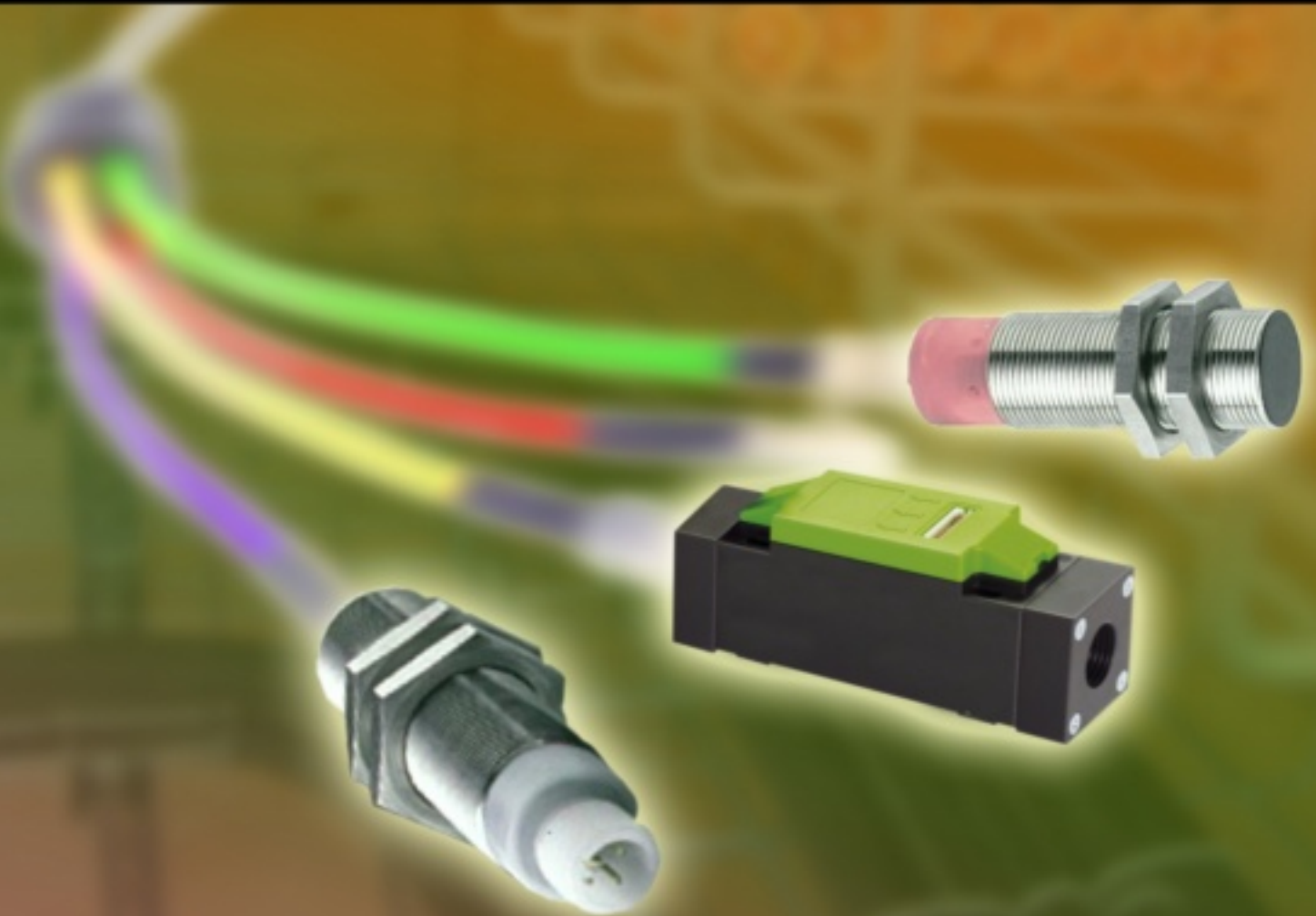


ISSN 1726-5749

SENSORS & TRANSDUCERS

vol. 79
5/07



Sensor Buses and Interfaces

International Frequency Sensor Association Publishing





Sensors & Transducers

Volume 79
Issue 5
May 2007

www.sensorsportal.com

ISSN 1726-5479

Editor-in-Chief: professor Sergey Y. Yurish, phone: +34 696067716, fax: +34 93 4011989,
e-mail: editor@sensorsportal.com

Editors for Western Europe

Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Università di Brescia, Italy

Editors for North America

Datskos, Panos G., Oak Ridge National Laboratory, USA
Fabien, J. Josse, Marquette University, USA
Katz, Evgeny, Clarkson University, USA

