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Introduction to the virtual special issue from the IFAC Symposium on Mechatronic Systems 2019

The 8th IFAC Symposium on Mechatronic Systems was held as a joint conference with the 11th IFAC Symposium on Nonlinear Control Systems (NOLCOS) in Vienna, Austria, from September 4th–6th 2019. The joint conference was motivated by bringing together scientists with a more theoretic background in nonlinear systems theory and control with more application-oriented scientists in mechatronics. The final program of the joint conference covered 55 sessions with 247 full papers by authors of 45 countries from all over the world.

This virtual special issue contains significantly extended versions of 13 selected papers from the 8th IFAC Symposium on Mechatronic Systems. The selection of these papers was strictly based on the high ranking of the corresponding conference papers within the peer-review process of the symposium. In the following, a short summary of these papers is given.

The controller and observer design of MIMO systems is a task that frequently arises when dealing with complex mechatronic systems. The authors of [1] study the design of MIMO multirate feedforward controllers with the goal to improve the overall tracking behavior. The authors concentrate on the continuous-time inter-sample tracking behavior, in particular for the systems controlled by a discrete-time feedforward controller with a rather large sampling time.

Another important aspect for MIMO mechatronic systems is the fault detection and disturbance estimation. In [2], a new method of disturbance observer-based control (DOBC) is proposed for coupled unstable MIMO systems. In this work, the authors use a number of parallel full-order state observers for fault detection, state and disturbance estimation. The design is based on game-theoretic detection filters and allows to achieve a disturbance decoupling. The authors show the advantages of the proposed concept by experimental results of an active magnetic bearing system.

Precision motion systems are very prominent applications of complex mechatronic systems. Precision motion systems are used, e.g., in wafer stage setups utilized in semiconductor production. Identification of a suitable mathematical model is often an important prerequisite for the model-based controller design for such systems. The paper [3] studies the optimal experiment design for the identification of frequency response function models for multivariable motion control. The design specifically addresses the frequency-wise directionality and is subject to element-wise power constraints. The authors propose two algorithms for the solution of the non-convex optimization problem that arises for this identification task. Experimental results of a wafer stage setup show a significant improvement of the model quality compared to traditional design approaches. Modeling the influence of thermally induced deformation on the control performance is another important aspect for precision motion systems, which is studied in [4]. The authors propose an approach for non-parametric identification that is suitable for the modeling of thermal effects in many mechatronic systems. By utilizing the transient data, a reduced experiment time can be achieved for the model identification. Moreover, the authors exploit the fluctuations of the ambient temperature as an additional input for the model identification. The resulting non-parametric model serves as a basis for the parameter estimation of a grey-box model that can be used for advanced control techniques in high-precision motion systems.

Mechatronic systems engineering is also relevant to many sensor systems. The papers [5,6] are concerned with the mechatronic design, optimization and control of optical sensors. In particular, Schlarp et al. [5] presents the mechatronic design and control of an optical scanning laser sensor with the application to 3D imaging. The core of this system is a compact fast steering mirror which, together with a laser source and a detector, allows to reconstruct the 3D geometry of objects. The authors study the influence of misalignments on the achievable resolution and propose an adapted scan trajectory that allows to obtain a uniform spatial resolution. Based on experiments, the authors show that the overall measurement time can be reduced by a factor 400 compared to classical state-of-the-art mechanical scanning triangulation sensor systems. A second topic in scanning-motion optical sensing is the accurate phase detection and control of micro-opto-electro-mechanical system mirrors (MOEMS), which is crucial for high-resolution imaging. The authors of [6] propose a novel precise phase-detection method and a digital phase-locked loop that uses an asynchronous logic for high-precision driving and immediate phase compensation. The authors further develop a fast start-up procedure that brings the MOEMS to its maximum amplitude within less than 100 ms and does not require detailed prior knowledge of the used device. It is demonstrated that a very high accuracy is obtained in closed loop operation that allows to measure 19000 pixels with high precision at a scanning frequency of 2 kHz.

The paper [7] discusses another application of lasers, in this case high-power lasers that are typically used in material processing (welding, cutting). The authors study the rejection of thermally-induced disturbances, which frequently limit the beam quality of high-power lasers. Spherical intra-cavity mirrors are used as actuators to dynamically compensate the impact of thermal disturbances. The authors propose an optimization-based moving horizon estimator that allows to systematically cope with the nonlinear system dynamics. Furthermore, a compensation strategy is developed that explicitly considers input constraints. The performance of the overall concept is studied by of experiments of a scalable experimental setup with output laser powers in the range of 500 W.

