Guest Editorial
Introduction to the Focused Section on Optomechatronics

I. Introduction

In the last two decades, the evolution of optical, mechanical, electronic, and information technologies has not only produced miniaturized products with better performance, but also fused these technologies together, labeled optomechatronic technology, to create products and systems with innovative functionality and greater intelligence. The production cycles of new devices, machines, and systems, from functionality design to manufacturing process, require engineers from optical and mechatronic fields to work closely, taking the concept of optomechatronics into account. Optomechatronics, in all respects, has now become a major driving force with increasing importance for next-generation technologies.

This "Focused Section on Optomechatronics" of the IEEE/ASME Transactions on Mechatronics is dedicated to recent advances in optomechatronic devices, systems, and metrology, aiming to stimulate future research in this direction. In this Editorial, we will highlight papers related to this topic previously published in IEEE/ASME Transactions on Mechatronics and then give an overview to papers published in this Focused Section. Potential research trends will also be addressed. It is sincerely hoped that this Focused Section will serve as an important source for researchers in the field of optomechatronics.

II. Related Papers Previously Published in IEEE/ASME Transactions on Mechatronics

During the past decade, a considerable number of papers related to optomechatronics were published in IEEE/ASME Transactions on Mechatronics. These papers can be generally classified into subcategories of optomechatronic actuators and manipulation, optomechatronic sensors and instrumentation, and optomechatronic control.

A. *Optomechatronic Actuators and Manipulation*

The advance of several research areas such as semiconductor industry and molecular biology has required samples to be manipulated and investigated at micrometer, nanometer, or molecular scale. Among various nanomanipulators, atomic force microscope (AFM)-based nanomanipulator has been proven to be one of the most powerful instruments. During last decade, much effort has been put on the development of real-time visual feedback and haptic control during nanomanipulation using AFM.

In 2000, Guthold *et al.* [1] proposed an AFM-based nanomanipulator, which creatively incorporated a virtual–reality interface by monitoring the AFM tip–sample interaction forces to give the manipulator a haptic feedback and a 3-D graphics. This system enables access to the nanoworld in a more intuitive way and helps scientists to manipulate and image nanometer-sized structures in a controlled manner. The proposed system was used to investigate carbon nanotubes (CNTs), deoxyribonucleic acid (DNA), fibrin, and viruses. Mechanical and electromechanical properties of CNTs were investigated. Rupture forces of DNA and fibrin fibers were measured. This system also made it possible to study elastic moduli of viruses.

In 2004, Li *et al.* [2] realized an augmented reality system for AFM-based nanomanipulation by incorporating real-time visual feedback information to facilitate the manipulator. A general model of AFM tip–substrate–object was established and real-time AFM images of the dynamic nanoenvironment were obtained by updating the real-time force information. The proposed augmented reality system eliminates the need for a new image scan and is capable of nanolithography and nanoassembly tasks. Liu *et al.* [3] published another paper in 2008 to further tackle the problem of faulty display in AFM-based nanomanipulation, which is caused by random drifting and deficient modeling. In this new configuration, the AFM tip was used as a force sensor as well as an end-effector during manipulation. Faulty display was detected online by a developed Kalman filter and corrected by a local scan during manipulation. Experiments to manipulate nanorods and nanoparticles were carried out to validate the effectiveness and efficiency of the proposed system.

Besides AFM-based equipment, optical microscope had also been combined with laser scanning micromanipulator to facilitate telemicromanipulation. In 2003, Arai *et al.* [4] reported the usage of laser-trapped microtools (MTs) to transport target microbe under their micromanipulation system. They designed customized holding chip for the MTs and explored new metrology for installing the MTs inside a microchamber. Their system is capable of transporting the target microbe with minimum laser irradiation. Other potential applications include lab-on-chip microbe separation, DNA and protein analysis, and other biological activity within microspace.

Automated handling is also of great interest under nanospace. In 2007, Fatikow *et al.* [5] reported the development of an automated nanohandling station within scanning electron microscope (SEM). Their station consisted of two mobile microrobots, three charge-coupled device (CCD) cameras, and various sensors. Position information of the microrobots was obtained from the three CCD cameras, and continuous pose estimation of the

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robots was realized by processing real-time SEM images. The automated control was then realized by a closed-loop client-server control architecture. Automated handling of transmission electron microscope lamellae was demonstrated to verify the system's automatic nanohandling capability.

