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THE IMPACT OF SMART TECHNOLOGY ON SOCIETY

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

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Approved:

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Abstract

The goal of this project is to study the impact of smart technology on society. We conducted a detailed survey of smart materials and systems that are currently being used in industry and determined how this technology has been beneficial to society. During the course of this study, we performed some interesting experiments that may be used for science demonstrations to grade school students. In addition, we suggested some potential applications for smart materials and systems and analyzed how they would affect society.

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1 Introduction

One of the most fascinating abilities of the human body is the dexterity with which it subconsciously responds to a multitude of stimuli. The fact that we are able to make decisions on an infinite range of issues makes us smart. The Oxford Dictionary defines smart as "characterized by sharp quick thought". From time immemorial, society has been in search of machines and systems that would be able to perform functions as adroitly and efficiently as human beings. Often, these machines and systems are limited by their inability to make decisions over a wide range of conditions.

A system is a group of elements that performs a function on an input to produce a desired response. Systems that are able to vary their action based on the input are considered to be smart. A smart system is one that monitors and adapts to a variety of situations without conscious human intervention. Smart systems often consist of smart materials. These are highly functional materials that have the ability to actively respond to stimuli. Smart materials and systems are collectively referred to as smart technologies. The terms active, intelligent, adaptive and smart are often used interchangeably to refer to these technologies.

The human body can be considered to be an ideal smart system. It is composed of many smaller smart systems that respond and adapt to stimuli and situations separately or in unison based on the needs of the situation. The body responds quickly and efficiently to changing situations, often without us realizing it. There is no limit to the manner in which the body can respond to changes. Another example of a smart system is the Worcester Polytechnic Institute (WPI) water fountain, depicted in Figure 1. This system is smart because the water pressure is adapted to suit the prevailing wind speed as measured by an anemometer. When the weather is calm, the height of the fountain is similar to as it is shown in Figure 1. However, when wind speeds increase the height of the projected water is lowered so that it will not be blown an undesired distance from the source.

Figure 1: Worcester Polytechnic Institute water fountain

Smart technologies are playing an increasingly important role in our daily lives. They are tailored for situations where the action performed by a system needs to be altered based on input conditions. The benefits they bring to society can only increase as more research and innovation is conducted in this field.

1.1 Project Goals

The aim of this project is to determine the impact of smart technology on society. We did this by first gaining an understanding of smart materials and the numerous applications in which they are being used. Using the knowledge acquired from this study, we analyzed how smart technology has benefited society, and how its usage may produce negative effects. Our final task was to come up with suggestions of applications where smart technology could be employed to the benefit of society.

During the course of the project, we performed a couple of experiments to demonstrate the smart behavior of some materials that we had studied. The results of these experiments are quite fascinating. We developed detailed guidelines on how to perform these experiments so that any interested persons may easily conduct them. These experiments will be used as demonstrations for elementary and middle school students who participate in some of the numerous programs for grade school students at WPI, such as Camp REACH and Frontiers. The aim of many of these programs is to encourage young students to pick up an interest and appreciation for science. We feel that performing these experiments and then carefully explaining the scientific phenomena behind them will be a great method to encourage students to take up a career in science.

The results of our project are particularly useful to anyone interested in the field of smart technology. The designs we developed may be of interest to any organization that is actively involved in the development of smart technology. We also compiled a list of books, websites and other resources concerned with smart materials and made it available to the public. This resource library will be extremely helpful to any person researching the field of smart systems as they will not need to go through the pains we experienced finding relevant literature on the subject. We constructed a website with information on the smart materials and systems that we studied and the results of our project. This website will serve as a means of communicating our results to interested persons in and out of the WPI community.

1.2 A Brief Introduction to Smart Technology

Probably the most popular smart materials are piezoelectric materials. The oldest and most widely used is the quartz crystal that is used in most watches and clocks. A piezoelectric material develops a potential difference across itself whenever it is subject to a stress or strain. Conversely, whenever an electric field is applied to such a material, it is deformed. Piezoelectric materials have numerous applications as both sensors and actuators and are of utmost importance in converting electrical to mechanical energy and vice-versa. This topic is explored in detail in section 2.2 of this report.

Another group of smart materials are the electrorheological and magnetorheological fluids. Applying electrical and magnetic fields can modify the flow properties of such fluids. These fluids are used in braking systems and vibration dampers. For further discussion please refer to section 2.3.

Shape memory materials are substances that can return to remembered shapes when stimulated. The substances include shape memory alloys, ferromagnetic shape memory alloys, and shape memory polymers. Shape memory alloys (SMA) are stimulated by thermal fields. These materials can be trained to return to a preprogrammed state when they reach a certain temperature. Ferromagnetic shape memory alloys (FSMA) return to their remembered shapes when stimulated by magnetic fields. Though FSMA's are still in development, there are high expectations of them replacing the thermal shape memory alloys because they can actuate at a far greater speed. Their faster actuation is due to their reliance on magnetic field adjustment speed rather than the enthalpy of the material. Shape memory polymers are plastic materials that will return to their remembered shape when stimulated by thermal fields. They are still in development but have many potential applications and are much more efficient and durable than alloys. A detailed discussion of shape memory materials can be found in section 2.4. [3], [4]

An excellent example of a smart structure is one that accomplishes active noise control, also referred to as active noise cancellation or simply anti-noise. Ordinary noise control systems (passive noise control systems) do not eliminate noise. Rather, they damp out all sound waves within a predefined range of frequencies. On the other hand, active noise control systems eliminate noise. This is achieved by generating sound waves that are out of phase with the noise. The destructive interference between the two sets of waves results in the noise being cancelled out. [5]

Microelectromechanical systems (MEMS) are micro-devices that combine mechanical elements, sensors, actuators and electronics on one chip. By integrating micromachines with microelectronics, MEMS allow us to combine the powerful computational abilities of microelectronics with active perception and control functions. MEMS can be considered smart systems, as they are able to actively respond to varying stimuli. More information on MEMS is available in section 2.5

The human body is rife with examples of natural smart systems. It is a complex system of sensors and actuators with the central nervous system acting as the processor. Many modern synthetic smart materials and systems closely resemble parts of the body. We can derive inspiration for future smart materials and systems simply by analyzing the various processes and systems in the human body. An analysis of some of the smart systems in the human body is found in section 2.6.

2 Background

2.1 Smart Materials vs. Smart Structures

Smart materials can be defined as materials that are able to respond to external stimuli with inherent intelligence. This response is a result of the intrinsic properties of such a material rather than the result of communication between its different components. Smart materials are functional as opposed to being simply structural and they may be stimulated by a variety of different sources. The most common of these sources are electrical, magnetic, and thermal fields, though there are many other sources for specific materials, i.e. pressure and chemical. [1]

Smart materials have varying degrees of intelligence. Most materials show gradual change due to external stimuli. This change is often so slight that it is hardly noticed. A material that is considered to be genuinely smart, however, shows sudden pronounced responses to such stimuli. [2]

Smart materials are often used as part of larger systems that incorporate some sort of feedback loop that processes information received from the smart material. Such structures are referred to as smart or intelligent structures. A smart structure is one that has embedded sensors and actuators whose actions are coordinated through a control system.

A simple example of a smart system is a thermostat. A thermostat is an electric device that is used to maintain the temperature of rooms. A thermostat consists of two layers of metal that are attached back to back to each other. One material is a conductor that will expand when excess current flows through it. A slight change in shape of the conductor results in a larger deformation of the other material and results in the circuit being broken. The metal bi-layer is not a smart material; like all metals, it is simply responding to heat dissipated due to the electric current. However, the system as a whole has smart characteristics in that it adapts to varying changes in temperature. [2]

Smart materials will eventually possess characteristics that are currently common to smart structures. They will have embedded sensors, actuators and control systems that are fully integrated into the structure. However, these sensors, actuators and control systems will be part of the structure of the material itself. An excellent example of the future generation of smart materials is zinc oxide. This compound emits visible radiation in water. However, when placed in water contaminated with chlorinated phenols, an organic aromatic pollutant, the amount of radiation drastically reduces. When exposed to the sun though, the zinc oxide is able to degrade organic contaminants. As the water becomes cleaner, the zinc oxide will glow brighter thus informing us that the water is clean. Thus, not only does the zinc oxide indicate the presence of the chlorinated phenols, but it also eliminates them and informs us when the contaminants have been removed. [3]

2.2 Piezoelectric Materials

The piezoelectric effect, discovered in 1880 by Jacques and Pierre Curie in France, provides a link between electrical and mechanical energy. A piezoelectric material is one that develops a potential difference across its terminals when subjected to a mechanical force. This effect is known as the direct piezoelectric effect. Conversely, when a piezoelectric material is subjected to an electric field, it undergoes some mechanical deformation. This is depicted in Figure 2.[6] Clearly, piezoelectric materials can be used in situations where there needs to be a conversion between electrical and mechanical energy.

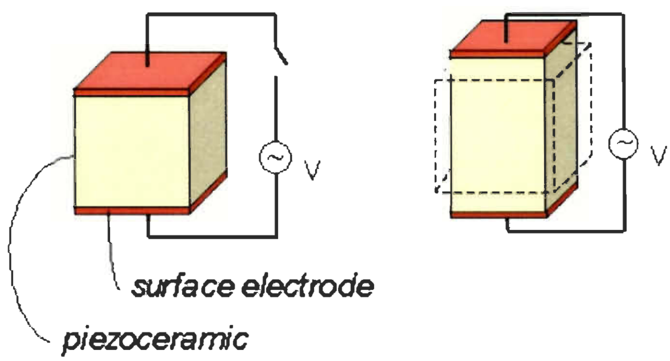

Figure 2: The Piezoelectric Effect[6]

Piezoelectrics have been used as resonators, and in other non-smart materials for some time now. However, their use in smart materials and structures has greatly increased over the past 15 years. Since piezoelectrics are able to convert electrical energy to mechanical energy and vice-versa, they are extremely useful in the design of sensors and actuators.

Probably, the most common and well-known piezoelectric material is quartz. Quartz crystals are used as timekeepers in computers and electronic watches. The quartz crystal is subjected to an oscillating electric field that causes it to vibrate at its natural frequency. The vibrations of this frequency are counted and are used to keep the clock or watch on time.

The piezoelectric effect observed in a quartz crystal is caused by the asymmetric arrangement of particles in the material's crystal structure. Quartz, which is silicon dioxide, consists of silicon atoms attached to four oxygen atoms, forming a tetrahedron. There is an imbalance of electric charge between the silicon and oxygen atoms that results in a dipole along each silicon-oxygen bond. At equilibrium, the four dipoles are positioned such that they cancel out each other's charge. However, upon displacement, the dipoles are no longer in a position such that they will be able to cancel out each other's effect. This results in a net electric charge across the crystal. This is shown in Figure 3.[2]

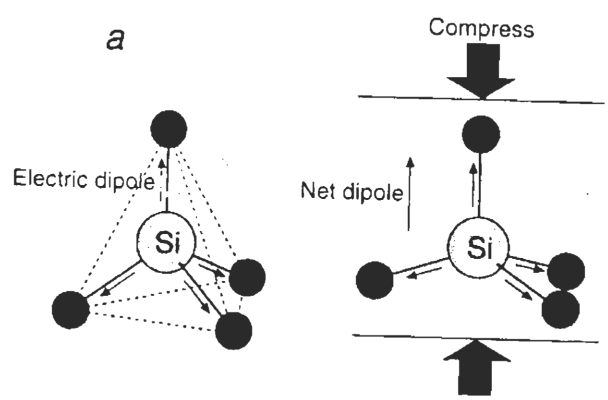

Figure 3: Quartz Crystal[2]

Rochelle salt, one of the materials discovered by the Curie brothers, consists of crystals that naturally have an electric charge. This is due to the asymmetric alignment of the atoms in the material. Placing the material in an electric field with an opposite polarity can reverse the direction of polarization of the crystal. Due to the similarity of this phenomenon and the response of ferromagnetic materials to magnetic fields, such materials are often referred to as ferroelectric materials. Ferromagnetic materials, such as iron, are materials that can be permanently magnetized by applying an external magnetic field. Due to their ability to reverse their polarity, ferroelectric materials are extremely useful in smart structures.