Printing, in particular 3D printing of plastics and metals, is already

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frequently used as a production process for complex parts. In contrast, printed electronic circuits are hardly used in current real-world applications. The paper [8] studies the automated fabrication of hybrid printed electronic circuits that offer great potential for new applications, as, e.g., wearables. Since the current technology only allows to print a limited number of electric functions, a hybrid process is studied. Here, silicon components are mounted on a printed electric circuit. The authors discuss the digital work flow and the multi-layer vector ink-jet process that allows to directly print onto foil surfaces. An improved setup of the printing system is described and a path planning strategy is developed. Finally, image processing is employed to handle deformations of the flexible foil substrates during the printing process.

Steel strip production is a process that lies on the opposite order of magnitude compared to the micro and nano scale of the previous applications. Nonetheless, complex mechatronic systems are also involved in these applications and complex control strategies are required to reach the desired product quality. The paper [9] discusses methods for the active rejection of harmonic vibrations of steel strips in hot-dip galvanizing lines. Such vibrations can significantly deteriorate the final product quality and, thus, must be suppressed as good as possible. The control task is particularly complex because the disturbance input, the measurement, the control input (electromagnetic actuators) and the system output to be controlled are all located at different positions. The authors propose a novel control scheme that minimizes the harmonic steady-state response while requiring only modest computational resources. It is shown that negative effects due to observation and control spillover are effectively avoided. The advantages of the proposed concept are shown by experimental results on a test rig.

The papers [10,11] are concerned with observer and controller design aspects in mechatronic systems arising in transportation systems. A hydromechanical powertrain, which is used e.g. in wheel loaders, is considered in [10]. In this system, the accurate and fast control of the swivel angle of the hydraulic motor and the pressure difference at the pump is important to follow the a-priori unknown reference signals of the driver. The authors propose a flatness-based feedforward and feedback control strategy that is combined with an online trajectory generation. The online trajectory generation allows to adhere to the system constraints without relying on a complex online optimization. Based on experimental results, the authors show that the proposed overall control concept yields a high system performance. The running gear of a future double-deck high speed train is considered in [11]. The authors discuss the estimation of the lateral position of the mechatronic running gear with independently rotating wheels. The lateral position is required for the control of the lateral dynamics, which is important for minimizing the wheel wear and optimizing the passenger comfort. It is demonstrated in an experimental setup that the proposed nonlinear observer strategy yields significantly improved results compared to the state of the art.

In the final two papers [12,13], the control of robotic systems is considered. Robotic systems combine complex mechanics, (electric) drives, and sensors with electronic control units, and thus constitute most prominent representatives of complex mechatronic systems. The compensation of common error sources, e.g., imprecise kinematics or mechanical compliance, is an important topic for high-accuracy robotic systems that are studied in [12]. The authors propose a nested loop iterative learning control strategy, with an inner loop to compensate the non-ideal motor dynamics and an outer loop to correct deviations along the tracked path. One main advantage of the proposed control concept is that only nominal kinematic parameters of the robot are required and that it can be readily implemented on existing robots. The authors show the effectiveness of the proposed control concept by experiments on a six degrees-of-freedom robot manipulator. In [13], a soft collaborative robot is studied. Such robots allow a safe inter-operation between robots and human users. One main task in the operation of robotic manipulators is the trajectory planning, which can be quite complex and requires highly skilled engineers, in particular for soft robots. The authors of [13] propose a kinesthetic programming approach for the path and trajectory planning. In contrast to earlier works, the authors aim to teach the whole trajectory in a single demonstration by a non-expert. The authors show the suitability of their approach by experiments on a soft-quasi-continuum manipulator.

The papers of this virtual special issue demonstrate the variety of possible application domains and the multitude of theoretical concepts available for the analysis, modeling, control, optimization, and design of mechatronic systems. In particular, the successful implementation in real-world applications studied in these papers emphasizes the practical feasibility of the proposed concepts and technologies.

In view of the permanent advances achieved in the areas of electronics, actuator and sensor technology, algorithmics and software design, the Guest Editors are convinced that the synergetic potential of mechatronic system design will even become more important in the future. In this sense, the Guest Editors hope that the readers enjoy the papers in this virtual special issue.

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