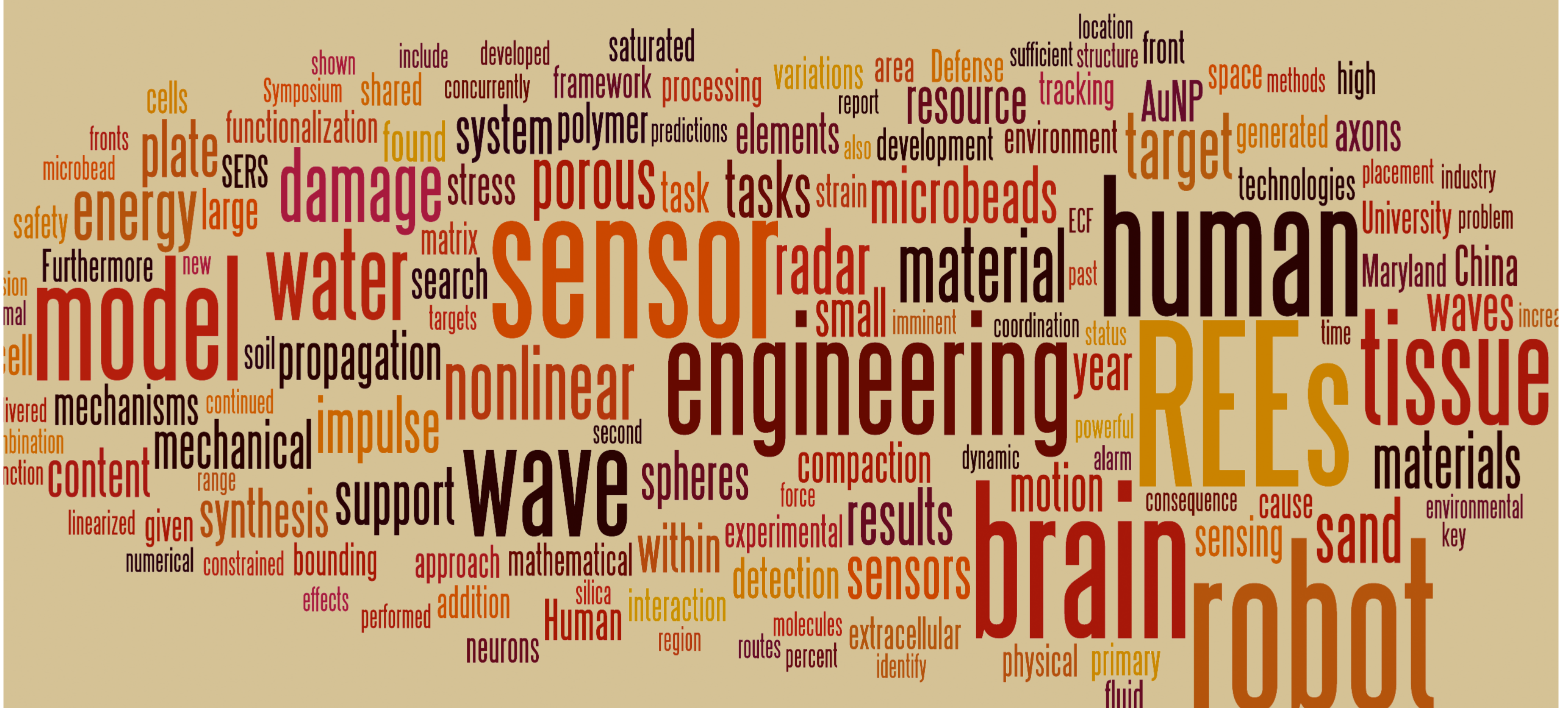
CECD

EXCELLENCE IN ENGINEERING RESEARCH AND EDUCATION

2012 Report



February 2013

Foreword

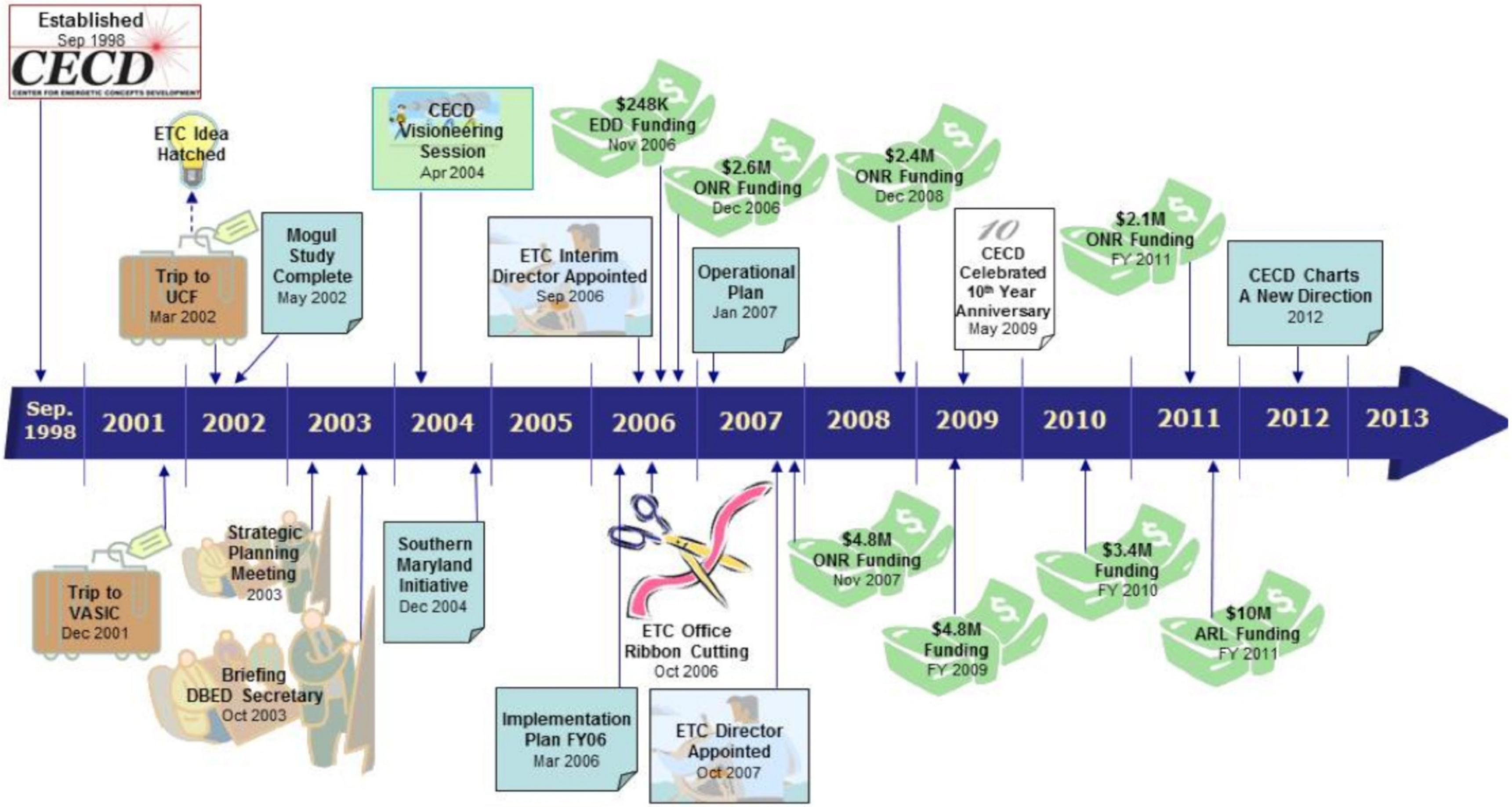
CECD spearheaded the establishment of ETC (a 501(c)(3) corporation) in 2006 as part of the *Southern Maryland Initiative for Energetics Capability Development: A Response to Emerging National Needs.* This gave rise to the CECD/ETC Enterprise that worked on a variety of joint projects, some which were supported by the U.S. Congress. With