Currently, the most popular piezoelectric material is lead zirconate-titanate (PZT). It is widely used in a multitude of applications, including accelerometers, hydrophones, ultrasonic applications and ink-jet print heads. This material is mostly used due to the large mechanical changes observed in it when exposed to even the slightest electric fields. PZT is ferroelectric and can be given a charge just as a ferromagnetic material like iron can be magnetized.

Piezoelectric materials are used in active noise control systems. Such a system requires some sort of sensing device that is able to detect the noise. This incoming signal then goes through a control system that generates sound waves that are out of phase with the noise; the antinoise. The antinoise is transmitted to the environment in such a way that there is destructive interference between the two waveforms so as to cancel out the noise. Piezoelectric materials, such as PZT, are used to create the noise detection device. The noise signals would cause the piezoelectric material to vibrate, hence setting up a potential difference across itself. This electrical signal could then be processed to gain information about the anti-noise signal. If the electrical anti-noise signal is applied to a piezoelectric material, it will start vibrating and thus set air molecules in the air vibrating at the same frequency. This is the anti-noise. In this system, piezoelectric materials are used as both sensors and actuators. Although the heart of the system lies in the circuitry that inverts the incoming signal, the piezoelectric materials provide the vital link between the sound waves and the electric signals.

At present, the most common active noise controls systems are used to cancel out low frequency noise. An example of such a device is noise cancellation headphones. They are designed to cancel out low frequency noise such that the user will only be able to hear high and mid-frequency sounds, such as sirens and conversations. Such technology is being used in vehicles and aircrafts. In an aircraft, the main source of noise is the fuselage. One such system is being used to cancel out noise at the fuselage rather than employing it in the cabin. Since the fuselage is the actual source of most of the noise, this system would be far more efficient as noise would be cancelled out before it could propagate. [5]

Piezoelectrics are often used in mechanical vibration damping systems. Ordinary vibration dampers, such as suspension springs, resonate at a particular frequency and thus are not that effective; if such a system were to be deployed in car seats to damp out vibrations, it would cause even more vibrations if the vehicle hit a bump and vibrated at the resonant frequency of the material. A smart system, that employs the use of piezoelectric materials, has been developed to counteract mechanical vibrations. The system is depicted in Figure 4 below.

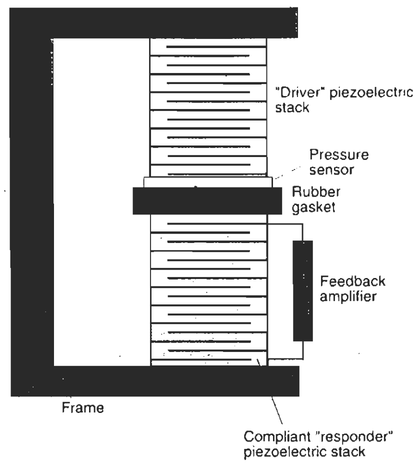

Figure 4: Smart Vibration Damping System[2]

It consists of two stacks of piezoelectric material connected to each other via a rubber gasket. An electric field is used to set one of the stacks into vibration. The rubber gasket links the end of one stack to the top of the other. Here a piezoelectric pressure sensor is present and produces electrical signals that are in phase with the vibrations of the stack. This is then passed through an electrical feedback circuit that causes the second stack to vibrate. If the feedback circuit produces a signal of the same frequency as the lower stack, then the two stacks vibrate in step. This is the compliant stage. However, if the output of the feedback circuit is not in step with the signal from the piezoelectric sensor, then both stacks vibrate at different frequencies. This causes the stacks to become stiff, thus resulting in damping of the vibrations. It should be noted that stacks are used to enhance the effect of the electric field applied. The displacement caused by a single layer of the material is much smaller than that of a stack. [2] This device is intelligent as it is able to respond to external vibrations and cut them out. As in the case of the active noise control system, piezoelectrics are used as sensors and actuators. Piezoelectric devices are also being used as vibration dampers in tennis rackets. The world famous tennis racket manufacturer *Head*, has designed a racket that contains piezoelectric ceramics in the handle. The piezoelectric ceramics in the handle convert the mechanical energy (from vibrations due to impact with ball) to an electrical signal. This electrical signal is then fed to a custom designed analog IC chip that releases necessary signals at appropriate intervals of time. The signals that come out of the IC are transmitted to the yoke of the racket. This has some embedded piezoelectric ceramics that will vibrate at the necessary frequencies to counteract the initial vibrations. Top players such as Andre Agassi have used such rackets as recently as May 2002. [4]

The previous examples introduced the idea of enhancing the behavior of piezoelectric materials. Often the mechanical distortion in response to an electric field may not be as pronounced as desired. One possible solution is to use a stack of the material as opposed to a single layer. Another trick used by engineers is that of bi-layers. For instance, if we wanted a certain strip of metal to bend when an electric field is applied, we could enhance the distortion of the piezoelectric material by attaching it to an elastic material. Thus, even a small distortion of the piezoelectric material would result in a significantly large distortion of the composite material. This is shown in Figure 5, below.

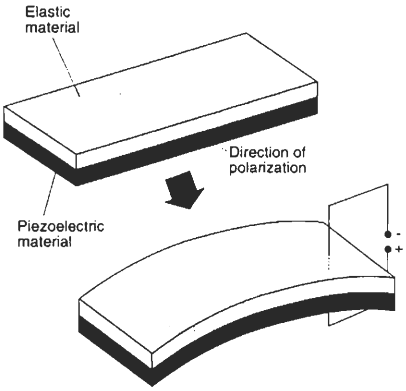

Figure 5: Bi-layer Structure Enhances Deformation[2]

Recently, piezoelectric paints have been developed to help detect cracks in walls. Conductive paint is doped with piezoelectric particles that will react to stress/strain by producing an electric current. This current is extremely important as it lets us know what kind of movement may have occurred in the wall. This information helps us find a solution that would help avert disaster. The ability of the material to constantly check for problems and relay the information to us makes it smart. In the future, a microprocessor may be used to monitor the outputs of the material and use this information to help predict future problems. [7]

Piezoelectric materials are also being used in the construction industry. Tests have been carried out on slabs of concrete and asphalt, doped with piezoelectric sensors, to see whether any meaningful electrical signals can be obtained when the material is put under stress/strain. The electrical signals observed varied substantially when the material was deformed. Thus, it is possible to use the signals coming from the sensors and send them to a computer that will analyze and interpret the data.

Piezoelectric materials are invaluable to smart structures and systems. Their ability to convert mechanical energy to an electrical signal is of utmost importance as it provides an opportunity for the use of powerful microprocessors in smart systems. Piezoelectric materials can be successfully deployed in systems that require a transition between electrical and mechanical energy.

2.3 Electrorheological and Magnetorheological Fluids

Electrorheological (ER) and magnetorheological (MR) fluids are two types of smart materials that can already be found in use in many fields and applications. They are composed of particles suspended in a fluid that responds to either an electric or magnetic field to alter the viscosity of the fluid. ER fluids were discovered in the late 1940's by Winslow. MR fluids were concurrently developed in the late 1940's by Jacob Rabinow. Commercial applications did not immediately arise because of various problems with the performance and development of these fluids. They had temperature limitations, storage problems, and were in need of other technologies to be developed before they could properly be utilized. Many of these problems have been fixed. ER fluids, however, are far more fragile outside of the laboratory, so they have been largely cast aside in favor of the more durable MR fluids. Another reason that they are not more widely spread commercially is that each fluid must be developed with the intended product; it must be tailored to its intended use. The commercialization of these fluids has also been delayed by production limitations. Large amounts of the fluid must be able to be made reliably and repeatedly to supply even a small operation. Finally in 1995, MR fluids were released in a commercial enterprise. They were used in the rotary brakes of aerobic exercise equipment, but frequent use of this product showed another weakness of MR fluids, in-use-thickening. In-use-thickening delayed the large-scale commercialization of MR fluids for two more years until finally a team of six people solved the problem. Now MR fluids are found in many commercial products and their applications continue to increase in number.

ER and MR fluids are materials that are composed of suspended particles in a fluid. ER fluids generally consist of starches, silica gels, polymers, ceramic materials and other particles in highly insulating liquids such as mineral oil or silicone oil. MR fluids consist generally of metal spheres in some form of synthetic oil. When an ER fluid is exposed to an electric field the suspended particles form dipoles and orient themselves parallel with the electric field, with all of the positive poles in the same direction. These poles act as surface charges on the particles and these surface charges are attracted to the opposite signed surface charges on other particles. The particles do not initially cluster because each particle repulses from all other directions than the poles, see Figure 6a. This causes the particles to line up head to tail forming chains parallel to the electric field, see Figure 6b. These chains then group and bond to form a fibrous structure. The chains resist fluid flow, making the fluid more viscous. The viscosity can be increased to the extent that the liquid will be in a nearly solid state. The strength of the bonds is proportional to the strength of the electric field applied to it and can be formed and deformed in a matter of milliseconds. MR fluids are very similar to ER fluids. Rather than applying an electric field, a magnetic field is applied to attain the desired effect. MR fluids are often preferable to ER fluids, however, because they endure the environment outside of the lab far better and are therefore more useful in application. [2]

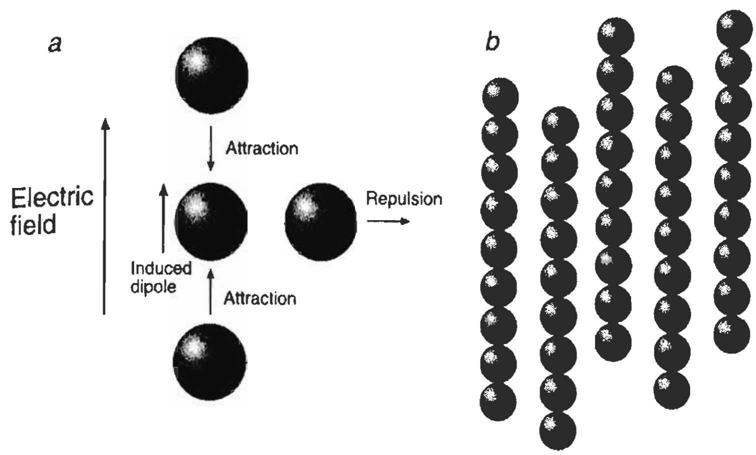

Figure 6: Effect of applying an electric field to an electrorheological fluid. [2]