Nanomanipulator and nanopositioner such as scanning probe microscope (SPM) may be subject to errors due to dynamics effect when rapid manipulation is required to explore dynamic surface phenomena. Thus knowledge of SPM dynamics is valuable in high-speed applications. Rather than using external sensors for SPM dynamics modeling, Clayton and Devasia [6] proposed an image analysis-based calibration procedure, using a standard calibration sample. Conditions on the standard calibration sample and the scan trajectories were developed to facilitate the identification of SPM dynamics. The proposed calibration method avoids potential error from sensor misalignment and actuator cross coupling and is proved superior when high-speed and high-resolution calibration is needed.

Magnetic resonance imaging (MRI) provides high-quality visualization and thus has great potential for guiding medical interventions. MRI compatible robotic systems to assist intervention have attracted great research effort during last decade. In 2008, a series of robotic systems for MRI-based operation were reported in a Focused Section. Fischer *et al.* [7] reported the usage of an MRI compatible pneumatic robot to assist prostate needle placement. The robot can be operated under 3 T MRI scanning. The needle alignment accuracy was reported to be better than 0.94-mm root-mean-square per axis. The pneumatic robot, controller design, and system configuration were given in details in their paper. Zemiti *et al.* [8] reported a CT or MRI image-guided puncture robot for safer intervention purpose. Innovative robot architecture, materials, and energy source were described. Image processing algorithms and specific control loop were also proposed to localize and control the robot under CT or MRI devices. Goldenberg *et al.* [9] reported the usage of an ultrasonic motor-driven robot for prostatic interventions under MRI visual guidance. A specific control method for the ultrasonic motor was proposed and robot tip positioning error of less than 2 mm was reported. Rea *et al.* [10] presented an MRI visual system for real-time tracking of a 5 degree-of-freedom (DOF) manipulator used for prostate biopsy. Their system used a passive fiducial microcoil as tracking marker and achieved 3-D tracking during interventional procedure by properly selection of two scan planes and real-time image processing. Compared to active fiducial microcoil with projection-based method, the proposed system was slower but less complex, independent of external hardware and providing visual confirmation of the device position. Frame rate of 0.42 frames per second (fps) and marker mean error of 0.36 mm were reported with a probe velocity of 10 mm/s.

B. Optomechatronic Sensors and Instrumentation

The fusion between electrooptical and mechanical systems in recent years has resulted in constant progress in the development of optomechatronic sensors and instruments to better serve the stringent testing requirements imposed by the rapid progress in the fields of semiconductors, microsystems, and industrial inspections.

Shen *et al.* [11] presented a multiple-sensor coordinate measuring machine (CMM), which integrates a high-precision CMM with a motorized touch probe and a 3-D active vision system. The integrated overall system has an information aggregation module for sensor fusion and feature extraction, and an inspection-planning module for surface digitization. The active vision system provides global information of the scene, which could be used to determine the position and orientation of the objects, or to determine the surface geometry or feature topology for unknown objects. This information is then employed to guide the motorized contact probe for rapid coordinate data acquisition or for control of the CMM for high-precision sampling of critical surface area.

Cusano *et al.* [12] designed and developed a multifunctional fiber-optic sensing system, which could be embedded into the host smart structure and used for process monitoring and manufacturing optimization. It could also be used for structural health monitoring during the operative life of the structure. The results of refractive-index sensor used for monitoring the curing process of thermoset-based composites were presented. Two cost-effective techniques for integration with fiber Bragg gratings (FBGs) technology were also reported.

Lee and Zhou [13] presented an optical sensor for simultaneous measurements of 3-DOF motions in real time. To demonstrate the feasibility of the proposed concept, the authors presented two prototyped dual-sensor systems for measurement of 3-DOF planar and spherical motions. The proposed optical sensing systems detect microscopic changes from a stream of images and compute the angular displacement of a moving surface and the instantaneous center of rotational axis.

Bes *at al.* [14] reported an approach to improve the resolution of a self-mixed optical displacement sensor based on extended Kalman filter (EKF). The sensor was tested on plates for measurement of the frequency response function when coated and uncoated with a passive damping layer. The proposed low-cost optical sensor uses self-mixed interferometry with laser diode to achieve accurate vibration displacement measurements.

Hung *et al.* [15] combined a fiber Fabry–Perot interferometer, a piezoelectric actuator, and a sliding controller to build a dual-stage nanopositioning system. The phase ambiguity problem was solved by a modulation scheme, which utilized high-order harmonic information. Experiments showed that the proposed system rendered a resolution beyond the limit of wavelength.

