ISSN 1726-5479

SENSORS & TRANSDUCERS

8/08
vol. 95

Sensors and Transducers Applications

International Frequency Sensor Association Publishing

Sensors & Transducers

Volume 95
Issue 8
August 2008

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, Universitá 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, RF Arrays Systems, 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, Jiming, Zhejiang University, China
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 Nacional de Colombia, 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
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
Ko, Sang Choon, Electronics and Telecommunications Research Institute,
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
Ferecean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
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 Rosa, Juan Jose, University of Cadiz, Spain
Granel, 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 Alcala, 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
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, 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

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
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Lee, Jun Su, Amkor Technology, Inc. South Korea
Lei, Hua, National Starch and Chemical Company, USA
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, University of Oklahoma, 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
Lukaszewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
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
Melnyk, Ivan, Photon Control Inc., Canada
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, Benemérita Universidad Autónoma 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 Lahoucin, 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
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politecnico de Setebal, Portugal
Petsev, Dimiter, 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
Raoof, Kosai, Joseph Fourier University of Grenoble, France
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politecnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politecnica de Cataluna, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhbha Atomic Research Centre, Mumbai, India
Schneider, John K., Ultra-Scan Corporation, USA
Seif, Selemani, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Sengupta, Deepak, Advance Bio-Photonics, India
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
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., Northwestern University, USA
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
Teker, Kasif, Frostburg State University, USA
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tian, Gui Yun, University of Newcastle, UK
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, Lisheng, The Chinese University of Hong Kong, Hong Kong
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
Yong Zhao, Northeastern University, China
Yu, Haihu, Wuhan University of Technology, China
Yuan, Yong, Massey University, New Zealand
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

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA). Available in electronic and CD-ROM. Copyright © 2007 by International Frequency Sensor Association. All rights reserved.

Sensors & Transducers Journal

Contents

Volume 95
Issue 8
August 2008

www.sensorsportal.com

ISSN 1726-5479

Research Articles

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

Sensors & Transducers Journal, Vol. 95, Issue 8, August 2008, pp. 134-145

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Photogrammetric Resection Approach Using Straight Line Features for Estimation of Cartosat-1 Platform Parameters

[1]Nita H. SHAH, [2]B. ISLAM and [3]B. Gopala KRISHNA

[2,3] Space Applications Centre, ISRO, Ahmedabad –380 015, India

[1] Department of Mathematics, Gujarat University Ahmedabad –380 009, Gujarat, India

E-mail: nitahshah@gmail.com

Received: 28 June 2008 /Accepted: 15 August 2008 /Published: 25 August 2008

Abstract: The classical calibration or space resection is the fundamental task in photogrammetry. The lack of sufficient knowledge of interior and exterior orientation parameters lead to unreliable results in the photogrammetric process. There are several other available methods using lines, which consider the determination of exterior orientation parameters, with no mention to the simultaneous determination of inner orientation parameters. Normal space resection methods solve the problem using control points, whose coordinates are known both in image and object reference systems. The non-linearity of the model and the problems, in point location in digital images are the main drawbacks of the classical approaches. The line based approach to overcome these problems includes usage of lines in the number of observations that can be provided, which improve significantly the overall system redundancy. This paper addresses mathematical model relating to both image and object reference system for solving the space resection problem which is generally used for upgrading the exterior orientation parameters. In order to solve the dynamic camera calibration parameters, a sequential estimator (Kalman Filtering) is applied; in an iterative process to the image. For dynamic case, e.g. an image sequence of moving objects, a state prediction and a covariance matrix for the next instant is obtained using the available estimates and the system model. Filtered state estimates can be computed from these predicted estimates using the Kalman Filtering approach and basic physical sensor model for each instant of time. The proposed approach is tested with three real data sets and the result suggests that highly accurate space resection parameters can be obtained with or without using the control points and progressive processing time reduction. *Copyright © 2008 IFSA.*

Keywords: Cartosat-1, GCPs, Space resection, Kalman filter, St. line equation of normal to 2D & 3D plane

1. Introduction

Cartosat-1 (IRS-P5) satellite, an Indian stereo mission, was launched in 2005 for catering to photogrammetric and cartographic applications. Launched into polar sun-synchronous circular orbit at an altitude of 618 km, the satellite continues to provide stereo data through its twin Panchromatic (PAN) cameras having high resolution of ~2.5 m and a swath of ~30 km. Both the cameras are tilted with respect to the nadir direction in order to get two views in along the track, one at an angle of +26 deg and the other at -5 deg. The camera looking ahead is called Fore camera and the other one looking near nadir is Aft camera. The primary goal and advantage of Cartosat-1 mission is generation of Digital Elevation Model (DEM) for orthoimage production and 3D terrain visualization on a global basis. Push-broom scanning technique is used in Cartosat-1 for acquiring images like in any other IRS satellites.

The imaging geometry of Cartosat-1 is well modeled by photogrammetric collinearity condition. This method is being used in Cartosat-1 Data Product Generation System (DPGS) s/w for generating high accurate data products as well as in Stereo Strip Triangulation System (SSTS) s/w for generation of country wide Digital Elevation Model (DEM) and Triangulated Control Points (TCPs) over a strip of 500 km. GPS based precise control points are used for this purpose. With the available control points and TCPs, data products team continues to study and carry out various approaches for modeling the imaging geometry of Cartosat-1. Some of the approaches undertaken earlier for modeling exterior platform parameters are using *Kalman Filter* [1, 2], Coplanarity model [3] for improving Cartosat-1 data products accuracy, while the most recent exercises carried in this direction is *Kalman Filter (recursive approach)* approach in space resection problem using straight line features [4], to estimate the Cartosat-1 platform parameters and hence improve the geometric accuracy of data products. This method works with linear features identified in the image or line formation using precise control or image points identified in the image plane.