the successful completion of these joint projects, ETC has now transitioned into a new role independent of the CECD.

The CECD continues to work with NSWC-IHD, ONR, ARL, and other entities and conducts a wide range of research activities and specialized studies to advance the development of the broad field of energetic systems. The *2012 Report* provides an overview of accomplishments as well as ongoing activities.

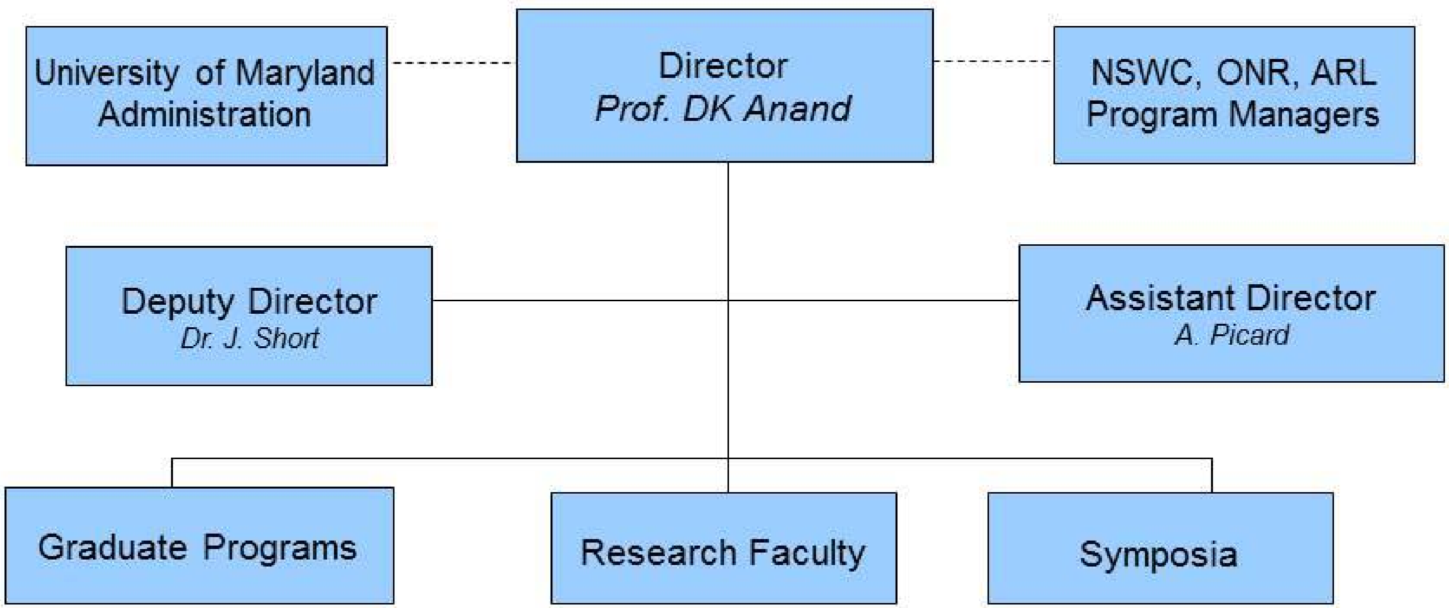
Davinder K. Anand
Professor and Director
CECD

