BOOK OF ABSTRACTS

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Bing-Shiang Yang
Frontal plane responses of stepping movements onto a laterally-ompliant structure

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Effect of age on detecting a loss of balance in a seated whole body balancing task

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Jeremy Mickalek
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# Dynamics, Systems and Controls

Chair: Bryon Sohns

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Chair: Gerald I Fernandes

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Frontal plane responses of stepping movements onto a laterally-compliant structure

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## Dynamics, Systems and Controls

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Three dimensional atomic forces and topographical imaging of atoms with atom force microscope

Wei Li Wang, S. Jack Hu, and Roy Clarke
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Keywords: AFM, atomic resolution imaging, graphite

A scanning tip on a surface is subject to the normal load and the scan direction friction force. This macroscopic model however breaks down for atomic resolution imaging in an atom force microscope (AFM) where the friction was found to be two dimensional. In this paper, a simple model is introduced to describe how these three-dimensional atomic forces and the induced deflections are coupled through tip-cantilever force sensors. In particular, we discuss a mechanism leading to an unexpected residual linear deflection due to the two dimensional lateral forces, which could be the main cause preventing optical-beam-deflection AFMs from obtaining true images of atoms in the contact mode. With this mechanism, some “topography” images of surface atomic structure previously observed can be interpreted as maps of the lateral force in the longitudinal direction. Some puzzling features such as the well-known “resolution of every other atom” of graphite topographical images can be readily explained.
Nanocrack patterning of poly-dimethylsiloxane (PDMS)

Kristen L. Mills and Professor Michael Thouless
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Keywords: PDMS mechanical properties, nano-patterning, thin films fracture mechanics

Poly-dimethylsiloxane (PDMS) is a low surface energy, rubbery elastomer. Due to its biocompatibility this material makes an ideal candidate for biomedical research. Nano-patterning is of great interest to those researchers trying to create cellular tissues in vitro. Several methods have been relatively successful at creating nano-patterns although these tend to be expensive and time consuming.

Recently, a simple method for creating nano-patterning in PDMS has been discovered. PDMS sheet is fabricated and then plasma oxidized to create a very thin oxide layer on the surface of the PDMS. Subsequently, cracks are produced in this layer in the direction perpendicular to an applied strain. Controlling the amount and direction of the applied strain determines the density and relative direction of the cracks created. A predictive capability is sought in this research for the most effective and efficient production of nano-patterning available.

The cracking not only depends on the magnitude of applied strain but the mechanical properties of the bulk PDMS as well as the oxide layer. The small dimension associated with the oxide layer thickness poses a unique challenge in determining the mechanical properties of the oxide material as well as the exact geometry of the cracks. All of these parameters, however, need to be unequivocally determined before a model of the system may be developed.

The various methods that have been used to determine the mechanical properties of the PDMS bulk material and the oxide layer will be discussed as well as those for studying the topographical features of the cracked oxide layer.
Mode-I cohesive-zone parameters for a polymer-matrix composite and adhesive joint

S. Li, M.D. Thouless, A.M. Waas, J.A. Schroeder and P.D. Zavattieri
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The use of linear-elastic fracture mechanics as part of a design methodology for predicting the behavior of adhesively bonded, polymer-matrix composites has several limitations, such as the need for assuming the presence of sharp cracks, and linear-elastic deformations with no large-scale bridging. Therefore, the use of cohesive-zone modeling is being explored as an alternative approach to predicting joint performance. For this particular system, it was found that the failure involves competing crack paths such as cracking across the fibers and cracking along the interface. To fully characterize the failure mechanism of the joint, all the fracture properties need to be addressed. In this paper, a systematic methodology will be proposed to determine the mode-I cohesive zone parameters for these crack paths. For the purpose of numerical simulations, first dog-bone tensile tests and Iosipescu shear tests were performed to obtain the constitutive properties of the composite. To determine the fracture properties across the fibers, a series of compact tension experiments were performed. A subsequent series of thin, adhesively-bonded, symmetrical, double-cantilever beams made of the composite were conducted to investigate the fracture properties along the interface. All of the tests involved monitoring the load, displacement and crack propagation, as well as making careful in-situ observations of the fracture process. Based on all of these observations, corresponding cohesive-zone models and appropriate parameters were proposed for each failure mode. It was found these numerical predictions for the loads and crack profiles showed excellent agreement with the corresponding experimental observations.
Effect of design parameters on TEI in an automotive disc brake

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Keywords: TEI, critical speed

When two bodies slide against each other, most of the frictional energy is converted to heat. If the heat generation is non-uniform, it produces non-uniform thermoelastic deformations in the contacting bodies. These deformations affect the contact pressure distribution, which, in turn, further affects the temperature distribution. Hence, a feedback process is established. This process becomes unstable when a particular sliding speed, called the Critical Speed, is exceeded. This phenomenon is called ThermoElastic Instability (TEI) and is of particular importance in energy-dissipating systems such as brakes and clutches.

This paper describes a parametric study of TEI in a disc brake for a mid-size European passenger car. The key components of the brake comprise a rotor (which rotates with the wheel) and four pads (which are non-rotating). Upon brake application, the pads are squeezed against the rotor by hydraulic pressure causing frictional forces and resulting heat generation at the pad/disc interfaces.

The critical speed for this system was determined by a perturbation method embodied in the software ‘HotSpotter’ developed by Dr. Yun-Bo Yi of the University of Michigan. A parametric study was performed to investigate the effect of materials properties, system geometry and pad support stiffness on the critical speed. The results showed that higher Critical Speeds could be achieved by (a) increasing the rotor thermal conductivity, (b) decreasing the stiffness of the pads, (c) reducing the pad length, and/or (d) softening the pad support. A mesh refinement study showed that critical speed was highly sensitive to mesh refinement in the axial direction, but largely insensitive to refinements in the radial and tangential directions.
Modeling void nucleation in polycrystalline solids:
The effect of compositional stress

Hashem Mourad and Professor Krishna Garikipati
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Void formation in metallic interconnects causes open-circuit failure in semiconductor devices. Prevention of this type of failure necessitates a better understanding of the process of void nucleation in polycrystalline solids. The underlying mechanisms are stress-driven self-diffusion and electromigration. These atomic level processes are incorporated into a continuum field formulation, in which the composition (diffusion) and mechanics problems are fully coupled.

In this coupled framework, the relaxation of the lattice around a vacancy gives rise to a local stress. This compositional stress introduces a non-convexity (spinodal) in the Gibbs free energy density when plotted against vacancy concentration. Thus, a high vacancy-concentration regime exists, in which the Gibbs free energy density decreases with increasing concentration. An interpretation of this result is advanced, and its relation to void nucleation is discussed.

Computations are presented for the initial and boundary value problem of fully coupled diffusion and mechanics. These show that the energy barrier that characterizes the spinodal disappears under physically attainable conditions. The computations remain stable in the high vacancy-concentration regime, and allow the calculation of void-nucleation rates.
Roller fatigue and residual stress in crankshaft in fillet rolling process

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Keywords: fatigue, fillet Roller, crankshaft, contact pressure, residual stress

Deep fillet rolling process has been utilized to improve the fatigue strength of crankshaft in the automotive industry. This study is motivated by the need to improve the fatigue life of the fillet rolling tool to reduce the manufacturing efforts and cost. In this study, a parametric study has been carried out by a two-dimensional finite element analysis to investigate the effects of the contact geometry between the primary roller and the secondary roller on the contact pressure distribution which has a direct influence on the stress inside of the primary roller. Residual stress distribution near the fillet of crankshaft is also investigated for different fillet radii and roller geometries. The results indicate that the fatigue of the primary roller highly depends on the contact geometry between the two rollers, however, the residual stress distribution near the fillet of crankshaft does not seem to be much affected by a change of the geometry. The information on the various contact pressure distributions between the two rollers in this investigation can be used as a design guidance to improve the fatigue life of the primary rollers.
Theoretical, experimental and computational Investigations of failure modes of resistance spot welds in dual-phase steel lap-shear specimens

P.-C. Lin, S.-H. Lin and Professor J. Pan
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Keywords: Resistance Spot Weld, Dual-Phase Steel, Lap-Shear Specimen, Elasticity Theory, Elastic-Plastic Finite Element Analysis

Failure modes of resistance spot welds in dual-phase steel lap-shear specimens are investigated based on experimental observations, elasticity theories and elastic-plastic finite element analysis. Optical micrographs of the cross sections of spot welds in lap-shear specimens before and after failure are examined to understand the failure processes. The experimental results show that under lap-shear loading conditions, the necking failure is initiated in the sheet near the middle part of the nugget and then the failure propagates along the circumference of the nugget in the sheet to final fracture. Based on a two-dimensional elasticity theory, an analytic solution for an infinite plate contains a rigid inclusion subjected to a shear force is used to understand the stress and strain distribution near the nugget in lap-shear specimens. The elastic analytic solutions and the results of elastic finite element analysis indicate that the initial yielding starts near the two sides of the nugget in the sheet. As the plastic deformation increases, the location of the maximum equivalent plastic strain shifts from the location near the sides of the nugget to the location near the middle part of the nugget. The results of the two-dimensional elastic-plastic finite element analysis suggest that the necking failure mechanism should occur in the location near the middle part of the nugget as observed in experiments.
A two state model for outer hair cell mechanics

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Keywords: outer hair cell mechanics, area motor model

Outer Hair Cells (OHCs) found in the mammalian cochlea exhibit remarkable piezoelectric-like properties. Under normal in vivo operating conditions, mammalian OHCs are motile up to many tens of kHz, much higher than the normal operating range of other motile tissues such as cardiac and skeletal muscle, which typically operate in the range of a few Hertz. In addition to activity represented by piezoelectric theory, recent in vitro measurements have also shown that OHCs possess a significant voltage dependent stiffness.

There are roughly 10,000 OHCs present in a typical mammalian cochlea. Each cell is internally pressurized and reacts to a transmembrane electrical potential. This transmembrane potential is modulated by the deflection of stereocilia attached to the apical end of each OHC. It is this change in the transmembrane potential in the physiological scenario, that gives rise to in vivo force transduction. The working hypothesis is that somatic force generation from the OHC is the main cochlear amplifier, providing for the sharpness of frequency filtering and large gain seen for low amplitude sound.

General nonlinear constitutive theories for OHC tissue will be presented. These constitutive theories include piezoelectric-like electromotility and voltage dependent stiffness. The constitutive models are analyzed with regard to their capability to replicate experimental results. We extend an existing model for OHC mechanics (the area motor model) to include elastic constants dependant on motor state. The modified model succesfully captures stiffness variations of OHCs and other features of OHCs seen in vitro. Additional modifications necessary to capture effects of changing internal cell pressure and temperature will be presented. Utility of the model in modeling the entire cochlea will be discussed.
Frontal plane responses of stepping movements onto a laterally-ompliant structure

Bing-Shiang Yang and James A. Ashton-Miller
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Keywords: stepladder; frontal plane; compliant structure; postural control; balance

Falls from raised surfaces such as stepladders, chairs and stools cause injuries across the age spectrum, but especially in the elderly. In the case of a stepladder, a lateral fall is the most common type of accident. One reason for this may be that stepladders, chairs, and stools are not usually rigid, but have structural compliance, often in the mediolateral (ML) direction. This study examines the interaction between that structural compliance and the strategy used to step onto the structure. Although lateral balance recovery under external perturbations has been widely studied, responses to the self-induced ML perturbations that can occur when stepping up onto a compliant structure have not been reported. The purpose of this study, therefore, is to test the null hypothesis that stepping strategy does not change when stepping up and onto rigid and compliant structures.