This paper describes the approach adopted for refining platform parameters of Cartosat-1 using line based resection method with *Kalman Filter*. Details of study and mathematical formulations are described in this report. Also, this report brings out results obtained using Cartosat-1 data sets along with summary of investigations and analysis on the proposed approach.

2. Mathematical Model for Space Resection Using Straight Lines as Features

The mathematical formulation on the approach using straight lines as features to solve photgrammetric space resection is described here. An explicit mathematical relation is established between straight lines in image space and object space. The mathematical model adopted for the solution of the space resection problem using straight lines is based on the equivalence between the vector normal to interpretation plane in the image space and vector normal to the rotated interpretation plane in the object space. The interpretation plane is defined as being the plane, which contains the straight line in the object space (L), the projected straight line in the image space (I), and the perspective center (**PC**) of the camera.

The vector normal to the interpretation plane in the image space is given by

$$\mathbf{N}^{\mathbf{T}} = - [f \cos\theta \ f \sin\theta \ -\rho] , \qquad (1)$$

where f is the focal length and θ and ρ are the parameters of the straight line in the image plane, using its normal representation ($x \cos\theta + y \sin\theta - \rho = 0$).

The vector **n**, normal to the interpretation plane in the object space, is defined by the vector product(symbol x) of the direction vector of the straight line (**d**), **PC** denotes the perspective center co-ordinates, **C** is corresponding object points vector and the vector difference (**PC – C**) (see Fig. 1): i.e.,

$$\mathbf{n} = \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix} = \mathbf{d} \text{ x } [\mathbf{PC} - \mathbf{C}] = \begin{bmatrix} -n.(Y_c - Y_1) + m.(Z_c - Z_1) \\ n.(X_c - X_1) + l.(Z_c - Z_1) \\ -m.(X_c - X_1) + l.(Y_c - Y_1) \end{bmatrix}, \tag{2}$$

where X_c, Y_c, Z_c are the coordinates of the perspective center of the camera; X_1, Y_1, Z_1 are the three-dimensional coordinates of a known point on the straight line; and ***l***, ***m***, ***n*** are the components of the direction vector **d** of the straight line; all are defined in the object space reference system.

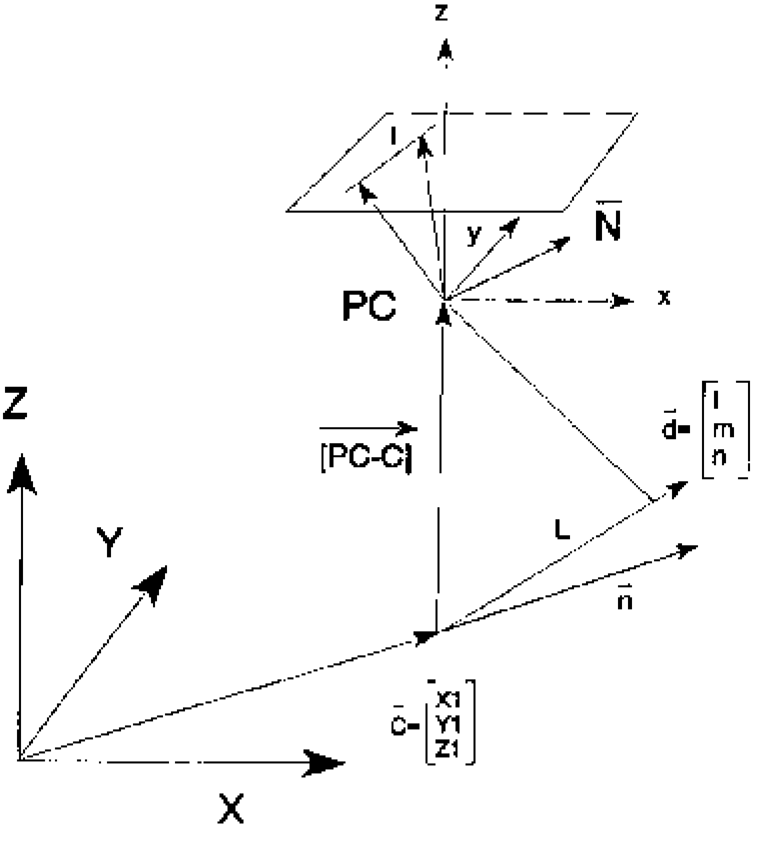


Fig. 1. Vector normal to the interpretation plane in object space and in image space.

Multiplying vector **n** by the rotation matrix **R** eliminates the angular differences between the object and the image reference systems and results in a vector normal to the interpretation plane in object space that has the same orientation as vector **N**, normal to the interpretation plane in the image space, but different in magnitude. Thus,

$$\mathbf{N} = \lambda\, \mathbf{R}\, \mathbf{n}\,, \tag{3}$$

where λ is a scale factor, defined by $\lambda = ||\mathbf{N}||/||\mathbf{n}||$, and **R** is the rotation matrix defined by

$$\mathbf{R} = m_1 * m_2 * m_3 \tag{4}$$

m_i's represents the different transformation matrices from object point to image point conversions (Earth centered inertial to orbit to body to payload system in the way defined for Cartosat-1).