Shan *et al.* [16] presented a study on characteristics of several low-cost infrared (IR) reflective sensors and their feasibility for micro to submicrometer scale position measurement and control. This paper reported the sensors' operating range, resolution, linear distortion, noise characteristics, and bandwidth and provided a comparative analysis with commercially available high-cost inductive sensors. Experimental results demonstrated the potential of IR sensors for positioning and control applications with microelectromechanical systems (MEMS).

Pugh *et al.* [17] presented an onboard relative positioning module for mobile miniature robots. Modulated IR signals were used for determining the range, bearing, and message of the sender with a high update rate, based on a received signal strength indication technique. Experiments with miniature robot formations were provided to demonstrate the effectiveness of the proposed method.

Recently, a series of novel optomechatronic systems had also been proposed for industrial nondestructive inspection and intelligent traffic systems.

Suzumori *et al.* [18] developed a micropipe-inspection robot for 1-in pipelines. The robot was furnished with a micro-CCD camera capable of identifying cracks with dimension of 25 μm in pipe structures. In addition, the robot consisted of the following micro-components: electromagnetic motor, planetary wheel mechanism, hand gripper, and a pneumatic motor for rotating the camera and the hands. The microrobot was capable of traveling through vertical pipes and curved sections. Besides the inspection task, the dual hands allowed manipulation and recovery of objects from pipes.

Duran *et al.* [19] reported a laser-based system for detection and classification of defects in tubular structures. The authors employed a laser-based profiler coupled with the closed-circuit television camera, to automatically detect pipe defects based on changes in the light intensity values of the projected rings extracted from the acquired images. A neural network algorithm with three layers of neurons was applied for classification of the defective and nondefective pipe sections.

Valle *et al.* [20] developed a new optomechatronic system based on nonflat mirrors for defects detection of highly reflective surfaces, which were difficult to detect using traditional optical metrology. Mathematical model of the light rays were given using optical geometry laws. Optimal nonflat mirror shape was then determined from simulation. Prototype was built and the experiment result validated the effectiveness of the proposed method.

Wu *et al.* [21] presented an innovative, compact, and parallel-structure optical system for solder paste inspection. Combining a hybrid-weighting algorithm, the system was able to conduct 2-D and 3-D solder paste inspection faster than traditional approaches. Experiments conducted on a printed circuit board demonstrated the speed and accuracy of proposed system.

Cheng *et al.* [22] reported a laser-based optical system for moving vehicle measurement in practical highway environment. This multilasers and photodetectors system employed triangulation metrology for real-time measurement. Their work demonstrated that both physical dimensions and moving speed could be detected with high resolution. This system provides useful information for use in intelligent transportation system.

Lu and Tomizuka [23] described an improved laser imaging, detection, and ranging (LIDAR) sensor for vehicle lateral guidance. LIDAR sensors can be installed on a moving vehicle to scan the horizontal plane and measure the relative distance from the preceding vehicle. It has great potential for applications in an automated highway system. A major drawback of current LIDAR sensors is that environmental clutter may cause failure in data processing. In this paper, a probabilistic data association-based algorithm was developed to improve the robustness of LIDAR system. Real-time experiments conducted on controlled vehicles verified the effectiveness of the proposed probabilistic algorithm and also revealed the relationship between LIDAR output with a magnetic reference system, providing guidelines on how this new sensors may be implemented for vehicle lateral guidance.

C. Optomechatronic Control

Optomechatronic control systems offer significant advantages over conventional control systems in terms of power, electromagnetic interference immunity, bandwidth, and safety. However, they also suffer from the challenges of system nonlinearities, time-varying properties, and larger disturbances. In recent years, tremendous effort had been placed on the development of optomechatronic control systems and metrologies for better performance, higher intelligence and multifunctionality, and to overcome their inherent disadvantages.

Zergeroglu *et al.* [24] proposed methods for uncalibrated visual servo (VS) control of a planar robot manipulator with a fixed camera configuration, which ensure global asymptotic convergence of the position tracking errors. First, an adaptive controller was designed to compensate for the unknown camera calibration parameters under assumption of exact knowledge of robot mechanical parameters (i.e., mass, inertia, and friction parameters). Afterward, another adaptive controller was developed to account for the parametric uncertainties of the entire robot-camera system. The control laws were extended for robust control and for the case of redundant manipulators.

