



# Emfit Sensor Technology in Scientific Research Articles

including  
Heart Rate,  
Respiration Rate and Heart Rate Variability Measurements  
Caretaking -, Medical -, Mental -, Sleep Disorder -  
and Sleep Staging Applications

## Heart Rate, Respiration Rate and Heart Rate Variability Measurements

*A New Method for Measuring the Ballistocardiogram using EMFi Sensors in a Normal Chair*

T. Koivistoinen, S. Junnila, A. Väri, T. Kööbi

Proceedings of the 26th Annual International Conference of the IEEE EMBS, San Francisco, CA, USA. September 1-5, 2004

*Advanced Occupant Detection System: Detection of Human Vital Signs by Seat-Embedded Ferroelectric Films Sensors and by Vibration Analysis*

Pierre Orlewski, Laurent Federspiel, Mark Cuddihy, Stephen Fuks  
IEE Sensing Inc., Paper Number 11-0205, USA

*An Electromechanical Film Sensor Based Wireless Ballistocardiographic Chair: Implementation and Performance*

Sakari Junnila, Alireza Akhbardeh, Alpo Väri  
J Sign Process Syst (2009) 57:305–320

*An EMFi-film Sensor based Ballistocardiographic Chair: Performance and Cycle Extraction Method*

Sakari Junnila, Alireza Akhbardeh, Alpo Väri, Teemu Koivistoinen  
IEEE Workshop on Signal Processing Systems Design and Implementation, 2005.

*An Intelligent Ballistocardiographic Chair using a Novel SF-ART Neural Network and Biorthogonal Wavelets*

Alireza Akhbardeh, Sakari Junnila, Teemu Koivistoinen, Alpo Väri  
J Med Syst (2007) 31:69–77

*Applying Biorthogonal wavelets and a Novel QuickLearn Algorithm for an Intelligent Ballistocardiographic chair*

Alireza Akhbardeh, Sakari Junnila, Alpo Väri  
2006 IEEE Mountain Workshop on Adaptive and Learning Systems

*Applying Novel Supervised Fuzzy Adaptive Resonance Theory (SFART) Neural Network and Biorthogonal Wavelets for Ballistocardiogram Diagnosis*

Alireza Akhbardeh, Sakari Junnila, Teemu Koivistoinen, Alpo Väri  
Proceedings of the 2006 IEEE International Symposium on Intelligent Control. Munich, Germany, October 4-6, 2006

*Automatic Wavelet Detrending Benefits to the Analysis of Cardiac Signals Acquired in a Moving Wheelchair*

Eduardo C. Pinheiro, Octavian A. Postolache, and Pedro S. Girão  
32nd Annual International Conference of the IEEE EMBS. Buenos Aires, Argentina, August 31 - September 4, 2010

*BSeg++: A modified Blind Segmentation Method for Ballistocardiogram Cycle Extraction*

Alireza Akhbardeh, Bozena Kaminska, Kouhyar Tavakolian  
Proceedings of the 29th Annual International Conference of the IEEE EMBS. Cité Internationale, Lyon, France August 23-26, 2007.

*Calibration and Validation of Homeostasis Parameters Estimates Produced by a DSP Embedded in a Wheelchair*

Eduardo C. Pinheiro, Octavian A. Postolache, Pedro Silva Girão  
2013 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)

*Comparative Analysis of Infrasonic Cardiac Signals*

K Tavakolian, B Ngai, A Akhbardeh, B Kaminska, A Blaber  
Computers in Cardiology 2009;36:757-760.