The rotation matrix as in equation (4) can be subdivided into three row vectors: i.e.,

$$R_1 = [r_{11}\ r_{12}\ r_{13}]$$
$$R_2 = [r_{21}\ r_{22}\ r_{23}]$$
$$R_3 = [r_{31}\ r_{32}\ r_{33}]$$

where the r_{ij}'s are the elements of the rotation matrix **R**, as defined in Equation (4). Using Equation (1) and (2), equation (3) can be rewritten as

$$\begin{bmatrix} f.\cos\theta \\ f.\sin\theta \\ -\rho \end{bmatrix} = -\lambda \begin{bmatrix} r_{11}.n_x + r_{12}.n_y + r_{13}.n_z \\ r_{21}.n_x + r_{22}.n_y + r_{23}.n_z \\ r_{31}.n_x + r_{32}.n_y + r_{33}.n_z \end{bmatrix} \tag{5}$$

Equation (5) can be rewritten as (by eliminating λ)

$$\cot\theta = \frac{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z}{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z} \tag{6}$$

$$\frac{-\rho}{f.\sin\theta} = \frac{r_{31}.n_x + r_{32}.n_y + r_{33}.n_z}{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z}$$

Using the relationships between the elements of the normal vector and the parametric representation of the straight line in the image, equation (6) can be rewritten as

$$\boldsymbol{a} = -\frac{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z}{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z} \tag{7}$$

$$\boldsymbol{b} = -f\,\frac{r_{31}.n_x + r_{32}.n_y + r_{33}.n_z}{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z},$$

where the elements of the parametric equation (y = ax + b) are

$$\boldsymbol{a} = -\cot\theta \text{ and } \boldsymbol{b} = \rho/\sin\theta$$

$$\tan\theta = \frac{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z}{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z} \tag{8}$$

$$\frac{\rho}{f.\cos\theta} = \frac{r_{31}.n_x + r_{32}.n_y + r_{33}.n_z}{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z}$$

In this case, a new parameters for the straight line must be introduced: i.e.,

$$x = \boldsymbol{a^*}\,y + \boldsymbol{b^*}, \tag{9}$$

where

$$\boldsymbol{a}^* = -\tan\theta \text{ and} \tag{10}$$

$$\boldsymbol{b}^* = \rho / \cos\theta \tag{11}$$

Using the equations (10) and (11), equation (8) can be rewritten as

$$\boldsymbol{a}^* = -\ \frac{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z}{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z} \tag{12}$$

$$\boldsymbol{b}^* = -\ \mathrm{f}\ \frac{r_{31}.n_x + r_{32}.n_y + r_{33}.n_z}{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z}.$$

This Equation (12) form the basic mathematical model used for making the partial derivative matrix, which is used as input for *Kalman Filter* recursive approach.

3. Kalman Filter Application to the Resection Problem

For dynamic systems, if the estimate for the motion parameters were available, it would be feasible for the extension of the recursive procedure to the next instant (next image). Using the system model, the estimated motion parameters and the filtered state (camera orientation parameters), the feature position is predicted for the next instant and the new position are computed.

From the earlier study and experiments conducted for Cartosat-1 with various approaches, the bias error is observed large in attitude components than any other error sources. Therefore, this approach is implemented to estimate the biases in roll, pitch and yaw components. Also, the IEKF (Iterated Extended *Kalman Filtering*) is a recursive method used for state estimation, which enables an observation to be processed once it becomes available. This property makes feasible the proposed recursive strategy in which feature identification in the image is improved by better state estimates. The original *Kalman Filter* approach [1] used for estimating attitude components for Cartosat-1 has been modified for the present study.

The application of the IEKF to the space resection model results in the following dimensions for matrices and vectors:

$$X_{3x1}\ M_{2x3}\ P_{3x3}\ K_{3x2}\ Z_{2x1}\ ,$$

where
$\mathbf{X_k} = [\boldsymbol{\kappa}, \boldsymbol{\varphi}, \boldsymbol{\omega}]^T$ is taken as a state vector defining the orientation (roll, pitch & yaw) of camera at time t_k,
$\mathbf{Z}_k^j = [a,b]^T$ are the observations vector for the jth feature in the image at time t_k,
K is the Kalman Gain matrix,
M is the partial derivative matrix and
P is the state covariance matrix.

Using this notation, Equations (7) and (12) can be rewritten as

$$\boldsymbol{a} = -\frac{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z}{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z} = -\ \frac{R_1.n}{R_2.n} \tag{13}$$

$$\boldsymbol{b} = -f.\frac{r_{31}.n_x + r_{32}.n_y + r_{33}.n_z}{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z} = -\ \mathrm{f}\frac{R_3.n}{R_2.n}$$

$$\boldsymbol{a^*} = -\ \frac{r_{21}.n_x + r_{22}.n_y + r_{23}.n_z}{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z} = -\ \frac{R_2.n}{R_1.n} \tag{14}$$

$$\boldsymbol{b^*} = -\mathrm{f}\ \frac{r_{31}.n_x + r_{32}.n_y + r_{33}.n_z}{r_{11}.n_x + r_{12}.n_y + r_{13}.n_z} = -\mathrm{f}\ \frac{R_3.n}{R_1.n},$$

where f is the camera focal length, **n** is the vector normal to the interpretation plane in the object space, and ***a*** and ***b*** ($\boldsymbol{a}^*$ and $\boldsymbol{b}^*$) are the observations, defined as

$$\boldsymbol{a} = \mathrm{G}_1\ (\mathrm{x_k}) = -\ \frac{R_1.n}{R_2.n} = -\ \frac{v}{u}\ \text{(say)} \tag{15}$$

$$\boldsymbol{b} = \mathrm{G}_2\ (\mathrm{x_k}) = -\ \mathrm{f}\ \frac{R_3.n}{R_2.n} = -\mathrm{f}\ \frac{w}{u}\ \text{(say)}$$

$$\boldsymbol{a^*} = \mathrm{F}_1(\mathrm{x_k}) = -\ \frac{R_2.n}{R_1.n} = -\ \frac{u}{v} \tag{16}$$

$$\boldsymbol{b^*} = \mathrm{F}_2(\mathrm{x_k}) = -\ \mathrm{f}\ \frac{R_3.n}{R_1.n} = -\mathrm{f}\ \frac{R_3.n}{R_1.n} = -\ \mathrm{f}\ \frac{w}{v}$$