Twenty healthy young adults standing on firm ground were asked to step forward and up onto a seven-inch high step at a comfortable speed. The ML compliance of the structure supporting the step could be covertly assigned one of three different values: low compliance (C_1 = 1\times10^{-4} \text{m/N measured at the step surface}), high compliance (C_2 = 2\times10^{-4} \text{m/N}) and rigid (C_0 < 10^{-5} \text{m/N}). Whole-body kinematics and force distribution under each foot were recorded at 100 Hz. Six trials were run with each structural compliance. Trial order was C_0, C_1, and C_2 interspersed by different numbers of blocks of six C_0 trials to prevent subjects knowing when a change occurred.

Only data from the first trial of each test condition are reported here. Different strategies were found in stepping movements onto the laterally-compliant and rigid structures. The time used for identifying structural properties and initiating stepping onto the compliant structure was significantly longer (19 to 25%) than onto the rigid structure. This difference indicates that subjects needed more information and time to transfer their weight onto compliant structures. Lateral center of mass (COM) velocity at the time of trailing-foot push-off decreased significantly (23%) with high structural compliance (C_2) apparently to prevent inducing unnecessary lateral oscillations in the human-structure system. After trailing-foot pushing off from the ground, subjects significantly shortened their unipedal support period, lateral COM excursion and decreased lateral COM velocity on the compliant structure in order to stabilize the human-structure system.

These results suggest that, without any practice, these healthy young adults naturally slow their lateral weight transfer once they have identified the compliance of the structure that they are stepping onto. Failure to do so may be one mechanism for a fall from a stool, chair, or stepladder. Future studies might address this situation in older adults.
Effect of age on detecting a loss of balance in a seated whole body balancing task

Alaa A. Ahmed and Professor James Ashton-Miller

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Falls in the elderly are associated with considerable morbidity and mortality. All unintentional falls are attributable to a ‘loss of balance’ (LOB). However, a precise definition of a LOB is lacking. It has earlier been proposed that a LOB is required for the central nervous system to trigger a compensatory response to prevent the ensuing fall (Ahmed et al., 2002). The LOB is posited as a loss of effective control, detectable, both internally and externally, as a control error signal anomaly (CEA).

A model-reference adaptive controller and failure-detection algorithm were used to represent central nervous system decision-making based on input and output signals obtained during a challenging whole-body planar balancing task. Control error was defined as the residual generated when the actual system output is compared to the predicted output of a simple model of the system. A CEA is hypothesized to occur when the error exceeds a threshold three standard deviations (3?) beyond the mean baseline signal. The quality of the signals involved is inherently dependent on the accuracy of the afferent signals which is known to decline with the neuropathic changes associated with aging. This deterioration could result in an inability to detect a CEA and respond appropriately.

We tested the null hypothesis (H1) that there would be no age effect on the successful detection of CEA using a 3? threshold criterion on the controller error signal. The secondary (null) hypothesis (H2) was tested that age would not affect the performance of the 3? threshold in predicting the occurrence of any compensatory reaction by 100 ms.
Mechanical and biochemical characterization of engineered tendons

Sarah Calve, Robert G. Dennis, Keith Baar, Professor Karl Grosh and Professor Ellen Arruda
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Tendon fibroblasts were induced to generate their own extracellular matrix to serve as a scaffold and form a three-dimensional construct. The stress-strain response of the constructs resembles the non-linear behavior of immature tendons where between 0 - 5% extension, there is a region of low stiffness after which the slope starts to increase until the construct starts exhibiting linear behavior until failure. The ultimate tensile strength is within the same order of magnitude as embryonic chick tendon, ~ 2 MPa. The longer the constructs are maintained in culture, the stiffer they become, a trend which is also seen over the course of development of tendons in utero.
Design optimization of vehicle crashworthiness using equivalent mechanism approximations

Karim Hamza and Professor Kazuhiro Saitou
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Keywords: Vehicle Crashworthiness, Design Optimization, Surrogate Models

Design of vehicle structures in order to achieve good crashworthiness is highly desirable yet difficult task that faces vehicle designers. Driven by ethical responsibility, government regulations and market competitiveness, vehicle designers strive to increase the safety of their vehicles while maintaining cost efficiency. Unfortunately however, design for crashworthiness is a difficult and expensive task. The best designs are not always obvious, for example, increasing the stiffness of the structure makes it strong but may decrease the crash energy absorption thereby degrading the vehicle safety. It is thus crucial to have thorough understanding of the pros and cons of design decisions in order to improve vehicle crashworthiness. Existing tools for analysis fall under three broad categories: i) experimental testing, ii) nonlinear finite element (FE) simulations and iii) surrogate (approximate) models.

Experimental crash testing is very expensive and is rarely used except in limited studies and final tests for vehicle certification. Nonlinear FE simulations using detailed models provide good prediction of vehicle performance during crash. However nonlinear FE simulations consume enormous computational resources and their results are often confounded by numerical noise. Therefore designers often resort to approximation techniques in conjunction with the detailed FE models. Different types of surrogate models have been used in the literature in order to aid designers in their task. The two major categories of such models are: i) abstracted functional approximations such as polynomial response surface and neural networks and ii) physical approximate models such as lumped masses connected by springs. The current research is dedicated to developing better physical approximate models that avoid extra abstraction and allow for recapturing the essence of the crash phenomenon.

This research models the collapse of the vehicle structure during crash using equivalent mechanisms composed of rigid masses connected by prismatic and revolute joints that have special nonlinear springs. The special equivalent mechanism approximations allow for faster and more efficient crashworthiness optimization of vehicle structures. Preliminary results include successful case studies involving two-dimensional sub-structures that were approximated using two-dimensional mechanisms. The equivalent mechanism approximations were also recently extended to space mechanisms, thereby becoming potentially capable of approximating full three-dimensional vehicle frames.
A study of emission policy effects on optimal vehicle design decisions

Jeremy J. Michalek, Steven J. Skerlos, and Panos Y. Papalambros

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**Keywords:** environmental policy, optimal design, game theory, oligopoly, emissions, CAFE, discrete choice analysis, logit, green engineering

A methodology is presented for studying the effects of automobile emission policies on the design decisions of profit-seeking automobile producers in a free-entry oligopoly market. Mathematical models of engineering performance, consumer demand, cost, and competition are integrated to predict the effects of design decisions on manufacturing cost, demand, and producer profit. Game theory is then used to predict vehicle designs that producers would have economic incentive to produce at market equilibrium under several policy scenarios. The methodology is illustrated with three policy alternatives for the small car market: corporate average fuel economy (CAFE) regulations, carbon dioxide emissions taxes, and diesel fuel vehicle quotas.

Several trends are observed in the policy scenarios examined in this study. For example, CAFE scenarios show that increased regulation penalties can result in cost savings for all parties. Without regulation, producers cannot afford to make smaller, cheaper engines because of competition; however, when all producers are subject to the same regulation costs, then all producers are driven to produce smaller engines. On the other hand, CO$_2$ tax scenarios show that increased regulation penalties can lead to diminishing returns. Therefore, modeling the effects of regulation on design decisions is important for evaluating regulation concepts and choosing appropriate regulation parameters such as penalty values. The study also shows that regulation is necessary to provide incentives for producers to design diesel or alternative fuel vehicles. While diesel engines have better fuel efficiency per unit of power, gasoline engines are cheaper to manufacture and are therefore preferred.

Overall, the models developed in this study were successful in predicting realistic trends resulting from several regulation scenarios. If individual cost structures can be formulated for existing manufacturers, the framework could be adapted to model specific short-term decisions of existing manufacturers. However, the abstract oligopoly analysis provided here yields a useful analytical perspective of long-term regulation effects in general. The analysis demonstrates the model’s predictive power and suggests that policy models that include design decisions can be used to improve understanding of the ultimate effects of regulation on industry, consumers, and the environment.
Propagation of uncertainty in optimal system design

Kuei-Yuan Chan, Professor Panos Papalambros and Professor Steve Skerlos

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**Keywords:** uncertainty propagation, reliability-based design optimization, multilevel design, hierarchical systems, probabilistic design

In product development process, engineers face great challenges to make appropriate decisions under various uncertainties. The variety of types and sources of uncertainty, along with lack of agreed terminology, can generate considerable confusion. Uncertainties may exist in the values of the variables considered or the accuracy of mathematical representations used during product development. Probability is often used as the measure of uncertain belief, and in this research, probability is incorporated with a representation of stochastic variables to quantify design and manufacturing uncertainties.

Through evaluating the system transfer functions, uncertainty sources in the design variable propagate to the model outputs as variation in the objective function or constraints. Traditional design optimization algorithms handle only deterministic variables and parameters where various difficulties are encountered when stochastic parameters and variables exist as part of the mathematical model. Constraint-bound optimal points of the deterministic problem become probabilistically infeasible under the propagation of uncertainty from underlying stochastic variables. This condition may even extend to interior optimal points, depending on the resultant distribution of the optimal point. In order to better capture the stochastic behavior of input uncertainties, probabilistic constraints and function expectations are introduced within optimization process.

This research investigates multi-level design optimization problem under uncertainty as the probabilistic extension of the Analytical Target Cascading (ATC) methodology which has previously proven useful for solving deterministic multilevel design optimization problems. ATC deals with the issue of propagating desirable top level design specifications (or targets) to appropriate targets at lower levels in a consistent and efficient manner.

One case studying the impact on vehicle fuel consumption created by manufacturing variation in cylinder-liner/piston-ring surface roughness is presented. Direct measurements of manufactured cylinder liners and rings in the case study indicate that surface roughness values outcome from manufacturing process could be modeled as normally distributed variables. Results indicate that the predicted optimal design targets for ring-liner manufactured surface roughness change significantly when uncertainty in manufacturing processes is accounted for.
A sustainable aqueous system-dream or reality?
A case study in metalworking fluids

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Keywords: sustainable system, metalworking fluids, microfiltration, green formulation, contaminant detection.

A sustainable aqueous system, by definition, aims to maximize the utility of aqueous resources for society without 1) reducing supply, quality, or distribution of water for future generations, and 2) without negatively impacting ecosystems or human health over the life cycle of the system. Although metalworking fluids (MWFs) are widely used in machine tool industry as lubricant and coolant, aqueous metalworking fluid systems are universally in violation of the principles of sustainable aqueous system. In this paper, MWF system is chosen as a case study for sustainable aqueous system development and technologies developed to achieve sustainability, which include recycle via microfiltration, on-line detection of microorganism contamination via flow cytometry, and environment-friendly MWF formulation design, are introduced.

Microfiltration is a membrane-based technology that can remove microorganisms and other contaminants from MWF and serve as a high-performance recycling technology with the potential to reduce environmental and health hazards as well as MWF related costs in the machine tool industry. The productivity and economical feasibility of this process is limited by the interactions between MWF ingredients and membranes, or fouling. In this research, the nature of fouling is investigated to gain better understanding on these interactions in order to develop novel MWF formulations and membranes with improved productivity.

To achieve fast and cost-effective detection of microorganisms present in MWFs, a micro-integrated flow cytometry (MIFC) is developed. The MIFC follows the same principles as the full-scale flow cytometry widely used for biomedical samples, but with components manufactured using MEMS technologies to bring down the cost. Specific procedure has been developed to eliminate the interference of MWF components.

With the microfiltration system as actuator and MIFC as sensor, the life span of MWFS can be greatly extended. However, the MWFs still impose a heavy burden to environment at end of life. To minimize the environmental impact of MWFs at disposal, green formulations have been developed using vegetable oil instead of mineral oil, and emulsifiers derived from agriculture produce instead of petroleum products. The greener fluids have been tested using a tapping machine and it is found higher machining performance can be achieved.
Design and Manufacturing

Design of heat-reversible snap fits for space frame bodies

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Recent legislative efforts to reduce the environmental impacts of the entire life cycle of the next generation automotive body structures, aluminum space frame bodies, have increased the need for non-destructive and standard means of the separation of external body panels from structural frames. Aluminum space frame bodies are considered to be the next generation body structures due to its lightweight and improved rigidity; they are also environmentally sound due to the improved fuel efficiency owing to its lightweight. The challenge in improving recyclability of an aluminum space frame body structure is the clean separation of incompatible alloys used in various body components, in particular, extruded structural beams and stamped external panels.