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editorial Advisory Board

- Abdul Rahim, Ruzairi**, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Nothern University of Engineering, Malaysia
Annamalai, Karthigeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vygantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, Priyadarshini College of Engineering and Architecture, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerda Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad de La Salle, Colombia
Courtois, Christian, Universite de Valenciennes, France
Cusano, Andrea, University of Sannio, Italy
D'Amico, Arnaldo, Università di Tor Vergata, Italy
De Stefano, Luca, Institute for Microelectronics and Microsystem, Italy
Deshmukh, Kiran, Shri Shivaji Mahavidyalaya, Barshi, India
Kang, Moonho, Sunmoon University, Korea South
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding Jian, Ning, Jiangsu University, China
Djordjevich, Alexandar, City University of Hong Kong, Hong Kong
Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Instersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, University of Ulm and KTB mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Ros, Juan Jose, University of Cadiz, Spain
Granell, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Hashsham, Syed, Michigan State University, USA
Hernandez, Alvaro, University of Alcalá, Spain
Hernandez, Wilmar, Universidad Politecnica de Madrid, Spain
Homentcovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia

Kaniasus, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Koh Young Technology, Inc., Korea South
Ko, Sang Choon, Electronics and Telecommunications Research Institute, Korea South
Kockar, Hakan, Balikesir University, Turkey
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kumar, Arun, University of South Florida, USA
Kumar, Subodh, National Physical Laboratory, India
Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Lacnjevac, Caslav, University of Belgrade, Serbia
Laurent, Francis, IMEC, Belgium
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Xian-Fang, Central South University, China
Liang, Yuanchang, University of Washington, USA
Liawruangrath, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, Michigan State University, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, Universidade NOVA de Lisboa, Portugal
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
Mendes, Paulo, University of Minho, Portugal
Mennell, Julie, Northumbria University, UK
Mi, Bin, Boston Scientific Corporation, USA
Minas, Graca, University of Minho, Portugal
Moghavvemi, Mahmoud, University of Malaya, Malaysia
Mohammadi, Mohammad-Reza, University of Cambridge, UK
Molina Flores, Esteban, Benemirita Universidad Autonoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, DIMET, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mukhopadhyay, Subhas, Massey University, New Zealand
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucine, University of Guelma, Algeria
Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India
Pan, Jisheng, Institute of Materials Research & Engineering, Singapore
Park, Joon-Shik, Korea Electronics Technology Institute, Korea South
Pereira, Jose Miguel, Instituto Politecnico de Seteбал, Portugal
Petsev, Dimitar, University of New Mexico, USA
Pogacnik, Lea, University of Ljubljana, Slovenia
Post, Michael, National Research Council, Canada
Prance, Robert, University of Sussex, UK
Prasad, Ambika, Gulbarga University, India
Prateepasen, Asa, Kingmoungut's University of Technology, Thailand
Pullini, Daniele, Centro Ricerche FIAT, Italy
Pumera, Martin, National Institute for Materials Science, Japan
Radhakrishnan, S., National Chemical Laboratory, Pune, India
Rajanna, K., Indian Institute of Science, India
Ramadan, Qasem, Institute of Microelectronics, Singapore
Rao, Basuthkar, Tata Inst. of Fundamental Research, India
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Rezazadeh, Ghader, Urmia University, Iran
Robert, Michel, University Henri Poincare, France
Rodriguez, Angel, Universidad Politecnica de Cataluna, Spain
Rothberg, Steve, Loughborough University, UK
Royo, Santiago, Universitat Politecnica de Catalunya, Spain
Sadana, Ajit, University of Mississippi, USA
Sandacci, Serghei, Sensor Technology Ltd., UK
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India
Schneider, John K., Ultra-Scan Corporation, USA
Seif, Selemeni, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Shearwood, Christopher, Nanyang Technological University, Singapore
Shin, Kyuho, Samsung Advanced Institute of Technology, Korea
Shmaliy, Yuriy, Kharkiv National University of Radio Electronics, Ukraine
Silva Girao, Pedro, Technical University of Lisbon Portugal
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technology, India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., Northwestern University
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Institute for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
Vaseashta, Ashok, Marshall University, USA
Vazques, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyou University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Advanced Micro Devices, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung University of Science and Technology, Taiwan
Wu, Zhaoyang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Wuqiang, The University of Manchester, UK
Ymeti, Aurel, University of Twente, Netherland
Yu, Haihu, Wuhan University of Technology, China
Yufera Garcia, Alberto, Seville University, Spain
Zagnoni, Michele, University of Southampton, UK
Zeni, Luigi, Second University of Naples, Italy
Zhong, Haoxiang, Henan Normal University, China
Zhang, Minglong, Shanghai University, China
Zhang, Qintao, University of California at Berkeley, USA
Zhang, Weiping, Shanghai Jiao Tong University, China
Zhang, Wenming, Shanghai Jiao Tong University, China
Zhou, Zhi-Gang, Tsinghua University, China
Zorzano, Luis, Universidad de La Rioja, Spain
Zourob, Mohammed, University of Cambridge, UK