Shen *et al.* [25] described a position-based VS method for the case when the homogeneous transformation matrix between the manipulator base frame, and the camera frame is not calibrated. It was assumed that the intrinsic camera parameters were known, and an adaptive visual feedback controller was proposed for on-line estimation of the transformation matrix related to the extrinsic camera parameters. Lyapunov method was employed to prove asymptotic convergence of the tracking errors. The performance of the proposed method was evaluated by both simulations and experiments.

Dean-Leon *et al.* [26] reported an uncalibrated image-based position/force control, using a second-order sliding mode adaptive controller. A direct-drive planar robot manipulator with a fixed camera was employed for visual tracking of a desired trajectory along a surface on which the end-effector exerts a desired force. Major challenges of the presented problem involved sensor fusion in a constrained nonlinear dynamical system and compensation of the viscous friction at the contact point and complex joint friction due to interaction of the robot end-effector with the environment. The presented controller was proven to guarantee simultaneous convergence of the position and contact forces between the end-effector and the constraint surface.

Bonkovic *et al.* [27] proposed a solution to the problem of uncalibrated image-based VS (IBVS) by using the population-based optimization method. This method generates a linear approximation of the inherently nonlinear model-free visual servoing problem, by building a secant model using a population of several previous iterates. The combined Jacobian matrix, which consists of the image and manipulator Jacobian matrices, is estimated online with the proposed approach. The provided simulation and experimental results confirmed the improvements in the convergence rate and robustness in comparison with the quasi-Newton optimization methods.

Kelly *et al.* [28] presented an IBVS controller for camera-in-hand robot architecture with a static target object. The controller was based on Jacobian transpose control scheme with gravity compensation terms and incorporated the full nonlinear robot dynamics. Lyapunov direct method was used to prove the closed-loop stability of the proposed controller, and it was found that local asymptotic stability was ensured under weak assumptions on the Jacobian. Experimental results with a two link direct-drive manipulator were presented to illustrate the feasibility of the proposed control scheme.

Cervantes *et al.* [29] addressed similar problem of control of a 2-DOF planar manipulator under uncertain gravitational torques. An IBVS system with a fixed camera configuration was analyzed, with a controller based on transpose Jacobian energy-shaping methodology. It was shown that the proposed controller, with an integral action for compensation of the errors due to incomplete knowledge of the gravitational torques, can guarantee asymptotic stability of the system.

Muis and Ohnishi [30] proposed an approach for VS, which involved cooperation of a main robot, which performed the servoing task, and a second mobile robot, which held the camera. As a result, the camera configuration was eye-to-hand for the task robot and eye-in-hand for the second robot. This architecture combined the advantages of providing a global view of the environment by eye-to-hand system and the precision of eye-in-hand system. It endowed mobility and maneuverability of the camera during the servoing task.

Shibata *et al.* [31] addressed the problem of development and integration of generic components for a teachable vision-based mobile robot. The proposed system consisted of vision, control, and host computer components. The vision system consisted of four cameras, high-speed tracking vision boards, and a video transmitter. The mobile robot received visual instructions from a human operator, e.g., by specifying the target on a touch panel and automatically navigated toward the target object using the vision sensors. Preliminary experiments with human-assisted navigation were presented.

Perez-Arancibia *et al.* [32] reported a frequency-weighted approach for adaptive minimum-variance control. This approach was used for control of a MEMS fast steering mirror to suppress laser beam jitter. Frequency weighting was incorporated in the adaptive control loop to constrain the high frequency gain of the adaptive filter that generates the adaptive control command. Experimental results showed satisfactory system performance, regarding elimination of the spikes in the output error due to amplification of high-frequency noise.

Li and Yang [33] presented an autonomous mobile robot with a visual landmark recognition system. A behavior-based artificial intelligence approach was used in the design of the mobile robot, with several modules developed for generating behaviors. The vision layer of the robot architecture used a genetic algorithm (GA) approach for recognition of artificial landmarks. Consequently, appropriate behaviors were generated, which corresponded to the recognized landmarks. A fuzzy controller was employed for the obstacle avoidance module, by using the information from eight ultrasonic sensors installed on the robot.