*Comparative analysis of two systems for unobtrusive heart signal acquisition and characterization*

Octavian A. Postolache, Pedro S. Girão, Gabriela Postolache  
35th Annual International Conference of the IEEE EMBS. Osaka, Japan, 3 - 7 July, 2013

*Design an Intelligent Ballistocardiographic Chair using Novel QuickLearn and SF-ART Algorithms and Biorthogonal Wavelets*

Alireza Akhbardeh, Sakari Junnila, Teemu Koivistoinen, Alpo Väri  
2006 IEEE International Conference on Systems, Man, and Cybernetics. October 8-11, 2006, Taipei, Taiwan

*Dual Architecture Platform for Unobtrusive Wheelchair User Monitoring*

Eduardo C. Pinheiro, Octavian A. Postolache, Pedro Silva Girão  
2013 IEEE International Symposium on Medical Measurements and Applications Proceedings (MeMeA)

*EMFi – Versatile Material for Monitoring of Human Functions*

Jukka Lekkala, Timo Salpavaara and Satu Kärki  
XVIII IMEKO WORLD CONGRESS, Metrology for a Sustainable Development. September, 17 – 22, 2006, Rio de Janeiro, Brazil

*EMFi Material as Wearable Heart Rate Sensor for Night Time Recordings*

Antti Vehkaoja, Timo Salpavaara, Jarmo Verho, and Jukka Lekkala

IEEE SENSORS 2010 Conference

*Estimation of Vital Signs in Bed from a Single Unobtrusive Mechanical Sensor: Algorithms and Real-life Evaluation*

Xavier L. Aubert and Andreas Brauers

30th Annual International IEEE EMBS Conference. Vancouver, British Columbia, Canada, August 20-24, 2008

*FFT averaging of multichannel BCG signals from bed mattress sensor to improve estimation of heart beat interval*

Juha M. Kortelainen and Jussi Virkkala

Proceedings of the 29th Annual International Conference of the IEEE EMBS. Cité Internationale, Lyon, France, August 23-26, 2007.

*Film-Type Sensor Materials PVDF and EMFi in Measurement of Cardiorespiratory Signals –A Review*

Satu Rajala and Jukka Lekkala

IEEE SENSORS JOURNAL, VOL. 12, NO. 3, MARCH 2012

*Film-type transducer materials PVDF and EMFi in the measurement of heart and respiration rates*

Satu Kärki & Jukka Lekkala

30th Annual International IEEE EMBS Conference. Vancouver, British Columbia, Canada, August 20-24, 2008

*Heart Rate Estimation on a Beat-to-Beat Basis via Ballistocardiography - A hybrid Approach.*

David Friedrich, Xavier L. Aubert, Hartmut Führ and Andreas Brauers  
32nd Annual International Conference of the IEEE EMBS. Buenos Aires, Argentina, August 31 - September 4, 2010

*Improvement of Force-sensor-based Heart Rate Estimation Using Multi-channel Data Fusion*

Christoph Bruser, Juha M. Kortelainen, Stefan Winter, Mirja Tenhunen, Juha Pärkkä, and Steffen Leonhardt

IEEE JOURNAL ON BIOMEDICAL HEALTH INFORMATICS, 2014

Measurement of heart sounds with EMFi transducer

Satu Kärki, Minna Kääriäinen and Jukka Lekkala

Proceedings of the 29th Annual International Conference of the IEEE EMBS. Cité Internationale, Lyon, France, August 23-26, 2007.

*Measurement of Respiratory Rate with High-Resolution Accelerometer and EMFi Pressure Sensor*

Tuomas Reinvuo, Manne Hannula, Hannu Sorvoja, Esko Alasaarela and Risto Myllylä

SAS 2006 – IEEE Sensors Applications Symposium. Houston, Texas USA, 7-9 February 2006

*Multi-channel architecture for evaluation of automated oscillometric blood pressure devices*

Octavian Postolache, Pedro Silva Girão, Gabriela Postolache

2013 IEEE International Symposium on Medical Measurements and Applications Proceedings (MeMeA)

*New Approach on Cardiac Autonomic Control Estimation Based on BCG Processing*

O. Postolache, P. S. Girão and G. Postolache

Canadian Conference on Electrical and Computer Engineering, 2007. CCECE 2007.