There are many parameters that are used to compare and contrast ER and MR fluids. These parameters include yield stress, strength when stimulated, dielectric constant, fluid stability, and the viscosity of the fluid when a field is not being applied to it, also know as the off-state viscosity. The decision of which fluid to use is based entirely on what its intended use is. For example, a device to counteract the effects of an earthquake needs to be strong and needs to be highly stable because it will receive a lot of force and could be lying dormant for an extended period of time. Yet the earthquake damper will not need to be able to be repeated with any great frequency, so the materials and attributes can be adapted accordingly. [8], [9]

There are various challenges encountered when using and designing ER and MR fluids in industrial applications. One such problem is that the particle bonds in the on-state break down after a certain amount of shear force or pressure is applied to them. This problem, however, is an illustration of the superiority of ER and MR fluids over regular solids. Unlike normal solids, after the bonds break, simply applying another magnetic or electric field can reform them. Regular solids simply break and can not be reused. [2]

Another problem is that the suspended particles have a tendency to settle to the bottom of the fluid. The particles clump together at the bottom of the fluid and form heavy aggregates. This causes problems in the formation of bonds and chains because the electric field will polarize the aggregate rather than the individual particles. A proposed solution to this problem is to use smaller particles that will experience a smaller gravitational force. The liquid resistance will be able to hold them in suspension and will therefore be less likely to form clumps. [2]

Temperature also affects ER and MR fluids. In some cases the fluids will evaporate at certain temperatures. Other fluids have temperature dependent viscosities. An uncontrolled viscosity change can inhibit the performance of the fluid when stimulated or can affect the system when in its off-state viscosity. Research is being done to find chemicals that do not experience low temperature changes. [8]

One problem that scientists have been able to correct is in-use-thickening (IUT). IUT occurs when the fluid has experienced high stress and a high shear rate over a long period of time. The fluid, even in its off-state viscosity, becomes extremely thick, similar to the viscosity of molasses, and completely unusable. This problem was solved by a six-person team working for the Lord Corporation in about two years time.[9]

No ER or MR fluid can escape the effects of aging. They all eventually show some deterioration. This is dependent on shear rate, temperature, and duration. The fluid will eventually thicken and possibly experience other problems. [9]

ER and MR fluids by themselves are not smart. In order for them to be made intelligent they need to be coupled with sensor devices. They can be found in many applications, intelligent and unintelligent. [2]

ER and MR fluids are found in many smart systems. One system is in automobile clutch systems. When the clutch is activated, the springs push the pressure plates against the clutch disc, which in turn presses against the flywheel. This locks the transmission to the input shaft to the engine. The system relies on friction to make the plates all rotate at the same speed. [11] After prolonged use this may lead to seizure and other problems due to corrosion. When ER and MR fluids are added to the system though, the plates never need touch. The fluid envelops the plates and when the clutch is activated a magnetic field is turned on, solidifying around the plates, causing them to rotate at the same speed. This method causes no wear on the plates. Figure 7 is an illustration of such a system. [2]

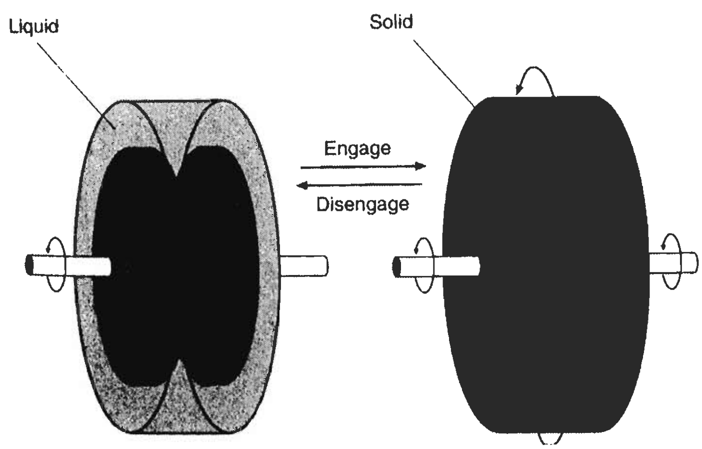

Figure 7: Magnetorheological fluid as used in a clutch system. [2]

One example of use in an unintelligent system is in the fight against cancer. Researchers from California State University, Long Beach, for example, theorize that MR fluids can be injected in the blood stream near the tumor. When a magnetic field is applied to the area the MR fluid solidifies, cutting off the blood supply to the cancer tissue. This causes tumor necrosis. This is currently being tested using a simulated blood network. It is hoped that they will be able to define the basic parameters for future tests in animal and human subjects. [10]

These fluids are also used in shock absorbers. When the car hits a bump or some other event occurs that sends a jolt through the system, a field is activated, increasing the viscosity of the fluid. The fluid is now able to absorb more energy. This method is preferable to other methods because the response time is much smaller and there is not a friction issue, meaning no wear. [2] These shock absorbers are currently used in truck seat shocks and have recently been implemented in the 2003 Corvette and the 2003 Cadillac STS. These new shock absorbers are accompanied by a complex sensory system and a dual processor computer that adjusts the field in the shock about 1000 times per second based on wheel travel and speed, vehicle speed, steering-wheel angle, lateral acceleration, and temperature. This process creates a very smooth drive and maximizes the contact of the tires with the pavement. [12]

ER and MR fluids are also found in high intelligence prostheses manufactured by the Lord Corporation. Conventional prostheses are designed to allow the amputee to walk at a particular pace relatively comfortably. If the person were to travel faster or slower, his walk would be awkward. The intelligent prosthesis adapts to the desired speed. There is a sensor located in the ankle area, a processor for analysis in the front, right below the knee, and then the control element behind the knee to control the movement. The MR fluid is in the control element and is activated by a field that is determined by the processor. The gait speed is determined by how much resistance the fluid applies in the active motion control. This entire system adapts to changes in milliseconds, allowing the user to climb stairs, carry heavy objects, and change pace rapidly with little to no awkwardness. [13] Figure 8 is an illustration of an actual prosthetic knee that has been developed by the Lord Corporation.

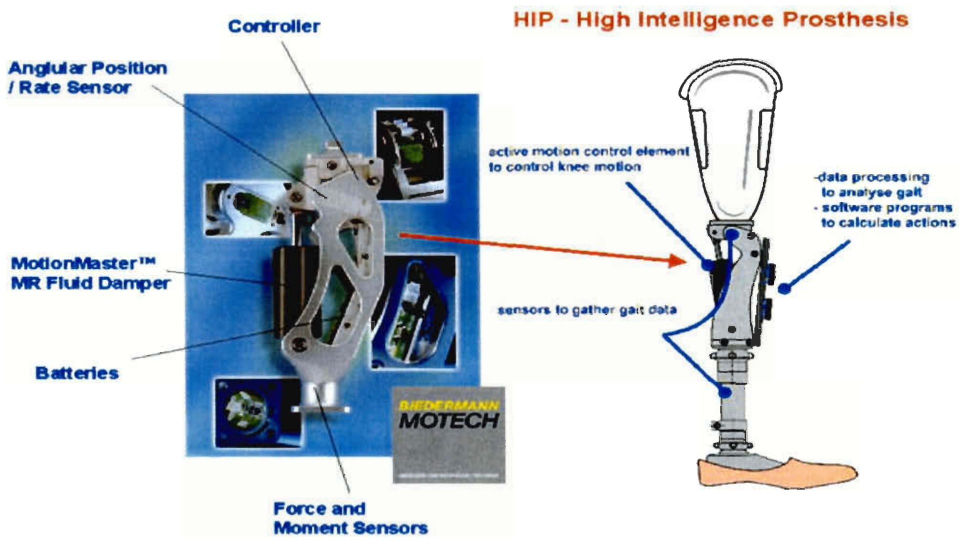

Figure 8: Prosthetic knee that utilizes MR fluids, developed by the Lord Corporation[13]

2.4 Shape Memory Materials

Shape memory materials are a class of smart materials that have the ability to return to remembered shapes. There are three types of shape memory materials: thermal shape memory alloys, ferromagnetic shape memory alloys, and shape memory polymers. All of these have at least one remembered shape that is activated by an external stimulus.

Shape memory alloys (SMA) are metal alloys that return to remembered shapes at specific temperatures. The most common SMA's are nitinol, an alloy consisting of nickel and titanium, and copper based alloys, most commonly CuZnAl and CuAlNi. The shape memory transformation was first observed in 1932 on the atomic level, but the shape memory effect was not seen until 1951 when a bent bar of silver-cadmium returned to its original shape. Intensive research and practical application did not begin until after the effect was seen in nickel-titanium in 1962. The commercial possibilities of shape memory nickel-titanium were almost instantly realized. It was much less expensive than silver-cadmium, soluble with many other elements, thermally stable, and has a high shape memory strain. Within ten years there were many products on the market and research was well underway. Many other alloys were later discovered to exhibit this effect.

Shape memory alloys have two main atomic states that are identified by their differing atomic crystal lattice structures. The "parent" state is found at high temperatures and is known as the autensite state. The lattice structure here is very ordered. The "skewed" state is at lower temperatures and is known as the martensite state. Here the lattice structure is deformed from the original shape. From the autensite state the alloy goes through a martensic transformation as the temperature of the alloy decreases. During the martensic transformation the alloy experiences changes in length, volume, and possibly electrical conductivity. The alloy may not revert to the same shape each time it goes through the martensic transformation. The alloy can then be deformed further through the use of shear force. When the alloy is heated it will return to its original autensite state. The transformation from autensite to martensite and the transformation from martensite to autensite occurs at different temperatures. The difference between these two temperatures is known as hysteresis.

Shape memory alloys can be trained to remember a second shape aside from the one already remembered in the autensite state. To accomplish this the alloy must first be in the martensite state. While in the martensite state, the alloy is deformed. This deformation shape is then constrained and the alloy is put through many temperature cycles, going from when the alloy is in the martensite state to the autensite state and then returning to the martensite state. After many cycles the constraints can be removed and the alloy will remember the deformed shape and return to it every time it returns to the martensite state. [2] Figure 9 is an illustration of one-way and two way shape memory effects.

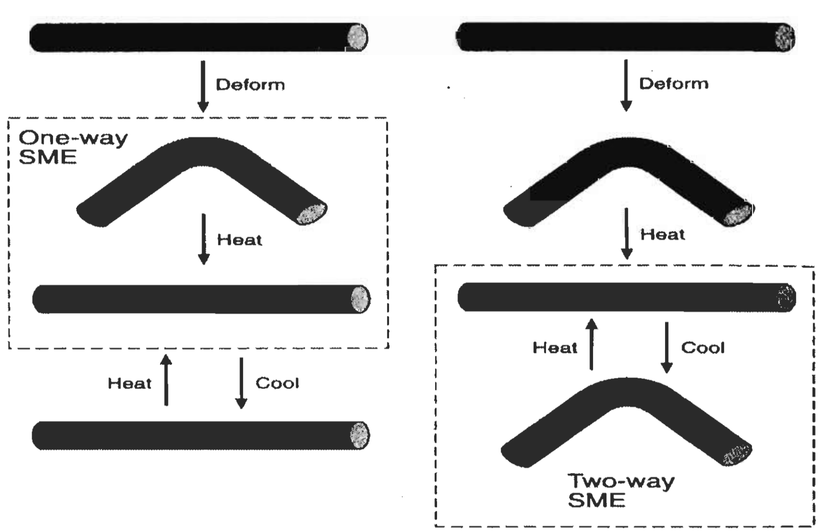

Figure 9: Illustrations of one-way and two-way shape memory effects. [2]

Not only are there shape memory alloys that respond to temperature but there are also those in development that respond to a magnetic field, these are called ferromagnetic shape memory alloys. These alloys will return to a remembered shape when they are exposed to a magnetic field. Otherwise they can be deformed and will remain in that state until they are stimulated further.