Hwang and Chang [34] proposed an approach for trajectory tracking and obstacle avoidance of a car-like mobile robot, based on mixed H_2/H_∞ decentralized control. The intelligent space was endowed with two cameras, used for extracting the pose of the mobile robot and the position of obstacles and subsequently for generating the reference trajectory of the robot. Two motors were used for control of the steering orientation and forward/backward motions of the car, respectively. H_2-norm of the output error and weighted control input was minimized, resulting in control characterized by small energy consumption and bounded tracking errors. H_∞ was employed to compensate for the interaction terms between the two subsystems and for the modeling errors. The performance of the proposed mobile car control was verified experimentally and compared with proportional–integral–derivative control for different microprocessor systems and different initial pose configurations.

Ferreira *et al.* [35] presented an approach for automatic visually guided teleoperation in microassembly tasks. The microassembly work cell was designed by combination of visual force/position servoing and reconstruction of a virtual microworld model from the 3-D CAD/CAM model of the environment. Vision-based positioning was employed for manipulation of the microobjects, followed by vision-based force sensing through measurement of the manipulator-tip deflection. The proposed approach was evaluated for microassembly tasks performed on millimeter-sized components.

Ho *et al.* [36] designed a distributed teleoperated system. The purpose of the presented system was to prepare the foundation at the foot of a volcano in Japan for construction of a dam. Due to the presence of poisonous gas at the site, a model-based supervisory control scheme was presumed, with the local control station and remote work site interacting with computer models functioning at their corresponding sites. The teleoperated vehicles at the remote site were monitored by sensors feedback information, which integrated visual feedback from four cameras and a GPS system.

III. Highlights of the Focused Section

This Focused Section consists of seven papers dealing with the development, characterization, and applications of various novel optomechatronic actuators, sensors, systems, and control metrologies.

Bai *et al.* report the fabrication technologies, evaluation process, and biomedical applications of a 2-DOF silicon-on-insulator (SOI) MEMS mirror. A new fabrication technology based on SOI wafer, bulk/surface micromachining, and a high-aspect ratio shadow mask is reported. The voltage response feature of the MEMS mirror has been studied by changing the size of the torsion bar and the sidewall and bottom electrodes. Large scanning angle with low-driving voltage is reported, and the mirror is applied for biomedical imaging.

The FBG-based sensors are becoming more and more popular for various sensing tasks due to their immunity to electromagnetic interference, high sensitivity, and long durability. Metal coating is normally necessary for FBG sensor protection before the sensor is embedded into metal structures. Such multiple-layer structure with different thermal expansion coefficients will be subject to thermal stress due to the unevenness of temperature field. In their paper, Feng *et al.* propose an analytical model to evaluate the effect of thermal stress on the performance of metal-coated FBG sensors, especially on the change of temperature sensitivity coefficient. Ni-Cu, Cu-Ni, and single-layer metal-coated FBGs have been studied. Variations in temperature sensitivity with different coating thickness are given. A real experiment inserting a Ni-Cu-coated FBG sensor into a #45 steel structure verifies the soundness of the proposed analytical model.

Photoelastic effect had previously been employed for stress visualization in vasculature model. In this paper, Tercero *et al.* extend their previous studies, propose the use of a polariscope for more accurate vasculature stress measurement of a urethane elastomer model, and quantify the photoelastic stress measurement error sources in blood vessel models. The transmittance equation for measuring optical path length is calibrated, the photoelastic coefficient of urethane elastomer is measured, and the optical system parameters are normalized to reduce the measurement error. An average error of 3.9% has been reported for pressure range of 60–189 mmHg inside the urethane model, and the measured stresses provide a useful reference for feedback control of the catheter insertion robot and for endovascular surgery simulation.

Nasibov *et al.* explore performance analysis of particle image velocity system by utilizing the binning option of the CCD camera. It is reported that the binning process can effectively increase the system's speed range without introducing noticeable error for displacement measurement. Other advantage of the binning process includes higher signal-to-noise (SNR), larger sensing element size, which allow for low-price light emitting diodes (LEDs) illumination, and faster computing speed.

Paraskevopoulos *et al.* develop an optical wireless (OW) communication system for high-speed indoor transfer of data for specific applications. OW communication has several advantages over its radio wireless counterpart. First, OW does not penetrate through walls, offering high security and privacy, which make it suitable for military application. Second, OW has huge unregulated bandwidth without interference with existing electromagnetic radio systems and hence makes it a valuable supplement. It is well believed that next-generation (4G) wireless communication system will be based on several complementary technologies including OW. Finally, OW is ideal communication method in hospital and airplane environment, where additional radio wave should be prohibited. In the light of the aforementioned advantages, Paraskevopoulos *et al.* propose the development of high-speed OW communication solutions and systems. Adaptive signal processing and diversity techniques have been proposed to achieve both high-bit-rate (more than 100 Mb/s) and high-spatial coverage. Prototype of a tailored optical data links, which comprises a high-speed data buffer, a 45-channel optical receiver, and an free-space optical transmission solution have been designed to demonstrate higher data volumes (100 Gb/s) transmission.