*Patch Type Integrated Sensor System for Measuring Electrical and Mechanical Cardiac Activities*

Eunjeh Hyun, Seungwoo Noh, Chiyul Yoon, and Hee Chan Kim

*Physiological Parameters Measurement Based on Wheelchair Embedded Sensors and Advanced Signal Processing*

Octavian A. Postolache, Pedro M. B. Silva Girao, Joaquim Mendes, Eduardo C. Pinheiro, and Gabriela Postolache

IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 59, NO. 10, OCTOBER 2010

*Pulse Arrival Time and Ballistocardiogram Application to Blood Pressure Variability Estimation*

Eduardo Pinheiro, Octavian Postolache, Pedro Girão

MeMeA 2009 - International Workshop on Medical Measurements and Applications, Cetraro, Italy, May 29-30, 2009

PVDF and EMFi sensor materials – A comparative study

Satu Rajala, Jukka Lekkala

Proc. Eurosensors XXIV, September 5-8, 2010, Linz, Austria

The smart car seat: personalized monitoring of vital signs in automotive applications

Marian Walter, Benjamin Eilebrecht, Tobias Wartzek, Steffen Leonhardt  
Pers Ubiquit Comput (2011) 15:707–715

Unobtrusive Heart Rate and Respiratory Rate Monitor Embedded on a Wheelchair  
Octavian Postolache, Joaquim Mendes, Pedro Silva Girão, Gabriela Postolache  
MeMeA 2009 - International Workshop on Medical Measurements and Applications, Cetraro, Italy, May 29-30, 2009

Unsupervised Heart Rate Variability Estimation from Ballistocardiograms

Christoph Brüser, Stefan Winter, Steffen Leonhardt  
International Journal of Bioelectromagnetism, Vol. 15, No. 1, pp. 1 - 6, 2013

Use of independent component analysis for reducing CPR artefacts in human emergency ECGs

Marcus Granegger, Tobias Werther, Hermann Gilly  
Resuscitation 82 (2011) 79–84

Vital Signs Monitoring System Based on EMFi Sensors and Wavelet Analysis

O. Postolache, P. Silva Girao, G. Postolache, M. Pereira  
Instrumentation and Measurement Technology Conference - IMTC 2007, Warsaw, Poland, May 1-3, 2007

## Care Taking Applications

A Database-Centric Architecture for Home-Based Health Monitoring

Wagner O. de Morais, Jens Lundström, and Nicholas Wickström  
C. Nugent, A. Coronato, and J. Bravo (Eds.): IWAAL 2013, LNCS 8277, pp. 26–34, 2013.

A "Smart Bedroom" as an Active Database System

Wagner O. de Morais and Nicholas Wickström  
2013 9th International Conference on Intelligent Environments

Ambient assisted living system with capacitive occupancy sensor

Francisco J. Fernandez-Luque Félix L. Martínez Ginés Domènech Juan Zapata and Ramón Ruiz  
Expert Systems, 2013

Concierge-Based Care Support System for Designing Your Own Lifestyle

Keiki Takadama  
Big Data Becomes Personal: Knowledge into Meaning: Papers from the AAAI Spring Symposium

Data Collection Capabilities of a New Non-Invasive Monitoring System for Patients with Advanced Multiple Sclerosis

Diego E. Arias, Esteban J. Pino, Pablo Aqueveque, Dorothy W. Curtis  
AMIA Annu Symp Proc. 2013 Nov 16;2013:61-8.

Designing a Pervasive Healthcare Assistive Environment for the Elderly

Rui Neves Madeira, Octavian Postolache, Nuno Correia, Pedro Silva Girão  
UbiComp '10, Sep 26–Sep 29, 2010, Copenhagen, Denmark.

EMFi-based low-power occupancy sensor

Francisco J. Fernandez-Luque, Félix Martínez, Ginés Domènech, Juan Zapata, Ramón Ruiz  
Sensors and Actuators A 191 (2013) 78– 88

Estimating Older People's Physical Functioning with Automated Health Monitoring Technologies at Home: Feature Correlations and Multivariate Analysis

Juho Merilahti, Juha Pärkkä, and Ilkka Korhonen  
M. Rautiainen et al. (Eds.): GPC 2011 Workshops, LNCS 7096, pp. 94–104, 2012.