For the measurement model as stated in equation (15), **M** matrix can be obtained by the partial derivatives of the measurement model with respect to the elements of the state vector as

$$\mathrm{M} = \begin{bmatrix} \frac{\partial F_1}{\partial \kappa} \frac{\partial F_1}{\partial \phi} \frac{\partial F_1}{\partial \omega} \\ \frac{\partial F_2}{\partial \kappa} \frac{\partial F_2}{\partial \phi} \frac{\partial F_2}{\partial \omega} \end{bmatrix},$$

where

$$\frac{\partial F_1}{\partial x_i} = -\frac{R_2'.n.R_1.n - R_2.n.R_1'.n}{(R_1.n)^2}$$

$$\frac{\partial F_2}{\partial x_i} = -\ \mathrm{f}\ \frac{R_3{}'.n.R_1.n - R_3.n.R_1{}'.n}{(R_1.n)^2} \quad \mathrm{i} = 1,2,\ \ldots..,6$$

and x_i is an element of the state vector, **′** (dash) denotes differentiation w.r.t state vectors.

The derivative of the rotation matrix with respect to state elements is

$$\frac{\partial R_1}{\partial \kappa}=\mathrm{R}_2,\ \frac{\partial R_1}{\partial \phi}=-\mathrm{R}_3\, c\kappa,\ \frac{\partial R_1}{\partial \omega}=\begin{bmatrix}0 & -r_{13} & r_{12}\end{bmatrix},$$

$$\frac{\partial R_2}{\partial \kappa}=-R_1,\frac{\partial R_2}{\partial \phi}=R_3 s\kappa,\frac{\partial R_2}{\partial \omega}=\begin{bmatrix}0 & -r_{23} & r_{22}\end{bmatrix}.$$

$$\frac{\partial R_3}{\partial \kappa}=0,\frac{\partial R_3}{\partial \phi}=\begin{bmatrix}c\phi & s\omega.s\phi-c\omega.s\phi\end{bmatrix},\ \frac{\partial R_3}{\partial \kappa}=\begin{bmatrix}0 & -r_{33} & -r_{32}\end{bmatrix}.$$

where ci = cosi and si = sini (i represents angle).

The partial derivative of the measurement model (Equation (15) with respect to the rotations are

$$\frac{\partial F_1}{\partial \kappa}=1+\frac{u^2}{v^2},\frac{\partial F_2}{\partial \kappa}=f.\frac{w.u}{v^2},\frac{\partial F_1}{\partial \phi}=-\frac{s\kappa.w.v+c\kappa.w.u}{v^2},$$

$$\frac{\partial F_2}{\partial \phi}=-f\frac{(c\phi.n_x+s\omega.s\phi.n_y-c\omega.s\phi.n_z).v+c\kappa^2.w}{v^2},$$

$$\frac{\partial F_1}{\partial \omega}=-\frac{(r_{23}.n_y \_ r_{22}.n_z).v-u.(-r_{13}.n_y+r_{12}.n_z)}{v^2},$$

$$\frac{\partial F_2}{\partial \omega}=-f\frac{(r_{33}.n_y+r_{32}.n_z).v-w.(-r_{13}.n_y+r_{12}.n_z}{v^2}.$$

The partial derivative for the measurement model are obtained and given as input to the sequential estimator as an initial estimate. The complete implementation approach is described in the next section.

4. Methodology

While implementing the above described model for Cartosat-1, the following points are considered viz.

1. The laboratory calibrated interior orientation parameters of both cameras are precisely known and they are used in this approach.
2. Ground Control Points(GCPs)' precise positions are known in the image(strip of 500 km) along with their GPS ground position. The object model is known by treating 2 GCPs as the end points of straight line corresponding to the two end points in the image plane. Also, the approach has been attempted with estimated ground positions of the two image points by treating them as straight line (joining the end points of two consecutive points) and this is to prove that only the image points are sufficient for estimating the platform parameters.
3. For initial approximation, a priori estimates of orientation parameters are taken from Cartosat-1 ancillary data.

4. At the initial time t_0, the priori estimate for state vector x_0 and its covariance matrix p_0 are assigned to variables x_{k-1} and p_{k-1} respectively.
5. Using the predicted state vector estimate x_k a perspective transformation is applied to the endpoints of all straight lines in the object model.

Let $\boldsymbol{x}_k = [\boldsymbol{\kappa}, \boldsymbol{\varphi}, \boldsymbol{\omega}]$ be the state vector defining the camera orientation at time t_k and p_k its covariance matrix, and let $\boldsymbol{z}_k^j = [\boldsymbol{a^*}, \boldsymbol{b^*}]^T$ be the observation vector for the j^th^ feature in the image.

