Guest Editorial Focused Section on Sensing and Perception Systems for Intelligent Manufacturing (SPIM)

I. Introduction

INDUSTRY 4.0 is on the horizon now. This industrial revolution calls for solutions to embedded intelligence, networked environment, interaction, autonomous, and high performance [item 1) in the Appendix]. Manufacturing industry is at the center of this wave of innovation with sensing and perception in focus. The main problem lies in front of the expected sensing and perception solutions is the need of detecting three-dimensional (3-D) profile within certain field, which results in a very challenging task of "field effect" sensing and perception. While some existing sensors such as visual [item 2) in the Appendix], ultrasonic [item 3) in the Appendix], and LiDAR sensors [item 4) in the Appendix] are applied; the potential of such applications is still far away from sufficiently realized due to the inherent complexities in these sensor devices. On the other hand, there might be no easy sensing solutions for measurement and/or detection of some "field effects," such as temperature or electromagnetic field. In this case, an indirect sensing approach, sometimes called "soft sensing," might be needed based on the models of field effects, rendering a so-called "model-guided measurement" methodology. However, there has never been a well-formulated research niche for the problems of concerns. Instead, the research activities spreads out in various areas such as manufacturing processes, sensors and actuators, and intelligent systems. Yet, to address these problems, one needs to explore integrated solutions from models of field sensors, 3-D reconstruction and recognition, embedded computing and processing, field sensor network and optimization, field sensor based mechatronic control, etc. In wake of this reality, it is both timely and beneficial to publish this Focused Section that includes carefully selected papers and serves as a collective demonstration of the fundamental and applied research on the field sensing and perception systems for intelligent manufacturing. It is our intention and wish that this Focused Section would attract intensive attention and interests for the filed sensing and perception systems and their applications to intelligent manufacturing.

II. Highlights of This Focused Section

There are a total of 11 papers included in this Focused Section, covering topics on optimization of visual sensor or sensor network (Zhang *et al.*; Rao *et al.*; Wang *et al.*), model-guided measurement of field effects Yu *et al.*; Lin *et al.*; Ji *et al.*), perceptions of surrounding environments (Wang *et al.*; Liu *et al.*; Sun *et al.*), and servoing mechanism for robotic interaction in manufacturing (Cencen *et al.*; Chen *et al.*).

Optimization of visual sensor and sensor network is an interesting development in practice as it is intended to tap the greatest potential out of the visual sensing through either a single sensor or a sensor network. There are three papers in this category: In Rao *et al.*, a real-time 3-D measurement of the normal direction is delivered and optimized for a robotic drilling surface with a performance description through a tensor voting method; the visual sensor network is addressed in a sensor fusion approach with both vision and ultrasonar in Wang *et al.*; and with a new performance characterization called "visual distance" in Zhang *et al.*

When direct measurement is not feasible due to either the difficulty to reach out the field effect targets, such as temperature and electric currents, physically, or, simply, unavailable devices to conduct the measuring function, an indirect method is desired. Three papers are presented in this Focused Section to address the following.

1) Measurement of cutting temperature in metal processing and machining (Ji *et al.*).
2) Intelligent sensing for monitoring the machining process of complex thin-wall components through displacement and strain field reconstruction (Yu *et al.*).
3) Geometric measurement (displacement and thickness) with an eddy current (EC) based sensing system through modeling the harmonic EC field induced in a nonferrous metal and its magnetic flux density (Lin *et al.*).

These papers carry a common feature: model-based or model-guided measurements of variables in certain physical fields.

Perception of surrounding environments is extremely important for intelligent manufacturing as a result of desired interaction between machines and environments. The collected papers in this category present a semantics-regularized dictionary learning method for the automatic identification of materials properties (Liu *et al.*), an intelligent perception system that generates the task program for robotic assembly through visual observation (Wang *et al.*), and RGB-D camera based 3-D simultaneous localization and mapping (SLAM) for an indoor environment (Sun *et al.*). While the SLAM is done offline, the highlighted feature of these three papers is that they all target on real-time application, one way or the other.

Finally, this Focused Section presents two papers related to servoing mechanism for robotic interaction in intelligent manufacturing: In Chen *et al.*, a visual servoing mechanism is developed for fringe pattern based path planning in a robotic spraying process, whereas in Cencen *et al.*, a collaborative human–robot coproduction framework is proposed to develop a reasoning

Digital Object Identifier 10.1109/TMECH.2018.2837008

mechanism on collaboration between human and robots in manufacturing, which targets on enabling intelligent manufacturing in practice.

These 11 papers share a common feature of the work presented, that is, the methodologies developed are all based on processing data generated by complex sensing devices acting on certain kind of physical fields, such as vision and temperature field, in order to render 2-D or 3-D information of fields. This kind of field sensing and perception development is the key to facilitate the intelligent operation of manufacturing systems in practices, which is the main theme of this Focused Section.

Acknowledgment

The Guest Editors wish to take this opportunity to extend their sincere gratitude to all of the contributors to this Focused Section and all anonymous reviewers for their time to make this Focused Section possible. All of these joint efforts are the critical pushing force to ensure the quality of accepted papers. Finally, they would also like to thank the Editor-in-Chief, Prof. G. Chiu, for his strong leadership and persistent support, and for all the help he offered during the whole process of preparing this Focused Section.

Appendix
Related Works

1) H. S. Kang *et al.*, "Smart manufacturing: Past research, present findings, and future directions," *Int. J. Precis. Eng. Manuf.-Green Technol.*, vol. 3, no. 1, pp. 111–128, 2016.
2) A. Mavrinac and X. Chen, "Modeling coverage in camera networks: A survey," *Int. J. Comput. Vis.*, vol. 101, no. 1, pp. 205–226, 2013
3) J. Tarraf *et al.*, "Application of ultrasonic waves towards the inspection of similar and dissimilar friction stir welded joints," *J. Mater. Process. Technol.*, vol. 255, pp. 570–583, 2018.
4) C. H. Jang, C. S. Kim, K. C. Jo, and M. Sunwoo, "Design factor optimization of 3D flash LiDAR sensor based on geometrical model for automated vehicle and advanced driver assistance system applications," *Int. J. Autom. Technol.*, vol. 18, no. 1, pp. 147–156, 2017.

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Prof. Zhang was the recipient of the AIAA Best Paper Award, Best of SIGGRAPH by the Walt Disney, IEEE ROBIO Best Conference Paper Award, NSF CAREER award, Stony Brook University's 40 under Forty Alumni Award, College of Engineering Early Career Research Excellence Award from both Purdue University and Iowa State University, and Discovery in Mechanical Engineering Award from Purdue University. He is a Fellow of SPIE—The International Society for Optics and Photonics, and a senior member of Optical Society of America.

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