Exploring Individual Care Plan for a Good Sleep

Keiki Takadama  
AAAI Technical Report SS-12-05. Self-Tracking and Collective Intelligence for Personal Wellness

Low-Power Bed / Seat Occupancy Sensor Based on EMFi

Francisco Fernandez-Luque, Juan Zapata, and Ramon Ruiz  
J.M. Ferrandez et al. (Eds.): IWINAC 2011, Part I, LNCS 6686, pp. 501–510, 2011.

Utilization of Wireless Sensor Network for Health Monitoring in Home Environment  
Mari Zakrzewski, Sakari Junnila, Antti Vehkaoja, Harri Kailanto, Antti-Matti Vainio, Irek Defee, Jukka Lekkala, Jukka Vanhala and Jari Hyttinen  
IEEE International Symposium on Industrial Embedded Systems, 2009. SIES '09.

Wireless, Multipurpose In-Home Health Monitoring Platform: Two Case Trials

Sakari Junnila, Harri Kailanto, Juho Merilahti, Antti-Matti Vainio, Antti Vehkaoja, Mari Zakrzewski, and Jari Hyttinen  
IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE, VOL. 14, NO. 2, MARCH 2010

## Medical Applications

A Feasibility Study on the Automatic Detection of Atrial Fibrillation using an Unobtrusive Bed-Mounted Sensor

Christoph Brüser, Matthias D H Zink, Stefan Winter, Patrick Schauerte, Steffen Leonhardt  
Computing in Cardiology 2011;38:13-16.

Accelerometry-based home monitoring for detection of nocturnal hypermotor seizures based on novelty detection

Kris Cuppens, Peter Karsmakers, Anouk Van de Vel, Bert Bonroy, Milica Milosevic, Stijn Luca, Tom Croonenborghs, Berten Ceulemans, Lieven Lagae, Sabine Van Huffel and Bart Vanrumste

Assessment of a quasi-piezoelectric mattress monitor as a detection system for generalized convulsions

Aditi P. Narechania, Irena I. Garic, Indranil Sen-Gupta, Mícheál P. Macken, Elizabeth E. Gerard, Stephan U. Schuele  
Epilepsy & Behavior 28 (2013) 172–176

Automatic Arrhythmia Detection Based on Heart Beat Interval Series Recorded Through Bed Sensors During Sleep

Matteo Migliorini, Ramona Cabiddu, Sergio Cerutti, Luca T Mainardi, Juha M Kortelainen, Anna M Bianchi  
Computing in Cardiology 2011;38:337-340.

Automatic Detection of Atrial Fibrillation in Cardiac Vibration Signals

Christoph Bruser, Jasper Diesel, Matthias D. H. Zink, Stefan Winter, Patrick Schauerte, and Steffen Leonhardt  
IEEE JOURNAL OF BIOMEDICAL AND HEALTH INFORMATICS, VOL. 17, NO. 1, JANUARY 2013

Detection of Epileptic Seizures based on Video and Accelerometer Recordings

Kris Cuppens  
Doctoral thesis, Katholieke Universiteit Leuven, 2012

Miniaturized Wireless ECG Monitor for Real-Time Detection of Epileptic Seizures

Fabien Masse, Martien van Bussel, Aline Serteyn, Johan Arends, Julien Penders  
Proceedings of WH '10 Wireless Health 2010

Non-EEG seizure-detection systems and potential SUDEP prevention: State of the art

Anouk Van de Vel, Kris Cuppens, Bert Bonroy, Milica Milosevic, Katrien Jansen, Sabine Van Huffel, Bart Vanrumste, Lieven Lagae, Berten Ceulemans  
Seizure 22 (2013) 345–355

Prevention and Risk Reduction in Hearth Health

B. Kaminska, K. Tavakolian, B. Ngai, Y. Chuo, A. Vaseghi, and B. Carmichael  
NSTI-Nanotech 2007

Prospective Study of the Emfit Movement Monitor

Kate Van Poppel, Stephen P. Fulton, Amy McGregor, Michelle Ellis, Andrea Paters, and James Wheless  
Journal of Child Neurology 28(11) 1434-1436, 2013.

Review Article - Sudden, Unexpected Death in Epilepsy

Orrin Devinsky  
N Engl J Med 2011;365:1801-11.