The filtered state parameters and their covariance matrix obtained using the j^{th} observation are used as the predicted values for the $(j+1)^{th}$ observation to update the perspective transformation from object to image space. After each iteration, the filtered state parameters obtained are better than the previous ones; hence, the displacement between the acquired image feature and the projected one is progressively reduced, resulting in a reduction of RMS error corresponding to each iteration. This procedure is repeated until all available lines have been processed. In our study, we have used only 4 points i.e. two straight lines, which is the minimum requirement by the model.

After platform parameters are updated by the *Kalman Filter* based resection model using lines as features, ground to image (G2I) mapping is used to evaluate the performance of the model by considering all other GCPs as check points.

5. Results and Discussions

Space resection approach with the help of sequential estimator (*Kalman Filter*) using straight line features for improving Cartosat-1 platform parameters is discussed here. The study includes various experiments conducted with different Cartosat-1 stereo data sets and analysis of the results achieved. The exercises were carried out for 3 data sets of Cartosat-1 with the help of a few control points from stereo pair (Table 1). Though control points are necessary for absolute calibration of platform parameters, this method was tried without using control points also (Table 2). Modeling the attitude parameters were carried out with and without control points while performance of this method was assessed using different set of control points as check points. Results were evaluated at check points at both pre and post model level. Statistical criteria viz. both RMS error and standard deviation (Std. Dev) were used for assessing accuracy measures. Results of pre adjustment (system level using Cartosat-1 onboard measured attitudes) are compared with post resection level (using improved attitudes) for both cases of with and without GCPs for each data set.

The following conclusions are derived from the present experiments conducted for Cartosat-1.

1. As can be seen from Table 1, post resection results show good improvement in terms of RMS error for both along and across directions. This confirms that biases present in attitude are better estimated by the proposed approach. This is seen for all the three data sets for both Fore and Aft cameras.
2. The overall behavior of the platform parameters (roll, pitch and yaw) are shown for one particular case (date of pass: 28th May 2005) in Fig. 2 (Fore) and Fig. 3 (Aft).
3. Further, it is clear from Table 1 that standard deviation at both pre & post level are nearly same in pixel direction whereas it is not so for scan direction. There is slight deterioration in scan direction. This could be due to the fact that the model does not use higher order attitude variation, as it estimates biases only using two line features. More number of line features may be necessary and this is to be tested.
4. It is observed that Aft camera post results are better than Fore camera results for all cases. However, it can be concluded that the overall accuracy of the model is well within 10 pixels for both

directions, which is better than the system level accuracy. Additional testing, experiments and investigations are required for improving further.

5. From Table 2, it can be seen that without using the actual control points it is possible to refine the biases for attitude components. More testing is required in this direction.
6. It is to be noted that the points considered for modeling are lying between 0.4 seconds to maximum 5.0 seconds while check points for accuracy evaluation are taken from extrapolated region, in the range of 1.0 to 10 seconds

The sequence of steps followed for this recursive approach to the solution of the space resection problem is described in the flow chart (Fig. 4).

Table 1. Pre- and Post- resection results.

DOP	**Cameras**	**Rms scan (in pixel)**		**Rms pix (in pixel)**		**Std. scan (in pixel)**		**Std. pix (in pixel)**	
		Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
28th May	Fore	47.49	7.95	3.47	5.48	2.47	7.94	3.12	2.87
	Aft	30.48	3.27	9.72	3.19	2.22	2.18	3.53	3.11
8th June	Fore	29.86	6.67	5.84	2.27	3.05	6.61	2.30	2.27
	Aft	12.69	2.47	3.21	1.81	2.13	2.09	1.86	1.79
4th Nov.	Fore	29.13	9.35	10.39	1.32	1.48	3.06	1.44	1.32
	Aft	17.20	3.46	26.77	1.002	1.06	2.84	1.10	0.96

Table 2. Results of resection without using control points.

DOP	**Cameras**	**Rms scan (in pixel)**		**Rms pix (in pixel)**		**Std. scan (in pixel)**		**Std. pix (in pixel)**	
		Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
28th May	Fore	47.49	7.92	3.47	2.50	2.47	7.53	3.12	2.26
	Aft	30.48	2.42	9.72	3.35	2.22	2.07	3.53	1.79
8th June	Fore	29.86	13.02	5.84	3.06	3.05	8.03	2.30	2.85
	Aft	12.69	6.64	3.21	3.11	2.13	2.18	1.86	3.11

6. Conclusions

The sequential iterative filter technique has been tested for estimation of Cartosat-1 platform parameters, which uses straight lines for space resection purpose. Three data sets have been used and promising results are obtained with and without using control points. More exercises and analysis are required to understand this method for various realistic imaging conditions. The preliminary results are only presented in this report Further scope exists to extend this method for longer duration, handling higher order variations in attitude, modeling state vector (position of perspective center) and incorporation of edge detection technique for line feature identification.