Contents

Volume 79
Issue 5
May 2007

www.sensorsportal.com

ISSN 1726-5479

Research Articles

| | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Standardized Interconnectivity of Sensors for Construction Machines via CAN Bus with the Higher-Layer Protocol CANopen <i>Christian Dressler</i> | 1143 |
| An Analysis of Sawtooth Noise in the Timing SynPaQ III GPS Sensor <i>Yuriy S. Shmaliy, Oscar Ibarra-Manzano, Luis Arceo-Miquel, Jorge Munoz-Diaz</i> | 1151 |
| Cross-Talk Compensation Using Matrix Methods <i>David Schrand</i> | 1157 |
| Model Based Evaluation of a Controller Using Flow Sensor for Conductivity Process <i>P. Madhavasarma, S. Sundaram</i> | 1164 |
| Investigation of Pull-in Phenomenon on a Extensible Micro Beam Subjected to Electrostatic Pressure <i>Ghader Rezagadeh, Hamed Sadeghian, Isa Hosseinzadeh , Alireza Toloei</i> | 1173 |
| SnO₂/PPy Screen-Printed Multilayer CO₂ Gas Sensor <i>S. A. Waghuley, S. M. Yenorkar, S. S. Yawale and S. P. Yawale</i> | 1180 |
| Characterization of Modified Rosen-Type Piezoelectric Transformers as a Function of Load Resistance <i>Selemani Seif</i> | 1186 |
| Lactate Biosensor Based on Cellulose Acetate Membrane Bound Lactate Oxidase <i>Suman and C. S. Pundir</i> | 1192 |
| A Novel Noninvasive Sensing Approach of Assessment of Pelt Quality <i>S. C. Mukhopadhyay, S. Deb Choudhury, Vijayant Suri, T. Allsop and G. E. Norris</i> | 1202 |
| Sol-gel processed Titania films on a Prism substrate as an Optical Moisture Sensor <i>B. C. Yadav</i> | 1217 |

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: <http://www.sensorsportal.com/HTML/DIGEST/Submition.htm>

Standardized Interconnectivity of Sensors for Construction Machines via CAN Bus with the Higher-Layer Protocol CANopen

Christian DRESSLER

CAN in Automation (CiA), Am Weichselgarten 26, DE-91058 Erlangen, Germany

E-mail: headquarters@can-cia.org, <http://www.can-cia.org>

Received: 1 February 2007 /Accepted: 11 May 2007 /Published: 31 May 2007

Abstract: The paper provides the functionality of CANopen and introduces the specifications, which define the integration of sensors in construction machines. The paper will finish with a detailed description of an example network configuration. *Copyright © 2007 IFSA.*

Keywords: Bus, Network, CANopen, Mobile, Construction

1. Introduction

When the European research project OSYRIS was looking for an appropriate sensor communication standard, the participating companies decided to chose CANopen. The requirements were plug-and-play capability, dedicated sensors and the specification of set points for the sensors.

The specification CiA 415, the “CANopen device profile for road construction machinery” was jointly developed within the OSYRIS project (Open System for Road Information Support) and supported by the European Asphalt Pavement Association (EAPA).

2. Fundamentals

The components for mobile usage have to prevail under extreme conditions and be easy to integrate and to be operated. There exist a lot of different types of construction machines on the market. But as different machines often have the same types of sensors installed, the amount of different sensor-types used on the machines is not as high. An overview of the sensor-types which have been specified in CiA 415 is shown in Table 1.

The requirements to the sensor devices are very high: Due to the rough conditions like extreme temperatures, very high humidity, vibrations or strokes, appropriate connectors, cables and packaging has to be used. Because in mobile machines the environment can't be controlled, the immunity to EMI is also an important factor. A sensor system for a construction machine should be quick and easy installed. This assumes that hardware and devices do already exist on the market. Existing software for development or diagnostics will also reduce the time-to-market. The sensors should have plug-and-play capability and the network should be able to be split to an integration network. This allows different bit-rates, longer distances and improved redundancy.

Table 1. Sensor Types supported by CiA 415.

| Sensor types | |
|----------------------------|---------------------------|
| 3D absolute position | Transversal roughness |
| Angle Position | Tool extend |
| Curvilinear coordinates | Material volume |
| Curvilinear angle position | Material core temperature |
| Geographical coordinates | Mass flow |
| Level-deviation | Volume flow |
| Horizontal deviation | Ambient temperature |
| Steering angles | Base temperature |
| Machine speed | Wind speed |
| Traveled distance | Surface temperature |
| Rotational speed | Wind direction |
| Layer measurements | Humidity |
| Longitudinal roughness | Barometric pressure |
| Water tank level | Rainfall |

Standardization has advantages for the sensor manufacturer. He doesn't need to customize his product to the requirements of each client every time. He gets the chance to compete with other OEMs. On the other hand, the system integrator is interested in huge choice of products which work together in the machine without customizing them first. The availability of standardized products on the market reduces the time-to-market of the machine.