Unobtrusive Non-Contact Detection of Arrhythmias using a "Smart" Bed

Christoph Brüser  
Acta Polytechnica Vol. 51 No. 5/2011

Critical evaluation of four different seizure detection systems tested on one patient with focal and generalized tonic and clonic seizures.

Van de Vel A, Verhaert K, Ceulemans B.  
Epilepsy Behav. 2014 Aug;37:91-4. doi: 10.1016/j.yebeh.2014.06.014. Epub 2014 Jul 7.  
PMID: 25010322

## Mental Applications

### Measuring Emotional Wellbeing with a Non-intrusive Bed Sensor

Gert van der Vloed and Jelle Berentsen

T. Gross et al. (Eds.): INTERACT 2009, Part II, LNCS 5727, pp. 908–911, 2009.

### On the Feasibility of Using Activity Recognition and Context Aware Interaction to Support Early Diagnosis of Bipolar Disorder

David Tacconi, Oscar Mayora, Paul Lukowicz, Bert Arnrich, Gerhard Tröster, Christian Haring

International Conference on Pervasive Computing Technologies for Health-care, 2008.

### Relationship of Psychological and Physiological Variables in Long-Term Self-Monitored Data During Work Ability Rehabilitation Program

Juha Pärkkä, Juho Merilahti, Elina M. Mattila, Esko Malm, Kari Antila, Martti T. Tuomisto, Ari Viljam Saarinen, Mark van Gils, and Ilkka Korhonen

IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE, VOL. 13, NO. 2, MARCH 2009

### Towards a Care Support System that Can Guess the Way Aged Persons Feel

Keiki Takadama

Data Driven Wellness: From Self-Tracking to Behavior Change: Papers from the 2013 AAAI Spring Symposium

## Sleep Disorder Applications

### Compressed tracheal sound analysis in screening of sleep-disordered breathing

Esa Rauhala, Joel Hasan, Antti Kulkas, Antti Saastamoinen, Eero Huupponen, Frank Cameron, Sari-Leena Himanen

Clinical Neurophysiology 119 (2008) 2037–2043

### Detection of compressed tracheal sound patterns with large amplitude variation during sleep

A. Kulkas, E. Rauhala, E. Huupponen, J. Virkkala, M. Tenhunen,

A. Saastamoinen, S-L. Himanen

Med Biol Eng Comput (2008) 46:315–321

### Emfit movement sensor in evaluating nocturnal breathing

Mirja Tenhunen, Ella Elomaa, Heli Sistonen, Esa Rauhala, Sari-Leena Himanen

Respiratory Physiology & Neurobiology 187 (2013) 183–189

### High frequency components of tracheal sound are emphasized during prolonged flow limitation

M Tenhunen, E Rauhala, E Huupponen, A Saastamoinen, A Kulkas and S-L Himanen

Physiol. Meas. 30 (2009) 467–478

### Increased respiratory effort during sleep is non-invasively detected with movement sensor

Mirja Tenhunen, Esa Rauhala, Jussi Virkkala, Olli Polo, Antti Saastamoinen, Sari-Leena Himanen

Sleep Breath (2011) 15:737–746

### New tracheal sound feature for apnoea analysis

A. Kulkas, E. Huupponen, J. Virkkala, M. Tenhunen, A. Saastamoinen, E. Rauhala, S.-L. Himanen

Med Biol Eng Comput (2009) 47:405–412

### Performance of Non-invasive Devices in Evaluation of Periodic Limb Movements and Sleep-disordered Breathing

Esa Rauhala

Doctoral Thesis, Faculty of Medicine of the University of Tampere, 2009.

### Periodic limb movement screening as an additional feature of Emfit sensor in sleep-disordered breathing studies

Esa Rauhala, Jussi Virkkala, Sari-Leena Himanen

Journal of Neuroscience Methods 178 (2009) 157–161

### Prolonged spiking periods pattern detection method by using Emfit and SCSB signals

Jarmo Alametsä, Antti Saastamoinen, Eero Huupponen, Alpo Värrä,

Atte Joutsen, Joel Hasan, Esa Rauhala, and Sari-Leena Himanen

Proceedings of the 12th Finnish Artificial Intelligence Conference STeP. 2006.