CONTENTS

The CECD Timeline



CECD Organization



Research Project

Wave Propagation Through Soft Tissue

Balakumar Balachandran

The interaction of blast waves with the human head involves propagation of nonlinear stress and strain waves within the brain, and this propagation is characterized by the transfer of a large amount of energy at high strain rates in a short time window. Experiments with swine and rat brain tissue subjected to tension, compression, and shear loads indicate that brain tissue behaves as a nonlinear visco-elastic material. A primary aim of this investigation is to gain a fundamental understanding of the influence of soft tissue nonlinear material properties on the propagation characteristics of stress waves generated by transient loadings. The soft tissue is modeled as a nonlinear visco-hyperelastic material; the geometry is assumed to be one-dimensional rod; and uniaxial propagation of longitudinal waves is considered.

The linearized system equations can be used to predict brain tissue material parameters through the use of available experimental ultrasonic attenuation curves. Furthermore, frequency thresholds for wave propagation along internal structures, such as axons in the white matter of the brain, have been obtained through the linearized model predictions.

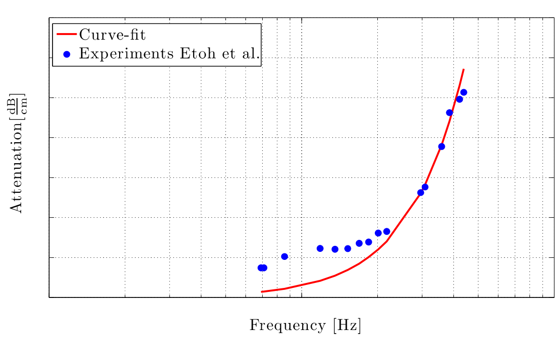


Fig. 1: Comparison between experimental measurements of attenuation in bovine brain tissue (Etoh et *al.*, 1994) and linearized model predictions.

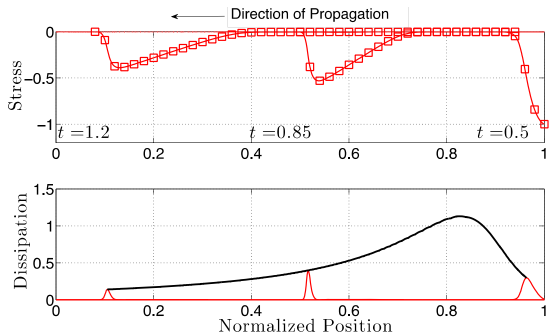


Fig. 2: Stress saves steepening as they travel through the rod (top). Dissipation concentrated at the location of the steep wave fonts (bottom).

With the nonlinear material model used, the numerical results illustrate that one of the imprints of the nonlinearity on the wave propagation phenomenon is the steepening of the wave front, leading to jump-like variations in the stress wave profiles. This phenomenon occurs as a consequence of the dependence of the wave speed on the local deformation of the material. As per the predictions of the nonlinear material model, compressive waves in the structure travel faster than tensile waves. Furthermore, it is found that wave pulses with large amplitudes and small elapsed times are attenuated over shorter spans.

In addition, it is shown that when steep wave fronts are generated in the nonlinear viscoelastic material, energy dissipation is focused in those wave fronts implying deposition of energy in a highly localized region of the material.

Novel mechanisms for brain tissue damage are proposed based on the results obtained. The first mechanism is related to the dissipation of energy, which is highly localized at the wave front as it travels through the structure. The second mechanism is related to the interaction of steep wave fronts with axons encountered across its way through the brain. If the diameter of the axons is comparable with the space scale of the wave front (width of the wave pulse), then a differential stress will be rapidly applied to the axon.