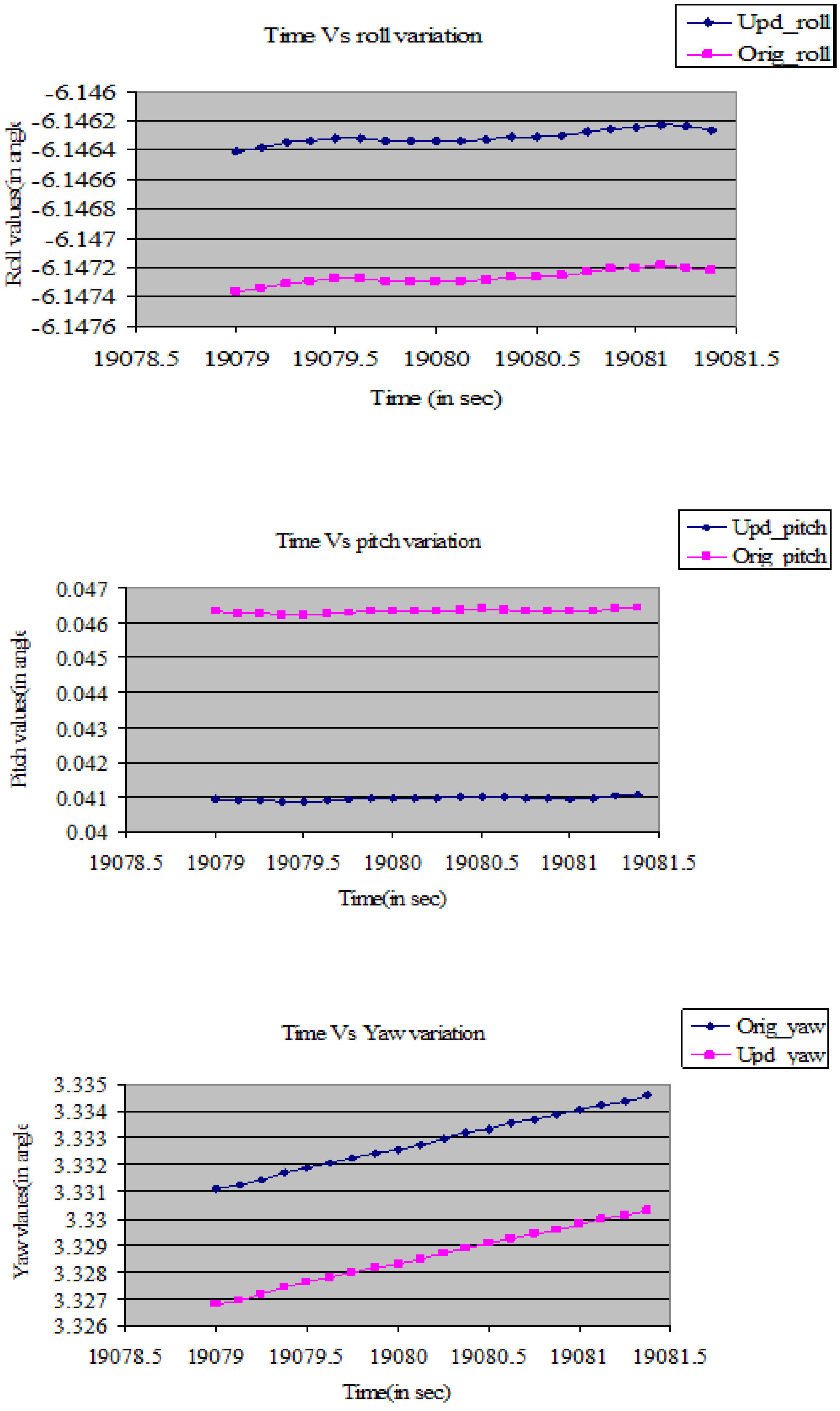


Fig. 2. Plots of Fore Camera Roll, Pitch & Yaw.