Shape memory alloys have found many applications in both intelligent and un-intelligent systems. They are used in the medical field as well as in engineering and even household appliances. Scientists have utilized SMA's to work as blood clot filters. The SMA is cooled and then placed in the blood stream where the body warms it and returns it to its original shape of a hooked apparatus, which anchors itself in the vein and catches passing blood clots. Companies such as the Raychem Corporation are also using them as couplings to create tight seals in pipes and hydraulic lines of aircraft. The alloy is cooled to its martensite state, where it is deformed to be a ring of larger diameter. The alloy is then placed in the desired area, and is heated to return it to the autensite state, which shrinks the alloy, forming a tight seal. SMA's have found applications in a fire safety valve. A CuZnAl actuator is designed to shut off toxic or flammable gas flow when fire occurs. [14]

The third type of shape memory materials is the shape memory polymer (SMP). These are plastic materials that have the same properties as thermal shape memory alloys. They return to their remembered shape when stimulated by a predetermined temperature change. The most commonly known SMP is shrink-wrap but since the mid-1980's scientists have been attempting to develop SMP's as a smart material that could be easily used and managed. It is hoped that SMP's will replace SMA's because they have greater deformation capabilities, high shape stability, and can be tailored to return to its remembered shape for a larger range of temperatures. SMP's are also biodegradable. [3]

The potential applications for shape memory polymers are extensive. It is hoped that they will be utilized to improve the efficiency of evasive surgery. They can be shrunk and deformed to a more manageable shape and then returned to their remembered shape after they have been positioned in the body correctly. SMP's also have potential to be implemented as auto panels. The panels will be programmed to remember the desired shape of the car. When dented they can simply be placed in the sun and the dents will smooth themselves out. [3]

2.5 MEMS

Microelectromechanical systems (MEMS) combine mechanical systems, sensors, actuators, and microelectronics on one microchip. This relatively new technology makes possible the integration of electromechanical systems with driving, controlling and signal processing chips. MEMS use the existing microelectronics infrastructure to create complex machines, with minimum feature sizes. Figure 10 depicts the components of such a system.[15]

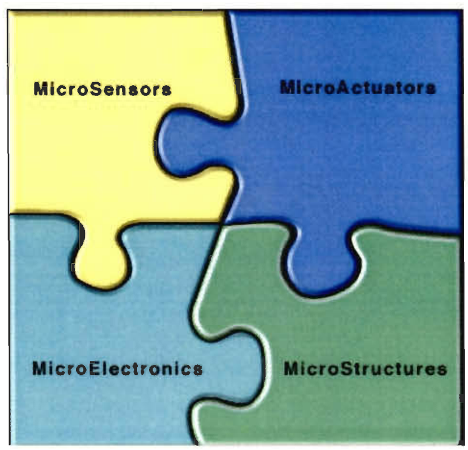

Figure 10: Components of MEMS [16]

Historically, integrated circuits (ICs) have been improved by increasing the number of transistors that can fit on one chip. Over the years, this has grown to be several million. Intel's Pentium 4 chip contains approximately 55 million transistors. [16] While the growth in the functionality of microelectronic circuits has been tremendous, it has been limited to the processing power of the chip.

Once this limit has been reached, the chip can only be made more efficient by adding more functionality. The additional structures should help the chip sense, act and communicate. The microelectronics can be viewed as the "brains" that co-ordinate the "eyes and ears" (sensors) and the "hands" (actuators) of the system.[17] In this way, we can utilize the powerful computational abilities of microelectronics with sensors and actuators to construct a smart system.

Integration of sensing, signal processing and actuating features on one chip will not only improve the performance of electromechanical devices, but also it will reduce costs incurred during manufacturing and packaging. The main advantage of MEMS is that batch fabrication technology being used to design ICs (CMOS, BICMOS, Bipolar, etc) can now be applied to the fabrication of electromechanical systems. [15]

Analog Devices recently developed and marketed a MEMS accelerometer, for use in air-bag deployment systems, which demonstrated the viability and commercial potential of a System-on-Chip (SoC) design. An accelerometer consists of a mass mounted upon a piezoelectric crystal and some external circuitry. When the mass vibrates due to vibration of the device to which the sensor is attached, the crystal produces a voltage that is proportional to the applied force. This voltage is then used to calculate the applied force. Conventional air-bag deployment systems consist of discrete components on the front of the vehicle as well as electronics near the air-bags. Such a system is rather bulky and costs about $50. The MEMS accelerometers are significantly smaller, more functional and more reliable and can be manufactured for less than $10. Furthermore, due to its compactness, this system could be used to deploy air-bags for protection from side-impacts. Clearly, a MEMS accelerometer has numerous advantages over a conventional system.[17]

2.6 The Body as a Smart Structure

The human body is a prime example of a smart structure. It is a complex system of sensors and actuators that are all controlled by a central processor, the nervous system. There are many smart systems in the body that function separately and for a variety of purposes, e.g. temperature control or balance. Inspiration for many smart materials and structures may have come from studying the body and there are still many sources of inspiration left untapped in the body.

2.6.1 The Autonomic Nervous System

The nervous system can be modeled as a control system that coordinates the sensors and actuators in our body. The actuators and sensors are connected to each other through the brain. Nerves are responsible for detecting stimuli and relaying this information to the brain. The brain interprets this data and responds by sending out instructions to the actuator. The actuator, usually muscles or glands, then performs the action as instructed.

An excellent example of a smart structure within our body is the eye. Whenever it is exposed to greater light intensity, the pupil contracts so as to restrict the amount of light entering the eye. Nerve cells (sensors) are responsible for sensing the stimulus, communicating the change to the brain (processor) and producing a response (via the actuator).

Nerves that carry information to the brain are known as afferent neurons, and those that carry information away are known as efferent. The autonomic nervous system can be divided into the sympathetic and parasympathetic nervous systems. One of the differences between the two is the manner in which information is transmitted. Different chemicals convey information from one neuron (nerve cell) to another in the two systems. However, the difference that is of more relevance to us is that of function.

The sympathetic neurons can activate all the body's organs, a few organs or part of an organ. A specific organ may be activated by a group of sympathetic cells, a set of receptors on an organ or a selective secretion of hormones from a specific gland. Sympathetic responses are often rapid and occur in a relatively short time after the stimulus is sensed.[18] The main function of sympathetic responses is to prepare the body for emergency situations.

One example of a sympathetic response is that caused by fear. Consider the following. If one were walking along a street and were suddenly confronted by a bear, pure instinct would cause one to run. Secretion of adrenaline triggers the heart to pump faster, respiratory rate increases and digestive processes slow down. The single trigger caused several organs and systems to be actuated. Furthermore, the response to the stimulus happens extremely fast.

The parasympathetic system starts in the brainstem and receives information from external organs. However, the quality of information received is not up to the standard of that in the sympathetic system. After the information has been received and analyzed, it is relayed to the secondary parasympathetic nerves that are local to the special organized organ. The parasympathetic division of the nervous system regulates activities that conserve and restore

An example of a parasympathetic response affecting the same organs would be that undergone when one is resting. A person's heart and respiratory rate drop and digestive processes start. However, a response such as this does not need to occur immediately and takes place over a considerable amount of time, as compared to the sympathetic response.[19]

Both these responses can be considered smart as they are involuntary. Although the parasympathetic response takes a considerably longer time to take effect, a person does not control such a response. It can be considered smart as the receptors (nerves) are able to detect a change, pass it on to the processor (brain) that then causes actuators (muscles and glands) to adapt. Clearly, the first response (imminent danger from the bear) needed to be fast in order to ensure the safety of the person. The latter, however, was not as vital and did not need to be as fast. The nervous system was able to detect this and respond accordingly. In this sense, the human body is much smarter than the fastest super computer simply due to the fact that it can perform actions when not instructed.

2.6.2 The Integumentary System

The integumentary system has certain smart qualities. It regulates the temperature of the entire body. Body temperature remains almost constant by controlling heat loss through the skin. Thermoreceptors in the body, namely Ruffini's corpusces and the end-bulbs of Krause, are stimulated by a shift in the body's temperature. This information is relayed to the central nervous system, which then signals the arterioles in the dermis to dilate or constrict. If the body temperature is increasing the arterioles dilate, allowing more blood to reach the body's surface via the vein network close to the surface of the skin so that more heat can escape. The sweat glands are stimulated at the same time, causing the skin's surface to become wet. The sweat then evaporates, releasing heat. When the body's temperature is decreasing the arterioles constrict, decreasing the flow of blood and limiting the heat that is able to escape. This is a smart system because it reacts to the changing environment independent of conscious thought and adapts to the situation. The thermoreceptors are the sensors, the central nervous system is the processor, and the arterioles and sweat glands are the actuators. [20]

This is similar to the severe weather clothing that is in development by Diaplex. This clothing's microstructure is composed of shape memory polymers that when heated will separate, allowing heat and humidity to pass through. When the material is cooled, the gaps will close so that the body's temperature will be maintained, serving the same function as the integumentary system. [3]

2.6.3 Balance

Within the ear there is a smart structure known as the vestibular apparatus that allows the body to control its balance, which is located in the inner ear and uses the receptor cells in the utricle, saccule, and ampullae of the semicircular ducts. The receptors in the utricle and saccule provide information about the position of the head. These receptors, called maculae, are tiny hairs embedded in a gelatinous substance. The gelatinous substance shifts when the head moves. The hairs are affected by this shift and send signals from the neurons at the base of the hairs, telling the brain the orientation of the head so that it can coordinate various body movements. The sensors in the ampullae of the semicircular ducts provide information on the movement of the head. Like those in the utricle and saccule the sensors are tiny hairs called crista embedded in a gelatinous mass known as cupula. The crista and cupula are located in the three semicircular ducts, which are all at right angles to each other. This orientation guarantees that the head can not move without being detected by the ampullae. The shifting of the cupula causes the cupula to relay signals to the brain about the acceleration, velocity, and direction of rotation of the head. The brain can then make corrections and adjustments throughout the rest of the body. [20]

2.6.4 The Eye

We are able to see due to the interpretation of neural signals received by the brain from the eye. These neural signals relate color and light intensity. The eye is sensitive to the intensity of light. It adapts to this by dilating and constricting the pupil. When it is dark, the pupil dilates in order to allow more light into the eye. When it is bright, the pupil constricts to block out the excess light. The pupil constricts and dilates in order to maintain the sharpest image possible on the retina. That image is then sent to the brain. [20]

A smart structure that performs a similar function to that of the eye is the photochromic lens. These lenses are made for glasses and respond to sunlight by adjusting the tint. The lens contains silver halide that when struck by ultra-violet rays changes from transparent to a shade of brown. The intensity of the light determines the darkness of the lens. This helps to maintain the amount of light that reaches the eye, serving the same purpose as the pupil. [11]

2.6.5 Peristalsis

Peristalsis refers to the distinctive pattern of smooth muscle contractions that propel foodstuffs distally through the oesophagus and down the intestines. This process is completely involuntary. The term is also used to refer to normal coordinated, rhythmic muscle contractions to move urine from the kidneys through the ureters into the bladder, and bile from the gall-bladder into the duodenum.

