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GROUP TITLES/ABSTRACTS

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"Design Optimization of Helical Compression Springs to Mitigate Axial Twist"

Mechanical springs provide key functionality in many mechanisms. A previous IMSM project team quantified the significance of spring forces in a nonlinear spring-mass-damper model of a rocket-mounted acceleration switch. A helical compression spring, which consists of a helical coil of wire that is compressed to generate force, is an effective, compact design for generating spring forces. Therefore, a subsequent IMSM project team investigated how to design helical compression springs to effect optimal forces while meeting a variety of design constraints and performance goals. That team focused on traditional spring performance measures such as spring index, effective stiffness, and dimensional change; however, a subtle, yet significant, aspect of helical compression springs was not considered: a helical compression spring tends to twist about its axis when compressed. This twisting action can cause alignment challenges in assembling springs into high-precision mechanisms, and it can lead to undesired residual stresses in both the springs and the mechanisms. Although the axial twist is recognized by the spring manufacturing industry, it largely does not factor this into their designs. In part, the neglect is due to the complexity of predicting the twist as a function of spring properties. To mitigate the twist, some manufactures have devised novel coil patterns; yet, these require non-standard spring manufacturing processes and are incompatible with industry design software. Optimizing the design of *conventional* helical compression springs to mitigate their axial twist is desired. This project aims to develop design guidelines for twist-mitigated helical compression springs that satisfy multiple performance objectives and constraints. The project's approach is to develop a computational modeling capability and subsequently to study axial twist for varying spring parameters. In support of project development, spring data and specifiable design parameters and constraints will be provided.

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Project Team References

• IMSM 2015 Report: "Flexible Optimization and Uncertainty-Enabled Design of Helical Compression Springs in Nonlinear Spring-Mass-Damper Systems" (https://www.samsi.info/wp-content/uploads/2016/03/IMSM15_report.pdf)

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• K. Michalczyk, "Analysis of Helical Compression Spring Support Influence on Its Deformation," *The Archive of Mechanical Engineering*, **56**(4), pp. 350-362, 2009.

Agustin Calaroni and **Petra LeBeau**
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"Analysis and Visualization of Continuous Glucose Monitoring Data"

Continuous glucose monitors (CGMs) are increasingly used to assess and manage glucose levels in patients with diabetes. CGMs provide an alternative to the daily self-monitoring of blood glucose (SMBG) which proves to be painful, inconvenient, costly, and difficult to maintain. Instead, CGMs use less-invasive, subcutaneous sensors to measure interstitial glucose levels at 5-minute intervals throughout the day and night. The collection of regularly timed, short interval data also leads to a better understanding of glucose patterns and trends. These data-rich glucose monitoring are percolating as primary or secondary outcomes into randomized clinical trials (RCTs) requiring a rethinking of ordinary statistical techniques.

CGMs generate very large and complex data sets (288 measurements per 24 hours). To analyze these data, researchers tend to derive summary variables that are then used in subsequent analyses, e.g. Area Under the Curve (AUC) or time spent above, below or within a specified target.[1,2] Although these indices are informative, they do remove much of the potential additional information embedded in this temporal data. This includes not only an indication of glucose levels at or across specific points in time but also measures of change (velocity), rate of change (acceleration), and variability. More advanced statistical techniques are required to access this additional information and making it available for clinical interpretation and application.

The goal of this project is to encourage the students to go beyond the usual summary statistics to determine individual and treatment group differences over time, and instead provide a comprehensive analysis and visualization framework using one or more novel statistical techniques that incorporate the temporal nature of CGM data (or an equivalent type data set in the event CGM data is not available for public use at the time of the workshop). One such technique could be Functional Data Analysis (FDA) [3] as it's capable of summarizing temporal trends of continuously recorded measurements in a form that is amenable to subsequent multivariable statistical analysis [4].

Citations

[1] Danne et al 2017. International Consensus on Use of Continuous Glucose Monitoring. Diabetes Care, 40 (12): 1631-1640; DOI: 10.2337/dc17-1600

[2] Hirsch et al 2018. Role of Continuous Glucose Monitoring in Diabetes Treatment. American Diabetes Association
https://professional.diabetes.org/sites/professional.diabetes.org/files/media/final_ada-abbott_cgm_compendium_final.pdf

[3] Ramsay, James O., and Bernard W. Silverman. Applied functional data analysis: methods and case studies. Springer, 2007.

