Introduction to the Special Section on Industrial Applications and Implementation Issues of the Kalman Filter

MANY industrial applications require measuring a large number of physical variables so as to own a sufficient quantity and quality of information on the system state and to ensure the required level of performance. However, the measurement of some physical quantities may not be possible or desired. The main reasons are the cost reduction and/or the increase of system reliability. In this context, the Kalman filter (KF), whose 50th anniversary occurred in 2010, has played a key role in many industrial applications of the engineering professions since the 1970s. Many research studies have been dedicated to the implementation and performance improvement of the KF, namely, the numerical stability improvement, the computation time reduction (fast algorithms), or the study of effective implementation.

It is our great pleasure to present a Special Section of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS dedicated to the **industrial applications and implementation issues of the KF**. The main objective of this Special Section is to highlight the latest theoretical and experimental advances and practical implementation issues of this state estimator.

This Special Section received 95 papers, and 30 papers were accepted for publication. All the topics of the IEEE Industrial Electronics Society have been treated and grouped as follows:

1) sensorless control of electrical machines;
2) power electronics;
3) monitoring of industrial systems;
4) data processing;
5) robotics;
6) automatic control.

I. SENSORLESS CONTROL OF ELECTRICAL MACHINES

Several papers of this Special Section are dedicated to state- and parameter-estimation problems in ac motor sensorless drives using different kinds of KFs. Among them, one paper by Shi *et al.* uses an extended KF (EKF) for interior permanent-magnet synchronous motor (IPMSM) drive, where the position reconstruction is based on the permanent-magnet flux estimation. In the paper written by Xu and Rahman, a comparison between an EKF and an adaptive sliding observer for IPMSM is shown, from the point of view of the estimation accuracy and complexity. The next paper, written by Smidl and Peroutka, discusses a fixed-point implementation of an EKF designed for PMSM drive using several decomposition algorithms of the covariance matrices.

The bi-input EKF, described by Barut *et al.*, is proposed to overcome the problems encountered in the simultaneous estimation of the stator and rotor winding resistances in addition to the load torque and all the state variables of the induction motor (IM) required for its speed-sensorless control in the wide speed range. The paper by Lascu *et al.* presents a discussion of several nonlinear unscented transforms used in the prediction step of the KF and tests them for the IM drive.

An application of EKF is also experimented with by Butcher *et al.* in the case of a sensorless stepper motor drive including a connection using a long cable between the pulsewidth-modulation inverter and the electric motor. Linear and nonlinear EKFs have been applied by Szabat and Orlowska-Kowalska for state and parameter estimations of drive systems with elastic couplings. The paper by Mercorelli has used an EKF for position and velocity estimation of an electromagnetic valve actuator used for sensorless control in camless internal combustion engines.

II. POWER ELECTRONICS

The KF is also used in power electronic systems. The paper by Kwan *et al.* presents a unified power quality conditioner. Here, KFs extract components of the distorted supply voltage and load current and therefore compensate sags and swells in the supply voltage and also control the power factor at the supply side. The paper by Jo *et al.* presents a novel method to estimate the composition rate of electric loads using a KF.

A current-control scheme for a voltage-source converter connected to the grid through an LCL filter is presented by Huerta *et al.* The proposed current control is based on the linear quadratic controller associated with a steady-state KF that estimates the unmeasured variables. Moreover, the paper focuses on some criterions and practical hints for the KF design procedure.

III. MONITORING OF INDUSTRIAL SYSTEMS

The paper by Huang *et al.* considers the fault diagnosis and fault-tolerant problem of a linear drive system. The authors first designed one KF in order to detect if a failure occurs,

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and second, they have designed two KFs to diagnose the fault type. The paper by Ondel *et al.* deals with a diagnosis tool for induction machines based on a pattern recognition approach associated with a KF interpolator/extrapolator. In their paper, the KF is developed in order to interpolate the known states and to predict the evolution toward new ones.

The paper by Lall *et al.* investigates the structural damages on ball-grid-array components due to mechanical vibration. A linear model associated with a KF estimates the remaining useful life. The paper by Gao *et al.* proposes a visual sensor system associated with a KF based on a nearly constant acceleration of the seam in order to improve the accuracy of the weld detection.

The paper by Kozek *et al.* investigates a new estimation method for the inner combustion torque of internal combustion engines and for misfire detection.

IV. Data Processing

The problem of mobile-phone localization in a rough wireless environment is addressed in the paper by Li and Xia. The multiple-model approach is applied to locate a mobile station, and a localization estimation algorithm is developed by using the basic interacting multiple-model approach to a Markov jump.

The paper by Song *et al.* addresses an approach for estimating the location of a mobile node based on the ranging measurements of a sensor network.

Autonomous mobile robot navigation in urban areas is considered by Kang *et al.* The authors propose using lidar measurements of the road surface to detect road boundaries and to estimate the roadside curb position thanks to a probabilistic decision-making algorithm deduced from an interacting multiple model.

A recursive estimation of traffic densities using the information provided by loop detectors is presented by Li and Singh. This paper investigates traffic flow modeling using both state-space models and Markov chains and traffic-density estimation obtained by Kalman filtering.

The paper by D'Errico presents an interesting application of KF theory to dimensional metrology. Simulation results confirm that the proposed strategy complies with the guidelines on uncertainty treatment in measurement science and more particularly in in-process metrology.

V. Robotics

The paper by Mitsantisuk *et al.* presents some KFs designed to estimate action/reaction forces in a haptic system. The paper by Li *et al.* proposes dynamic balance control using KF and fuzzy logic. The method can stabilize a biped robot under different ground conditions. The paper by Chen presents an interesting survey on the robot vision applications proposed in recent years.

VI. Automatic Control

The paper by Lee *et al.* investigates the implementation of an EKF that is used for the purpose of training nonlinear neural networks to perform desired input–output mappings. This approach has been applied for respiratory motion estimation.

The next three papers illustrate the interest in using the KF for complex control applications. The first one, by Ding *et al.*, investigates the problem of nonfragile H^∞ and H_2 filter designs for continuous-time linear systems. In the second paper, written by Khanesar and Kayacan, the feasibility of using type-2 fuzzy neurostructure controllers is shown for anti-lock braking systems (ABS). The paper by Toscano and Lyonnet is concerned with solving nonconvex optimization problems arising in various engineering sciences. In particular, we focus on the design of a robust flux estimator of induction machines and the optimal design of on-chip spiral inductors.

The paper by de Marina *et al.* applies the unscented KF for unmanned aerial vehicles to estimate their attitude. The paper by Lee *et al.* details a new distributed parallel fusion filtering algorithm for linear multiple-time-delay systems. The high accuracy and efficiency of the proposed distributed filter are then demonstrated through its implementation on a vehicle suspension system.

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