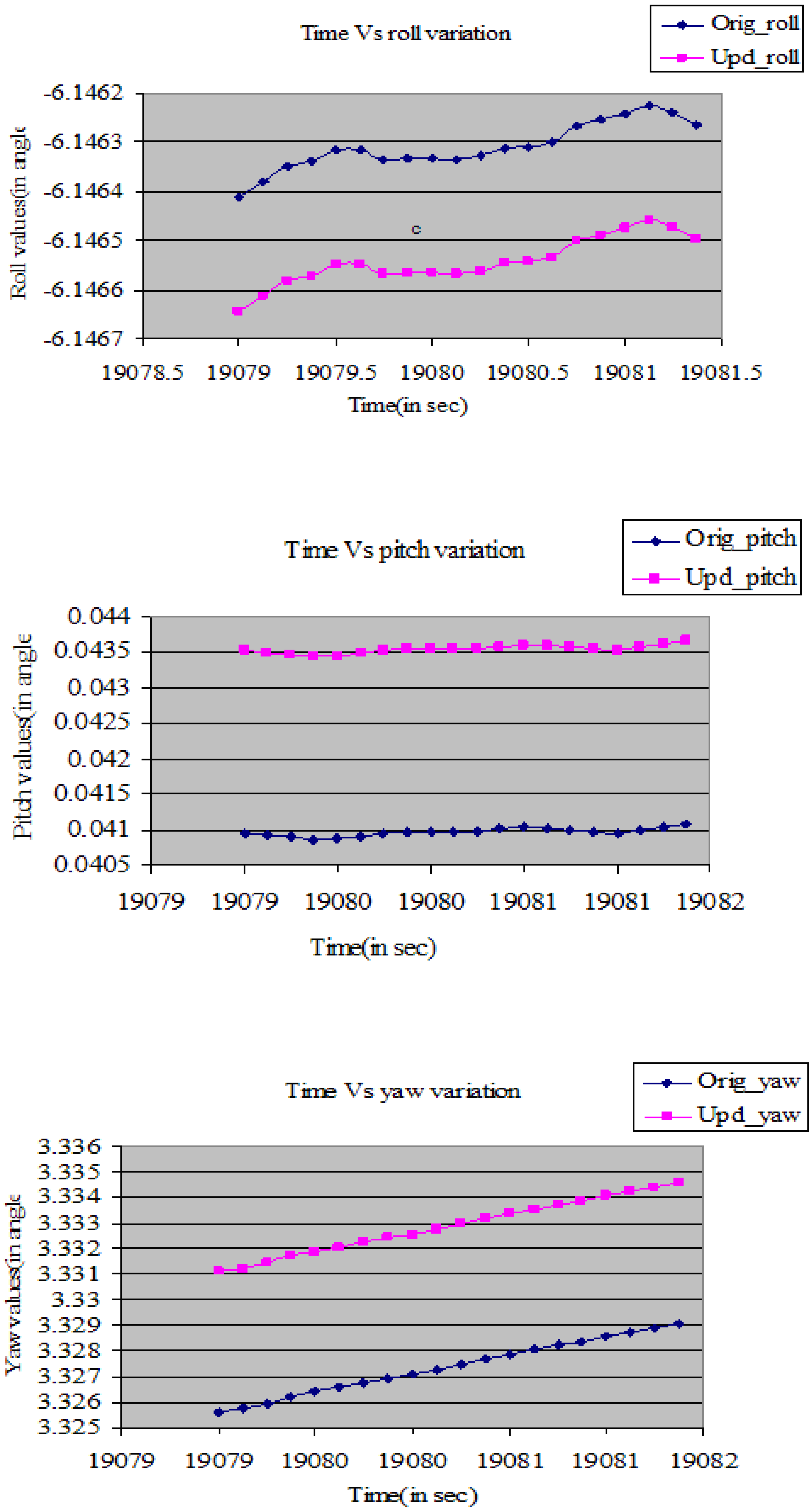


Fig. 3. Plots of Aft Camera Roll, Pitch & Yaw.

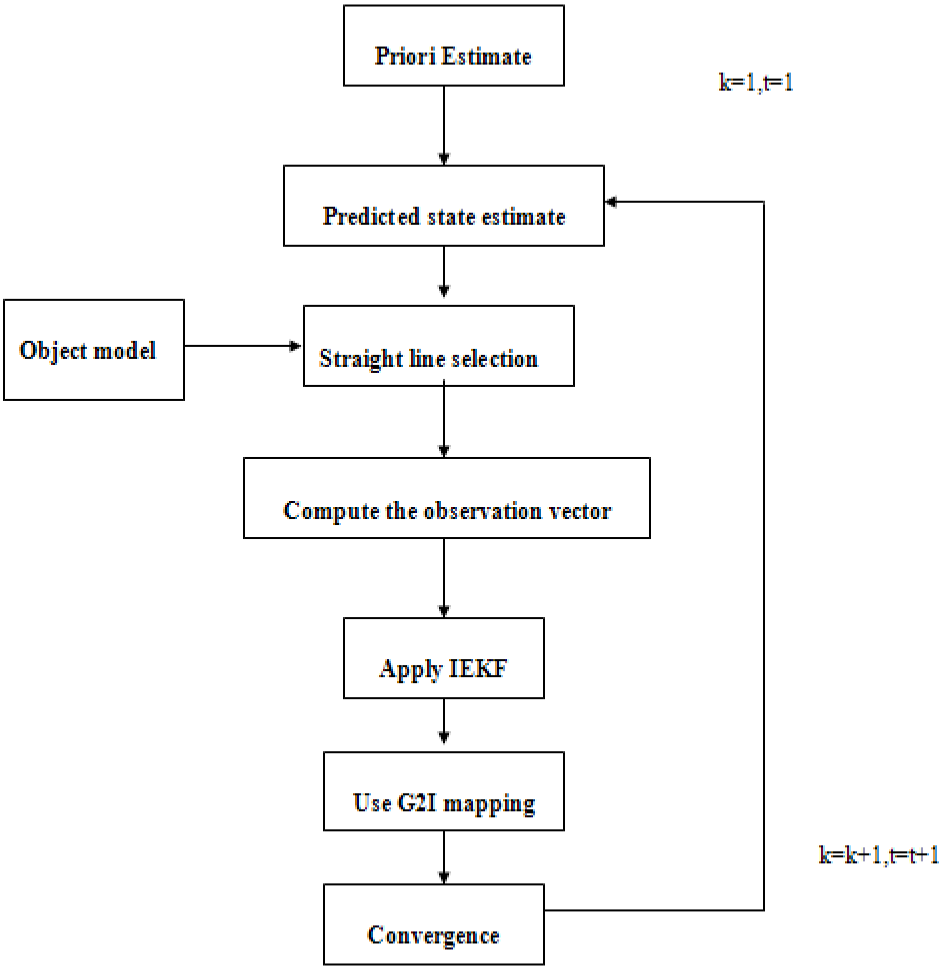


Fig. 4. Kalman Filter recursive procedure using lines for space resection.

Acknowledgement

The authors are thankful to Dr. P. K. Srivastava, Deputy Director, SIPA/SAC for giving an opportunity to work on this topic and also thankful to scientists of SPDCG who have given their support for this work.

