

IEEE INDUSTRIAL ELECTRONICS SOCIETY

The Industrial Electronics Society is an organization, within the framework of the IEEE, of members with principal professional interest in electronics and electrical sciences as applied to control, treatment, and measurement of industrial processes. All members of the IEEE are eligible for membership in the Society and will receive this TRANSACTIONS upon payment of the annual Society membership fee of \$9.00 plus an annual subscription fee of \$30.00. For information on joining, write to the IEEE at the address below. *Member copies of Transactions/Journals are for personal use only.*

Editor-in-Chief

LEOPOLDO GARCIA FRANQUELO, *Professor*
University of Seville, Spain
phone: +34 954 48 73 65 e-mail: lfranquelo@ieee.org

IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS



Past Editor-in-Chief

CARLO CECATI, *Professor*
Dept. of Inform. Engr., Comp. Science & Mathematics -
Univ. of L'Aquila, 67100 L'Aquila, Italy

Co-Editors-In-Chief

HUIJUN GAO, *Professor*
Harbin Institute of Technology, China

K. GOPAKUMAR, *Professor*
Indian Inst. of Sci. Bangalore, India

KOUHEI OHNISHI, *Professor*
Keio University, Japan

MARIA VALLA, *Professor*
Universidad Nacional de La Plata, Argentina

Associate Editors

- | | | | | |
|---|--|---|---|--|
| H. ABU-RUB
Texas A&M Univ. at Qatar, Qatar | G. ESCOBAR
Univ. Autonoma de Yucatan, Mexico | M. K. KAZIMIERCZUK
Wright State Univ., Dayton, USA | G. D. MARQUES
I. Superior Tecnico, Lisboa, Portugal | K. SRIDHARAN
IIT, Chennai, India |
| V. AGELIDIS
Univ. of New South Wales, Australia | J. FANG
Beijing Univ. of A&A, China | M. KAZMIERKOWSKI
Warsaw Univ. of Tech., Poland | S. MAZUMDER
Univ. of Illinois, Chicago, USA | T. STRASSER
AIT Austrian IT, Vienna, Austria |
| H. S. AHN
Gwangju Inst. of S&T, Korea | F. FNAIECH
ESSTT Univ. Tunis, Tunisia | V. KHADKIKAR
Masdar Inst. of Sci. & Tech., UAE | E. MONMASSON
Univ. of Cergy-Pontoise, France | H. SURYAWANSHI
Visvesvaraya Nat. I. of Tech., India |
| V. AMBROZIC
Univ. of Ljubljana, Slovenia | J. M. FUERTES
Tech. U. of Cat., Barcelona, Spain | S. T. W. KWONG
City Univ. of Hong Kong, Hong Kong | T. MURAKAMI
Keio Univ., Japan | P. N. TEKWANI
IIT, Nirma Univ., Ahmedabad, India |
| F. J. AZCONDO
Univ. of Cantabria, Spain | Y. FUJIMOTO
Yokohama Nat. Univ., Japan | Y. S. LAI
Nat. Taipei Univ. of Tech., Taiwan | S. NIHTIANOV
TU Delft, The Netherlands | S. VAZQUEZ
Univ. of Seville, Spain |
| E. BABAEI
Univ. of Tabriz, Iran | Z. GAO
Northumbria Univ., U.K. | J. J. LEE
KAIST, Daejeon, Korea | R. OBOE
Univ. of Padova, Italy | L. WANG
Peking Univ., Beijing, China |
| S. BACHA
G2Elab, France | G. GARCERA
Univ. Politecnica de Valencia, Spain | J. M. LEE
Pusan Nat. Univ., Korea | K. OHISHI
Nagaoka Univ. of Tech., Japan | C. WEN
Nanyang Tech. Univ., Singapore |
| B. BANDYOPADHYAY
IIT, Mumbai, India | L. GOMES
Univ. Nova Lisboa, Portugal | J. LEON
Univ. of Seville, Spain | R. M. PALHARES
Federal Univ. of Minas Gerais, Brazil | B. WILAMOWSKI
Auburn Univ., USA |
| M. BENBOUZID
Univ. of Brest, France | G. GRANDI
Univ. of Bologna, Italy | E. LEVI
Liverpool John Moores Univ., U.K. | S. K. PANDA
National U. of Singapore, Singapore | S. WILLIAMSON
U. Ontario IT, Oshawa, Canada |
| R. BOJDI