In the current aluminum space frame bodies, joining between the extruded beams and stamped external panels is achieved by permanent joints such as self-piercing riveting and resistance spot-welding. These permanent joints can only be detached destructively, inevitably leaving residues of mating materials that prevent the “closed loop” recycling of aluminum alloys. It is essential, therefore, to develop a joining method that allows easy, non-destructive detaching at a desired time. In this research, the use of heat actuated reversible snap fits for car frame/panel assembly is proposed. Snap-fit is a preferred joining method because: no need of separate fasteners, easy assembly action, can be disassembleable, reduces the overall product cost and makes the recycling process more economic.

In the initial stage, different designs of a joint (snap fit) shape, dimensions and location on the panel for the disassembly process are proposed, since all these parameters affect the structural properties and manufacturing cost of a body. Heat is applied to different parts of the panel and the behavior of the panel and its snap fits are analyzed. Each proposed design is examined using computer simulations using the finite elements software package ABAQUS. The snap fit shape and dimensions, the heating zones and the heating time are varied to obtain the optimum snap fit tip deflection and satisfy the stiffness requirements. The final proposed design satisfies all these initial requirements.
Analytical craftsmanship in vehicle interior design

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**Keywords:** craftsmanship, customer preferences, attribute importance weights, vehicle interior design

Craftsmanship is what makes a product have the immediate appeal of being well made and well functioning at its very early interactions with the customer. This study attempts to extend the understanding of the craftsmanship concept in vehicle interior design into a quantitative domain, so that it can be included in the product development and decision making stages from design, engineering and manufacturing points of view. The strategy is to look at preference data and try to uncover the underlying dimensions of people’s craftsmanship perception. The analyses are intended to be used as a tool to assist both engineers and designers in the design process.

The starting point of this project was a checklist of 41 craftsmanship attributes for vehicle interiors created at Johnson Controls Inc. (JCI) as a tool for experts to (1) evaluate vehicle interior designs, and (2) develop a craftsmanship index which is a scoring system that allows comparison between different interior designs.

Regarding the evaluation of interiors, previous work has shown that perception differences exist between designers, engineers and customers. The craftsmanship checklist, however, was intended to be used by engineers and designers only. Therefore, investigation of customer perceptions started with a pilot survey to test the efficiency of the checklist on customers. Analyses showed the need for the checklist to be improved in terms of clarity of attribute meanings. A refined list of vehicle interior characteristics and perceived craftsmanship attributes was developed; the dependencies among them were represented in a functional dependency table (FDT). A second survey was conducted to test the efficiency of the new list of perceived craftsmanship attributes. The results showed an improved performance of the new list. Multidimensional scaling techniques and cluster analysis were used to model craftsmanship perception of vehicle interiors based on the survey data.

As for developing a craftsmanship index, there is both empirical and theoretical evidence suggesting that a certain number of contributing elements can create a positive or negative attitude, which sets in and “tips the balance”, even if other attributes point to the opposite direction. Along this observation our approach was to develop a methodology that allows us to incorporate relative importance weights of attributes in the overall craftsmanship score of an interior.
A logic controller design methodology with fault handling for reconfigurable manufacturing systems

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Keywords: Reconfigurable Manufacturing System (RMS), Petri-Net (PN), Resource Control Net (RCN), Rule-Based Matrix Formalism, Serial and Parallel flow Line, Deadlock

The main purpose of this paper is to model and analyze a reconfigurable manufacturing system (RMS) applying existing controller design and analysis methods. The RMS introduced in this paper was originally developed to replace traditional large-volume production lines, allowing more flexibility. In RMS, each dedicated machine in a traditional serial line is replaced with multiple flexible CNCs arranged in parallel to give routing flexibility on the system while manufacturing large-volume production. However, control theories for this kind of system have not been studied rigorously.

In this paper, the way to model controllers and the deadlock avoidance resource allocation for RMS are performed with two existing controller design and analysis methods. One method is based on the Petri-Net (PN) synthesis method using Resource Control Nets (RCN). The other is a Rule-Based Matrix formalism constructed with traditional industrial engineering tools. Deadlock avoidance resource allocation for the system with shared resources is accomplished to limit the number of tokens in siphon operations of a circular wait. Some theoretical limitations on this real-time resource allocation are discussed to handle more general situations.

In addition, it is shown how to integrate a modular fault handling control into the normal sequence control. Since the existing modular fault handling method was dedicated to the transfer line without shared resources, the extension of this method for the system with shared resources is given.

A typical example of RMS with serial and parallel flow allowing multiple part types is presented. Also, the applicability of each method for RMS is investigated.
Fidelity in variation simulations for multi-station manufacturing

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**Keywords:** uncertainty, compliant assembly, multi-station, variation analysis

In manufacturing process the variation analysis and synthesis plays an important role in improving the quality, reducing the cost and thus obtaining competitive products. Especially in multi-station process, variation analysis is more complicated because variation can propagate from one station to another station. In order to provide the designer a flexible and inexpensive means to evaluate and analyze this complicated process, simulation models for variation analysis for manufacturing system have been developed in some papers. However, because it is generally recognized that there always exist uncertainties in the simulation-based model for the real engineering system resulted from ambiguity and vagueness. This research mainly focuses on uncertainty in variation simulation model for multi-station compliant assembly process which is very common in automotive, aircraft and other industries and which is also a complicated process because of the deformation of the compliant parts in assembly process.

At the beginning of our research, the uncertainty sources in variation simulation model for multi-station compliant assembly process are analyzed and then classified as two types: parameter uncertainty and model uncertainty. Based on a simple state space model of multi-station assembly process, the uncertainty propagation effects are studied. The conclusion that model uncertainty is more significant than the parameter uncertainty is made based on the results of this example. In order to mitigate uncertainty effects of multi-station, reducing the model uncertainty of single station level will be one of the most important approaches.

This research is done on the CAVA (Compliant Assembly Variation Analysis) model, which is a variation simulation model for single station level, and MS-CAVA (Multi-Station CAVA) which is for multi-station level. After analyzing the CAVA simulation model, two problems to be solved are identified to mitigate the uncertainty of single station level: contact effects and part representation problem. Contact effects problem results from the interactions between parts which always happen in compliant assembly process. In the CAVA model, these effects are not included for simplification. Part representation problem arises because the original representation of source shape of parts in CAVA can not give a more accurate result in some case. In this research, only results for part representation are obtained and the contact effects will be solved in the future research.
Direct metal deposition (MDM) in die and mold manufacture: An environmental analysis

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The use of tooling, dies and molds, has become a key element of fast, reliable, and cost-effective manufacturing. However, die and mold manufacturing is complicated, time consuming, and expensive, while carrying the potential for significant energy consumption, resource use, and environmental emissions. Alternatively, state-of-the-art direct metal freeform manufacturing processes, like Direct Metal Deposition (DMD), present an opportunity to manufacture dies and molds with a short design cycle, and with less energy consumption, emissions, and primary material waste during mold manufacture. The goal of this research is to better understand the potential environmental benefits, along with potentially negative environmental impacts, for the DMD process in the application of die and mold manufacture by performing a comparative Life Cycle Assessment against current die and mold manufacturing processes.

Life Cycle Assessment (LCA) is an ISO supported methodology meant to comprehensively analyze the environmental impact of a given product system. In order to accomplish this, the product system must be clearly defined, a Life Cycle Inventory (LCI) of material and energy flows must be developed, and a Life Cycle Impact Assessment (LCIA) must be applied to the LCI to characterize the environmental impact of the set of material and energy flows associated with the product system. This study applies energy as a proxy of environmental impact, and correspondingly a comparative inventory of energy flows has been developed in accordance with standard LCA practice. Implications of expanding the assessment into the full LCI/LCIA domain are qualitatively addressed.

While DMD can produce functionally identical dies and molds to those traditional produced, it also can produce functionally improved parts and repair/remanufacture existing tooling. These two technological advances are perceived to be highly beneficial from the economic perspective. Functionally improved dies and molds, primarily in the form of improved heat conduction, have been shown to drastically reduce cycle times in injection molding, leading to large in-production cost reductions. Repair and remanufacturing capability introduces an “industrial ecology opportunity” that can drastically reduce material expenditure, subsequently reducing overall tooling cost. The environmental characteristics of these advances are addressed building on the characterization of DMD and traditional operations from the life cycle energy perspective.
Development of volumetric error measurement system for meso-scale machine tool

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Keywords: meso-scale machine tool (mMT), geometric error measurement system, six-degree-of-freedom displacement measurement, laser module, cube beam splitter, position sensitive detector (PSD)

A miniaturized machine tool system, henceforth referred to as a meso-scale machine tool (mMT), has been recently proposed to manufacture mechanical components with machined features in the range of a few to a few hundred microns on components in the size range of about a hundred to ten thousand microns (micro/meso-scale). In order to successfully develop the mMT and produce micro/meso-scale components with high accuracy, the performances of the mMT should be properly evaluated in terms of its geometric errors. Direct and indirect measurements of geometric errors of conventional machine tools have been carried out by using laser interferometers and telescopic ball bars (TBB). However, none of these devices can be applied to the mMT due to its small working volume. Therefore, it is essential to develop a new method for identification of geometric errors of the mMT.

Several six-degree-of-freedom displacement measurement systems using lasers, position sensitive detectors, and special cooperative targets (diffraction grating or three facet mirror) have been explored to investigate their applicability to geometric error measurement of the mMT. However, they suffer from limited measurement ranges and poor accuracy.

A novel non-contacting geometric error measurement system is proposed with an increasing measurement range and high accuracy for an mMT. It consists of a laser module containing a beam splitter and a diode laser, three two-dimensional position sensitive detectors (PSDs), and an additional beam splitter. The laser module attached to a measuring target generates two perpendicular laser beams, and one of them is also divided into two laser beams when it hits an additional beam splitter located at central region of measurement system. These three laser beams are detected by three PSDs, and the position and orientation of the laser module, which will be interpreted as geometric errors of an mMT, are then calculated simultaneously by forward and inverse kinematic analyses. A series of experiments are performed to demonstrate the effectiveness and accuracy of the proposed measurement system. The experimental results show the applicability of the proposed measurement system to the identification of geometric errors of an mMT with allowable measurement accuracy.
Flow of fine powders through miniature hopper nozzles and its application to multi-material solid freeform fabrication

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Keywords: Solid Freeform Fabrication, Selective Laser Sintering

The variety of applications for multi-material composite structures is both well established and growing rapidly. However, a present obstacle to continued growth lies in the approaches to manufacturing these types of artifacts. The development of new approaches for fabricating multi-material components is in part dependent upon developing solid freeform fabrication (SFF) techniques capable of depositing and consolidating multiple materials. In particular, the selective laser sintering (SLS) process is well suited to this challenge. The SLS process presently uses a roller device to sweep thin layers of a single powdered material across the build area. We propose to replace this roller device by an array of hopper-nozzles that can deposit lines, dots and regions of multiple powdered materials to form a heterogeneous patterned bed.

The designated name “hopper-nozzle” refers to the design of experimental nozzles based on existing hopper theory. In the chemical and process industries, hoppers have been inexpensively designed to store, discharge bulk solids, and eliminate undesirable flow instabilities (i.e. arching, rat-holing, and oscillatory flow). Unfortunately, difficult hopper and powder sizes are avoided due to the lack of fundamental understanding of flow phenomena. This can be attributed to the complex interaction of granular solid and interstitial fluid that plays a large role in delivery through small orifice diameters.

Many researchers have investigated the flow of a powder through orifices under gravity and have established empirical correlation to predict the mass flow rate. Among all these correlations, Beverloo’s correlation is the most widely used to predict the discharge rate.