Valdez, M. and Balachandran, B. (2013). Longitudinal nonlinear wave propagation through soft tissue, Journal of the Mechanical Behavior of Biomedical Materials, in press. DOI: http://dx.doi.org/10.1016/j.jmbbm.2013.01.002

Research Project

Safe Human Robot Interaction by using Exteroceptive Sensing based Human Modeling

Satyandra K. Gupta

We have developed an exteroceptive sensing based framework to achieve safe human-robot interaction during shared tasks. Our approach allows a human to operate in close proximity with a robot, while pausing its motion whenever a collision between the human and the robot is imminent. An overview of the overall system is shown in Fig. 1. The human's presence is sensed by an *N*-range sensor based system, which consists of multiple range sensors mounted at various points on the periphery of the work cell. Each range sensor, based on a Microsoft Kinect sensor, observes the human and outputs a 20-joint human model. Usage of multiple sensors takes care of occlusion problems. Based on the class of collaborative tasks considered in this work, the shape of the work volume is cylindrical by nature. Therefore, there is no need for a sensor to be placed directly above the robot. However, there is a need for multiple sensors to be placed radially surrounding the periphery of the work cell. Accordingly, we find that four sensors, mounted on the four corners of the work cell are sufficient to cover the work volume. Positional data of human models from all the sensors are fused together to generate a refined human model.

Next, the robot and the generated human model are approximated by dynamic bounding spheres that move in a 3D space as a function of the movements performed by the robot and human in real-time. We designed a pre-collision strategy that controls the robot motion by tracking the collisions between the two bounding spheres. For this purpose, a virtual simulation engine is developed based on Tundra software. A simulated robot, with a configuration identical to the physical robot, is built and instantiated within the virtual environment. The simulated robot replicates the motion of the physical robot in real-time by using the same motor commands that drive the physical robot. Similarly, a simulated human model replicates the motion of the refined human model generated by the sensing system. Now, as the robot and human move in a shared region during a collaborative task, any intersection between the two bounding spheres is detected as an imminent collision condition, which is used to pause the robot's motion; a visual alarm (sphere changes color from white to red) and an audio alarm are raised to alert the human. The robot automatically resumes its task after the human moves into a safety zone.

Whereas most previous sensing methods relied on depth data from camera images to build a human model, our approach is one of the first successful attempts to build it directly from the skeletal output of multiple Kinects. Real-time behavior observed during experiments with a 5 DOF robot and a human safely performing shared assembly tasks validate our approach. An illustrative experimental result is shown in Fig. 2.

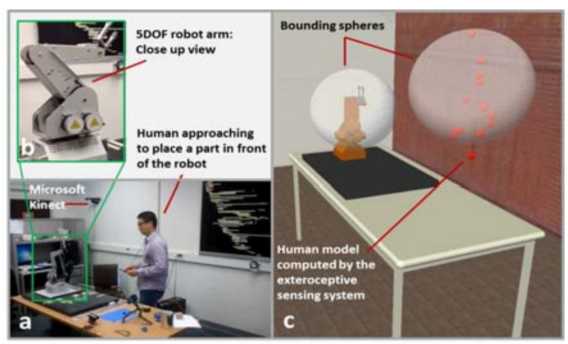


Fig. 1: Overall System Overview: (a) Work cell used to evaluate human-robot interaction during a shared task. (b) 5 DOF robot used for experiments. (c) Visualization of the interference between robot and the human.

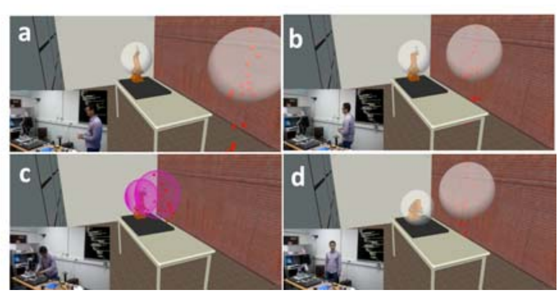


Fig. 2: (a) Human is far away from the robot. As the distance between the spheres is significant, robot performs its intended task. (b) Human carries a part toward the front of the robot, which still continues its task as the spheres are not intersecting. (c) An imminent collision is detected by the system; therefore, the robot is paused and a visual alarm is raised (bounding spheres change color). (d) Human returns to a safety zone; therefore, the robot resumes its motion.

