Automation Technologies for Sustainable Production

By Andrea Matta

Sustainability has become a major component of competition among manufacturers worldwide. Approximately one-third of the energy consumed in the United States is used for manufacturing. Sustainable production is the top concern for manufacturers and consumers because generating greenhouse gases and harmful emissions and disposing of waste generated during the manufacturing processes could pollute the environment. Therefore, production system design, analysis, and control play key roles in providing cleaner energy and reducing emissions, waste, and pollution, as well as minimizing the impact of climate change and conserving natural resources and energy during the product's entire life cycle. Therefore, sustainable production automation (SPA), which involves designing, structuring, and engineering operations and products, is a significant part of manufacturing.

The technical committee (TC) on SPA promotes the idea of developing innovative algorithms, models, heuristics, hardware, and software in broad areas. This approach focuses on designing, analyzing, and managing the processes involved in the product's life cycle—from design to delivery to return—to have only a minimally negative impact on society, including environmental, economic, and social impacts. Figure 1 highlights some developments in various industry sectors.

The main goals of the TC are to

- establish an SPA community
- foster theoretical development in promoting sustainable products and processes
- advance the theoretical understanding of the complexity of SPA
- offer innovative and efficient solutions for real-world problems in sustainable production
- demonstrate the practical and relevant aspects of the developed methods.

The TC began in 2012 and currently has more than 150 members from more than 15 countries in North America, Europe, Asia, and the Pacific region. Members include both early-career and senior researchers who share a common interest in the latest technological and scientific advancements achieved in the field of automation technologies for sustainable production. In the broad area of sustainability, the TC launches initiatives continuously, ranging from organizing workshops and special sessions during the major IEEE Robotics and Automation Society (RAS) and non-RAS conferences (Figure 2) to editing books and organizing special issues in prestigious scientific journals. Our TC members are very active, winning various awards (Figure 3) and research recognition.

Research Activity Highlights

SPA makes production systems more *green*, or energy efficient and environmentally friendly. This vision stems from the perspectives of both manufacturing of green technology products, such as renewable energy and clean technology products, and the design and control of traditional manufacturing processes to address energy and environmental concerns, such as minimizing energy usage, recycling, and reusing waste. It will contribute not only to the rapidly growing clean energy sector but also to society as a whole. In recent years, numerous opportunities and challenges have arisen based on how rapid technology developments and the economy have reshaped sustainability and automation and expanded the scope of research. You can find more details in [1].

Research in battery manufacturing has attracted attention because it relates to the increasing demand for alternative energy sources for hybrid and electric vehicles [4]. To satisfy diverse demands, battery-manufacturing systems need to be smart enough to respond rapidly to production disruption and make timely decisions on the factory floor. Additionally, rapid development in battery technology and the unique features of battery products have introduced enormous challenges in manufacturing. The manufacturing industry has been eagerly seeking effective solutions to manage production difficulties. The national Advanced Manufacturing Partnership recognizes that high-fidelity modeling methods, as well as effective theory and algorithms for smart manufacturing process control, are needed to fill high-priority gaps in manufacturing. These techniques must take into account the main specificities of battery manufacturing systems, such as the complexity of quality issues in the process or the transient behavior of systems that never reach their steady state due to continual changes. Such techniques can be applied to manufacturing other renewable energy products as well, such as fuel cells, biofuel, and solar energy products [5]–[7].

Digital Object Identifier 10.1109/MRA.2019.2892313
Date of publication: 12 March 2019

Minimizing the acceleration of industrial robot systems reduces energy consumption by up to 30% while retaining production times. Energy savings occur by optimizing robot motions to reduce acceleration and deceleration, as well as the time the robot is at a standstill, because standstills also consume energy. A basic idea of the proposed optimization concept is to let a robot move more slowly, instead of waiting for other robots to catch up, and then carry out the next operation sequence. The optimization also determines the order in which various operations are carried out, to minimize energy consumption without reducing the total execution time. The result is an energy-optimal schedule that can include all robots (and other moving resources and machines) in the optimization procedure. The optimal solution still maintains a desired production time, which is crucial to win industrial acceptance; reduced production capacity rarely is a satisfactory solution. Additionally, it is necessary to preserve the robots' paths. Only velocity profiles and waiting times should be adjusted in the optimization, which means that the original robot path planning is maintained. Detailed energy models are included in mathematical optimization models.