The orifice size used in experiments by various past researchers was very large on the order of 2-100mm, because their research was mostly concerned with industrial processing systems, such as feeding of catalyst pallets to a cracking plant, etc. For development of SLS hopper-nozzle powder delivery system we intend to use orifice sizes in the range 10 µm-2 mm. The powders used with SLS are typically 0.1-150µm in diameter. Flow behavior for this range of particle size and nozzle size combination has not been investigated previously. The intent of the current work is to determine whether a simple correlation for SLS powder sizes flowing under gravity through intended orifice sizes can be extended from Beverloo’s correlation. Also, this work focuses on developing techniques to get a continuous flow rate of powders when it is not achievable under gravity.
A computational design-of-experiments study of hemming processes for automotive aluminum alloys

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Keywords: hemming, aluminum alloy, finite element analysis, DOE, roll-in/roll-out, maximum surface strain

Hemming is a three-step sheet folding process utilized in the production of automotive closures. It has a critical impact on the performance and perceived quality of assembled vehicles. Using two-dimensional (2D) finite element model, this paper presents a design-of-experiments (DOE) study of the relationships between important hemming process parameters and hem quality for aluminum alloy AA 6111-T4PD flat-surface-straight-edge hemming. The quality measures include roll-in/roll out of the hem edge as well as the maximum true strain on the exposed bent surface. The FEM model combines explicit and implicit procedures in simulating the three forming sub-processes (flanging, pre-hemming and final hemming) along with the corresponding springback (unloading). The results show that pre-hemming die angle and flanging die radius have the greatest influence on hem edge roll-in/roll-out, while pre-strain and flanging die radius impact the maximum surface strain significantly. The computational DOE results also provide the basis for process parameter selection to avoid hem surface cracking and particular insights for achieving acceptable formability.
Seams are one of the major types of surface defects in hot rolling processes. Due to the continuous production and harsh environmental conditions, real-time detection has proved an elusive goal of the steel industry. Recent innovations in on-line imaging technology have provided the capability for real-time surface inspection, allowing the measurement of bar surface conditions at high temperatures and rolling speeds. This paper investigates a seam detection method based on data obtained from such an on-line imaging sensor. The developed methodology consists of two stages. In the first stage, the entire image is segmented with suspect defect regions (sub-images) isolated using a region-growing algorithm. The objective of the second stage is to discriminate between real seams and false seams based on the suspect sub-images, and consists of three steps: (1) A feature-preserving sampling procedure which converts the sub-image into a 1-D waveform sequence is conducted. (2) Discrete wavelet transform (DWT) is performed on the sequence with features extracted from the wavelet coefficients. (3) Finally, Bayesian classifier is used for classification of the resulting feature space.
Tolerance allocation for compliant assemblies

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During the design phase of a new product, engineers focus on the allocation of component tolerances. Component tolerance allocation is important as it influences the ease of assembly, the final product quality and ultimately the cost of the product. One measure of product quality is whether or not the Key Product Characteristics (KPC’s) are met. Tight component tolerances positively affect product quality and adversely affect product cost. As a result, the optimal assignment of tolerances is desirable.

The focus of this study is the allocation of tolerances to compliant components that satisfy the surface profile requirements of the final assembly. In industry, profile KPC’s are important as the surfaces of assemblies and sub-assemblies often serve as mating surfaces for other components or affect the final part appearance. Whereas, the profile of rigid bodies can be controlled by merely controlling component dimensions, tolerance allocation to compliant components poses more challenges. Since the component sources of variation of compliant components are not independent, component deformation due to clamping and welding is inevitable. This implies that in addition to component geometry, material, joint type and joining method should also be taken into consideration. For simplicity, in this study it is assumed that the material remains within the linear elastic range during joining. For the same reason, welded joints as opposed to mechanical joints are considered. The joints considered here are both lap and butt joints.

In the initial stage of the tolerance allocation algorithm, tolerances are assigned to components within the recommended ranges for the material. Using the method of influence coefficients, the component deformations due to clamping and welding are then determined. As the material remains in the linear elastic range, the assumptions of the method of influence coefficients are applicable. Then, using proportional scaling within a cost minimization algorithm, tolerances that satisfy the assembly KPC’s are determined. A sensitivity matrix for a 3-D space frame structure created by a multi-station process is used as an example to illustrate that both the final assembly KPC’s can be satisfied and that part interference can be avoided when the proposed algorithm is used.
Packet based control

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Keywords: network control systems, optimal control

The use of networks is becoming ubiquitous in control systems. A key advantage of controlling a system over a network is the absence of point to point wiring infrastructure. A node connected to the network automatically shares information with all other nodes. Thanks to this inherent quality, the implementation of complex systems is greatly alleviated. Systems become more configurable and can easily be expanded and monitored. Furthermore, distributed control systems can be realized without imposing any extra demands on the system realization. Finally, new configurations become possible through wireless technology.

There are several setbacks, however, that arise when a control system is networked. Most of these problems can be attributed to either the sharing of the communication median or the extra complexity associated with data transmission. In traditional digital control systems the quality of performance asymptotically approaches the continuous time performance level as the sampling period goes to zero. This is not the case with networked control systems. In networked control systems discrete signals are encoded into a packet, sent across the network, and then decoded at the destination point. As a result, a tradeoff arises between a performance gain associated with an increase in sampling frequency and a performance degradation caused by encoding/decoding and network traffic induced delays.

Traditionally, the synthesis problem for a networked control system is dealt with by first transforming the problem into classical discrete or sampled data framework and then designing the controller to deal with the network issues. The development of controllers that fully utilize the packet structure is here considered. These types of controllers are referred to as packet based controllers. In this work the synthesis problem of an output feedback packet based controller is studied in an H2 optimal setting. Finally, the performance of such a controller is compared to more traditional control mechanisms.
The setting and management of design targets in complex systems using system norms: extension to multiple attributes

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Keywords: Complex system design, Linear fractional transformation, Mu synthesis

A system is a “mathematical description of a relationship between externally supplied quantities (i.e., those coming from outside the system) and the dependent quantities that result from the action or effect on those external quantities”. The externally supplied quantities are the “inputs” to the system and the dependent quantities are the “outputs”. “Complex” systems include numerous design variables, interactions between constituent subsystems, uncertainties in the values of the design variables and system parameters, and performance requirements encompassing multiple disciplines. The design of such systems is a difficult, and often lengthy, process that utilizes a significant amount of resources: human, computational, etc.

The overall design task is often decomposed into several smaller subtasks, each to be undertaken by a design team. The need to group these people into design teams and distribute the various design tasks among design teams motivates the need for system decomposition. The goal is to divide the overall design task into several subtasks each small enough to be manageable by the team responsible for executing that subtask. The solution obtained by solving the different sub-problems should correspond to the solution of the original problem, i.e. the “truth” of the original problem should be “maintained”.

A new approach to the design of complex systems with performance specifications from multiple disciplines is proposed. Rather than apply hierarchical optimization methods to the decomposed system, we cast the problem in the framework of robust control design. This reformulation allows us to apply existing results from the field of robust control to traditional robust design. Key elements of this reformulation include using linear fractional transformations to pull out design variables and system parameters. The concepts of small gain and small mu are then used to determine limits on the magnitudes of the uncertain parameters that would enable the design of the subsystems to proceed in parallel, as called for by the Systems Engineering methodology. The uncertain parameters for one subsystem will include design variables and outputs from other subsystems that are needed in that subsystem analysis. The results are illustrated using a simple example representing a corner-car model.
Data-based evaluation of collision warning / avoidance algorithms

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Keywords: Collision warning, collision avoidance, automotive, signal detection theory, Kalman smoothing, ICC FOT

Recently, CW/CA systems are getting attention because of the overlap with ICC systems and targeting major traffic accidents. However, both false alarm and missed detection might decrease system effectiveness. Our research started as investigation into the real human driving data collected by UMTRI ICC FOT project. We processed signal with Kalman smoothing and extracted two subsets of the data: “dangerous” and “safe” driving situations. Using confusion matrix to calculate the performance, we evaluated three of them: Honda, Mazda and the Johns Hopkins University (APL), which is later used as part of the CAMP algorithm. So far, JHU-APL logic shows the best performance. All this research is based upon the data sets; hence with different selection of the data sets, result can be different. ACAS FOT is being carried out now. Its data base is expected to provide invaluable resource to this type of research.
Impact of thermally induced bearing load control on spindle performance

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Keywords: spindle dynamic behavior, bearing load control

It has long been believed that spindle dynamic performance is related to spindle bearing loads. Because these loads can change drastically with a change in process conditions, the dynamic behavior is altered causing potentially poor cutting performance. Recently, it has been shown that thermally induced bearing loads can be controlled through heating of the spindle housing. It has been argued that changing these thermally induced bearing loads will impact the spindle dynamic behavior, however, the quantitative relationship between the bearing loads and the spindle’s dynamic behavior as represented by the natural frequencies is not currently known.

The objective of this research is to study how the thermal bearing load controller affects the natural frequencies of the spindle. A specific spindle type and process, a box spindle with a locked set of angular contact steel ball bearings used for boring operation, will be analyzed because of its assumed sensitivity to thermally induced bearing loads.

The proposed tasks in this analysis are the following: experimentally testing the feasibility of a dual thermal-actuated control, creating a computer model of the spindle system to predict thermally induced dynamic behavior, and testing, both through simulation and experimentation, the ability of the controller to change the spindle’s dynamic behavior.

This presentation will show preliminary results highlighting load control and affected natural frequencies. The effectiveness of the actuators on the bearing loads will be shown, as well as their effect on the dynamic behavior of the spindle.
Device delays and networked control system (NCS) performance

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Keywords: variable time delays, device delays, networked control systems, linear systems

It is well known in control systems that time-delays can degrade a system’s performance and even cause system instability. The problem of constant time-delays, present in the system, is often taken into account while designing the controller for that particular system. It works perfectly well in that case, but at times there are random delays present in the control system. In this study we investigate the random nature of the device delays present in a distributed control system and its effects on the control system performance in terms of Integrated Absolute Error (IAE). These random device delays result in part because of the processing and waiting times in the sensor and controller devices, A/D encoding speeds, dynamics of the devices, etc. In a Networked Control System (NCS), network transmission delays, though small in comparison with the device delays, are also a source of random delays. In a large and complicated control system, usually requiring many sensor devices, the selection of appropriate devices can be facilitated by analyzing the effects of variability of delay present in the devices, to have the least affect on a given controller performance. On the basis of this study we can make appropriate decision in the selection of sensor devices based on their random delay characteristics, i.e., mean and variance.
Synthesis bounds for distributed manipulation using logarithmic-radial potential fields

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Keywords: Distributed manipulation, logarithmic potential, subharmonic function

Distributed manipulation systems induce motions on objects through the application of forces at many points of contact. Current forms of distributed manipulation include multiple mobile robots, vibrating plates, actively controlled arrays of air jets, and planar micro and macro-mechanical arrays of actuators. The authors have presented a new form of distributed manipulation using passive air flow fields, which has been experimentally demonstrated and a computational method to locate equilibria. This paper presents a methodology for guaranteeing the existence of the equilibria and its synthetic usage for efficient manipulation of objects using passive air flow fields.

For searching for total equilibrium, we can incrementally construct the force equilibrium curve set when the sinks are placed relatively far enough each other as discussed later in detail. Then we can search this curve set for moment equilibrium.