Research Project

Nanotechnologies for Trace Explosives Detection

Donald DeVoe

We have continued our exploration of nanotechnology-enabled platforms for trace gas-phase explosive detection, with a primary focus on developing functionalized nanoporous materials as novel surfaces for ultrasensitive analysis of adsorbed explosives by surface-enhanced Raman spectroscopy (SERS). A variety of nanostructured porous surfaces have been demonstrated with high specific surface areas for enhancing analyte adsorption/concentration and increasing SERS signals through optical interactions with the structured substrates. While our previous work was focused on nanofilament silicon dioxide and microporous anodic alumina, our recent efforts over the past year have been primarily directed toward the attachment of gold nanoparticles (AuNPs) to porous polymer and silica monoliths as SERS-active substrates for performing remote optical gas-phase detection of explosive molecules. In particular, we have developed a microfluidic-enabled method to produce large numbers of monodisperse porous microbeads fabricated from glycidyl methacrylate polymer (Fig. 1).

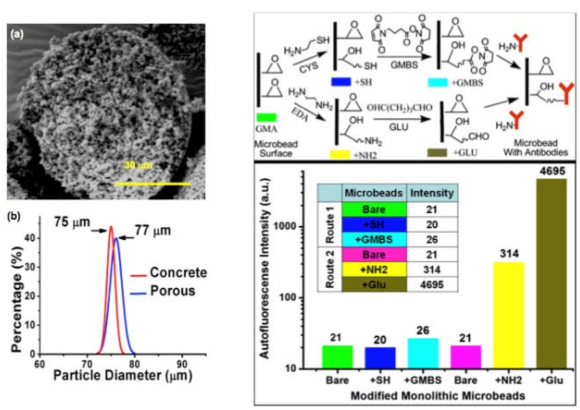


Fig. 1 (a) cleaved polymer microbead showing porous interior matrix. (b) Porous and non-porous bead sizes revealing nearly monodisperse distributions. (c) Microbead functionalization route for antibody attachment, and evaluation of autofluorescence demonstrating moderate optical background for SERS detection.

The microbeads serve as discrete sensing elements that can be functionalized with (bio)molecules for selective capture and concentration of target molecules, and AuNP functionalization has been optimized for the porous polymer sensor particles.

Two routes for AuNP functionalization have been optimized based on either pre-mixing of nanoparticles with the prepolymer solution used to prepare the porous microbeads, or in-situ growth of AuNPs after microbead synthesis (Fig. 2). Both routes were found to yield good nanoparticle coverage, with the first method providing more controllable distributions of AuNP clusters suitable for SERS sensing.

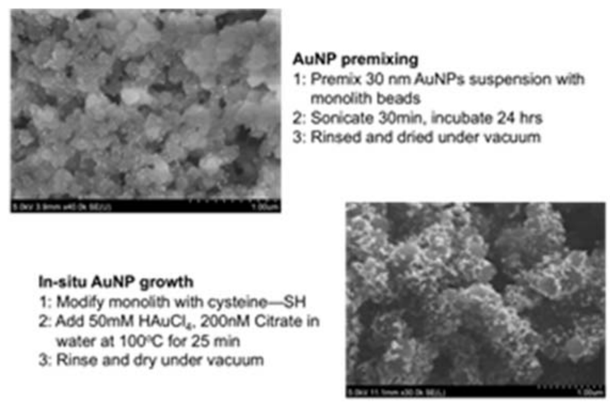


Fig. 2. Comparison of AuNP premixing and in-situ growth routes for SERS-active nanoparticle integration within monolith microbeads.

While experimental results for TNT vapor detection using AuNP functionalization microbeads have been promising, the limit of detection was found to be constrained by the background fluorescence of the polymer matrix (Fig. 1c). To overcome this limitation we have begun work on a process to prepare porous microbeads from a silica matrix, using a similar microfluidic-enabled synthesis route but using high-temperature batch processing of the microbeads collected from the outlet of the microfluidic chip. Continuous porous silica structures have been successfully achieved, and microbead processing is currently in progress.

Research Project

Investigation into effects of compaction and water content on impulse delivered to a plate

William Fourney

We currently have three tasks underway: 1) Investigate effects of compaction and water content on Impulse delivered to a plate; 2) Effect of overburden and target standoff on target response; & 3) Detailed examination of loading mechanisms on target plates. We have made progress on all three but this report will concentrate on Task 1.

In previous work we had concentrated our efforts on examining the impulse applied to a target plate from sand and water. We used dry sand, saturated sand, and water and found for a plate that was big enough to catch all of the impulse that the impulse from saturated sand was twice that of dry sand and the impulse from water was about twice that of saturated sand. Our sponsor was interested in seeing the effect of water content and compaction was on the impulse delivered.

We have devised methods of carefully controlling both water content and compaction and have investigated an additional two soils in the study. We have also performed testing with two different target plate sizes – one large enough to catch all of the ejecta and one small in comparison to the size of the charge. The results of our studies to date are given in the two graphs (Figures 1 and 2).

Note that we are plotting impulse versus air filled voids (a combination of compaction and water content) and that although soil type (plotted on these graphs are water, a red soil, a brown soil, saturated sand, and dry sand) make some small difference, the largest effect is from the amount of air in the soil.