Similar to robot-manufacturing systems, research on improving energy efficiency when using machine tools is also underway. To improve energy efficiency, it is crucial to make better use of any energy that would otherwise be lost. Indeed, machine auxiliary equipment, i.e., suppliers, can easily require more energy than is necessary, because they need power during nonproductive machine states. These systems must be available when production has to resume, generating an overabundant supply that we could reduce by switching the machine state according to an appropriate control strategy.

The control of machine states is one of the most promising measures at the machine level. This state control reduces the energy demand when the machines are idle by using start/stop features to switch the machine on or off according to predetermined rules. The popularity of remanufacturing, an industrial process to restore discarded products/components back to their useful lives, has surged recently. As a result, there are many publications on this topic, and more work will continue to appear. This problem is generating a good deal of interest due to its complexity and the various associated challenges.

Remanufacturing, compared to manufacturing, is more complicated in that 1) the timing and quantities for the supply of returned products is unpredictable, 2) the quality and composition of returned products vary, and 3) the process routings are not necessarily fixed but adapt to the condition of actual products/components instead. From a logistical perspective, the new set of product recovery and remanufacturing operations close the loop (known as *reverse logistics*) to a conventional supply chain flow. This addition brings two distinct characteristics to system modeling: analysis and control. A stochastic, autonomous inbound item flows, and two alternative supply options (i.e., recovered products and new products) fulfill demands. Because the variability is highly uncontrollable with respect to production conditions, it is worthwhile to implement the inspection and sorting of returns in the system as a way to identify product quality and organize necessary activities for their recovery and remanufacturing (i.e., products with recoverable quality) or reuse (i.e., products with good quality).

Future Directions

Sustainable manufacturing has been a critical element in manufacturing strategies for at least a decade. Earlier efforts focused on environmental initiatives, such as GE's Ecomagination (2017) or IBM's Smarter Planet (2017) to enhance resource productivity and reduce the environmental impact.

