A. PROJECT SUMMARY

This proposal seeks to develop an integrated research and educational framework for surrogate-based modeling of articular (i.e., surface-surface) contact in dynamic musculoskeletal models. The two main objectives are (1) develop novel surrogate modeling approaches to permit rapid dynamic simulations and optimizations of musculoskeletal models with multiple articular contacts, and (2) expose a broad audience ranging from minority and female high school students to researchers in academia and industry to surrogate-based modeling concepts and applications.

Musculoskeletal computer models are useful for estimating internal quantities that cannot be measured experimentally, designing new medical devices and rehabilitation approaches, and predicting the outcome of surgical procedures. Unfortunately, use of articular contact in such models makes computational speed a limiting factor, rendering dynamic simulations either completely intractable or else so slow that optimization is impossible. Specific quantities predicted by musculoskeletal computer models and that can be significantly affected by articular contact conditions include muscle forces, ligament strains, bone loads, and cartilage and implant wear. Though surrogate modeling techniques have successfully eliminated computational bottlenecks in other fields, they have not yet been applied to articular contact problems.

This project proposes to develop state-of-the-art surrogate-based modeling techniques tailored to the specific challenges of simulating articular contact mechanics under dynamic conditions. Surrogate-based modeling involves fitting a model to a model, where the original model is computationally expensive and the surrogate model is computationally cheap. The sample data points used to fit the surrogate model are generated by running the computational model repeatedly with different combinations of input variables. Once fitted, the surrogate model can be used in place of the original model in simulations or optimizations to eliminate computational cost as a limiting factor. Natural and artificial joint contact models of hips, knees, and ankles will be used to demonstrate the broad applicability of the proposed technology.

(1) Intellectual Merit of the Proposed Activity

While surrogate modeling techniques have been used in the aerospace, automotive, and oil industries to make optimizations possible that were previously intractable, no studies have focused on developing surrogate models to replace computationally costly articular contact models. Contact problems pose a number of unique challenges to surrogate modeling approaches, including difficulties in defining feasible sample points for constructing the surrogate model, a large sample space for the input variables, and sharp gradients in the contact quantities to be predicted. A novel surrogate modeling approach is proposed to address these challenges and make surrogate contact modeling available for most joints in the human body.

(2) Broader Impacts Resulting from the Proposed Activity

Because of the range of problems influenced by interactions between muscles, ligaments, and bones, successful completion of the proposed project could have a significant impact on biomechanical research and ultimately clinical problems involving joint contact mechanics. For example, the proposed technology could be used to develop improved rehabilitation and surgical procedures for people with joint problems as well as improved designs for joint replacements. In addition, the proposed technology could be applied to contact connections in traditional dynamic mechanisms (e.g., cam-followers, slots, clearance connections, latches, hard stops). The educational aspect will also have a broad impact through dissemination of the research concepts, methods, and freely available source code to the general public through the PI’s web site.