[4] CRAN Task View: Functional Data Analysis https://cran.r-project.org/web/views/FunctionalData.html

Dr. Ty Hesser and **Dr. Matthew Farthing**
US Army Corps of Engineers

"Coastal Imagery Analysis and Hydrodynamic Estimation with Machine Learning"

Estimates of local scale nearshore hydrodynamics (e.g., wave height, wave period, wave direction, current velocity) and morphological features (e.g., sand bar location, foreshore slope, beach width) are important for both the civil works and military missions of the Army Corps of Engineers. The safety of people from rip channels and sneaker waves as well as flood protection from hurricanes rely on designing beaches and coastal structures correctly. However, estimating local scale hydrodynamics requires accurate representation of boundary conditions (bathymetry/underwater topography, and wave forcing offshore) and high-fidelity numerical models that are both fiscally and computationally expensive.

To address this issue, we are interested in exploring a different approach. We aim to use modern machine learning tools to infer local scale effects, from estimates at a regional scale. As a test case, we will use a rich set of field measurements at the Field Research Facility in Duck, NC to determine the plausibility of such an approach.

In this project, students will consider the estimation of localized nearshore bathymetry and hydrodynamics based on nearshore imagery and regional scale wave conditions in deep water. They will be asked to perform image processing to estimate local bathymetry features based on surface properties of the ocean. Additionally, they will be asked to evaluate computational techniques, from the machine learning literature, to resolve the differences between regional to local scale estimates. Based on the interest of the students, they will be asked to explore different data sources and numerical modeling techniques, or probabilistic boundary formulation based on historical datasets.

Dr. Kimberly Kaufeld and **Dr. Mary Frances Dorn**
Los Alamos National Lab

"Power Outage Forecasting for Hurricanes, Tropical Storms and Winter Storms"

Tropical and winter storms can cause widespread damage to electric distribution networks. These distribution networks are mostly above ground and are exposed to direct damage from severe weather conditions associated with these storms. For example, during winter storms, the combined stress of the weight of ice, the increased wind resistance of the conductors, and broken tree limbs can damage lines, poles, and support structures. The goal is to develop a model to predict electric power outages in near-real time when severe storm conditions are forecasted. This is especially important as predicting power outages during hurricanes is one with important practical ramifications. As part of this work, we will address the problem of forecasting power outages knowingly only information about the incoming hurricane and basic environmental, social, and economic indicators in the affected areas. These data are available and uniformly measured across the US, making for a scalable model. Moreover, we will explore data driven approaches, using standard prediction metrics to evaluate performance of flexible machine learning techniques.

Dr. Adam Attarian
Pacific Northwest National Lab

"Analyzing Extreme Deviations in Power Grid State Estimation Models"

The power grid is operated using state estimation algorithms that (by applying steady-state assumptions) solve linear systems of equations to assess fitness of the current operating condition. Greater fidelity can be included by relaxing the steady-state assumption and including power generation dynamics modeled by systems of ordinary differential equations coupled to the linear steady state system. A third, even higher fidelity approach is to include very rapid transient effects which relies on further complex dynamic differential equations. For all models, the goal is to quantify the fitness of the current state (or possible next states) based on the collection of contingencies (failure models) that may occur.

For large grid systems, nonlinear optimization is often used to solve for several contingencies simultaneously. As an alternative, brute-force methods may also be used to serialize evaluation of given contingencies, followed by some sort of search over the solutions for an optimal solution. In practice, this is a useful for contingencies that occur via naturally occurring faults that have an associated distribution, as well as "rare-event" faults. This optimization framework does not support when considering large-scale events such as cyber-attacks or natural failures such as weather or earthquakes. These cases lead to large deviations from steady/current-operating state and cause poor numerical conditioning and failures. This model failure does not imply operating system failure, only our inability to predict how it will behave.

We propose development of new mathematical approaches to handle cases of extreme deviations in grid state estimation models. These approaches could include discrete or continuous optimization and won't rely on proximity to a solution. This project is expected to result in new algorithms with provable reliability and convergence properties for large deviations. Base models will be representative grid/cyber systems and validation would occur in partnership with appropriate testbed practitioners.