CAN is standardized in ISO 11898-1 to 3, the CANopen profile CiA 301 "Application Layer and Communication Profile Version 4.0" is described by EN 50325-4.

CAN is a serial bus system, which was originally developed for automotive applications in the early 1980's. CAN, which is by now available from around 40 semiconductor manufacturers in hardware, provides two communication services: the sending of a message and the requesting of a message. All other services such as error signaling, automatic re-transmission of erroneous frames are user-transparent, which means the CAN chip automatically performs these services.

The voltage of the differential signal is according to ISO 11898-2 between -2 and +7 Volt which provides great immunity to EMI. The nominal specific propagation delay of the two-wire bus line is specified at 5 ns/m. CiA 102 defines the bit-timing for rates of 10 Kbit/s to 1 Mbit/s. The data is protected by the data link layer very well (worst case residual error probability of $P = 7 \cdot 10^{-9}$).

3. CANopen Basics

Since the CAN standard just describes the transmission of data over the bus, CANopen describes how to

interpret the content of those data messages. According to the OSI Reference Model, CAN provides layer 1 (Physical Layer) and layer 2 (Data Link Layer), whereas CANopen acts as layer 7 (Application Layer). CANopen is a widely used and flexible standard which can be adapted to many different applications.

The CANopen Object Dictionary:

The Object Dictionary (OD) is a data storage which has to be implemented in the application of every node. It is a grouping of objects stored in a look-up table. The OD is the interface between the communication on the bus and the software application of the nodes. It is organized as index, so every object has a unique index-number and can additionally be divided into sub-index-numbers.

An object consists of the object-name, the object-code (e.g. variable, array), the data type (e.g. unsigned16, integer8), the entry category (if implementation of the object is mandatory or optional), the access type (e.g. read-only, read-write), the value range and a default value. The OD stores data such as process data, identification properties or configuration and communication parameters.

CANopen communication model:

CANopen defines two types of transmission services. They are called Process Data Object (PDO) service and Service Data Object (SDO) service. Additionally, it provides a Network Management (NMT) service, Node monitoring services and an emergency object (EMCY), which indicates errors quickly.

PDO: The CAN message consists besides some status flags just of a unique identifier and the data field. A PDO is a data message with no overhead data, the whole space of the data field can be used to transmit the process data, no CANopen specific control-bits are sent. The size of the process data per message is limited to 8 byte, due to ISO 11898-1. The message is broadcasted (producer/consumer-model) to all nodes and is unconfirmed. So it can be received by zero or more nodes, depending on whether the connected nodes are accepting the message-identifier or not. The transmission type describes the kind of trigger to send a PDO. A message can be sent if a timer runs out, if a specific value changed, or if the so-called sync-signal is received. A PDO which is sent to another node is called Transmit PDO (TPDO). A TPDO which is received from another node is called Receive-PDO (RPDO). To configure PDO communication, the PDOs have to be mapped: The PDO mapping assigns the content of an object to a message-identifier. This applies for TPDOs as for RPDOs. A TPDO reads out the mapped object before sending its content, the content of an RPDO is written into an object according to the mapping in the OD. The mapping in the OD can be configured whether via SDO or can already be pre-defined. The PDO service is normally used to submit data under real-time conditions with no need for confirmation.

SDO: The SDO protocol defines the communication between two nodes (server/client-model). The service is confirmed and the amount of the data to be transmitted is not limited. If the size of the data which shall be transmitted exceeds the maximum available space, the data is split into many messages. As the service is confirmed, two CAN-IDs are required for the communication between server and client. One CAN-ID for messages to be received by the server and one ID for those messages intended to be received by the client. This service is normally used to configure a network: The configuring node is a client, whereas the rest of the nodes are servers. SDOs are used for example for: setting device parameters, assigning application data to PDOs or assigning message identifiers.

Figure 1 depicts the interface functionality of CANopen. The raw data of a sensor device, e. g. voltage, is sent to an application. This software is the manufacturer-specific interpretation of the requirements, described by a CANopen profile. In the next step the calculated values are assigned to the right indices of the Object Dictionary as defined in the CANopen profile. To enable read- and write-access from other devices to the Object Dictionary, the protocol stack defines the communication protocols.