In the oesophagus, peristalsis is triggered by a lump of food, known as a bolus. The initial force with which the bolus enters the oesophagus causes distension of muscles. The oesophagus has an inner lining of mucus that is disturbed by the bolus, upon entrance. These two factors lead to the stimulation of two groups of neurons.

One group causes the contraction of smooth muscle above the bolus of food. The other stimulates the relaxation of smooth muscles below the bolus of food. The contraction and relaxation of the muscles moves the bolus down the oesophagus. Figure 11 depicts the process of oesophagal peristalsis.[21]

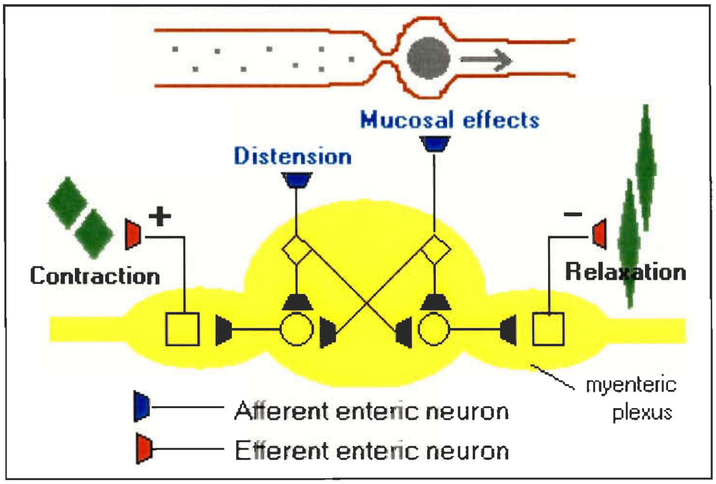

Figure 11: The Process of Peristalsis [21]

Peristalsis can be considered a "smart process" in the sense that a response to a stimulus is automatically produced. The bolus of food is the stimulant that activates the sensors, the neurons. These in turn are connected, via synapses, to a control system, the brain. The control system instructs the actuators, smooth muscles, to contract and relax at the appropriate times.

2.6.6 Hearing

Hearing is another function of the ear that behaves very similarly to a smart system. Sound waves enter the external auditory meatus and push against the tympanic membrane. This causes the membrane to vibrate at the same frequency as the sound wave. These vibrations are then trasmitted further into the ear via the malleus, incus and stapes, to the chochlea. The vibration travels through the cochlea to the basilar membrane. The basilar membrane contains many hair fibers of various lengths and thickness. These hairs respond differently to vibrations and send nerve impulses to the brain when stimulated. The brain then interprets these impulses and is able to differentiate between tones and pitches.[20]

The hearing process is similar to the sensory part of the active noise control system. In active noise control, the sound waves cause a piezoelectric material to vibrate at the same frequency. The piezoelectric then sends a signal to a processor which then sends a signal to an actuator to counter the noise.

2.7 Work done on Smart Technologies at WPI

A number of Major Qualifying Projects (MQPs) and Interactive Qualifying Projects (IQPs) have been completed by WPI students in the field of smart technologies. There were four MQPs and one IQP. In the MQPs the students designed and tested systems that used smart materials. The IQP focused on the applications of one group of smart materials to a specific industry.

In their MQP, Mark Bonczek, Kirk Johnson and Nicole Roy worked on the design of a smart ribbon control system under the guidance of Professor Michael Demetriou and Professor David Olinger. The goal of the project was to test the abilities of shape memory alloys to limit vibrations in cables due to vortex shedding. The vibrations occur at the resonant frequency of the cable. When the cable starts vibrating, a current is passed through the cable, hence changing the shape of the shape memory alloy. This change in shape alters the natural frequency of the cable and eliminates the vibrations.[24]

A team of students working under Prof. M. Noori and Prof. F. Hart of WPI, and Prof. Hamid Davoodi of the University of Puerto Rico, Mayaguez completed an MQP that investigated the possibility of using shape memory alloys in the structural design of a three-story building. The goal of the project was to design the system so as to reduce vibrations of the structure that may arise in situations such as earthquakes. The performance of the system and the effectiveness of the use of SMAs were tested by subjecting the system to simulated earthquake vibrations. In addition, a similar system that employed the use of a steel structure instead of shape memory alloys was tested. The performance of the two different systems was compared and it was established that the system using shape memory alloys was more effective. [25]

Matthew Gaffney, Robert Holmes, and Jason Leboeuf also performed research on vibration suppression in buildings in their MQP. They were advised by Professor Zhikun Hou and Professor Shaukat Mirza. They tested the potential for shape memory alloys to be used as vibration dampers in buildings. They propose that SMAs will be effective in a cross bracing system that will help support the building during times of turbulence. [26]

Under the supervision of Professor Satya Shivkumar, Deborah Vandenburgh completed an MQP that analyzed the effectiveness of replacing common metals with shape memory polymers as surgical stents. Often metal stents cause harmful side effects. These side effects can be fatal. The shape memory polymers are less intrusive, are as effective, and do not cause the negative side effects. [27]

Brett Downing and Kevin Hawkins completed an IQP on the therapeutic applications of stimulus sensitive polymers under the supervision of Professor Satya Shivkumar. The aim of this project was to identify current technologies and to evaluate emerging applications based on shape memory polymers. The research conducted revealed that these technologies are assisting in cutting down the negative side effects of conventional surgical procedures. [28]

3 Procedure

The first step towards achieving the goals of this project was to thoroughly research the topic of smart materials and structures. This research included the classification of smart materials and structure, information on current smart materials and structures, and examples of current applications of these smart technologies. The research for this project was performed in George C. Gordon Library on the Worcester Polytechnic Institute Worcester campus. Research was also done extensively online in order to acquire the most recent developments and information in this field.

After the research was completed, the next step was to determine how the use of smart technologies is affecting, and possibly will affect, our society. This was accomplished through critical thinking and observation. Designs for potential smart technologies were also proposed with the hopes that they could be used in order to benefit society. This was accomplished through the critical thinking and imagination of the authors as well as from informal interviews with various individuals. Punit Prakash interviewed eight people who were upperclassmen at WPI. Robert O'Connell interviewed five upperclassmen from WPI, one student from the University of Vermont, and three people with little scientific background. The format for the interview was relatively straightforward. The person being interviewed was first asked if he/she was familiar with the term smart technology. The person was then given a brief description of smart technology. The example provided to elucidate this explanation was that of the water fountain at WPI. In certain cases where the user was not satisfied with this example, further examples were provided before proceeding. The person being interviewed was then asked to suggest a couple of scenarios in which the use of smart technology would be beneficial to society. These ideas are discussed in detail in section 4.2.

We set up a website to serve as an informative guide on the field of smart materials. The website has general information on some of the smart technologies that we studied in this project. In addition, we included a section on the pros and cons of the various technologies that we studied. Our website further includes instructions on how to perform the experiments that we conducted. This serves as an efficient method of reaching interested parties outside the WPI community. We will also post a copy of our final project report upon completion of the project. The website can be accessed via the following URL:

http://www.wpi.edu/~punit/iqpweb/

3.1 Experiments

An experiment dealing with the properties of electrorheological fluids was performed. This experiment was inspired by a video of a television show called *Archimede* featuring an experiment performed by Mihai Ganciu. The video was provided by Professor Bogdan Vernescu of the Mathematical Sciences department of WPI and was performed to verify the results of this previous experiment so that it could be used for educational purposes. This experiment was completed with the assistance of Roger Steele, the lab manager of the physics department at WPI, James O'Rourke, lab manager of the electrical engineering department at WPI, and Professor of Physics at WPI, Dr. Germano Iannachione. To perform the experiment we needed a Wimshurst generator, corn oil, cornstarch, rice, a petri dish with a metal plate at the bottom and a place to connect the wire, a taller container with a metal plate at the bottom with a place to attach the wire, and a metal wire with a stand to hold it in place. For the construction of the petri dish, we simply took an ordinary lab petri dish, and cut a piece of metal that would fit in the bottom of the dish with a tab that would fold up the side of the dish and over the edge. The taller container was fashioned from a plastic cup. A piece of metal was cut to fit in the bottom. A wire was wrapped around the metal plate in such a way to ensure that the wire touched the plate at at least one point. A hole was poked in the side of the cup and a piece of wire was run through the hole. The hole was then filled with hot glue so that it would not leak.

The setup for the first part of the experiment was simple. The metal wire was positioned so that it ran over the diameter of the petri dish without touching it. The Wimshurst generator was connected to the metal wire and to the metal tab in the petri dish. The Wimshurst generator was turned on, creating an electric field between the metal plate and the wire. Cornstarch was mixed with corn oil such that the concentration was thick but still flowed freely. This mixture was poured onto the metal plate and it was noted that the material became highly viscous. The electric field was then turned off and it was noted that the mixture then flowed freely. When the electric field was applied again, it was noted that mixture became highly viscous again.

The second part of the experiment was performed with a similar set up. The cup was filled with corn oil and some rice. The metal wire was placed over the diameter of the cup. The connections were attached to the wire above the cup and to the wire that was coming out of the bottom of the cup. The electric field was turned on. It was noted that a portion of the rice rose in the oil off of the bottom of the cup. Some of these pieces of rice formed chains from the bottom of the cup to the top of the cup. The electric field was turned off and it was noted that the rice fell to the bottom of the cup.

The set up, procedure, and expected results were written in a clear, easily understood form so that teachers and students can repeat this experiment without difficulty. This form can be found in Appendix A and is accompanied by pictures of the experiment from when the authors performed it.

4 Analysis

The use of smart technologies affects our lives, even though we may not realize that we are using them. There are many positive aspects to using these technologies with very few negative ones to counter-balance them. Smart technologies are used for many purposes in our society and their influence will continue to grow as inspiration and future research dictates.

4.1 The Impact of Current Smart Materials and Structures on Society

Smart materials and structures are increasingly being integrated into many aspects of society. These technologies are being used in industrial, medical, and commercial applications. The integration of smart technologies into these fields is due to their unique abilities to actively monitor situations and adaptively respond to maintain optimal performance. They have impacted these fields in positive ways and have very little potential of having negative side effects.

Smart systems have improved our ability to maintain standards through their ability to actively monitor and respond to changing situations. The fact that smart systems can automatically react to varying situations spares us the task of monitoring and manually correcting systems. This is illustrated by the Worcester Polytechnic Institute water fountain in Freeman and Reunion plaza on the Worcester campus. The water coming out of the fountain is controlled by a system that adapts the projected water's height to the wind speed as measured by an anemometer. This ensures that the water will not be blown an undesired distance from the source. This saves the maintenance department from having to alter the flow manually each day, while also keeping the pedestrians dry.