1. For an arbitrary starting orientation, use a numerical search to find all fixed-orientation equilibria for only where the object covers at least one sink. This is only a 2-D search. Incremental searching starts at these points.
2. Increment the orientation and search for fixed-orientation equilibria only in the neighborhood of each previous fixed-orientation equilibrium.
3. Repeat second step until all the curves are searched.
4. Search moment equilibrium along the force equilibrium curves with increasing orientation to find points where M=0, M’<0
Modeling of electric accessories and fuel cell APU for the FMTV truck

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The reduction of parasitic losses is an important milestone on the road to future highly efficient trucks. Current trucks, depending on the duty cycle, may have parasitic losses that account for up to 45% of the total energy losses. Hence, compounding the techniques for reducing parasitic losses with the use of advanced diesels and hybrid propulsion systems holds a promise of achieving the aggressive fuel economy goals set by the Future Combat Systems and the 21st Century Truck initiatives. This work investigates the potential to reduce parasitic losses on the hybrid medium tactical truck (FMTV) through electrification of accessories. The electrified accessories are decoupled from the engine for more efficient operation and a Fuel Cell APU provides the electric power for these accessories. The engine oil pump, power steering pump, air compressor and air conditioning compressor are selected for electrification.

This study mainly focuses on the modeling of the accessories and the Fuel Cell Accessory Power Unit (APU). Proper models are critical for providing accurate predictions of power consumption and fuel economy. Accessories models are developed within the Vehicle Engine Simulation (VESIM) environment, which is also previously employed to develop the engine, drivetrain, and vehicle dynamics models of the FMTV trucks. In addition, representative and realistic duty cycles for the decoupled accessories are also developed in order to provide accurate power consumption predictions. The overall results reveal a promising benefit for the hybrid medium tactical truck (FMTV) in terms of fuel efficiency and provide a clear path for future work on the APUs.
String stability analysis of adaptive cruise control algorithms

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**Keywords:** Adaptive Cruise Control, String Stability, Proportional Controller, Sliding Mode Controller

This study focuses on the string stability conditions for vehicle Adaptive Cruise Control (ACC) systems. In ACC, the speed of the host vehicle is adjusted to match that of the preceding vehicle while maintaining a proper range. For an autonomous ACC, the vehicle is controlled by using on-board information only whereas communications with adjacent vehicles or roadside systems are required for a non-autonomous ACC system. ACC is commonly designed in a hierarchical manner. A main loop controller determines the proper acceleration or velocity, and a sub-loop controller manipulates engine and brake inputs to achieve the desired acceleration/deceleration, or sometimes the target speed.

The String Stability of an ACC system refers to a property in which the range errors are guaranteed not to amplify as they propagate upstream towards the tail of the string. It is dependent both on range policy and control law. In this study the Constant Time-Headway range policy is employed and the infinity norm of range error propagation transfer function is used as a metric to evaluate string stability.

Algorithms for both autonomous and non-autonomous ACC are analyzed and unified. They include UMTRI’s velocity-based algorithm, basic proportional control laws relying on range rate and range error, augmented sliding mode control algorithms based on range rate, range error and vehicle acceleration. It is demonstrated that the more feedback information an ACC system can gather, the less stringent the condition for string stability is. For autonomous ACC systems with proportional control on range and range rate, it is verified that time-headway must be at least twice the vehicle acceleration constant. This constraint can be relaxed by additionally feeding back acceleration term. For non-autonomous ACC systems, by properly devising control scheme, the string stability constraint can be completely removed.

Although experimental data shows that the driver actually adopts a nonlinear quadratic range policy, the above analysis based on linear systems provides much insight into the design of nonlinear controller to ensure string stability.
Determining model accuracy as a function of inputs and system parameters

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Keywords: model validity, model accuracy

Evaluating model validity is a vital part of any simulation-based process. Models are used to simulate real-world systems in order to improve our understanding of these systems and help us improve their performance. However, it is vital that the models being used are of sufficient quality for the purpose at hand. Otherwise a model that is fine for one purpose may be misleading and worse than useless for another purpose. Validity of a model, therefore, can be defined with respect to how well the model allows the user to understand the system and predict the effect of design changes. Whether a model is of sufficient quality (and is therefore valid) or not relies on two things. One is the ability of the model to predict the effect of design changes. The second is whether or not the model can accurately predict the response of the system to the entire range of desired inputs.

Previous researchers have already developed an algorithm called AVASIM that systematically and qualitatively assesses model validity. This algorithm defines accuracy in terms of physically meaningful specifications. However, the derivation of both the accuracy and the validity of the model are based on a specific input and set of system parameters. As stated above a model’s validity must be considered under all operating conditions expected. A model’s validity also depends on its ability to predict the effect of design changes. It is then important to know for what combinations of inputs and system parameters the model is valid. Also, many times models are developed by one company or group and then shared among their partners. In this case it is important to supply information about what inputs and system parameters the model is valid for along with the model. A range of validity of the model for the inputs and system parameters has been defined using the AVASIM algorithm that will solve both these problems. By applying AVASIM over the expected range of inputs and systems configurations a range of validity for the model can be determined. Case studies of simple illustrative system and a hydrogen fuel cell model will be presented. Preliminary results show the feasibility of quantifying a range of validity by studying AVASIM output as a function of input and system parameters.
Model predictive control for control of oxygen level in fuel cells

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Keywords: Model Predictive Control, Fuel Cells, Energy Management

A fuel cell generates electricity as a direct result of a chemical reaction between hydrogen and oxygen. While the idea is fundamentally simple, implementation of it requires a relatively complicated system of components. The generated power and response time to a demand load depends on how well each component is performing. Humidity and temperature of the fuel cell membrane directly affect the generated power. Also timely supply of the right amount of oxygen is crucial to the performance of a fuel cell. If the load on a fuel cell suddenly increases, the level of oxygen at the cathode drops rapidly. If the compressor fails to compensate for this drop in oxygen level, the power generated by fuel cell can not follow the load.

Maintaining the level of Oxygen Excess Ratio is then a critical concern in operation of a fuel cell system. In this presentation we propose to use Model Predictive Control (MPC) for control of oxygen level in a fuel cell stack. MPC has attractive features that make it suitable for this problem. The most important of these features is capability of handling hard constraints on inputs and outputs, which suits our specific problem very well. Both inputs and outputs of this problem are limited by hard constraints and therefore MPC can be an effective tool for addressing this control problem. We propose two different architectures for this control problem.

First a SISO control architecture is used in which the compressor voltage is manipulated as a control input to achieve desired Oxygen Excess Ratio. Performance of the controller is evaluated without and with constraints. In the second approach we propose to use a hybrid fuel cell-battery architecture. Model predictive control is used for optimization of power demand distribution between the battery and fuel cell. This allows enforcing hard constraints on the battery’s state of charge and oxygen excess ratio. Inclusion of the battery reduces the drop in the oxygen level during fast increase in power demand. Good performance was shown in simulations with linear and a detailed nonlinear model of a fuelcell system.
Decentralized control and dynamics effects for a team of physically cooperating robots

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Keywords: Mobile Robots, Co-operation, Controls, Dynamics

Mobile robots can be used for applications such as search and rescue, urban infiltration etc, where the goal is to explore unknown, potentially hazardous terrains. Large teams of small, cheap robots have advantages over small numbers of large robots, such as covering more ground in less time, access to tight spaces, redundancy, and expendability. One of the major challenges in employing small mobile robots is their restricted mobility on a rough terrain.

We are working on designing mechanisms and behaviors for a team of small, cheap robots that cooperate to enhance the team’s overall mobility. The idea is that the robots link up and push or pull on each other to overcome obstacles. The length of a gap that robots can cross is one measure of mobility. For a wheeled robot such length is determined by the size of the wheels and is usually only a small fraction of the length of the robot. We start with the goal of improving the gap crossing ability of robots by cooperation between two robots.

Static Analysis of the gap crossing operation shows that motor torque and ground friction limits drive the robot and the connecting link design. Study shows that a decentralized control architecture requiring minimal communication between the two cooperating robots is feasible for gap crossing operation. Simulation demonstrates successful implementation of the de-centralized control architecture. Effects of exploiting robot dynamics in reducing the friction requirement are studied.
Vibration feedthrough cancellation in joystick controlled vehicles

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The inertial forces acting on operators of joystick controlled machinery (tanks, frontloaders, helicopters, fighter jets) in moving vehicles can produce unintentional control signals through the joystick. These forces tend to deteriorate the continuous tracking performance of the operator and further, when the machinery in control is the vehicle itself, they may cause unstable oscillations that jeopardize that vehicle’s safe operation. A system ID based controller was designed to cancel the inertial forces though a force-reflecting joystick. Simulations and experiments carried out on ride motion simulators indicate that the cancellation controller stabilizes the system and improves tracking.
Comparison of control methods and metrics for computing systems: preliminary results with a simple queueing system

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Keywords: feedback control, queueing system, performance management

As computing systems become increasingly complex, tuning the system manually turns out to be more and more time-consuming, error-prone and skills intensive. Thus it’s interesting to examine feedback control as a means to automate the system tuning loop.

Queueing models are widely used in computing system analysis since computing tasks scheduling always generates queueing problems. The study on how to control a queueing system would be a valuable step into the performance management field. Specifically, the simple but widely used MM1K queueing model is chosen as our controlled plant in the current work.

Due to the stochastic nature of the queueing system, many traditional metrics for a deterministic control system, such as settling time, overshoot, steady state error, etc., are neither accurate nor adequate to evaluate the controller performance. Thus we redefined old metrics and introduced new metrics to describe the feedback control effect more exactly.

Previous studies have shown that a first-order model well captures the dynamics of a MM1K queueing system. Following this idea, we formulate it as a regulation problem. Our desired outputs include small response time and high throughput. The controlled variable is the buffer size. Both a PI feedback controller and a Model Reference Adaptive Controller (MRAC) are designed to regulate the queue length, and in turn the response time. Based on the metrics we defined specifically for the feedback control of queueing system, these controllers’ performance is evaluated and compared.
A stochastic approach to control strategy development for hybrid vehicles

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The control strategy for hybrid vehicles plays a crucial role in managing and coordinating overall vehicle systems in order to maximize the potential for improving the fuel economy and reducing the exhaust emissions. However, most of the control strategy developments rely on intuition and a heuristic way to identify the controller. The result of the control strategy is often inherently cycle-beating and is lack of an optimal battery management (charge-sustaining) strategy. In this study, the problem is tackled from a stochastic point of view. An infinite-horizon stochastic dynamic optimization problem is formulated to simultaneously minimize the fuel consumption and emissions. The power demand from the driver is modeled as a random process by using Markov chain. The estimated Markov model can be used to determine the probability distribution of future demands or generate samples of synthetic demands, which creates diversified random driving scenarios. The optimal control strategy is then solved by using Stochastic Dynamic Programming (SDP) technique. The control law is in the form of stationary full-state feedback, which is directly implementable. More importantly, an optimal charge-sustaining strategy is imbedded in the control law from this SDP approach. Simulation results over standard driving cycles and random driving cycles will be presented to demonstrate the effectiveness of the proposed control strategy.
Developing a method to assess vehicle performance capability using quasi-steady state and dynamic analyses

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Keywords: Vehicle Dynamics, Milliken Moment Method, Simulation

In the evaluation of vehicle handling, it can be very useful to objectively calculate how close a vehicle operates to the limits of its capability. This project seeks to illustrate the effectiveness of the Milliken Moment Method (MMM) combined with dynamic simulation to create a physically insightful, efficient way of measuring a car’s handling performance.

The MMM was invented by Bill Milliken in the 1960s as an analogue to the wind tunnel test of the aerospace industry. It is a quasi-static experiment where the vehicle is set to a fixed state by fixing the steering and vehicle sideslip angle, and the steady state forces required to hold it in that state are measured. Those forces would be available to accelerate the vehicle if it was not held in position. The primary means of interpreting MMM results is the CN-AY diagram, which plots the non-dimensional yaw moment vs. the lateral acceleration of the vehicle for each state. The vehicle’s performance envelope can be easily seen and calculated on this diagram as a function of the steering and sideslip angles.

For this project, the author proposes to measure the states of a vehicle while executing a single lane change in a dynamic simulation environment. The states will then be used to map a trajectory of the maneuver onto that vehicle’s CN-AY diagram. To measure the proximity to the performance envelope during the maneuver, a new metric has been proposed. The minimum distance along a constant vehicle sideslip (traversing lines of constant steering) during the lane change represents the maximum steering input that the driver could give at that critical time before the boundary is reached.

