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PIERS 2018 in Toyama, Japan, 1-4 August, 2018

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Quick Links

- PIERS Guidelines
- Paper Submission
- Session Organization
- Registration
- Locale&Hotel
- PIERS Exhibition
- PIERS Shortcourse
- PIERS Gallery
- PIERS2018 Organization
- PIERS2018 Sponsors
- Author Login
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- PIERS2018 in Toyama
- PIERS2017 in Singapore
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- PIERS2016 in Shanghai
- PIERS2015 in Prague
- PIERS2014 in Guangzhou
- PIERS2013 in Stockholm
- PIERS2013 in Taipei
- PIERS2012 in Moscow
- PIERS2012 in Kuala Lumpur
- PIERS2011 in Suzhou
- PIERS2011 in Marrakesh
- PIERS2010 in Cambridge
- PIERS2010 in Xi'an
- PIERS2009 in Moscow
- PIERS2009 in Beijing
- PIERS2008 in Cambridge
- PIERS2008 in Hangzhou
- PIERS2007 in Prague
- PIERS2007 in Beijing
- PIERS2006 in Tokyo
- PIERS2006 in Cambridge
- PIERS2005 in Hangzhou
- PIERS2004 in Pisa
- PIERS2004 in Nanjing
- ......

We are speaking the same language, Maxwell's Equations.
--- In memory of Jin Au Kong

The 40th PIERS in Toyama, JAPAN

1 - 4 August 2018 (From Wednesday to Saturday)

Venue: Toyama International Conference Center and ANA Crowne Plaza Toyama

Important Dates

- **1 April, 2018--- Extended Deadline of Abstract Submission [Submit] [Guidelines]**
- **1 May, 2018--- Pre-registration Deadline [Login First] [Instruction]**
- **5 May, 2018 --- Extended Paper Submission Deadline [Submit] [Guidelines]**
- **1 June, 2018 --- Preliminary Program available**
- **15 June, 2018 --- Advance Program available**
- **1 July, 2018 --- Final Program is available now** hot!

PIERS 2018 Toyama Program

- Final Program is available now. [download PDF version of final printed program]
- Proceedings (extended papers only) have been published on IEEE Xplore. hot!
- **Welcome Message by PIERS 2018 Toyama General Chair** is now available.
- **Install PIERS App into your mobile -** Installation Instructions
- **Program at a Glance**
  Please visit here at the local website, where the Program at a Glance is posted. You can easily have an idea about the entire program by taking a look at this webpage.
- **Opening Ceremony**
  Date and time: 16:00-16:40, Wednesday, August 1, 2018
  Venue: Toyama International Conference Center
  Please visit here for the program of the Opening Ceremony.
- **Symposium Banquet**
  Date and Time: 19:00-21:30, Friday, August 3, 2018
  Venue: ANA Crowne Plaza Toyama
  Please visit here for the program of the Symposium Banquet.
- **General Lectures**
  During PIERS 2018 Toyama, four General Lectures (GLs) by leading scientists in the electromagnetics community will be scheduled as plenary sessions. There are no other sessions running in parallel to these GLs, and all the PIERS 2018 Toyama participants are invited to join the GLs. Please visit the GL program at this webpage.
- **Pre-Conference Workshop**
  Prior to the Conference, a Workshop will be held on July 31, 2018, and all the registered PIERS 2018 Toyama participants are invited to attend the Workshop without extra fees nor advance reservation. Please plan on attending this Workshop! Please visit the Workshop schedule at this webpage.
- **Toyama City Fireworks Festival**
  The Toyama City Fireworks Festival will be held 19:45-20:30, August 1, 2018, right after the Symposium Reception. Please get out of the venue and enjoy Toyama's great summer event! Fireworks festivals held in Toyama in the past can be seen from this website.

PIERS 2018 Toyama

Progress In Electromagnetics Research Symposium

Program

August 1–4, 2018

Toyama, JAPAN

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PIERS 2018 TOYAMA TECHNICAL PROGRAM

Session 1A1
FocusSession.SC5: Remote Sensing for Hydrological Applications 1

Wednesday AM, August 1, 2018

Room T1

Organized by Jian-Cheng Shi, Hui Lu

Chaired by Jian-Cheng Shi, Hui Lu

08:30 Keynote — Fully Coherent Model for Layered Bicontinuous Medium Using Analytical Method of Feynman Diagram for Applications in Microwave Remote Sensing of Snow Cover
Jiyue Zhu (*University of Michigan*); *Leung Tsang* (*University of Michigan*); *Shurun Tan* (*University of Michigan*); *Son V. Nghiem* (*California Institute of Technology*);

09:00 Invited — Improving Snow Fraction Spatio-temporal Continuity Using a Combination of MODIS and Fengyun-2 Satellites over China
Lingmei Jiang (*Beijing Normal University*); *GongXue Wang* (*Beijing Normal University*); *Jian-Cheng Shi* (*Institute of Remote Sensing Applications, Chinese Academy of Sciences*);

09:20 Invited — Time-series Passive Microwave Observations Applied for Snow Estimation
Jinmei Pan (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Science*); *Chuan Xiong* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Jian-Cheng Shi* (*Institute of Remote Sensing Applications, Chinese Academy of Sciences*); *Deyuan Geng* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Science*); *Haokui Xu* (*University of Michigan*);