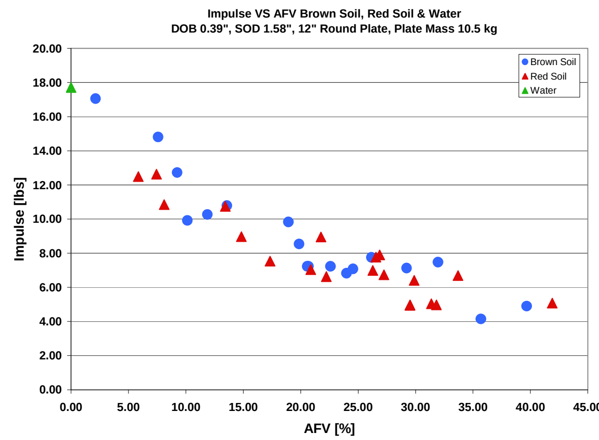


Fig. 1: Impulse VS AFV Brown Soil, Red Soil and Water

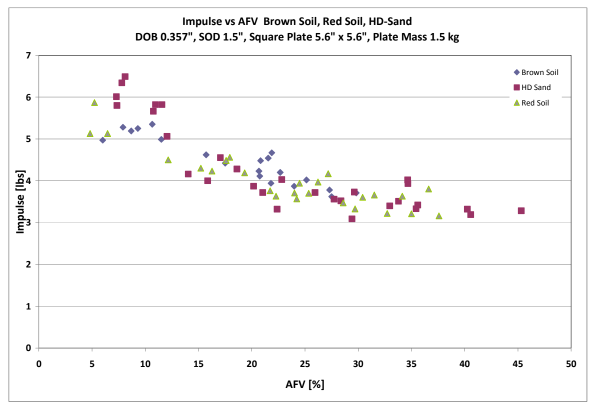


Fig. 2: Impulse VS AFV Brown Soil, Red Soil, HD-Sand

The first plot is for a large target plate while the second is for a small plate. These results are very promising from the standpoint of better understanding the loads applied to a vehicle subjected to the detonation of a buried charge.

The other two tasks are also well along and providing promising results.

Research Project

Contribution of Brain Extracellular Fluid in Mild Damage of Brain Tissue from External Insults

Henry W. Haslach, Jr.

The mechanical processes that underlie mild traumatic brain injury from physical impact, shock wave, or sudden acceleration insults are not well understood. Subtle small-scale mechanical damage mechanisms in brain tissue that can modify brain function may be involved in the initial cause of mild traumatic brain injury (mTBI). Another possible contributor, often overlooked in mechanical testing, is the fact that brain tissue is biphasic, composed of water and solid phases, and its mechanical properties are strongly influenced by the high fluid content of the brain tissue itself, whether extracellular or intracellular. The tissue fluid is known to be critical in the mechanical function of other organs.

Brain tissue, which is about 80% water, is composed of roughly equal amounts of neurons and glia, such as astrocytes, (Fig. 1) and a non-load bearing perinueronal net of extracellular matrix proteins that surrounds cellular substructures, but lacks, however, major fibrous structural components. The neurons have protruding dendrites in addition to the signal-conducting axons, whose ends may have several unsheathed branches that communicate with other neurons (Fig 2). Fluid, called the extracellular fluid (ECF), fills the space between these cells; it is this fluid that we postulate transmits the force from external insults to the brain cells.

The pattern of links between neurons, astrocytes and each other forms a mechanically weak network structure that maintains, along with the capillaries, the structural integrity of the brain by a combination of tension in axons, dendrites, and glial processes that is balanced by hydrostatic pressure in the ECF (Van Essen, 1997), rather than any extracellular framework.

The behavior of the ECF that we propose could be one immediate cause of the increase in axonal tension and thus may be a link between the external insult to the brain and cell damage in mTBI.

This project is expected to lead to a mathematical model for the mechanical response of brain tissue and to identify the immediate mechanisms that cause mechanical damage and induce the secondary biochemical effects studied by others. We believe that these results show that a successful mathematical model for brain tissue under insults must account for damage, perhaps through a damage parameter such as permeability, in the range from small to larger strains.

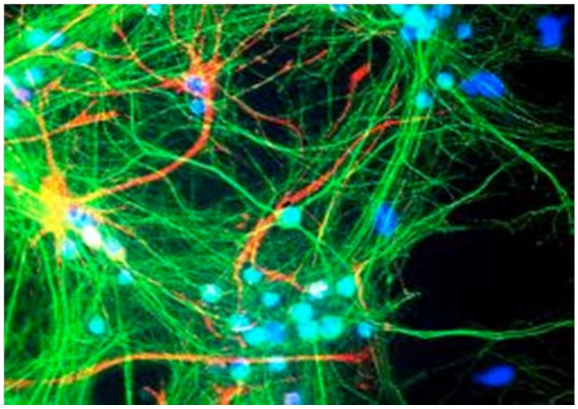


Fig. 1: Rat cortical neurons and glia in mixed tissue culture. Source: http://www.encorbio.com/Album/pages/ChkMAP2-GFAP-Hoe-40X-1.htm