In the current work, a Matlab code has been written to implement the MMM for a simple vehicle handling model. Using this code, the CN-AY diagram has been created for 15 different vehicle configurations, and the new metric will be analyzed, validated, and compared to known metrics. Preliminary results show promise, and the author believes that this new method will allow engineers to gain deeper insight than previously possible with other handling performance metrics and tests.
A distributed simulation environment based on a “gluing algorithm”

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Modern automobile industries are operating in a way that distributes the production processes with multi-layered supply chains, in which the need for cooperation increases among dispersed units has arisen. Even within a supplier unit, it has become a common practice that different groups work on different components of the product. A simulation environment that can simulate mechanical system whose models are distributed amongst disparate production units could provide valuable support to these distributed design process. This research is to address this topic. Such a environment should fulfill the following requirements: 1) Integrate different models and software codes in a plug-and-play manner; 2) Communicate across distributed computing resources; 3) Maintain the integrity (independence) of the separated component models.

This paper presents the efforts we made to build a distributed simulation environment that meets the challenges of the distributed cooperation. Our efforts are focused in three directions. First, a gluing algorithm was developed, denoted as the T-T method, which enables distributed simulation models to be coupled while maintaining the independence (integrity) of the separate component models. Second, we developed a general and efficient model description for simulation, using XML. Each model is described with a XML file and stored in model database. New integrated models can be assembled based on these model descriptions. Simulation of a model is started by simply sending its description to the simulation server. Third, we worked on the design of a logical distributed architecture that can be implemented with one of the existing distributed technologies. Also, interfaces between different network components have been standardized to enable the extensibility of the architecture. These separate efforts have been combined into a prototype distributed simulation system that demonstrates the potential for a distributed simulation environment that is based upon the use of gluing algorithms.

We have been able to extend the T-T gluing algorithm to the simulation of multibody systems, including rigid and flexible. Now it can be used to integrate static, dynamic, and multibody dynamic component models of a mechanical system. It relies only on the interface information without requiring internal details of the subsystem models and maintains the integrity of subsystem models. Therefore, each component model is treated as a black box, and only minimal information at the interfaces is required.
Writhing dynamics of cables and DNA

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Keywords: Torsional buckling, DNA supercoiling, Single molecule study

Cables can buckle under dynamics called “writhing” to form loops and tangles (intertwined branches). There is a wide range of applications that motivates us to study writhing dynamics of cables. For example, marine cables during laying and recovery operations can tangle and/ or kink. Quite surprisingly, the long chain bio-molecule, deoxy-ribonucleic acid (DNA) has similar dynamical behavior when supercoiling. Their geometric similarity to underwater cables can be appreciated by realizing that “if the longest of human DNA were enlarged to have a width of ordinary kite string, it would extend to about 100km” [Calladine nad Drew, 1997]. Experiments show that large scale conformation and dynamics of DNA are vital to its biological functions including replication and transcription. Researchers foresee a variety of advantages in bio-technology and nano-mechanical devices resulting from understanding DNA dynamics.

Simulating cable/ DNA writhing is a challenge because of the geometric nonlinearities, self-contact, instabilities and fluid interactions that are involved. Various finite differencing and finite element techniques have been tried to solve the equations of motion (partial differential equations in space and time). Numerical methods still compete for stability, accuracy, speed and generality of application. Apart from numerical difficulties, there is also the challenge in modeling DNA as a continuum (cable). For example, experiments give good estimates of the (homogenized) elastic properties of DNA, but the sequence-dependent properties are still unknown.

Previous researchers have studied the equilibrium shapes of cables/ molecules under various boundary conditions and often ignore self-contact. Others have studied small perturbations about the equilibrium shapes using linearized theories. Only recently have researchers begun to simulate the dynamics of loops and tangles due to buckling under compression. Our research has extended these studies to include torsional buckling leading to intertwining with multiple self-contact sites. The resulting geometry is qualitatively similar to plectonemic supercoiling of DNA. We now look forward to introducing more complexities in our simulations in progressing towards a deterministic model for single molecule studies of DNA. Two goals are to predict the sequence-dependent interaction of DNA with various proteins and enzymes and to simulate DNA in micro-fluidic channels.
Real-time simulation of tracked vehicles

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This study is motivated by the need to develop a high mobility model of tracked vehicles that can be used in a real time simulator and controller design. The challenges in modeling tracked vehicles result from difficulties in characterizing the mechanics and surface topology of the terrain, the nonlinear mechanics of the track, the mechanics of track-terrain interaction, and the coupling to the remainder of the vehicle. To reduce the extensive numerical effort, this study contributes simple analytical approximations of track-terrain interaction that then lead to real-time computations of tracked vehicle response.
Optimized and humanized gear-shift-scheduling system

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**Keywords:** automatic transmission, shift-map, gear-shift-scheduling system, rule-based transmission shift algorithm

The gear-shift-scheduling systems used in many of the commercial automatic transmissions are primarily lookup-table-based shift-maps. The calibration of these shift-maps is mainly based on the experience and know-how of engineers and tuned in a heuristic manner. Usually, it takes quite some work to generate a balanced shift map to achieve acceptable tradeoff between fuel economy, performance and derivability. This heuristic-based design process has several undesirable features: it is time consuming; is not very re-usable; and the relative quality of the map vs. achievable performance is unknown. A systematical and re-usable design procedure that can generate an optimal shift map is thus desired and is the main goal of this proposed research. This computer-based procedure is expected to accelerate the design process, achieve guaranteed performance level, and the design process is expected to be re-usable and more flexible compared with current practice.

The current lookup-table-based transmission shift-map takes the throttle opening and vehicle speed as the only input signals to determine shift points. To further optimize and humanize the gear-shift-scheduling system, other factors such as road grade, vehicle weight, vehicle acceleration and driver’s style, etc. should be considered in the determination of the shift schedule. This increased complexity in shift-map design makes it more difficult for calibration engineers to come up with satisfactory designs. Furthermore, recent push for six-speed transmissions also presents several new issues that require a fresh look at gear-shift-scheduling determination. All these factors point to the need of a systematic design method, which could guide the development of rule-based transmission shift algorithms.

This study aims to establish a model-based optimization procedure, which addresses all the three issues mentioned above, namely, (1) the design procedure should be model based and is re-usable for future designs; (2) the performance is clearly bench-marked against theoretical limit; and (3) the overall design cycle is shortened compared with current practice.

This model-based approach is also expected to lay the foundation for future integrated powertrain control synthesis, with coordinated engine operation and transmission gear selection.
Analysis, decomposition and superposition of quadratic potential force fields for distributed manipulation

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**Keywords:** Distributed Manipulation, Quadratic Fields

Distributed manipulation systems induce motions on objects through the application of many external forces. An actuator array performs distributed manipulation using a planar array of many stationary elements, which cooperate to manipulate larger objects through the generation of a programmable force field.

This paper generalizes the study of a class of fields (including elliptic fields) called quadratic fields and how they can be superimposed to simplify the design of useful manipulation fields.

We define and classify quadratic fields to elliptic, circular, hyperbolic, critical and null fields and we describe their action on objects. We present a decomposition of general quadratic potentials into a combination of circular and quadratic fields. Based on the decomposition, we introduce methods to superimpose general quadratic fields in both a vector form and a geometric form. This is done for all the possible combinations of quadratic fields. Finally, we apply this superposition approach to the problem of trajectory following, improving on a more direct brute-force approach taken by the authors in an earlier paper.
Modeling of fuel processor components and system integration for PEM fuel cell application

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Keywords: PEM Fuel Cell, Microchannel, fuel processor

This presentation is an overview of various modeling strategies that are applied to the fuel processor system, as an attempt to guide and facilitate the design and system integration. The objective of the study is to develop a compact fuel processor that converts gasoline to hydrogen to be used in PEM fuel cells. Modeling of a fuel processor needs to be approached in two interlinked paths: detailed modeling of individual component and the system integration. To understand the performance characteristics of the various reactor components (auto-thermal reformer, water-gas shift reactor, preferential oxidizer, etc.), a simplified one-dimensional heat exchanger model is developed and validated against detailed CFD simulations using FLUENT. Given the target design specifications, the analysis provides useful design guideline such as the catalyst loading, water flow rate, and optimal geometries to maximize the efficiency of the reactor. The detailed knowledge will then be simplified and integrated into a system design and control strategies using MATLAB SIMULINK. A brief account on the modeling results and design challenges will be discussed.
Effects of mixture inhomogeneity on the auto-ignition of reactants under HCCI environment

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As a potential application to the homogeneous charge compression ignition (HCCI) engines, the effects of exhaust gas recirculation (EGR) on the autoignition and reaction front propagation are studied. EGR is considered an effective means to control the autoignition behavior in order to achieve smooth combustion under a wide range of operating conditions.

The model problem is an opposed-flow configuration in which a homogeneous fuel/air stream is impinging on the exhaust gas stream, where the degree of mixing and scalar dissipation is characterized by the strain rate. The premixed reactants are chosen at an equivalence ratio of 0.3, the temperature of the reactant and EGR streams are at 800K and 1100K, respectively, and the system pressure is constant at 40 atm. The unsteady transition of this system from its frozen initial condition to a reactive state is computed at different strain rates.

The results show that the scalar dissipation rate and inhomogeneities have a significant effect on the auto-ignition of the local mixture. In general, it was observed that an increase in the strain rate increases the ignition delay. Furthermore, two different modes of reaction front propagation were observed; the auto-ignitive mode and the flame propagation mode. The former occurs in mixtures which are already reactive and transport of heat and radicals is not necessary for reaction to occur. In this case, mixing slows down ignition by the loss of radicals from the ignition kernel. On the other hand, in the flame propagation mode, the reaction front propagates through the mixtures which were otherwise not very reactive, and transport of heat/radicals was essential for reaction to occur. In both these modes an increase in the scalar-dissipation rate was found to decrease the front propagation speed. This study suggests that different modeling strategies may be needed to capture the two distinctive ignition characteristics in the HCCI application.
Modeling homogeneous charge compression ignition (HCCI) combustion with high levels of residual gas fraction

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Keywords: HCCI, CFD, Combustion, Mixing, Variable Valve Actuation

Adjusting the residual gas fraction by means of Variable Valve Actuation (VVA) is a strong candidate for controlling the ignition timing in Homogeneous Charge Compression Ignition (HCCI) engines. It has been demonstrated that valve timing strategies such as early exhaust valve closing (negative overlap), and reopening of the exhaust valve during the intake stroke (rebreathing) can be used effectively to control HCCI combustion.

Reliable simulation models can simplify the task of identifying the best valve timing strategies and help understand the interactions between the amount of internal Exhaust Gas Recirculation (EGR) and in-cylinder temperature and composition stratification. The effects of temperature distribution on HCCI combustion have been investigated in recent years, primarily under the assumption that the composition of the charge is homogeneous. However, at high levels of residual gas fraction, insufficient mixing can lead to the presence of significant composition variations.

This work extends previous modeling efforts to include the effect of composition stratification on the onset of ignition and the rate of combustion. A multi-dimensional fluid mechanics code (KIVA-3V) is used to simulate the gas exchange processes (exhaust and intake) and compression up to a point before which chemical reactions become important. The results are then used to initialize the zones of a multi-zone code with detailed chemical kinetics, which computes the combustion and expansion processes. For the initialization of the zone, both the distributions of temperature and fuel/O2 equivalence ratio are taken into consideration. It is shown that under certain conditions the effect of equivalence ratio distribution is significant and cannot be captured by a single-zone model or a multi-zone model using only temperature zones.
Integration of Boltzmann transport equation and molecular dynamics simulations in phonon thermal conductivity prediction

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Keywords: phonon thermal conductivity, molecular dynamics simulations

While the lattice dynamics of a harmonic solid can be readily analyzed, such a model predicts an infinite phonon thermal conductivity for a perfect crystal. To obtain a finite thermal conductivity, anharmonicities in the interatomic potential, which lead to three-phonon (and higher) processes, must be considered. A number of solution techniques based on the Boltzmann transport equation (BTE) have been developed. Notable are those involving the single mode relaxation time (SMRT) approximation. A lack of understanding of multi-phonon interactions requires that the predictions be fit to the experimental data. Therefore, while such approaches are useful for qualitatively validating the models developed, the quantitative validity of the models cannot be assessed. As they are currently used, SMRT techniques are thus not suitable for the analysis of materials whose thermal properties are not already known.