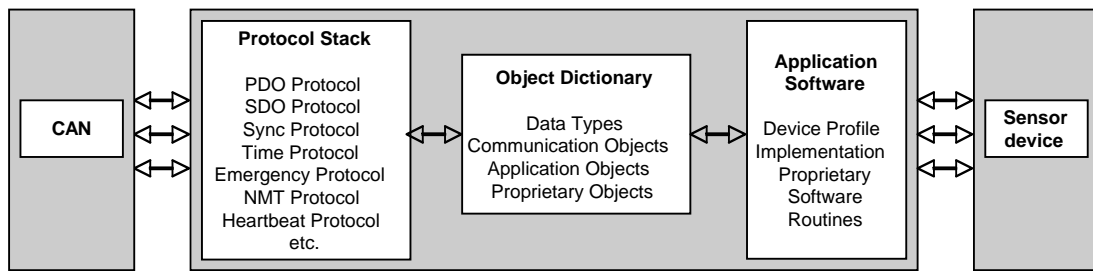


Fig. 1. Between sensor device and CAN, the CANopen application manages the communication.

4. CANopen Documents for Sensor Integration

Since the specification CiA 301 just defines the basics of communication, CiA 415 defines each sensor of a whole sensor application. To use the sensor application profile in an integrated network, the application profile CiA 436 has been developed. It defines the communication between sub-networks, such as sensors, user interface, engine or transmission (Figure 2).

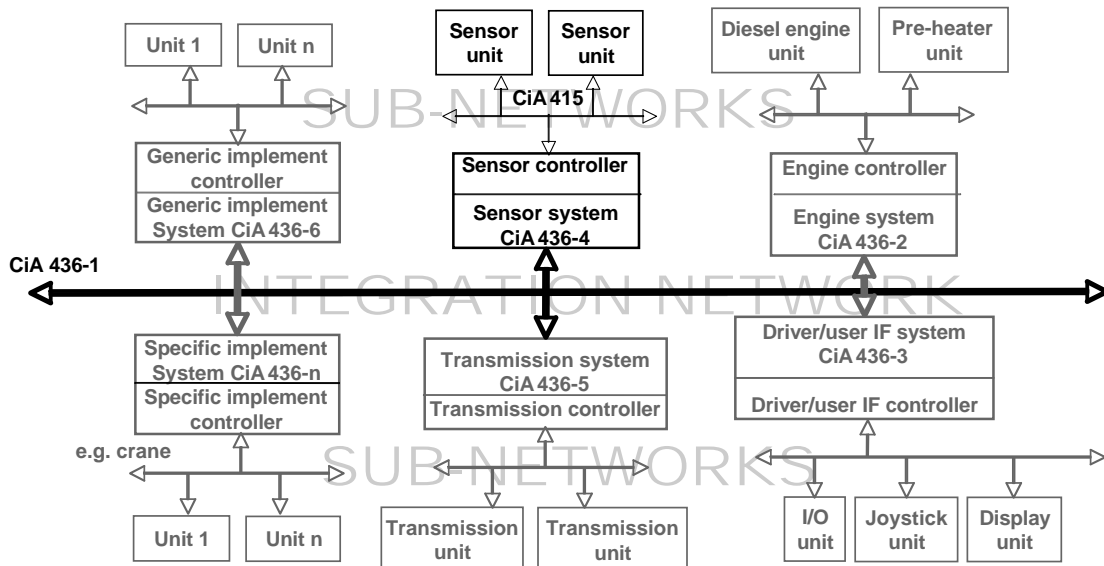


Fig. 2. The structure of the integration network according to CiA 436 including CiA 415.

CiA 301: This specification provides services like SDO, PDO, EMCY, Heartbeat or NMT. CiA 301 has to be implemented in every device, which shall be conforming according to CANopen.

CiA 415: This specification defines extra services, connectors and the data provided by the sensors. To provide auto-configuration of the sensor devices, a master-slave structure is required. The sensor controller (master) provides the CANopen manager functions. The specification defines a special boot-up process as shown in Figure 3: The sensor controller scans all 127 node-IDs available in one network. The request to the sensor devices is done via the SDO service. If the access to object 0x1000 (device type) of a node does not fail, the object 0x6010 of the object dictionary is read. The amount of provided sensor process data can be read from sub-index 0x00. The following sub-indices are a list of supported objects. Such objects provide process data such as the temperature of the processed layer or the wind speed. With this information, the TPDO mapping and communication parameters for the sensor devices are generated and downloaded to them. Thus, the sensor controller has determined which device receives which messages. The control unit also knows now, how many physical devices according to CiA 415 are available in the

network and how many virtual devices (functionalities) each physical device includes. The next information the controller unit is interested in, is the kind of data each sensor wants to receive. This information is stored in object 0x6020 of each sensor device. After successful receiving this data, the control unit can generate the RPDO parameter for the sensor devices and download them to the devices. Now, every sensor has selected, which of the other sensors' TPDOs will be received. After this process, the recognized nodes are being started (set to NMT state "Operational"). A "Data Status Request" is sent via PDO, and when no error occurs, the sensor application master will be started.