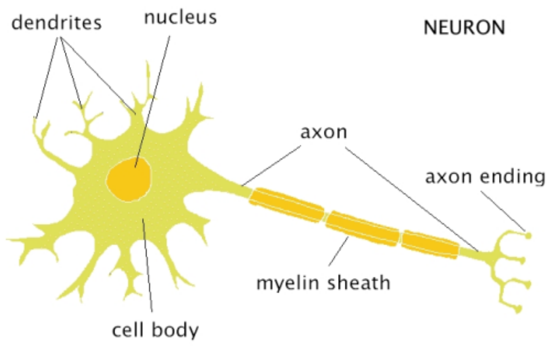


Fig. 2: Neuronal Structure. Source: http://webspace.ship.edu

Information on the damage mechanisms is needed to interpret the results of any FEM model; knowledge of the location of the maximum stress and strain is not sufficient because a given strain level may cause damage in one brain region and not in another.

Research Project

Rare Earths: Insights and Concerns

Dylan A. Hazelwood, Davinder K. Anand

Rare earth elements (which are seventeen elements on the periodic table) are used in an ever-growing variety of applications that are key to our modern technology (Fig. 1). In addition they are essential for a wide variety of defense technologies that are critical to national security. Global demand for rare earth materials is projected to grow, fueled in part by continued development and deployment of emerging energy technologies, and as a result, a global shortage of rare earths is anticipated in the near future. Although the United States has 13 percent of the world's exploitable reserves, nearly all rare earth materials used in the country are imported from China. In contrast, China has only 48.3 percent of the world's rare earth reserves, yet accounts for more than 97 percent of global rare earth production. Furthermore, China has been reducing its export quotas in order to satisfy growing domestic demand, and is placing further emphasis on strengthening its vertically integrated supply chain in the rare earth industry by focusing on downstream rare earth products.

Fig. 1: Overview of uses of rare earth materials in modern electronics (Source: Hocquard, 2010)

Prices for rare earths experienced a dramatic increase throughout the first half of 2011 – for instance, prices for some key REEs, such as europium and dysprosium, increased by more than eightfold from January to August. Several key factors contributed to this significant increase. An incident in 2010 between Japan and China resulted in rare earth exports to Japan being halted for a month, indicating to the rest of the world that China's supply could be constrained at any time. During the same period the Chinese government continued to reduce export quotas, and the country's rare earth producers began to account for the cost of excessive resource exploitation and environmental damage through increases in government taxation.

To address a possible rare earth shortage crisis, the United States needs to actively pursue policies to ensure supply security. In addition to developing domestic resources and stockpiling specific rare earths, we must support the development of new technologies for their mining and processing. We must also develop more efficient manufacturing and recycling methods for consumer goods containing rare earths, investigate synthetic rare earth substitute compounds, and continue research into rare-earth-free technologies.

CECD's 2012 book *Rare Earths: Insights and Concerns* was the result of a study performed to create a body of knowledge, and was intended to be a compendium of open literature. Its purpose was to provide timely information in sufficient detail to support the development of appropriate policy decisions, as well as to provide a resource for U.S. commercial concerns. The book provides an insight into the current status of availability, processing and uses of rare earths in the world. Particular attention was given to the role of China, since it is by far the largest provider of these elements worldwide. The status of the U.S. was also reviewed, as were the implications of current and future policies relating to rare earths.

Research Project

Distributed Spatiotemporal Optimization for Radar Mission Coordination using Cooperative Control

Derek A. Paley

In support of the Missile Defense FNC Program, Force Level Radar Resource Management for IAMD project, the Collective Dynamics and Control Laboratory at the University of Maryland has contributed to the design of the conceptual architecture for dynamic management of radar tasking among multiple forces by applying tools from optimization and control to address the problem of dynamic, autonomous sensor coordination to maximize the collective sensor search volume and concurrently optimize the sensor-to-target assignment for long-range and short-range targets. This report describes the first year of a multi-year effort. Project deliverables include:

- A mathematical modeling framework for ship placement and radar resource allocation
- Analytic and numerical techniques to identify optimal strategies within the parameter space
- Metrics and candidate scenarios for algorithm evaluation

Background

The Office of Naval Research is conducting several science and technology projects as a part of the Sea Shield FNC MD Program, which is focused on improving active missile defense. In a high threat-raid density environment, management of sensor resources supporting surveillance, tracking, combat identification, engagement, and kill assessment is critical to maximize the likelihood of defeating all threats targeting defended assets. Current known capabilities are limited to setting sensor doctrine and manual engagement support coordination. Technical challenges to sensor resource management across the force include: variations in sensor capabilities; variations in sensor interfaces and controllability; how to define force level sensor support tasks; how to prioritize sensor support tasks; how to coordinate sensor support tasks; variations in sensor location (surface or airborne); differences between ballistic and airborne threat trajectories and threat complex diversity, and multiple sensor bands, accuracies, and update rates (e.g., rotating versus phased-array). Furthermore, this coordination may be constrained by available communications links, but must degrade gracefully relative to a nominal communications environment.