Politecnico di Torino, Italy | J. M. GUERRERO
Aalborg Univ., Denmark | Y. W. LI
Univ. of Alberta, Edmonton, Canada | J. POU
Univ. of New South Wales, Australia | S. WON
Pohang Univ. of S&T, Korea |
| C. BUCCELLA
Univ. of L'Aquila, Italy | V. GUNGOR
AGU, Kayseri, Turkey | X. LI
Xi'an I. of O&P Mech., China | M. PUCCI
I. of Intelligent Sys., Palermo, Italy | W. XIAO
Masdar Inst. of S&T, UAE |
| G. BUJA
Univ. of Padova, Italy | Q. L. HAN
C. Queensland Univ., Australia | B. R. LIN
Nat. Yunlin Univ. of S&T, Taiwan | A. K. RATHORE
Concordia Univ., Canada | D. XU
Harbin Inst. of Tech., China |
| D. CAO
Cranfield Univ., U.K. | G. HANCKE
Univ. of Pretoria, South Africa | M. LISERRE
Christian-Albrechts-U. Kiel, Germany | J. RODRIGUEZ
U.T.F.S. Maria, Valparaiso, Chile | W. L. XU
The Univ. of Auckland, New Zealand |
| G. A. CAPOLINO
U. of Picardie, Amiens, France | L. HARNEFORS
ABB Power Sys., Västerås, Sweden | H. LIU
Univ. of Portsmouth, U.K. | J. J. RODRIGUEZ-ANDINA
Univ. of Vigo, Spain | X. YANG
Harbin Inst. of Tech., China |
| R. CARDENAS
Univ. of Santiago de Chile, Chile | H. HENAO
U. Picardie J. V., Amiens, France | T. H. LIU
N. Univ. of S&T, Taipei, Taiwan | X. RUAN
Nanjing Univ. of Aeronautics, China | S. YIN
Harbin Inst. of Tech., China |
| A. CARDOSO
U. of Beira Int., Covilhã, Portugal | M. HILAIRET
U. Franche-Comté, Belfort, France | L. LO BELLO
Univ. of Catania, Italy | A. SABANOVIC
Sabanci Univ., Istanbul, Turkey | X. YU
Royal Melbourne I. Tech., Australia |
| A. CAVAGNINO
Politecnico di Torino, Italy | R. Y. HUI
Univ. of Hong Kong, Hong Kong | K. LU
Chinese A. of Sci., Beijing, China | M. SAEEDIFARD
Georgia Inst. of Tech., Atlanta, USA | B. ZHANG
Univ. of South Carolina, USA |
| C. CECATI
Univ. of L'Aquila, Italy | Y. A. R. IBRAHIM
Univ. of Alberta, Edmonton, Canada | O. LUCIA
Univ. of Zaragoza, Spain | F. SALMASI
Univ. of Toronto, Canada | J. ZHANG
Sun Yat-sen U., Guangzhou, China |
| C. CHAKRABORTY
IIT, Kharagpur, India | K. IDE
Yaskawa E. C., Kitakyushu, Japan | R. C. LUO
N. Taiwan Univ., Taipei, Taiwan | G. SERRA
Univ. of Bologna, Italy | Q. C. ZHONG
Illinois Inst. of Tech., Chicago, USA |
| A. CHANDRA
É. de Tech. Sup., Montreal, Canada | A. IOINOVICI
Holon Inst. of Tech., Israel | A. LUQUE
Univ. of Seville, Spain | Y. SHI
Univ. of Victoria, Canada | |
| E. CHENG
Hong Kong Polytech. U, Hong Kong | M. IWASAKI
Nagoya Inst. of Technology, Japan | U. K. MADAWALA
The Univ. of Auckland, New Zealand | F. SILVA
Tech. Univ. of Lisbon, Portugal | |
| M. N. CIRSTEAN
Anglia Ruskin U., Cambridge, U.K. | M. KAMADA
Ibaraki Univ., Japan | A. MALINOWSKI
Bradley Univ., Peoria, USA | B. SINGH
Indian Inst. of Tech., Delhi, India | |
| C. DE ANGELO
Univ. Nac. de Rio Cuarto, Argentina | H. Y. KANAAN
Saint-Joseph Univ., Beirut, Lebanon | K. MAN
City Univ. of Hong Kong, Hong Kong | J. SOLSONA
UNS-CONICET, B. Aires, Argentina | |
| D. DORRELL
UKZN, Durban, South Africa | H. R. KARIMI
Politecnico di Milano, Milan, Italy | M. MANIC
Virginia Commonwealth Univ., USA | G. SPAGNUOLO
Univ. of Salerno, Italy | |
| D. DUJIC
Ecole P.F. Lausanne, Switzerland | S. KATSURA
Keio Univ., Kanagawa, Japan | F. MARIGNETTI
Univ. of Cassino, Italy | | |
| M. O. EFE
Haceteppe Univ., Ankara, Turkey | O. KAYNAK
Bogazici Univ., Istanbul, Turkey | | | |