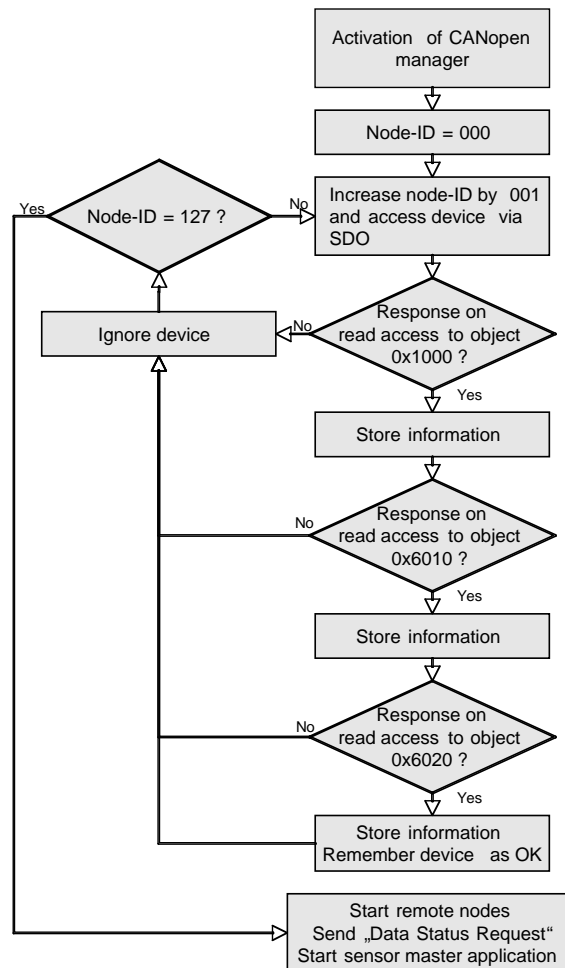


Fig. 3. Boot-up procedure of the CANopen manager.

The object dictionary begins with machine- and tool-specific objects and objects for the event transfer system are defined. Then, the sensor objects are divided into four parts. Each of the four parts contains the same list of sensor names, but with different indices and access types. These four parts are called: "Provided process data" with access type read-only, "Required process data" (read-write), "Configured reference-values (set-points)" (read-only) and "Requested reference-values (set-points)" (read-write). A sensor device needs those objects as follows: The data provided by an e.g. ambient temperature sensor is stored in the object "ambient temperature" shown in part one. If this sensor wants to receive data from the sensor "wind speed", the object "wind speed" listed in part two has to be implemented in the ambient temperature sensor. The communication directions of this example can be seen in Figure 4. The set-point of the sensor is stored in the object "ambient temperature" of part three, and if the set-point of the "surface temperature" sensor shall be received from ambient temperature sensor, object "surface temperature" from part four has to be implemented.

CiA 436: This specification defines special gateways, which are connected between a sub-network and the

integration network. Real-time data can be mapped from the sub-network to the integration network. At the moment, CiA 436 consists of five parts: The first part defines common objects. They apply to all gateway devices, which are specified in the parts 2 to 6. The parts describe the sub-networks as shown in Figure 2.

5. An Example Configuration

The theory of the preceding clauses shall now be demonstrated with the aid of a pictorial example. This is not an example taken from the practical use. In our imagination, the sensor application providing the ambient temperature around the machine wants to adjust the temperature values in real-time. The sensor shall receive the wind speed and the surface temperature directly to take their values into account of its calculation. In Figure 4 a flowchart is shown, which describes the data transfer of the devices in the sensor network. Each of the three sensor devices submits its process data to the master. Additionally, the sensor application which is processing the ambient temperature shall receive the process data of the other two sensors. As we are dealing with a bus system, Figure 4 doesn't show the physical connections. In our example, the manufacturer of sensor 1 and sensor 2 has decided to integrate them into one physical device. The physical realization is shown in Figure 5. The three devices are connected to a bus. When a device is sending a message, every other device will select, if it wants to receive this message. This selection is done by the CAN-IDs. If Sensor 2 is sending a TPDO with the CAN-ID being 0x190, all devices which have RPDOs listening on CAN-ID 0x190 configured, will receive this message. In our example, the master and sensor 4 in Figure 5 will receive the wind speed as shown in Figure 4. Thus, the communication can be described with RPDOs and TPDOs.