Accomplishments

The University of Maryland Collective Dynamics and Controls Laboratory's primary responsibilities include constructing a mathematical modeling framework for ship placement and radar resource allocation and utilizing analytic and numerical techniques to identify optimal strategies with the model parameter space. Future work will entail development of a distributed spatiotemporal optimization algorithm. The contributions of this year were (1) we provided a nonlinear, two-dimensional model of multiple multifunction radar systems that concurrently search for and track targets within a specified area, subject to a radar resource constraint; (2) we solved the problem of maximizing the collective search area of multiple multifunction radar sensor systems while concurrently tracking a prescribed number of targets within that area; and (3) we posed and solved a novel target-to-radar assignment problem for coordinated radars that balances the radar tasking. While the item's focus is on radar sensors, we believe its contributions may be of interest to a broad community seeking an approach to optimal sensor placement and target tracking for linear and nonlinear sensors in a resource-constrained environment. All of the algorithms were implemented in real time assuming minimal network delays and can be run on a standard laptop computer.

IPA Activities

CECD Energetics

James Short

In February CECD concluded a final report for the Army Research Office, summarizing the status of energetic materials synthesis. During the past 30 years the emphasis on synthesis of new materials in search of more powerful conventional weapons has given way to a sophisticated role for energetic materials in the design of a weapon system. Explosive performance is no longer a primary imperative in energetic munitions. As a consequence the synthesis focus in search of powerful new compounds has diminished. The adjectives that emerged describing synthesis projects that are small, fragmented, and suboptimal. Chemical energy is no longer the Holy Grail, rather it is a combination of energy, safety and environmental consequence. Materials that were synthesized in the past and set aside because they were not more powerful than TNT, HMX or CL-20 (or other examples) are now once again candidates if they are found to have useful safety characteristics or attractive life-cycle environmental attributes.

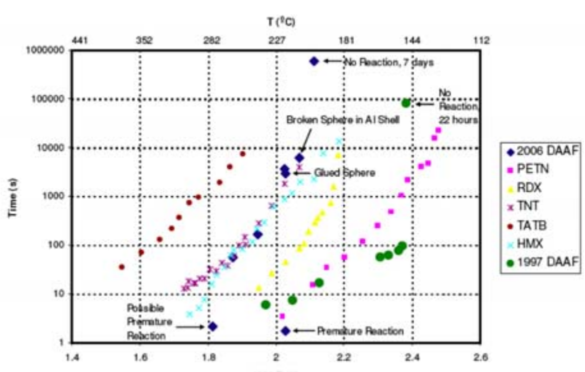


Fig. 1: ODTX comparing DAAF 2006 to DAAF from 1997-1998 long with other common explosives.

During the first half of the year James Short completed a four year commitment to the Office of the Assistant Secretary of Defense for Operational Energy Plans & Programs. Among the public duties was organizing a booth at the ARPA-Energy Summit in February, meeting with Michigan Senator Carl Levin concerning renewable energy research capacity in the State of Michigan, and a presentation entitled "Managing Operational Energy" at an American National Standards Institute Energy Efficiency meeting that prompted ANSI to establish an Energy Efficiency Standards Panel.

Fig. 2: Getting Fuel to the Fight: A Tactical Challenge

During the second half of the year James Short assisted the Deputy Assistant Secretary of Defense for Test & Evaluation to assess the DoD T&E infrastructure in light of the budget reductions likely in the 2014 Defense budget request.

2012 Symposia

The first University of Maryland Center for Energetic Concepts Development Symposium on Strategic Materials was held on 12 June 2012 at the Inn and Conference Center facilities located on the University of Maryland College Park campus. The Symposium discussions focused on Rare Earth Elements (REEs), and on the specialized materials in batteries and fuel cells. The Symposium was organized to provide balanced perspectives and insights by Government and DoD experts, prominent academic investigators, as well as experts from industry intimately and directly involved with rare earth elements, batteries, and fuel cells. For each of the three areas of interest, two speakers from industry and academia provided a state-of-the-art review for their area. Keynote speakers including Mr. David Cammarota (OSD), Mr. Andy Davis (MolyCorp), Prof. Greg Jackson (CECD), Dr. Chris Guzy (Ballard Power), Prof. Robert Moore (Virginia Tech) and Dr. Kamen Nechev (Saft Batteries) presented focused briefings as keynote addresses in the morning; panel sessions were conducted in the afternoon to allow additional perspectives and substantial interactions between the panelists and all the participants.

Attendees of the 2012 CECD Development Symposium on Strategic Materials

A recently published CECD book titled **Rare Earth Materials: Insights and Concerns** was made available at the symposium. This book surveyed key trends and discussed issues and concerns in the field of rare earth materials.

Recent CECD Publications

CECD
EXCELLENCE IN ENGINEERING RESEARCH AND EDUCATION