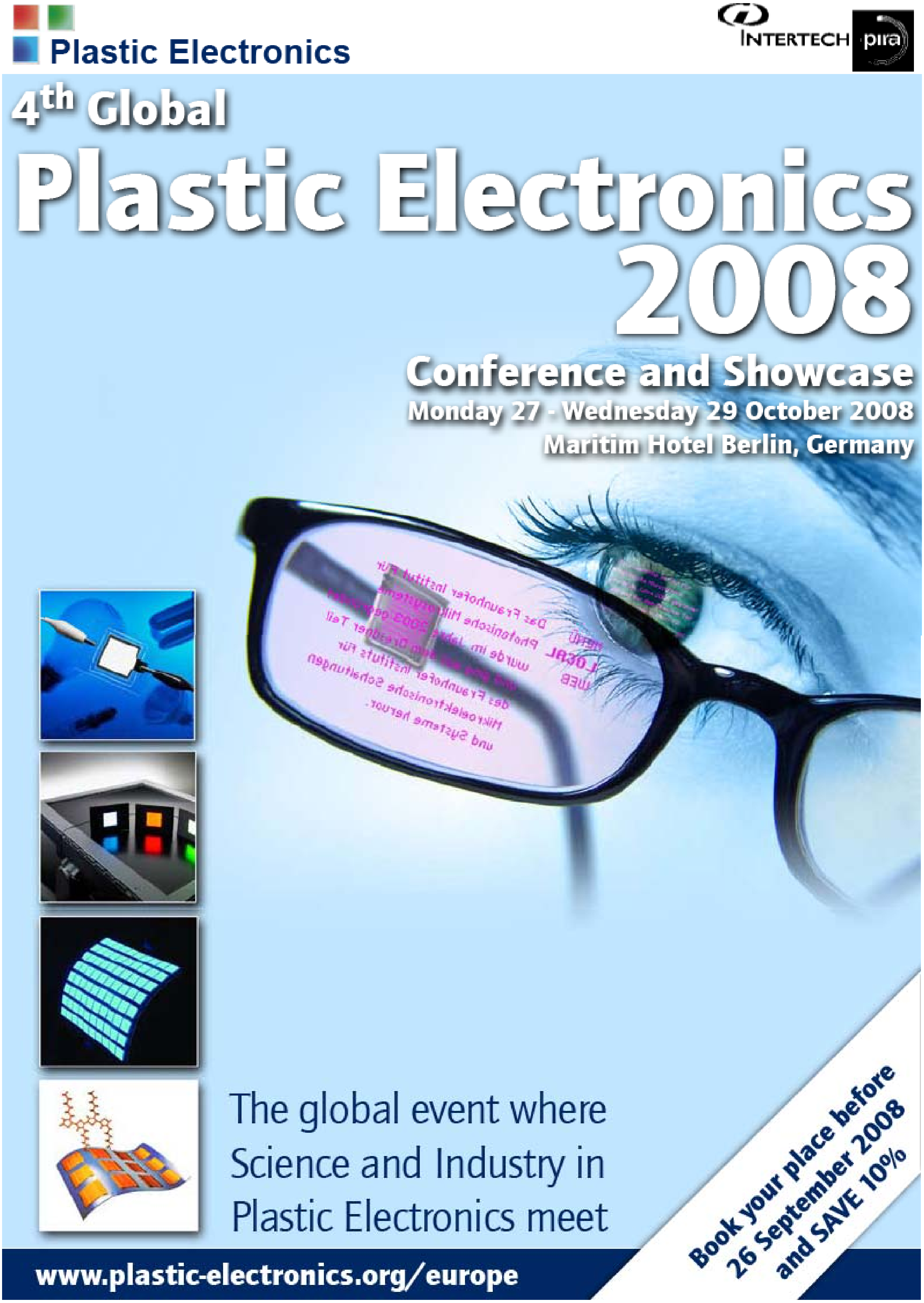
References

[1]. Islam B., Singh K. Sanjay, Srinivasan T. P., Gopala Krishna B. and Srivastava P. K., Attitude modeling using Kalman filter approach for improving the geometric accuracy of Cartosat-1 data products (SAC/RESIPA/SIPG/SPDD/TR-06/June 2006).

[2]. Caron R. H. and Simon K. W., Attitude Time-series Estimator for Rectification of Space Imager, *Journal of Spacecraft and Rockets*, 12, 1975, pp. 27-31.

[3]. Islam B., Srinivasan T. P., Singh K. Sanjay and Gopala Krishna B., An approach for attitude modeling using Coplanarity model for Cartosat-1 (CARTOSAT-1/DP/SAC/SIPA/SPDCG/TN-01/Feb. 2008).

[4] Tommaselli A. M. G, Tozzi C. L., A recursive Approach to Space Resection Using Straight Lines, *Photogrammetric Engineering & Remote Sensing*, Vol. 62, No. 1, January 1996.



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 additional, 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 6-14 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/Submition.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_2008.pdf

Smart Sensors Systems Design

A five-day advanced engineering course

10-14 November 2008, Barcelona, Spain

SMARTSES

Marie Curie Chair (EXC) project

General Information

This course is suitable for engineers who design different digital and intelligent sensors, data acquisition, and measurement systems. It is also useful for researchers, graduate and post graduate students. Course will be taught in English.

Course Description

An advanced engineering course describes modern developments and trends in the field of smart sensor systems and digital sensors design.

After a general overview of data acquisition methods, modern smart, digital and quasi-digital sensors, smart systems details are discussed. A systematic approach towards the design of low-cost high-performance smart sensors systems with self-adaptation and self-identification possibilities is presented.

Contact Person

Susana Escriche
Fundació UPC. Edifici Vèrtex
Plaça Eusebi Güell, 6, 08034 Barcelona
Tel.: +34 93 401 08 94
E-mail: susana.escriche@fundacio.upc.edu

Course Instructor

Prof. Sergey Y. Yurish,
Centre de Disseny d'Equips Industrials (CDEI),
Universitat Politecnica de Catalunya (UPC-Barcelona)
Tel.: + 34 93 401 74 37, fax: + 34 93 401 19 89
E-mail: syurish@sensorsportal.com

Online Registration:

http://www.sensorsportal.com/HTML/SSSD_Course_2008.htm

Deadline for Registration:

31 October, 2008

Fundació UPC

MARIE CURIE ACTIONS

IFSA

www.sensorsportal.com