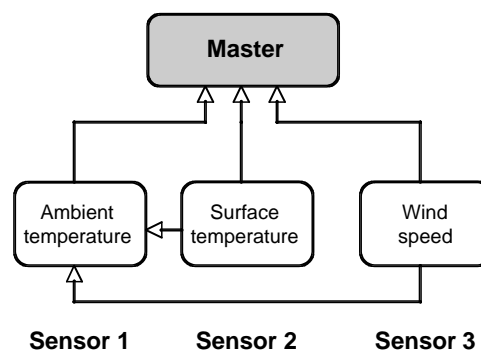


Fig. 4. The arrows describe the desired communication between the sensors and the master.

As Sensor 1 and Sensor 2 have been merged to sensor 4, they share the same micro-controller and thus the CAN-connection, the object dictionary and the application. To transmit the surface temperature to sensor 1 like shown in Figure 4, no RPDOs or TPDOs are required. The application has already access to the values. But when transmitting process data to the bus, each virtual sensor uses its own CAN-ID, so other sensor devices don't have to bother about the physical constitution of the devices in the network.

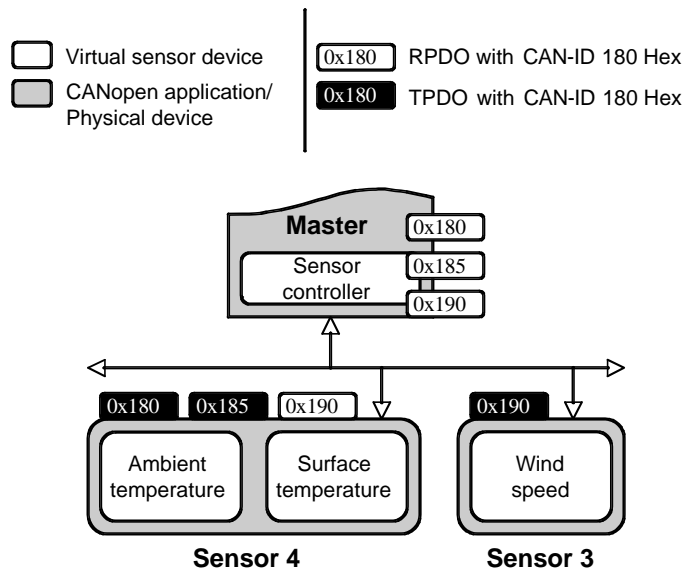


Fig. 5. An example how a sensor network can be realized with CANopen, showing the functionality of virtual devices.

To work over long distances, with different baud rates or with a limited band-width, it is recommended to split communication into own networks. To connect these networks in a standardized way, an integration network is required as shown in Figure 2.

Our example sensor 3, which is indicating the wind speed shall now be alone in the network according to CiA 415, connected to the integration network. The interface will be CiA 436-4. The second network, connected to the integration network shall include devices which have to be represented by two virtual interfaces, CiA 436-3 and CiA 436-2 as shown in Figure 6. As CiA 436 is an application profile, such as CiA 415, it also deals with virtual devices. Each interface connected to the integration network is a virtual device and thus can be merged.

If the current wind speed shall be shown on the display, the values can be read out either by access via SDO or by waiting for the appropriate PDO. When the sensor controller has received the values, it provides them to the object dictionary of the interface device according to CiA 436-4 at index 0x6542. An excerpt of each object dictionary is shown in Figure 6. The communication over the integration network to network 2 can happen on both ways, via SDO or PDO. The values are now stored in object 0x63AA of the controller's object dictionary. Now the software application has access to the values and can send them to the display. This communication can be manufacturer-specific. Due to this, the object dictionary doesn't contain any display-specific objects. Note that the indices of the integration network controllers are different to those of the sub-networks. This is because no overlapping of indices is allowed, when all parts of CiA 436 would be merged into one single object dictionary.

To enter a desired engine speed via HMI, part 3 describes object 0x64D0 where this entered value can be provided to the integration network. As part 2 and part 3 are now physically combined, these objects are not required any more for the communication between HMI and engine. But as the HMI may not be the only way to change the engine speed, the objects are still useful.