Iqbal *et al.* propose a novel adaptive optics system, based on magnetic fluid deformable mirrors (MFDM) for waveform correction, and a mixed sensitivity H_∞ controller. MFDM have been recently employed for waveform correction of optical aberrations in the human eye, mainly due to their competitive cost and performance features. The challenging part of their implementation for that purpose remains control of the shape of the deformable surface. As opposed to the existing control algorithms, which are used to compensate for static high-order aberrations, the control algorithm proposed in this paper is capable of compensating dynamic wavefront aberrations. The authors have multiple motivations for using an H_∞ controller. First, aberrations of the human eye can be modeled as a combination of static, harmonic, and random components. Second, the temporal frequency content of the aberrations in the human eye has a limited range. Furthermore, the proposed control scheme minimizes the magnitude of high-frequency components, which is beneficial for avoiding saturation of the control signals and for attenuation of unmodeled high-frequency modes of the waveform corrector. The experimental results with a prototype 19-channel magnetic fluid deformable mirror demonstrate the efficiency of the proposed method.

In a short paper, Dupont *et al.* use a pair of optimized acousto-optic deflectors (AODs) to build a compact and electronically-controled structured light projector with wider tuning range over the fringe period. Two custom paratullurite AODs are designed with a prismatic cut so that the deflected beam at minimal driving frequency is aligned with the optical axis of the system, making the system compact without additional optical components for beam alignment. A specific anisotropic interaction has also been used to reduce the inter-modulation products, enabling multi-frequency operation of the AODs. These AODs are then placed in a Mach-Zehnder setup to produce interference fringe patterns with maximized bandwidth for capturing 3D profile, enabling measurement of objects with significantly disparate sizes.

IV. Future Trends

The fusion between optical elements and mechatronic components has been accelerating in recent years. Due to its synergistic capability for sensing, actuating, illumination control, material properties variation and data storage, transmitting, computing, and display, optomechatronics is attracting unprecedented research effort and playing an important role in the advances of modern technologies. Here, the authors would like to share some thoughts about future research fields with great potentials in optomechatronics.

Microoptoelectromechanical systems (MOEMS), which are the combination of microoptics with MEMS, have very important applications in the fields of telecom, sensing, projection, display, and mobile devices. The design, microfabrication, microassembly, and characterization of MOEMS will serve as a promising research field for optomechatronics. The fundamental challenges for precise microoptics manufacturing, complementary metal-oxide-semiconductor (CMOS) compatible process design and high-yield automatic packaging of heterogeneous microcomponents remain major obstacles for industrialization of MOEMS and need to be properly addressed by researchers in related fields.

Another interesting research field is the development of biosystems with micro- or nanosensing and manipulation capability. The in-depth R&D in bioscience depends greatly on instrument capability to manipulate and characterize biological specimens in decreasing scales. When combining with various microscopes, optomechatronic systems enable the capability of visualization, actuation, characterization, feedback control, and automatic handing, thus offering ideal tools for biological applications.

The vision integrated nature of optomechatronic systems make it more adaptive to unstructured environments and being more versatile for various applications over conventional mechatronic systems. However, the successful applications of optomechatronic systems depend greatly on the degree of intelligence of the systems, which in turn depends on the development of robust algorithms for pattern recognition, feature extraction, and decision making, which involves data fusion from multiple sensors and artificial intelligence using neural network, fuzzy logic, expert systems and generic algorithms. All these fields require continuous evolution to fulfill the high-level automation requirements of future optomechatronic systems and will certainly serve as essential research directions with great potentials.

Optomechatronic control deals with the control of heterogeneous optical and mechatronic components under unstructured environment. Comparing to control of simple systems, optomechatronic control suffers from great challenges such as system nonlinearities, time-varying properties, and uncertainties. Addressing such control problems is essential for popularity of optomechatronic technologies and serves as an important future research field. The ultimate objective of optomechatronic control is to achieve high-precision, high-product quality, and complete automation.

Due to its synergistic and complementary effects, R&D in the field of optomechatronics will greatly contribute to the progress in optical, mechanical, and electronical engineering. Eventually, it will boost and incubate various advanced technologies of the future.

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