functions. Smart structures will create possibilities never before open to the construction industry. They have/will have several applications in both the architectural

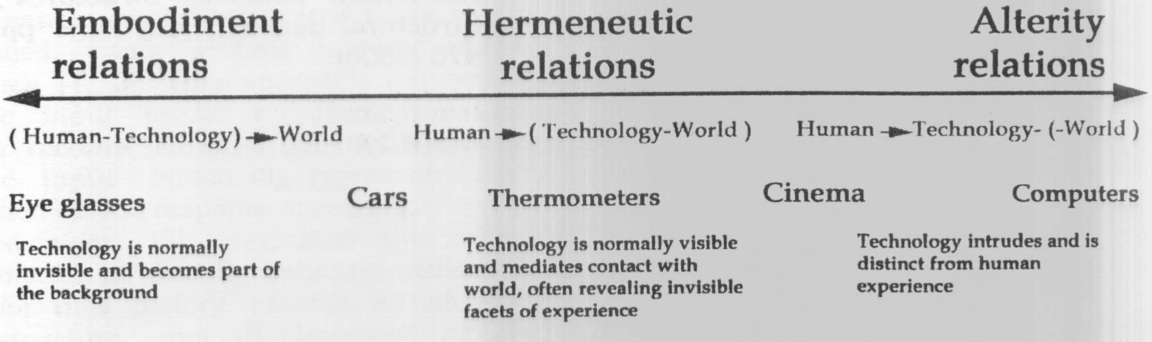


Fig .6. Types of human-technology relations [9].

and civil engineering fields, some of which have been reported. However many others are continuously developing. They can be used for cost effective, innovative repair/retrofitting methods, novel high-performance homes, buildings, infrastructure systems and actuating elements for active structures. In addition, new, long lasting and cost effective high performance construction materials and systems may be developed. Smart structures design will reduce the mass and energy needs of the system to enable it to perform its adaptive functions. However smart structures cannot and will not replace engineers' and architects' decisions and judgment. Architects and engineers must still design smart structures and determine where and how smart materials fit into buildings and projects, and how to assess such structures performance. As the properties of smart materials could be tailored, hence designers could design the material for the desired application instead of designing an application around fixed material properties. Integrating smart technology with traditional forms of architecture is a matter of fit rather than creative design. The smart technology will be hidden in the floors, walls, and ceilings so there seems to be no visible evidence of a changed architecture, at least from a materialistic point of view. Some architects propose that increased comfort ought to be accommodated through intelligent design rather than incorporation of more intelligent devices embedded in the design

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