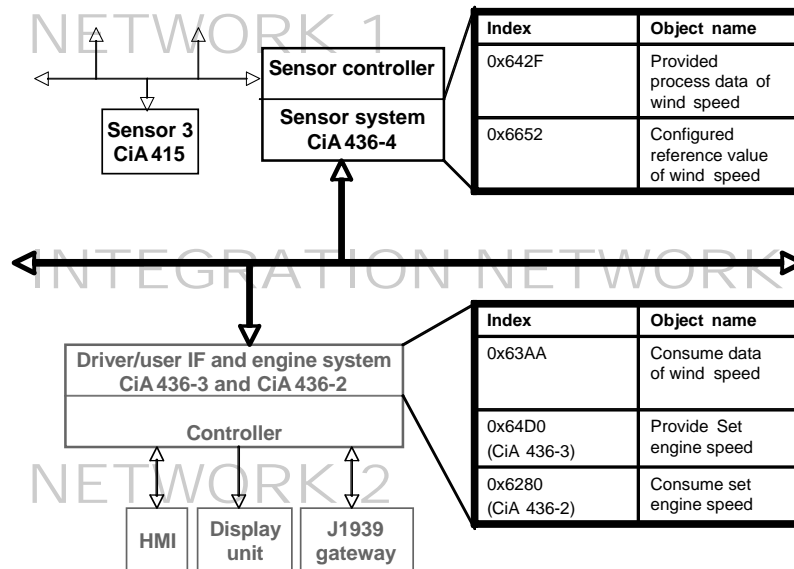


Fig. 6. An example constellation of sub-networks and integration network.

6. Conclusion

It is not easy to meet all the demands when integrating sensors on construction machines. But the car-proven robustness of CAN in combination with the customizable CANopen, which provides a special standard for a sensor system, is able to solve this task in a proper way:

The robust cables (CAN 5-wire cable including power supply), the EMI immunity due to the CAN differential balanced line, the quick and easy sensor integration and installation because of standardized components according to CiA 415 are important factors. Also the possibility of distributed sub-networks with standardized integration network according to CiA 436, the hardware availability (CAN and CANopen are wide spread) and last but not least the already existing proven software and diagnostic-tools, are part of the required features.

2007 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
 (<http://www.sensorsportal.com>)

Universal Frequency-to-Digital Converter (UFDC-1)

- 16 measuring modes: frequency, period, its difference and ratio, duty-cycle, duty-off factor, time interval, pulse width and space, phase shift, events counting, rotation speed
- 2 channels
- Programmable accuracy up to 0.001 %
- Wide frequency range: 0.05 Hz ...7.5 MHz (120 MHz with prescaling)
- Non-redundant conversion time
- RS-232, SPI and I²C interfaces
- Operating temperature range -40 °C...+85 °C

www.sensorspor.com
info@sensorsportal.com
SWP, Inc. Canada

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726- 5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In addition, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

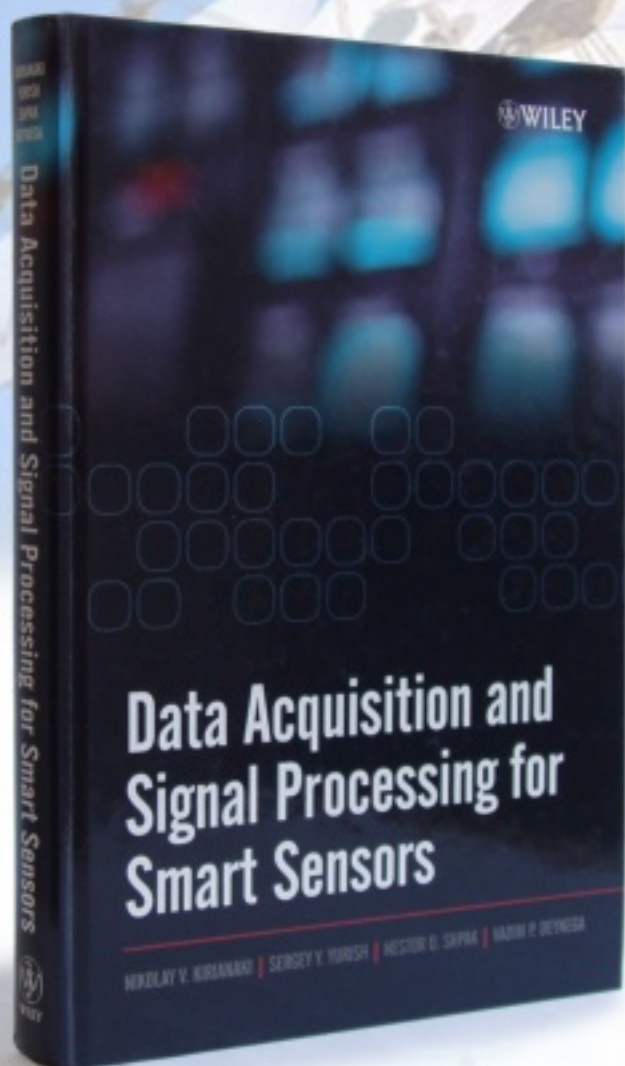
Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 4-12 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: <http://www.sensorsportal.com/HTML/DIGEST/Submission.htm> Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2007.PDF



KNOWLEDGE FOR GENERATIONS



'This book provides a good basis for anyone entering or studying the field of smart sensors not only for the inexperienced but also very useful to those with some experience'

(from IEEE Instrumentation & Measurement Magazine review)



Order online:

http://www.sensorsportal.com/HTML/BOOKSTORE/DAQ_SP.htm

www.sensorsportal.com