An “Industrialized” methodology for material characterization: Moving away from P/A

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Introduction

My presentation aims to report on how computational technologies, computational modeling, and mechatronic technologies have evolved, especially in recent years, in order to facilitate “Industrialized,” data-driven constitutive characterization of materials subjected to complex loads. The desire to be able to predict the behavior of physical systems under complex generalized loading conditions is primarily driven by the need to design and utilize such systems in various areas of human technological endeavors. The means of predicting the behavior of physical systems since Robert Hooke has been generally encapsulated by an approach that seeks to develop a system model within the context of continuum mechanics using hypothesized constitutive models. While these hypothesized constitutive models are based upon theorized laws of physics, observer invariance for example, they are not always successful in accurately reproducing actual (experimentally established) behavior of existing systems. A data-driven approach forgoes hypothesizing material behavior by relying on a database of sampled behavior.

Rationale

The rationale to develop an “Industrialized” (data-driven methodology in conjunction with an automated mechatronic system) is to provide more reliable and cheaper materials and structural systems faster than the current process for mate-

rial and structural system certification. A major area where researchers might look for improving the ability to produce more reliable and cheaper materials and structural systems is the enormous potential of the computational technology and other associated (data acquisition for example) technologies. The need and ability to test and analyze complex materials and structural systems are simultaneously being pushed and pulled. The contemporary demands for cost and time reduction, multi-mission design requirements, and increased systemic complexity constitute the technology-push motivators for automation of material characterization. In particular, systemic complexity, resulting from the need for realistic systems predictive simulation, often requires computationally intensive mathematical models. On the other hand, the desire for engineering elegance using simple “unified theories” and need for efficient solutions that solve problems on a societal scale and the evolution of computational and data acquisition technologies are the primary science pull motivators for automating the material characterization process.

Overview

My presentation begins with a brief historical overview of Leonardo da Vinci’s first attempt at material characterization Figure 1; pointing out that material characterization has not changed in principle since then. The subsequent section introduces a theoretical view of the general structural and material system with an emphasis on the black box input output relation and its differential equation system specification to set the framework for the data-driven material characterization approach. I also show how this computational modeling works in conjunction with the automated mechatronic test systems. In the sections that follow, I provide two successful examples of data-driven material characterization on wood-plastic composites and structural insulated panels which demonstrate the validity and robustness of the data-driven methodologies. For details and comparison to hypothesized constitutive models see Lockyear[1] and Alwin.[2] The last section describes ongoing collaborative research between myself at the

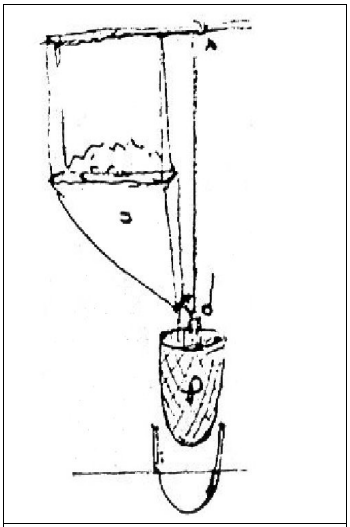

Figure 1. Leonardo da Vinci’s first test machine for determining the strength of wire

Forest Products Laboratory and John G. Michopoulos and Athanasios Iliopoulos at the Naval Research Laboratory to develop a mechatronic system for automated material characterization. We have incorporated a Stewart platform to create a six degree of freedom test machine (Figure 2) and the corresponding data acquisition and data-driven modeling. In this work we are using inverse methodologies to develop a fully defined multi-axial constitutive characterization which accurately reproduce behavior of existing systems.

Figure 2. An instantiation at the Forest Products Laboratory of a mechatronic system capable of 6 degree of freedom motion (3 translations and 3 rotations) to test structural materials and systems.

References

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