### Snoring seconds detection with EMFi sensor strips

Jarmo Alametsä, Jari Viik, Eero Huupponen, Antti Kulkas, Alpo Värrä, and

Sari-Leena Himanen

2010 12th Biennial Baltic Electronics Conference (BEC2010), Tallinn, Estonia, October 4-6, 2010

### Heart rate variability evaluation of Emfit sleep mattress breathing categories in NREM sleep.

Tenhunen M, Hyttinen J, Lipponen JA, Virkkala J, Kuusimäki S, Tarvainen MP, Karjalainen PA, Himanen SL.

Clin Neurophysiol. 2014 Sep 6. pii: S1388-2457(14)00468-4. doi: 10.1016/j.clinph.2014.08.012. PMID: 25241203

### Screening sleep disordered breathing in stroke unit.

Väyrynen K, Kortelainen K, Numminen H, Miettinen K, Keso A, Tenhunen M, Huhtala H, Himanen SL.

Sleep Disord. 2014;2014:317615. doi: 10.1155/2014/317615. Epub 2014 May 27. PMID: 24991437

## Sleep Staging Applications

### Automatic Detection of sleep macrostructure based on bed sensors

M.O. Mendez, M. Matteucci, S. Cerutti, A.M. Bianchi and Juha M. Kortelainen

31st Annual International Conference of the IEEE EMBS. Minneapolis, Minnesota, USA, September 2-6, 2009

### Automatic sleep staging based on ballistocardiographic signals recorded through bed sensors

Matteo Migliorini, Anna M. Bianchi, Domenico Nisticò, Juha Kortelainen, Edgar Arce-Santana, Sergio Cerutti, and Martin O. Mendez

32nd Annual International Conference of the IEEE EMBS. Buenos Aires, Argentina, August 31 - September 4, 2010

### Combining Unobtrusive Electrocardiography and Ballistography for more Accurate Monitoring of Sleep

Antti Vehkaoja, Mikko Peltokangas, Jarmo Verho, and Jukka Lekkala

Proceedings of the 2012 IEEE 12th International Conference on Bioinformatics & Bioengineering (BIBE), Larnaca, Cyprus, 11-13 November 2012

### Multichannel Bed Pressure Sensor for Sleep Monitoring

Juha M Kortelainen, Mark van Gils, Juha Pärkkä

Computing in Cardiology 2012; 39:313-316.

### Review Article - Recent Developments in Home Sleep-Monitoring Devices

Jessica M. Kelly, Robert E. Strecker, and Matt T. Bianchi

ISRN Neurology Volume 2012, Article ID 768794

### Sleep Staging Based on Signals Acquired Through Bed Sensor

J.M. Kortelainen, M.O. Mendez, A.M. Bianchi, M. Matteucci, S. Cerutti

Information Technology in Biomedicine, IEEE Transactions on (Volume:14, Issue: 3), 2010

### Sleep-Wake Detection based on Respiratory Signal Acquired through a Pressure Bed Sensor

Guerrero-Mora G, Palacios Elvia, Bianchi AM, Kortelainen J, M Tenhunen,

SL Himanen, Méndez MO, E Arce-Santana, O Gutiérrez-Navarro

34th Annual International Conference of the IEEE EMBS, San Diego, California USA, 28 August - 1 September, 2012

### Long-Term Subjective and Objective Sleep Analysis of Total Sleep Time and Sleep Quality in Real Life Settings

Juho Merilahti, Ari Saarinen, Juha Pärkkä, Kari Antila, Elina Mattila and Ilkka Korhonen

Proceedings of the 29th Annual International Conference of the IEEE EMBS, Cité Internationale, Lyon, France, August 23-26, 2007.

### Time-frequency analysis of the ballistocardiogram for sleep staging

Matteo Migliorini

Doctoral thesis, POLITECNICO DI MILANO, Facoltà di Ingegneria dei Sistemi, 2010