Data-Enhanced Sensing: A New Approach to Information Acquisition

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Abstract—Increasing digital transformation of manufacturing has highlighted physics-based sensing and data-driven analytics as the drivers and cornerstones of Industry 4.0. At the same time, new manufacturing processes such as additive manufacturing (AM) and robot-assisted assembly highlight the need for new sensing capabilities to overcome constraints in signal transduction principles that underly sensor designs, sensor operation resources, and real-world deployment. Advancement in information theory and artificial intelligence (AI) over the past decade has provided the technological foundation for new ways to tackle constraints in time, bandwidth, and energy consumption for sensing, leading to data-enhanced, optimal strategy for data sampling and information recovery. Furthermore, it enables inference of information that is hidden from direct measurements. This article highlights the latest development in this field and introduces data-enhanced sensing as a new paradigm that propels innovations in sensing, instrumentation, and measurement.

Index Terms—Codesign, compressed sensing, virtual sensing.

of data has also been accumulated at high velocity (due to increasing data acquisition rate) and often with low veracity (due to the uncertainties involved) [6], [8]. To describe this new phenomenon, the phrase "big data" has been coined. Big data analytics, which refers to *sense making* of data, expands the envelope of data processing from deductive methods such as statistical process control (SPC) [9], [10] that has been broadly investigated over the past several decades, to inductive data-driven methods such as deep learning [11], [12].

The rapid development of both sensing and data analytics has made them the building blocks of Industry 4.0, along with the advancement in computational infrastructure as represented by industrial Internet of Things (IIoT), and cloud and edge computing. These new technologies have introduced both new opportunities and challenges for research in instrumentation and measurement [13], [14], [15], [16].

On the one hand, the synergistic integration of sensing and data analytics has led to the emergence of smart industries [6].