In a molecular dynamics (MD) simulation, the position and momentum space trajectories of a system of particles are predicted using the Newton second law of motion. The only required inputs are an atomic structure and appropriate interatomic potential. Observations at the atomic level, not possible in experiments, can be made. The purpose of this study is to use MD to generate the input necessary for the BTE-SMRT thermal conductivity model.

The Lennard-Jones argon face-centered cubic crystal is considered at temperatures between 20 K and 80 K. The simple geometry and associated interatomic potential are well suited to a preliminary study. A method for predicting the phonon relaxation times using MD is presented. A continuous model for the relaxation times is developed, and together with temperature dependent dispersion and specific heat data, is used to predict the thermal conductivity with the BTE-SMRT method. To our knowledge, this is the first such calculation performed with no fitting parameters. The BTE-SMRT results agree with those predicted using the Green-Kubo method to within their respective uncertainties, establishing the quantitative validity of the BTE-SMRT approach. The assumptions commonly made in the BTE-SMRT approach (e.g., no phonon dispersion) lead to poor predictions, which suggests that the previous success of these models was strongly dependent on fitting the results to existing experimental data (i.e., using empirical constants). The predicted phonon relaxation time functions can be applied to larger systems, not accessible with MD, but of great interest in the understanding of conduction heat transfer in micron and millimeter sized devices.
Micro thermoelectric cooler fabrication: Growth and characterization of patterned Sb$_2$Te$_3$ and Bi$_2$Te$_3$ films

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Keywords: micro thermoelectric cooler, thermoelectric film deposition

A column-type micro thermoelectric cooler is being fabricated using $p$-type Sb$_2$Te$_3$ and $n$-type Bi$_2$Te$_3$ films (approximately 4 µm thick). Tellurium compounds are used, since they have the highest known cooling performance at room temperature. The goal for the cooler is to lower the temperature of a micro vapor sensor 10 K below ambient in less than 30 seconds, while using minimal power with a 3 V battery. The device design is based on predictions from a thermoelectric cooler model. The deposition and characterization of the thermoelectric films are described, and initial results of the device fabrication are presented.

In the fabrication of the Sb$_2$Te$_3$ and Bi$_2$Te$_3$ columns, the thermoelectric films are grown by thermal co-evaporation of the constituent elements and patterned on Cr/Au/Ti/Pt (hot) connectors, which are deposited onto a silicon dioxide coated wafer. The column height is limited by control of the Te deposition rate. Although a high substrate temperature during thermoelectric film deposition is desired, it has been limited by the degradation of the photoresist used for patterning.

Energy dispersive x-ray analysis was used to identify the elements present in the thermoelectric films, and their relative concentrations. The orientations of the crystals were characterized using x-ray diffraction. The results confirm the formation of Bi$_2$Te$_3$ and Sb$_2$Te$_3$ and show that the films are polycrystalline without strong preferential orientation. The Seebeck coefficient $a_S$ and electrical resistivity $\rho_e$ were measured. The films with the highest electrical power factor, $a_S^2/\rho_e$, have $a_S$ and $\rho_e$ equal to -84 mV/K and 2.4x10$^{-5}$ W-m (n-type film deposited with a maximum substrate temperature of 94 °C), and 120 mV/K and 1.9x10$^{-5}$ W-m (p-type film deposited with a maximum substrate temperature of 90 °C). For the Sb$_2$Te$_3$ films, an increase of the substrate temperature increases $a_S^2/\rho_e$, and an increase of the Te content increases $a_S$.

The steps needed to complete the fabrication process are the patterning of a contact area on top of the columns for the deposition of a thin layer of Cr/Au, and the subsequent photolithography process, which is required to define the area where Au (the metal that forms the cold connectors and closes the electrical circuit of the thermoelectric cooler) will be deposited. The resulted structure will be bonded to the load. So far, complete pairs (electrically connected $n$- and $p$-type thermoelectric elements) have been produced. Future designs will focus on the implementation of higher substrate temperatures and yield improvements.
Dependent scattering and field enhancement in monochromatic irradiated, random porous media

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Keywords: field enhancement, dependent scattering, photon localization, porous media

Radiation heat transfer in random porous media has received growing interest recently, due to its important applications in up-conversion laser, nano-manufacturing, etc. Traditionally, porous media are treated as a single continuum with effective properties using the equation of radiative transfer (ERT). Because the random character of porous media is averaged out, however, this effective treatment masks some important physical phenomena and can not tell the whole story. In this study, a direct simulation treatment based on Maxwell’s equations is developed, and the phenomena of field enhancement and photon localization are determined.

In the direct simulation treatment, using a one-dimensional random porous medium composed of parallel solid and fluid layers with random thickness, and using the transfer matrix method to solve the Maxwell’s equations, we obtain the electromagnetic field distribution in the medium exactly. It is shown that for some realizations, at a location inside the medium, the field may be one order larger than the incident field! At this site, the photons are localized and “stored”, and heat generation is the largest. The ensemble average shows that the probability of enhanced field and its locations of this enhancement are influenced by the solid complex refractive index and particle size distribution. Some two-dimensional random porous media are treated using HFSS, and field enhancement is also found.

The radiation transport within the same composite is treated using the effective property treatment with ERT, the intensity profiles are obtained and compared to that of direct simulation. By introducing corrections to the scattering and absorption coefficients based on dependent scattering, ERT is shown to be the statistical average of the direct simulation. Thus, ERT is not suitable for the prediction of any field enhancement and photon localization.
Qualitative estimation of female urethra closure pressure using a 3-D Finite element model

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A 3-D finite element model was developed to simulate female mid-urethra. Three muscle layers and a vascular layer are included in the model. The effects of muscle contraction, elasticity on the urethra closure pressure (UCP) and its transmission are studied.

Frontal plane responses of stepping movements onto a laterally-compliant structure

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Keywords: Stepladder; Frontal plane; Compliant structure

A lateral fall is the most common type of accident from stepladders. One reason for this may be that stepladders are not usually rigid, but have lateral structural compliance. The purpose of this study was to investigate the strategy changes of postural control in stepping movements onto rigid and laterally-compliant structures, without subjects’ prior knowledge of the structural compliance, in order to prevent falls. Young adults adapted to the presence of unexpected structural compliance as they stepped up and onto the structure by identifying its compliance, slowing their lateral motion, decreasing lateral COM excursion, and shortening the unipedal support phase.

Metabolic cost and muscle contraction during human leg swing

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Leg swing is an important part of human locomotion. Evidence suggests that pendular dynamics may be responsible for much of the swing phase of gait. As it would require mechanical energy to swing a pendulum fast, it may require metabolic energy to swing a leg at a high frequency. Studies have shown that short, intermittent contraction of muscles cost more energy than long, sustained contractions. We hypothesize that the increase in metabolic cost of leg swinging at high frequencies may be linked to short bursts of muscle contractions. Metabolic cost increased sharply as swing frequency increased, while muscle contraction time decreased with swing frequency.
Inverse heat transfer solution of the induction heat flux

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The finite difference formulation of an inverse heat transfer model to calculate the heat flux generated by induction heating is developed. The experimentally measured temperature data is used as the input for the inverse heat transfer model. This model is particularly suitable for long workpiece with low cross-section Biot number. Induction heating experiments are carried out using a carbon steel rod. The finite difference method and thermocouple temperature measurements are applied to estimate the induction heat flux and workpiece temperature. Compared to measured temperatures, the accuracy of proposed method is demonstrated. The effect of non-uniform temperature distribution, particularly in the heating region during the heating, is studied using the finite element method. Analysis results validate the assumption to use the uniform temperature in a cross-section for the inverse heat transfer solution of induction heat flux.

Modeling homogeneous charge compression ignition (HCCI) combustion with high levels of residual gas fraction

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Keywords: HCCI, CFD, Combustion, Mixing, Variable Valve Actuation

Adjusting the Residual Gas Fraction (RGF) by means of Variable Valve Actuation (VVA) is a strong candidate for controlling the ignition timing in Homogeneous Charge Compression Ignition (HCCI) engines. At high levels of RGF, insufficient mixing can lead to the presence of considerable temperature and composition variations in the cylinder. This work extends previous modeling efforts to include the effect of composition distribution on the onset of ignition and the rate of combustion using a multi-dimensional fluid mechanics code (KIVA-3V) sequentially with a multi-zone code with detailed chemical kinetics.
Dependent scattering and field enhancement in monochromatic irradiated, random porous media

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Keywords: field enhancement, dependent scattering, photon localization, porous media

Solving the Maxwell’s equations, an electric filed enhancement is observed in monochromatically irradiated, one- and two-dimensional dispersed dielectric solids with random size distribution. This enhancement is a few orders of magnitude higher than the incident field, for some arrangements. The probability density and the location of enhanced field are determined forgiven solid complex refractive index and particle size distribution. Using the two-flux model, the equation of radiative heat transfer (ERT) is solved for the local intensity. It is shown that ERT can represent a statistical average behavior of the intensity (by introducing corrections to the scattering and absorption coefficients based on dependent scattering). However, ERT is not suitable for predicting field enhancement and photon localization.

In-cylinder friction measurement techniques and total engine friction reduction through advanced materials and lubricants

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Reduction in engine friction leads directly to increased fuel economy, power output, and longevity which are of paramount importance to today’s engine manufactures and consumers. The objective of this research is to develop a robust tool for measuring instantaneous, in-cylinder engine friction* in modern, high speed, multi-cylinder engines. Two telemetry techniques are being investigated 1) a wireless, inductively powered, microwave signal transmission system and 2) a mechanical linkage and hardwire system. Once developed, this tool will be used to investigate and quantify the effects of various engine component designs and tribology on in-cylinder engine friction culminating in more efficient and longer lasting engines.
Effect of fuel injection parameters on diesel engine combustion and emissions

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The effect of fuel injection parameters, such as injection timing, nozzle geometry and number of injections on diesel engine combustion and emissions is being investigated with multidimensional CFD simulations. Appropriate fuel spray breakup, combustion and soot formation models have been selected and calibrated in order to perform parametric studies at various engine operating conditions and indicate optimum fuel injection strategies.
Three dimensional atomic forces and topographical imaging of atoms with atom force microscope

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Keywords: AFM, atomic resolution imaging, graphite

A scanning tip on a surface is subject to the normal load and the scan direction friction force. This macroscopic model however breaks down for atomic resolution imaging in an atom force microscope (AFM) where the friction was found to be two dimensional. In this paper, a simple model is introduced to describe how these three-dimensional atomic forces and the induced deflections are coupled through tip-cantilever force sensors. In particular, we discuss a mechanism leading to an unexpected residual linear deflection due to the two dimensional lateral forces, which could be the main cause preventing optical-beam-deflection AFMs from obtaining true images of atoms in the contact mode. With this mechanism, some “topography” images of surface atomic structure previously observed can be interpreted as maps of the lateral force in the longitudinal direction. Some puzzling features such as the well-known “resolution of every other atom” of graphite topographical images can be readily explained.

Phase field method in solving regular void/bubble super-lattice problem

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Keywords: void/bubble super-lattice, Phase Field Model, solid precipitation, atomic diffusion

Regular array of voids or bubbles within some specific materials has been observed for decades. It was found that the voids agglomerated by defects or vacancies generated by irradiation, forming a regular 3-dimensional structure, which shows a lattice-like structure (called void/bubble super-lattice). One popular explanation in the past years for the formation of void lattice is the elastic interaction between those voids.