BARRY L. SHOOP, *President*
KAREN BARTLESON, *President-Elect*
PARVIZ FAMOURI, *Secretary*
JERRY L. HUDGINS, *Treasurer*
HOWARD E. MICHEL, *Past President*

S. K. RAMESH, *Vice President, Educational Activities*
SHEILA S. HEMAMI, *Vice President, Publication Services and Products*
WAI-CHOONG WONG, *Vice President, Member and Geographic Activities*
BRUCE P. KRAEMER, *President, Standards Association*
JOSE M. F. MOURA, *Vice President, Technical Activities*
PETER ALAN ECKSTEIN, *President, IEEE-USA*

ROB REILLY, *Director, Division VI*

IEEE Executive Staff

DR. E. JAMES PRENDERGAST, *Executive Director & Chief Operating Officer*

THOMAS SIEGERT, <i>Business Administration</i>	CHERIF AMIRAT, <i>Information Technology</i>
JULIE EVE COZIN, <i>Corporate Governance</i>	PATRICK D. MAHONEY, <i>Marketing</i>
DONNA HOURICAN, <i>Corporate Strategy</i>	CECELIA JANKOWSKI, <i>Member and Geographic Activities</i>
JAMIE MOESCH, <i>Educational Activities</i>	MICHAEL FORSTER, <i>Publications</i>
EILEEN M. LACH, <i>General Counsel & Chief Compliance Officer</i>	KONSTANTINOS KARACHALIOS, <i>Standards Association</i>
SHANNON JOHNSTON, <i>Human Resources</i>	MARY WARD-CALLAN, <i>Technical Activities</i>
CHRIS BRANTLEY, <i>IEEE-USA</i>	

IEEE Periodicals

Transactions/Journals Department

Senior Director, Publishing Operations: FRAN ZAPPULLA

Director, Editorial Services: DAWN MELLEJ Director, Production Services: PETER M. TUOHY

Associate Director, Editorial Services: WILLIAM A. COLACCHIO Associate Director, Information Conversion and Editorial Support: KEVIN LISANKIE

Senior Managing Editor: JEFFREY E. CICHOCKI Journals Coordinator: KEITH H. EDICK

IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS (ISSN 0278-0046) is published monthly by The Institute of Electrical and Electronics Engineers, Inc. Responsibility for the contents rests upon the authors and not upon the IEEE, the Society, or its members. **IEEE Corporate Office**, 3 Park Avenue, 17th Floor, New York, NY 10016-5997. **IEEE Operations Center**, 445 Hoes Lane, Piscataway, NJ 08854-4141. **NJ Telephone**: +1 732 981 0060. **Price/Publication Information**: Individual copies: IEEE members \$20.00 (first copy only), nonmembers \$143.00 per copy. (Note: Postage and handling charge not included.) Member and nonmember subscription prices available on request. **Copyright and Reprint Permissions**: Abstracting is permitted with credit to the source. Libraries are permitted to photocopy for private use of patrons, provided the per-copy fee of \$31.00 is paid through the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923. For all other copying, reprint, or republication permission, write to: Copyrights and Permissions Department, IEEE Publications Administration, 445 Hoes Lane, Piscataway, NJ 08854-4141. Copyright © 2016 by The Institute of Electrical and Electronics Engineers, Inc. All rights reserved. Periodicals Postage Paid at New York, NY and at additional mailing offices. **Postmaster**: Send address changes to IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, IEEE, 445 Hoes Lane, Piscataway, NJ 08854-4141. GST Registration No. 125634188. CPC Sales Agreement #40013087. Return undeliverable Canada addresses to: Pitney Bowes IMEX, P.O. Box 4332, Stanton Rd., Toronto, ON M5W 3J4, Canada. IEEE prohibits discrimination, harassment and bullying. For more information visit <http://www.ieee.org/nondiscrimination>. Printed in U.S.A.