Many situations require responses that must be performed within a particular time frame. These time frames are often extremely short. Smart technologies are able to respond to a variety of stimuli in a highly efficient manner. Their ability to respond to varying stimuli in real-time makes them viable for numerous applications. One such application is the smart ski. While skiing, skis are exposed to uneven surfaces that cause unwanted vibrations. These vibrations put strain on the skis and the skier's legs. A system that would be able to damp these vibrations quickly is highly desirable. The vibrations need to be damped as soon as they are encountered in order to minimize damage and to ensure the skier a smooth ride. Smart skis are designed to counter these vibrations. They work with an electronic chip that uses an input signal created by a piezoelectric material and outputs an appropriate signal to piezoelectric actuators that counteract the initial vibration. The speed of the circuitry coupled with the fast response time of piezoelectric materials ensures that the vibrations are damped efficiently. *K2* is currently the largest manufacturers of such skis. [5]

Smart technologies have the unique ability to respond to a large range of situations at the optimal level for each situation. Traditional materials and systems respond to situations in a uniform manner, they respond the same way to every scenario. They are not able to alter their response according to the needs of the immediate situation. For instance, steel girders often reinforce buildings in order to support the structure during an earthquake or other natural disasters. These girders are limited in their abilities to respond to the added strain on the building, as they cannot adapt to varying strengths and directions of stress. A smart system that is being developed by the Lord Corporation uses magnetorheological dampers to absorb the excess energy that is being applied to a building during an earthquake. These dampers are controlled by a magnetic field, which is altered in order to respond to various quake strengths in an optimal manner. Unlike the steel girders this smart system can vary its response according to the magnitude and directions of forces.

One negative aspect of the use of smart systems is negligence. Over-reliance on smart systems to perform a certain function could cause a drop in alertness levels of the concerned individuals. This behavior is similar to a situation that is a problem today. Drivers with four-wheel drive feel overly safe and confident while driving in bad weather conditions. They do not feel that they need to be careful when the roads are slippery because they believe that their superior vehicle will keep them safe. While it is true that their vehicle performs better than ordinary vehicles in such conditions, its performance is not necessarily perfect. This over-confidence is the cause of many accidents, particularly in the winter when there has been a lot of snow fall and the roads are particularly slippery. A similar over-confidence may occur with the use of smart technologies. Take the example of the smart fault detection system in a bridge. Without the use of such a device, an engineer would routinely be dispatched to inspect the status of the bridge. However, with a smart system in place, the engineer might not be required to do this so often. Nevertheless, since safety is the primary concern in this situation, an engineer should still inspect the bridge at regular intervals in order to ensure that the smart system is reporting accurate information. Failure to do this may result in tragedy.

Smart structures and systems are already in the process of being integrated into our daily lives. Their active monitoring, quick and efficient response, and adaptive nature make them very useful in improving our daily lives. Smart technologies are being integrated in such a way as to save lives, prevent damage, provide luxury, and improve efficiency in the work place. While there are possible negative side effects depending on the application, the positive aspects make using smart materials and structures worthwhile.

4.2 Smart Systems We Would Like to See

Society has needs and desires that smart materials have a great potential to satisfy. As part of the process, we informally interviewed some WPI students in order to obtain some ideas they may have. This was important, as we were able to determine what sort of systems society desired. In addition, some particularly interesting suggestions from the public could serve as inspiration for future designs. The following is a summary of the ideas that were expressed by the people we interviewed. Some of the products that were proposed are already commercially available or are in development. These ideas are discussed first. On the other hand, some of the ideas expressed were fairly novel. We carefully analyzed the suggestions put forth and developed detailed descriptions of these designs. These descriptions can be found in sections 4.2.1 through 4.2.10.

Many individuals expressed an interest in temperature and weather adaptive clothing. In regions where abrupt changes in weather are common, one is often caught unprepared and this may be detrimental to one's well being. Smart clothes would adjust to varying temperature conditions such that one's temperature is maintained at optimum levels. Apart from the fairly obvious health benefits, such clothes would be extremely convenient because people would not need to carry an assortment of clothing with them at all times. Research is being actively conducted in this field and companies such as Mitsubishi have come up with designs for such clothes. The design of these clothes is described in section 2.6.2.

Many individuals expressed an interest for a noise cancellation system in automobiles. Noise in automobiles is commonplace and is often detrimental to the quality of audio entertainment systems. One common problem that people face is that noise increases tremendously when a window is rolled down. A knee-jerk response of a person would be to turn up the volume so that the music can be heard clearly. However, turning up the volume beyond certain extents is often unpleasant and results in cacophonous noise. A system that would be able to monitor the noise levels in the car and amplify only desired components of the audio signals being transmitted would be highly desirable. Such a system is already being manufactured by the Bose Corporation and is readily available in variety of automobiles.

One individual suggested the possibility of designing smart pens that would monitor the user's writing and account for any changes. Many times, one makes mistakes when writing due to a slip of the hand or other uncontrolled behavior. This often results in illegible characters appearing on the document being worked. In order to avoid such mishaps, a smart pen that is trained to remember how an individual usually writes characters may be used. When a character is written that does not resemble the remembered shape the pen will provide the necessary correction so that one's handwriting always appears to be uniform. Although this idea does sound useful, these pens might not be so successful on the market given the widespread use of the computer in today's world.

Many individuals expressed an interest in buildings with earthquake protection devices. Earthquakes often cause damage to buildings. They destroy property and often cause serious injury and death to individuals. Though some systems are already in place, additional devices are desired to help support the building during these times of excess strain and abuse. Such devices are already in development. They utilize magnetorheological fluids to absorb the energy from the vibrations of the building during the earthquake, reducing the amount of damage to the building and hence protecting property and well being. These systems are described further in section 4.1.

One individual desired a medical device that could be easily manipulated. She has plastic pins in her knees that were put there during surgery after a skiing accident. When these pins get bent or shifted she has to undergo surgery to straighten them. She wants the pins to be able to be adjusted and returned to their original shape without having to undergo the surgery. If shape memory materials were used as pins then applying either thermal or magnetic fields would adjust them. Additional surgery would not be necessary.

Two individuals desired a mattress that could be adjusted to a desired firmness. They found that their beds are often uncomfortable after a period of time and that when other people use their beds they are often unhappy with the firmness. Technologies that accomplish this task already exist. Air mattresses are easily adapted to desired firmnesses and are readily available on the market. Though air mattresses are not smart technologies, they serve the function effectively and negate any need for a more technologically advanced substitute.

Many individuals wanted to be able to remove dents from their cars without having to have them professionally repaired. These technologies are in development by companies such as Mitsubishi. They utilize shape memory polymers. Simply applying a heat source to the dented area results in the panels returning to their original shapes.

Some of the ideas that were suggested by the people that we interviewed were original and were incorporated into the potential designs described in detail below.

4.2.1 Smart Shoes and Tires

Slippery surfaces have always been a source of trouble for both pedestrians and vehicles. Take the example of a person walking on dry pavement. The person does not slip because there is sufficient friction between the person's shoe and the ground. However, during icy conditions, the amount of friction between the person's shoe and the ground is drastically reduced. This often results in injury due to the person slipping.

One solution to this problem is to wear shoes with a better grip. These are shoes with a rougher sole which provides greater friction between the shoe and the ground. However, these shoes are often more expensive and the sole tends to wear out after some time. Since one cannot anticipate slippery conditions, one often has to wear these shoes even when they are not necessary. This results in the sole wearing out even though the shoe was not really necessary at the time. Eventually, one spends more money on shoes than one really needed to.

We propose a smart shoe whose grip would actively change based on the prevailing ground conditions. The shoe would incorporate temperature and moisture sensors that would determine whether there is need for greater grip. The output from these sensors would then be fed to a processor that would send the appropriate instructions to the actuators. The actuator would be a system that would cause "pimples" to form on the sole of the shoe, similar to the fashion in which we develop "goose pimples" when temperature drops. When the sensor detects normal moisture conditions, the pimples are withdrawn so as to preserve the texture of the sole.

The advantages of a smart shoe like this are quite obvious. One would not need to replace one's shoes very often as they will not wear out as quickly. This is because the sole will always only be as rough as current ground conditions demand. Furthermore, this will reduce the number of mishaps that pedestrians encounter during unfavorable weather conditions. Some of the drawbacks include a rise in the cost of shoes, although this is balanced by the fact that one would need to buy a shoe as often. Another possible side effect is people being negligent and oblivious to the pavement they are walking on as they feel their shoes will be able to take care of any source of a mishap. While it would be wonderful for smart shoes to be reliable in every possible situation, this is not possible and so pedestrians should always be on the look out for trouble.

In a similar manner, this technology could be applied to tires. Driving in the snow has always been dangerous due to the ease with which tires lose their grip against the road. One solution to this problem is using snow tires. These are tires that are manufactured for optimum performance in the snow. While these tires do perform well, drivers have to go through the hassle of changing their tires before and after storms. In addition, drivers may be caught unawares by bad weather. We propose smart tires that are similar in function to the smart shoes described above. The grip of these tires will actively vary according to the prevailing road condition. This will save drivers the hassle of changing tires. In addition, drivers will not need to worry about when their tires need to be changed as the tires will adapt to changing driving conditions.

4.2.2 The Smart Rope

Conventional ropes and straps tend to break without warning after extensive use or when they experience too much tension. Possessions are damaged, people are injured, and lives are even lost when such breakages occur. These accidents could be avoided if either we had stronger ropes or there was a warning system in place for when the rope was experiencing too much strain and would most likely break. A possible solution to this would be to create a smart rope that would give such a warning. The rope would contain a lattice structure of piezoelectric material. These materials could send signals to a processor at one end, or even at strategic locations, of the rope. As the rope would stretch and begin to snap, so would the piezoelectrics. When the tension reaches a certain point or breakage begins to occur, the piezoelectric would send a signal to the processor and the processor would activate a noise system, which would sound an alarm. The people using the rope would then know that something was wrong and they could take the appropriate steps.

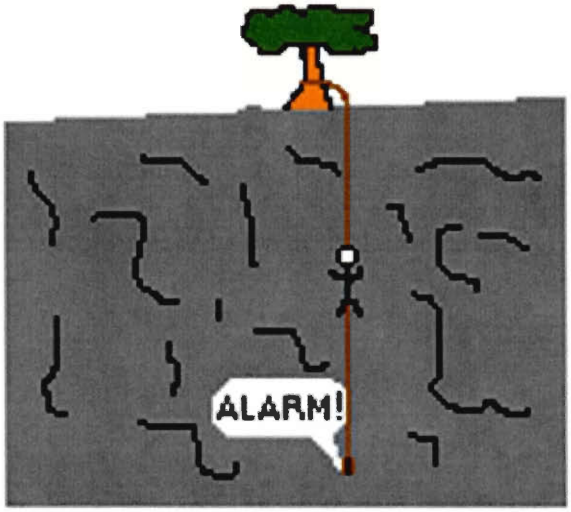

Figure 12: The smart rope in use.

The benefits of the use of this rope are very clear. It would provide rock climbers with enough warning so that they could secure themselves before their rope snapped, saving themselves from injury and possibly death, as seen in Figure 12. It would also be of assistance to people transporting objects by truck or other vehicle because they would have ample warning to stop and readjust their possessions so that they will not be thrown off and damaged or lost.

4.2.3 The Smart Pipe

In plumbing systems there are sometimes problems with fluid flowing in an undesired direction in a pipe. This undesired flow causes flooding, damages possessions, and may even create unsanitary conditions. These floods result in the expenditure of both time and money that could have been avoided had there been some way to detect and therefore prevent the problem. Having a pipe that could sense which direction the liquid was flowing could solve this. The pipe would be equipped with a section of hair-like sensors. These sensors would shift in the direction of the liquid's flow. At the base of the sensor would be a set of piezoelectrics that would then send a signal to a processor, which would determine the direction of flow. If it were in the undesired direction, the processor would send a signal to close a valve further up the pipe, ahead of the flow, preventing flooding. This pipe system is illustrated in Figure 13.