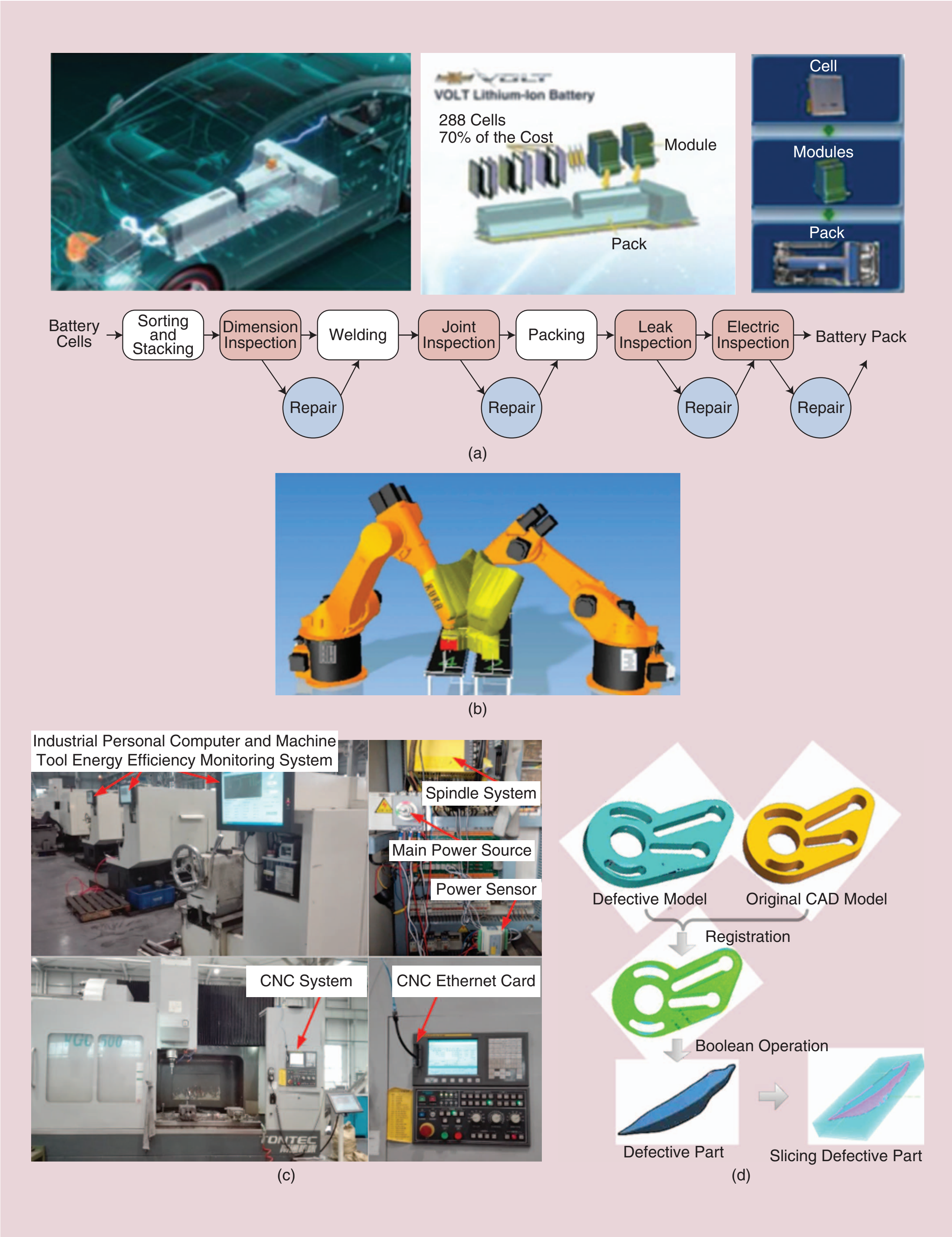

Figure 1. Examples of SPA development in various areas: (a) battery management, (b) energy optimization for industry robot systems, (c) an energy-efficiency monitoring system [1], and (d) additive repair and remanufacturing of mechanical parts [2]. CNC: computer numerical control.

(a)

(b)

Figure 2. The SPA TC organized special sessions in various conferences: (a) IEEE SMC 2017 and (b) IEEE CASE 2016.

These initiatives have typically had one of three objectives: 1) decreasing the manufacturing cost by reducing energy and waste, 2) enhancing corporate reputation as part of companies' corporate social responsibility efforts, and 3) complying with governmental regulations. While these initiatives continue to be important, four disruptive technologies will dramatically influence the future of sustainable manufacturing. First, smart manufacturing (or digital manufacturing) technologies will be integrated into a real-time factory and supply chain optimization, allowing companies to make instantaneous tradeoffs among energy consumption, productivity, quality, fulfillment, and cost. Second, the models that aid these optimality tradeoffs will be driven by the Internet of Things, artificial intelligence, and cognition. In other words, the models will continuously learn from real-time data that humans and machines in the factory generate, as well as similar machines in other factories and also simulations [8], [9]. Third, additive manufacturing will completely change not only the design of products but also the structure of supply chains through decentralized flexible production, volume-independent cost, and zero-cost customization. Finally, dramatic cost reductions will enable companies to use renewable energy that is generated onsite, reducing the energy cost and $C0_2$ emissions, and becoming significantly more sustainable.

Overall, we believe that sustainable manufacturing (as well as remanufacturing) will become as commonplace as lean manufacturing, because companies will have to embrace it to survive. Growing government regulations will increase the speed of its adoption. The disruptive technologies discussed will provide incredible opportunities for both industrial and academic researchers to contribute to the success of sustainable manufacturing and a sustainable planet.

Figure 3. A presentation during the 2017 IEEE International Conference on Automation Science and Engineering, 20–23 August 2017, Xi'an, China.

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and trimming setups to fit the required applications. The development of innovative robotized solutions for in situ interventions is critically important to ensure safe and economical operation of strategic industrial sectors.

In this context, this special issue of *IEEE Robotics and Automation Magazine*, through a selection of carefully selected peer-reviewed articles, draws the attention of both roboticists and industry specialists to the importance of developing bespoke, but versatile, robotic solutions that can have a significant impact on robotic innovation as well as provide economic and societal benefits.

The articles in the issue report on recent innovative developments in the onsite repair of aeroengines and in autonomous radiological monitoring of nuclear facilities. Two articles describe innovations in in situ interventions using aerial robots, and another article emphasizes the contribution competitions make to robotic in situ interventions. We hope this special issue will serve as a catalyst, bringing robotics researchers and specialists closer to the exciting challenges offered by in situ inspection and repair in restricted/hazardous industrial environments.

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