Phase field model has become one of the most popular methods in simulating solid precipitation. Our current project is to apply Phase Field Model to re-solve the regular void/bubble lattice problem. This new method will provide the simulation result of void lattice without pre-assumed void-solid boundaries, which will become the basis of our future research in nano-scale self-assembly modeling.
Variational multiscale methods to embed macromechanical formulations with fine scale physics

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**Keywords:** multi-scale methods, strain gradient plasticity

As deformation phenomena approach the length scale of grains, the interaction between defects and the effects of their elastic fields play increasingly important roles. Conventional macroscopic theories of inelasticity – such as plasticity – fail to resolve these effects. However, these effects can be explained with notable success by various classes of Strain Gradient Plasticity theories which are microscopic theories. The approach of embedding micromechanical models in macroscopic ones comes as an answer to the computational cost which would be involved in the inclusion of fine scale physics associated with microscopic features in an otherwise macroscopic domain.
A distributed simulation environment based on a “gluing algorithm”

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Three key concepts are presented in this paper, which comprise the foundation of a distributed simulation platform for the virtual prototyping of general mechanical systems that have their subsystems distributed amongst dispersed development units in multi-layered supply chains. First, a new gluing algorithm, denoted as the T-T method, is developed, which maintains the independence of the separate component simulations. Second, a general model description for simulation is defined using XML. Each model is described with an XML file and stored in model database. A complete model then can be assembled based on these model descriptions. Simulation of a model is started simply by sending the model description to a simulation server. Third, a logical distributed architecture is laid out that can be implemented with one of the existing technologies for distributed computing. Interfaces between different network components have been standardized to enable extensibility of the architecture. These concepts have been incorporated into a prototype distributed simulation system that demonstrates the potential of the new techniques for solving real engineering design problems.

Writhing dynamics of cables and DNA

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The objective of this research is to simulate efficiently the nonlinear writhing dynamics of cables. This research is motivated by sub-sea cable applications as well as by DNA (Deoxy-ribonucleic acid) supercoiling. Supercoiling plays a crucial role in the biological functions of DNA. The current challenges include modeling DNA as cable, modeling self-contact and intertwining, and modeling fluid and surface interactions. It is also proposed to model the cable as being perfectly flexible in high tension zones to reduce computational effort while as a “rod” in low tension zone to capture flexural and torsional effects.
Real-time simulation of tracked vehicles

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This study is motivated by the need to develop a high mobility model of tracked vehicles that can be used in a real time simulator and controller design. The challenges in modeling tracked vehicles result from difficulties in characterizing the mechanics and surface topology of the terrain, the nonlinear mechanics of the track, the mechanics of track-terrain interaction, and the coupling to the remainder of the vehicle. To reduce the extensive numerical effort, this study contributes simple analytical approximations of track-terrain interaction that then lead to real-time computations of tracked vehicle response.

Data-based evaluation of collision warning / avoidance algorithms

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Keywords: Collision warning, collision avoidance, automotive, signal detection theory, Kalman smoothing, ICC FOT

Recently, CW/CA systems are getting attention because of the overlap with ICC systems and targeting major traffic accidents. Our research started as investigation into the real human driving data collected by UMTRI ICC FOT project. We processed signal with Kalman smoothing and extracted two subsets of the data: “dangerous” and “safe” driving situations. Among various CW/CA algorithms, we evaluated three of them: Honda, Mazda and the Johns Hopkins University (APL), which is later used as part of the CAMP algorithm. So far, JHU-APL logic shows the best performance.
Device delays and networked control system (NCS) performance

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It is well known in control systems that time-delays can degrade a system’s performance and even cause system instability. The problem of constant time-delays, present in the system, is often taken into account while designing the controller for that particular system. It works perfectly well in that case, but at times there are random delays present in the control system. In this study we investigate the random nature of the device delays present in a distributed control system and its effects on the control system performance in terms of Integrated Absolute Error (IAE). These random device delays result in part because of the processing and waiting times in the sensor and controller devices, A/D encoding speeds, dynamics of the devices, etc. In a Networked Control System (NCS), network transmission delays, though small in comparison with the device delays, are also a source of random delays. In a large and complicated control system, usually requiring many sensor devices, the selection of appropriate devices can be facilitated by analyzing the effects of variability of delay present in the devices, to have the least affect on a given controller performance. On the basis of this study we can make appropriate decision in the selection of sensor devices based on their random delay characteristics, i.e., mean and variance.

Synthesis bounds for distributed manipulation using logarithmic-radial potential Fields

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Distributed manipulation systems induce motions on objects through the application of forces at many points of contact. Current forms of distributed manipulation include multiple mobile robots, vibrating plates, actively controlled arrays of air jets, and planar micro and macromechanical arrays of actuators. The authors have presented a new form of distributed manipulation using passive air flow fields, which has been experimentally demonstrated and a computational method to locate equilibria. This paper presents a methodology for guaranteeing the existence of the equilibria and its synthetic usage for efficient manipulation of objects using passive air flow fields.
Determining model accuracy as a function of inputs and system parameters

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The ability to quantify the Range of Validity of a model is essential to ensuring accurate simulation-based design. "Range of Validity" refers to a) bounds on the inputs to the system from the environment within which the model has acceptable predictive value, and b) the space of parameter values - design points - in which the model accurately predicts system behavior. An initial approach to quantifying Range of Validity with respect to inputs is presented based on an extension of earlier Automated Modeling Laboratory research on determining model accuracy. Preliminary results show the feasibility of the approach as applied to an illustrative linear model and to an empirical nonlinear fuel cell model from a current ARC project. The ability to determine Range of Validity will ensure that appropriate models are used in the design cycle. Future applications include mapping the input or design space over which model partitions exist, or ensuring that a given simulation model is valid over the expected range of variation of uncertain design parameters.

Decentralized control and dynamics effects for a team of physically cooperating robots

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A team of small, low cost robots is useful in operations such as search and rescue, urban exploration etc. However, the performance of such a team is limited due to restricted mobility of the team members.

We propose to overcome the mobility restrictions by physical cooperation among the team members. We carry out a feasibility analysis of a particular behavior of two robots cooperating to cross a gap. We simulate the dynamic equations describing the motion which leads the relaxation the requirements derived from the static analysis. A decentralized control architecture is designed which avoids continuous communication between the robots.
Contemporary manufacturing systems are incredibly complex, consisting of hundreds of machines working together in a coordinated fashion to produce parts. The complexity of the machines leads to complexity in their control systems, and complexity is expensive. The controls for a new machining system can often consume half of the systems construction time and cost. A more effective way to program these types of manufacturing controllers could lead to significant economic savings. The Modular Finite State Machine (MFSM) framework is a new way of designing and programming control logic. This framework allows complicated control problems to be broken down into manageable blocks for design purposes. A module can be dedicated to a single mechanical module, or to a single logical function. A designer can then focus on the logic of that module, its interaction with the adjacent modules, and a small portion of the physical system. We are applying this methodology to implement the logic control on one manufacturing cell of the new Reconfigurable Factory Test Bed (RFT), using software developed at the University of Michigan called FSMTools. This cell shall consist of a Fanuc robot and two Denford milling machines, which receive and forward production parts through a single conveyor. The robot retrieves the parts from the conveyor and places them inside the respective machines, and after the machining operations, it picks up the machined parts and places them back on the conveyor, from where they proceed to other manufacturing cells. The logic has been set up in a modular fashion, which facilitates future changes and allows it to be more easily verified. This work is to be shown at the next CIRP conference in August, and for the future we plan to implement the MFSM framework on the whole RFT.
Design optimization of vehicle crashworthiness using equivalent mechanism approximations

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This research is motivated by the difficulty that faces vehicle designers when tackling the task of crashworthiness design. Vehicle structure behavior during crash is often unpredictable and requires enormous computational resources to simulate. Approximate models are introduced, which draw upon the analogy between the collapse of the vehicle structural members and the motion of space mechanisms. The equivalent mechanism models offer physically sound approximations, which retain the gross behavior of real vehicle structures. Preliminary results show success in increasing the efficiency of the design task, as well as potential for synthesizing specialized crash optimization algorithms and robust design.

A Study of emission policy effects on optimal vehicle design decisions

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Keywords: environmental policy, optimal design, game theory, oligopoly, emissions, CAFE, discrete choice analysis, logit, green engineering

A methodology is presented for studying the effects of automobile emission policies on the design decisions of profit-seeking automobile producers in a free-entry oligopoly market. The study does not attempt to model short-term decisions of specific producers. Instead, mathematical models of engineering performance, consumer demand, cost, and competition are integrated to predict the effects of design decisions on manufacturing cost, demand, and producer profit. Game theory is then used to predict vehicle designs that producers would have economic incentive to produce at market equilibrium under several policy scenarios. The methodology is illustrated with three policy alternatives for the small car market: corporate average fuel economy (CAFE) regulations, carbon dioxide emissions taxes, and diesel fuel vehicle quotas. Interesting results are derived, for example, it is predicted that in some cases a stiffer regulatory penalty can result in lower producer costs because of competition. This mathematical formulation establishes a link between engineering design, business, and marketing through an integrated optimization model that is used to provide insight necessary to make informed environmental policy.
Decomposition-based assembly synthesis for structural Consideration

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Keywords: Design for Manufacturing, Assembly Synthesis, Structural Design, Genetic Algorithms

Complex structural products such as automotive bodies are made of hundreds of components joined together. While a monolithic design is ideal from a structural viewpoint, it is virtually impossible to economically manufacture complex structures as one piece, requiring them to be assemblies of components in smaller sizes with simpler geometry.

This research presents a method of optimally determining component set and corresponding joint properties in the early structural design stage considering the stiffness of the assembled structure under given loading conditions, as well as the manufacturability and assemblability of each component in order to reduce the total time and cost of product developing process.

Aqueous sustainable system-dream or reality?
A case study in metalworking fluids

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Keywords: sustainable system, metalworking fluids, microfiltration, green formulation, contaminant detection.

A sustainable aqueous system, by definition, aims to maximize the utility of aqueous resources for society without 1) reducing supply, quality, or distribution of water for future generations, and 2) without negatively impacting ecosystems or human health over the life cycle of the system. Research is currently undergoing to develop requisite technologies necessary to support the development of sustainable aqueous systems. Metalworking fluids that are widely used in machine tool industry as lubricant and coolant are chosen as a case study. Technologies for environment-friendly formulation design, recycle and reuse via microfiltration, and on-line detection of contaminants are under development.
The impact of system configurations on the reusability of manufacturing systems

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Keywords: manufacturing system reusability, system configuration, product architecture

How to economically produce diverse products while maximally reusing a manufacturing system has been a challenging task in manufacturing engineering. The main goal of this research is to quantitatively evaluate the effect of reusing manufacturing systems. Quantitative metrics were developed to evaluate products changes, manufacturing systems reusability, and system performance. The research also includes developing mathematical methods to evaluate the impact that system configurations have on the system reuse. The metrics and methods are verified by being applied to an assembly system in the automotive industry.

Analytical craftsmanship in vehicle interior design

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Craftsmanship is what makes a product have the immediate appeal of being well made and well functioning at its very early interactions with the customer. This study attempts to extend the understanding of the craftsmanship concept into a quantitative domain to include it in the product development and decision making stages from design, engineering and manufacturing points of view. The strategy was to look at preference data and try to uncover the underlying dimensions of people’s craftsmanship perception in vehicle interior design. The analyses are intended to be used as a tool to assist both engineers and designers in the design process.

Design and control of MICSE palm power system

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This study is motivated by the strong needs for a high-density portable micro power source. A new concept of Micro Combustion Swing Engine (MICSE) is proposed and carefully studied in this paper.