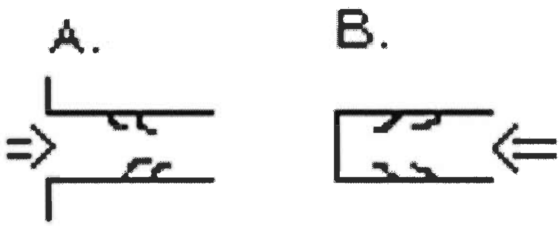

Figure 13: Image A illustrates the pipe during normal fluid flow. Image B illustrates the pipe when the fluid is flowing in the opposite direction. The pipe has closed.

This idea was inspired by the balancing system in the ear. A system of gel and hair-like sensors sends signals to the brain, relating in which direction and at what speed the head and the body are moving. The brain then adapts the body to counter adverse effects.

4.2.4 The Automobile That Won't Flip Over

Many automobiles will flip over if they take too sharp of a turn too quickly. The center of mass is too high and when the automobile goes into the turn the centripetal force pulls the center of mass towards the center of the turn. This causes the outside tires to lift and when the center of mass shifts past the wheelbase the automobile falls onto its side. An automobile will often tip over when struck from the side as well. When these accidents occur, the minimum damage is to the vehicle, which requires time and money to either repair or replace. These rollovers also injure and kill many people every year. Figure 14 shows a car driving on two wheels, in danger of flipping over.

Figure 14: A car driving on two wheels. [22]

A device that could reduce the number of accidents due to the vehicle rolling over is a balancing system in the base of the automobile. This device would be similar to the system in the ear. It would have three perpendicular tubes, each filled with a fluid and equipped with wall sensors that could monitor the motion of the fluid. These sensors would send the information to a microprocessor that would process the data and monitor whether or not the car is in danger of flipping over. The system would also have pressure sensors in the tires that would be able to distinguish between when the wheels are on the ground and when they are not. This would help distinguish between when the vehicle is flipping over and when it is simply on a steep bank or hill. The actuator in this system would be a mass redistributor. It would have a way to shift a large portion of mass from one side of the automobile to another very quickly, whether using liquid or moving metal parts. This would shift the center of mass of the vehicle in the appropriate direction to avert disaster. Since the system would know as soon as the wheels of the vehicle left the ground, it will be able to make small corrections so that large-scale distribution will seldom be necessary. The mass shifting is illustrated in Figure 15. The arrow indicates the direction of the mass redistribution.

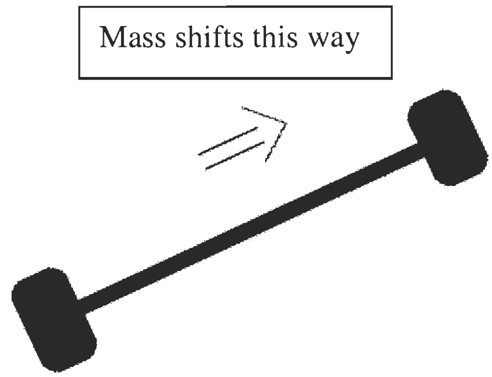

Figure 15: Illustration of mass redistribution system

4.2.5 Correctable Paint

Often paint jobs are not perfect. Either the paint is not smooth due to bad application so that there are streaks and bumps, or the damage to the paint is done later on, either by scratches, chips, or holes due to nails or tacks. This causes the painted surface to not be aesthetically pleasing as it could be otherwise. In the case of scratches or nicks to a car's paint job, the cost to fix it is quite high. Sometimes these corrections are a necessity, otherwise more of the paint will be eaten away and the car will be more apt to rust. An easier, less expensive solution to this would be to have a paint product that could be adjusted after it had dried originally. This procedure would entail re-liquefying small portion of the paint and smoothing it out until it has attained the desired appearance. The actuator would either be chemical or possibly even magnetic. It would stimulate the paint and cause it to resume its liquid form. This would be a luxury item that would simply improve the aesthetics of one's household. It could also save great expense and time if the paint job would have to be completely redone otherwise.

4.2.6 Smart Light System

Inadequate lighting is often the cause of vehicular mishaps. Many drivers do not turn on their headlights unless it is extremely dark outside. While it is not necessary to have one's headlights on at all times, it is sometimes hard to determine whether one should turn them on. In addition, drivers often forget to turn on their lights resulting in tragic consequences. This is clearly illustrated in Figure 16. We propose a smart system that would be able to monitor the light intensity in regions around the car and adjust the brightness of the lights accordingly.

Figure 16: The danger of not turning on your lights.[23]

Photovoltaic sensors have been available on the market for a long time now, however one potential problem that may be encountered in the design of such a system would be the location of the sensors. They would have to be placed such that they can accurately measure the light intensity reliably at all times. One interesting problem is how the car would respond to streetlights. Our suggestion is to have the monitoring system designed such that it can detect periodic changes in light intensity. If the bright light that is detected is periodic it is probably due to streetlights and not the sun. Therefore the car's headlights should be adjusted accordingly.

The major advantage of such a system is that it would ensure that a driver always has sufficient lighting. One would not need to worry about adjusting the brightness of one's headlights as this would be taken care of by the system. In addition, we propose that the current system where the driver has control of the lights continue to be maintained. This way if the driver feels that the smart lighting system is not providing the optimum level of light intensity, he/she can perform the necessary change manually. Provided that reliable locations for sensors are found, there are no obvious side effects to this system. As is often the case in many systems, this smart system can only be fully tested once put into use.

Another type of smart lighting system would be for household use. Achieving optimum levels of light intensity in a room is a challenging task. Older buildings only provide for two situations; lighting or none. Modern buildings often provide an assortment of switches that can be used to alter the lighting in a room. A smart system that is capable of actively monitoring light intensity levels in a room and modifying the light provided would be extremely handy. The definition of optimum would of course vary from application to application and such a system would have to allow the appropriate persons to modify optimum settings. In short, the function of this system would be to adjust the light intensity inside the room based on the light that was entering the room from outside.

4.2.7 Smart Pool

The level of chlorine in swimming pools has always been a health concern. We propose a smart chemical that would actively monitor the levels of chlorine in a swimming pool and then alert us whenever the chlorine levels were alarmingly low or high. The action of this chemical would be similar to that of the zinc oxide that was discussed in the introduction to this document. One potential method of alerting us would be water glowing or a color change of some sort. In this manner, one would always be aware of the chlorine levels before using the pool thus allaying any health concerns. An improvement to this system would be one that would check the pool for chlorine levels and then alter the chlorine content accordingly. Both of the systems mentioned above would eliminate the need for one to constantly check the chlorine levels of their pool as the smart system would take care of this.

4.2.8 Health Monitoring Systems

Coronary heart disease has been a major cause of deaths in recent years. Constantly monitoring ones cholesterol levels is highly advisable in order to help reduce the chances of experiencing this misfortune. A system that could be attached to one's hand, similar to a wrist watch, that would actively monitor one's blood cholesterol content would be of great use and would save a person the hassle of constantly checking his/her cholesterol level. When cholesterol levels are dangerously high, this system would alert the person of the imminent danger. An even smarter system would provide suggestions on how to respond to the rise in cholesterol levels.

Diabetics are in constant need of replenishing their insulin. While most diabetics periodically inject themselves with insulin, occasionally they fall short of the required amounts of insulin before the injection. A system, similar to the active cholesterol monitoring system described above would help prevent such occurrences.

4.2.9 Smart Clothes

As was established from the interviews we conducted, clothes that are able to actively regulate the amount of heat that they retain are highly desirable. We propose the use of a system that would consist of a combination of shape memory materials and piezoelectric materials embedded into the garment. The shape memory material would react to temperature changes by varying its shape. We suggest coupling this with a piezoelectric material such that the piezoelectric material's shape is altered when the shape memory material's shape changes. The mechanical deformation of the piezoelectric material produces a voltage across the material. We propose that the current realized from this potential difference be used to heat up the garment. This is similar to the functionality of the electric blanket, which uses a coil to heat up the blanket. Clearly, our material is suited towards providing heat for cooler conditions and is not very effective for cooling. Care should be taken when designing this system such that the current produced is not harmful to the body. The main difference between our design and that in development by Mitsubishi is that our design uses piezoelectric materials to provide heating whereas Mitsubishi's design uses the expansion and contraction of the shape memory material to regulate temperature.

4.2.10 Smart Houses

A centralized heating system is the hallmark of most households in the northern hemisphere. Such systems ensure that the residents of the dwelling do not feel extremely cold or warm. Usually such systems are based on an electric or gas heating system. This is often expensive. Houses that are constructed of materials that would be able to vary their properties so as to alter the temperature conditions of the inside would be of great benefit to society. Shape memory materials are one kind of smart materials that would be readily applicable for this design. By altering their shape according to prevailing temperature conditions, they will control the heat that is retained within the house.

One consideration that would have to be taken into account when constructing such houses would be the stability of the structure. The change in shape of the shape memory material would have to be limited to such a range that the buildings stability is not altered. On the other hand, this range should be wide enough to cater for the climate of the region where the house is located.

Not only would such houses provide the optimum conditions that are desired, but also they would do so at a significantly lower cost. This is because the initial investment on the material for the house would be the only expense incurred. Periodic payments would be totally eliminated.

5 Conclusions

Smart technologies are increasingly being integrated into our society. Their active monitoring, efficient response, and adaptability make them prime candidates for commercial, medical and industrial applications. The foundations for smart systems lie in a variety of smart materials that have been developed over the years. These smart materials include piezoelectric materials, electrorheological and magnetorheological fluids, and shape memory materials. These materials also include chemicals developed to be used as sensors and/or actuators e.g. zinc oxide used to eliminate water pollutants. These smart technologies help to improve the performance of many systems and devices, creating more efficient and reliable structures. They are being utilized to improve the lifestyles of people, catering to each individual's needs or desires. Their benefits to society far outweigh any possible detrimental effects. Their influence continues to grow as imagination and research dictates.

This project serves as an informative guide for any individual interested in the study of smart materials and systems, or who is simply curious about the latest technologies being used in the world today. The website we developed is an interactive source of information on the field of smart technology. In addition, the website includes a compilation of sources for useful information in the field of smart technology. Any interested party would find this a good starting point for a detailed study in this field.

During the course of this project, we performed experiments to study the behavior of electrorheological fluids. We performed experiments that could be utilized for a variety of educational purposes. We supplied a set of instructions that could be utilized by any interested party, willing to conduct these experiments. Please refer to Appendix A for this.

We also provided some designs for potential smart technologies for the future. These designs are intended to be a starting point for the further use of smart technologies to benefit society in various ways. These benefits include public safety, convenience, luxury, and even medical applications. These designs have not been tested and are purely abstract ideas yet we believe that they may be a step in the right direction.

For input into the designs we had talked to various people in order to obtain their ideas. For the most part we found that people were largely interested in designs that were already in development. This leads to the conclusion that the field is headed in the correct direction. Industries are developing products in accordance with the needs and wants of society. Although public knowledge in this field is limited, the field of smart technologies is actively growing to fulfill the needs and desires of society.

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7 Appendix A: Electrorheological Fluid Lab Experiment

7.1 Introduction:

Electrorheological fluids are being used increasingly in our society. They are found in commercial, medical, and industrial fields. Electrorheological fluids have the unique ability to increase their viscosity when in the presence of an electric field. The following experiments will illustrate this effect.

7.2 Experiment 1: Fluid or Solid?

7.2.1 Equipment:

Corn Oil	Corn Starch	mixing container with spoon	metal wire
Metal plate	Wimshurst generator (or other large power source with connectors)		

7.2.2 Procedure:

1. Mix the corn oil and corn starch together until you have a somewhat thick off-white color mixture similar to the substance seen in Figure A.
2. Connect one wire from the generator to the metal plate and connect the other wire to the metal wire. A picture of the Wimshurst generator is shown in Figure B.
3. Position the metal wire so that it is about 1 ½ inches above the center of the metal plate. Make sure that the metal plate does not touch the wire at any points and that the adjoining connections do not touch.
4. Turn on the generator and allow the power to build until there is a large electric field between the wire and the plate.
5. Pour the mixture onto the plate near the wire. It should become very viscous and resemble Figure C.
6. Turn off the generator. What happens?
7. Turn on the generator again. What happens if you prod the substance with something like wood or cardboard?

Figure A: Corn oil and starch mixture under electric field

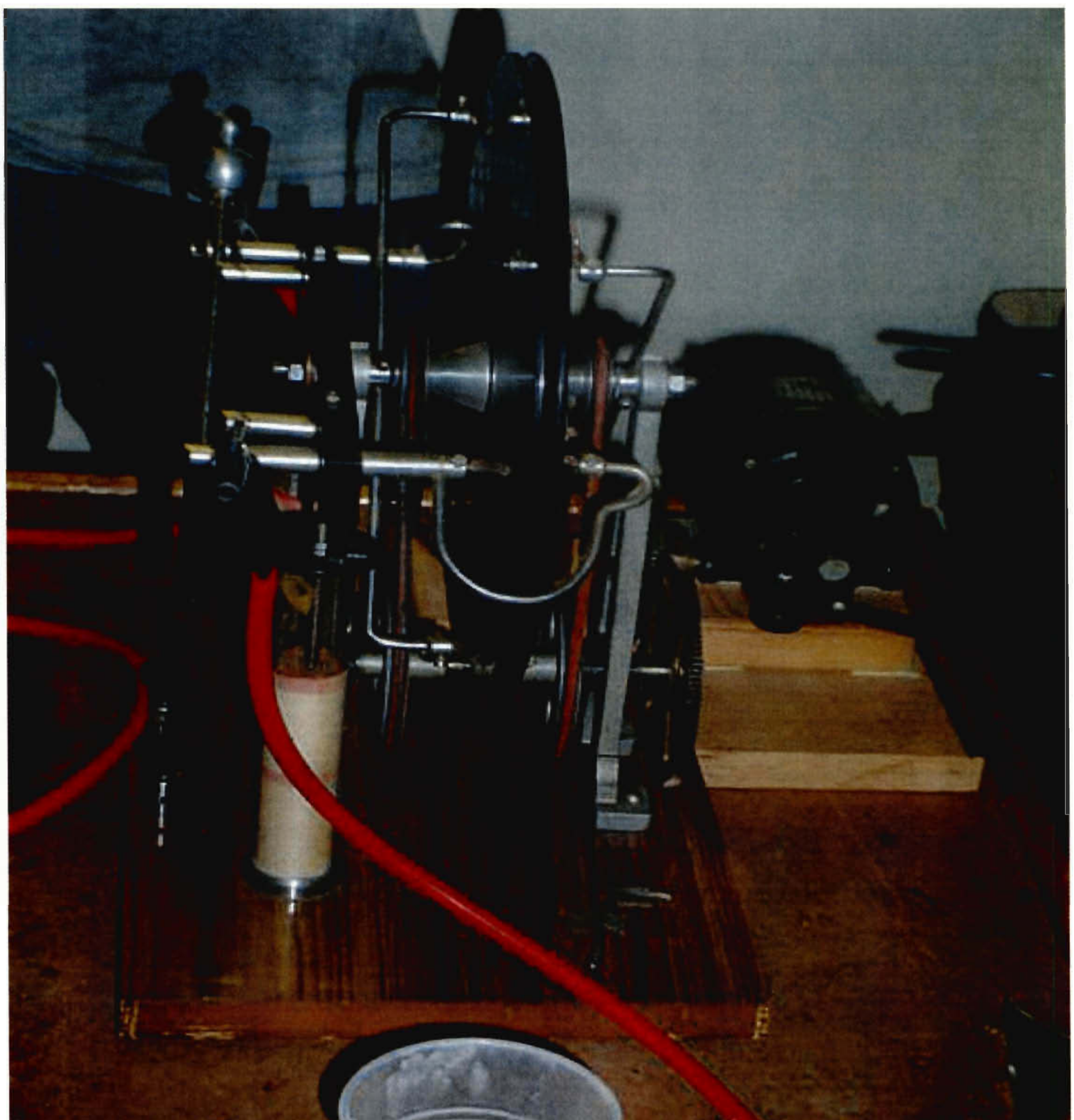

Figure B: Wimshurst Generator

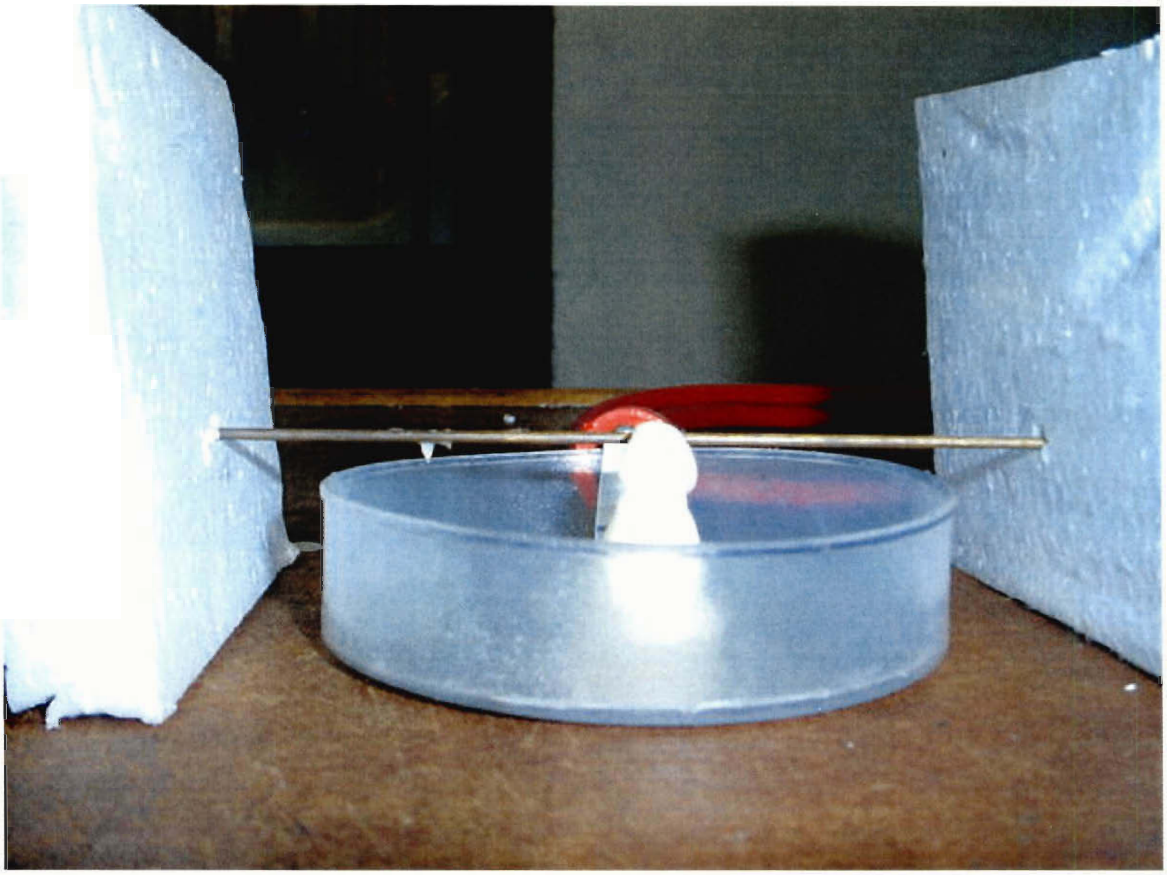

Figure C: Mixture exposed to strong electric field

7.3 Experiment 2: Visible Particle Effect

7.3.1 Equipment:

Corn Oil	Rice	Metal wire	Plastic cup	Metal plate	Hot glue gun
Metal wire	Wimshurst generator (or other large power source with connectors)				

7.3.2 Procedure:

1. Take the metal plate and cut it so that it will fit in the bottom of the plastic cup. Wrap some wire around the plate making sure that metal touches metal at at least one location. Poke a hole in the side of the cup near the bottom. Put the metal plate at the bottom of the cup and run the wire through the hole. Plug the rest of the hole with hot glue and allow to dry. It should resemble Figure D.
2. Put rice and oil into the cup. A picture of the apparatus before turning on the Wimshurst generator is shown in Figure E.
3. Connect one wire from the generator to the wire in the bottom of the cup and the other connector to the other metal wire. Position the second wire directly above the diameter of the cup. It is important that there be no plastic or glass between the wire and the metal plate. A picture of this set up is shown in
4. Turn on the generator. What happens? Increase the voltage if nothing happens.

Figure D: Cup with conducting base

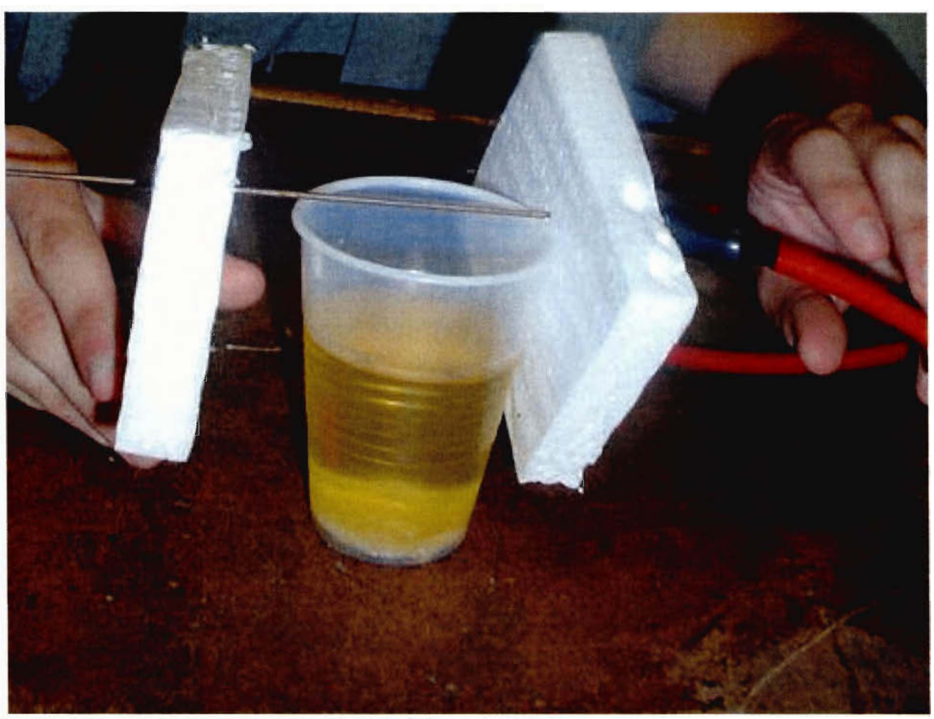

Figure E: Apparatus before setting up electric field

Figure F: Rice and oil mixture when exposed to electric field