09:40 Invited — Time-series Ground Based X and Ku Band SAR Observation of Seasonal Snow: Modeling and Retrieval
Chuan Xiong (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Jiancheng Shi* (*Institute of Remote Sensing and Digital Earth, CAS*); *Jinmei Pan* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Science*); *Haokui Xu* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Science*); *Tianjie Zhao* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Science*); *Deyuan Geng* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Science*);

10:00 Invited — Measurement and Modeling of Multi-frequency Microwave Emission of Soil Freezing and Thawing Processes
Tianjie Zhao (*Jointly Sponsored by Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Jian-Cheng Shi* (*Institute of Remote Sensing Applications, Chinese Academy of Sciences*); *Shaojie Zhao* (*Beijing Normal University*); *Kun-Shan Chen* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Pingkai Wang* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Shangnan Li* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Chuan Xiong* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Qing Xiao* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*);

10:20 — Z-R Relationships for Weather Radar in Indonesia from the Particle Size and Velocity (Parsivel) Optical Disdrometer
Marzuki (*Andalas University*); *Hiroyuki Hashiguchi* (*Kyoto University*); *Mutya Vonnisa* (*Andalas University*); *Harmadi* (*Andalas University*); *Muzirwan* (*National Institute of Aeronautics and Space*); *Sugeng Nugroho* (*Indonesian Agency for Meteorological, Climatological and Geophysics*); *Meri Yoseva* (*Andalas University*);

10:40 **Coffee Break**

16:40 Validating SMAP SSS with in Situ Data and Process Oriented Analysis
Wenqing Tang (California Institute of Technology); Simon H. Yueh (California Institute of Technology); Alexander G. Fore (California Institute of Technology); Akiko Hayashi (California Institute of Technology);

17:00 Accurate Surface Fields and Emissivities in Ocean Scattering and Emission Using Neighborhood Impedance Boundary Condition (NIBC) with Dense Grid in Surface Integral Equations
Yanlei Du (Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences); Tai Qiao (University of Michigan); Leung Tsang (University of Michigan); Xiao Feng Yang (Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences);

Session 3P1b
SC5: Inverse Scattering 1

Friday PM, August 3, 2018
Room T1
Organized by Motoyuki Sato, Toshifumi Moriyama
Chaired by Motoyuki Sato, Toshifumi Moriyama

17:20 Adaptive Array Radar Imaging of Moving Human Body for Measurement of Vital Signs
Takuya Sakamoto (University of Hyogo); Kentaro Konishi (University of Hyogo); Masashi Muragaki (Kyoto University); Shigeaki Okumura (Kyoto University); Toru Sato (Kyoto University);

17:40 Accuracy Enhanced Distorted Born Iterative Method with Envelope Based Boundary Extraction for Microwave Mammography
Shouhei Kidera (The University of Electro-Communications); Kazuki Noritake (The University of Electro-Communications);

18:00 Development of Microwave CT Mammography Device
Yoshio Nagayama (Nihon University); Tomoya Hanashima (Nihon University); Tomohiko Asai (Nihon University); Soichiro Yamaguchi (Nihon University); Toshifumi Moriyama (Nagasaki University); Toshiyuki Tanaka (Nagasaki University); Hayato Tsuchiya (Nihon University);

Session 3P2a
FocusSession.SC5: SAR Imaging and Applications

Friday PM, August 3, 2018
Room T2
Organized by Kun-Shan Chen, Toshifumi Moriyama
Chaired by Kun-Shan Chen, Toshifumi Moriyama

13:00 Invited Compound Scattering Matrix by Dipoles in the Range Direction
Yoshio Yamaguchi (Niigata University); Yoshihiro Yamazaki (Niigata University); Hiroyoshi Yamada (Niigata University);

13:20 An Experimental Assessment of Polarimetric L-band Backscattering Using GB-SAR Data
Sevket Demirci (Mersin University); Betul Yilmaz (Mersin University); Serhat Gokkan (Mersin University); Hakan Isiker (Mersin University); Caner Ozdemir (Mersin University);

13:40 RCS Characteristics Analysis of Trihedral Corner Reflector for Bistatic SAR Tandem Mode Radiometric Calibration
Qiaona Zheng (Institute of Electronics, Chinese Academy of Sciences); Jun Hong (Institute of Electronics, Chinese Academy of Science); Yu Wang (Institute of Electronics, Chinese Academy of Sciences);

14:00 Research on the Sparse Aperture Remote Imaging System Based on the Freeform
Quanying Wu (Suzhou University of Science and Technology); Junliu Fan (Suzhou University of Science and Technology); Baohua Chen (Suzhou University of Science and Technology);

14:20 Invited Airborne Single Pass X-band FMCW INSAR Instrument for the Accurate DEM Generation — Principle and Validation
Masanobu Shimada (Tokyo Denki University); Akira Nohmi (Alouette Technology); Hitoshi Nohmi (Alouette Technology); Mayumi Noguchi (The Geospatial Information Authority of Japan); Sho Takahashi (The Geospatial Information Authority of Japan);

14:40 Invited Integration of Heterogeneous InSAR Measurements for Mapping Complete and Accurate Three-dimensional Surface Displacements: A Case Study of 2016 Mw 7.8 Kaikōura Earthquake, New Zealand
Jun Hu (Central South University); J. H. Liu (Central South University); Lixin Wu (Northeastern University); Zhi-Wei Li (Central South University); Q. Sun (Hunan Normal University);

30 Detection of Small and Large Hidden Metallic Objects via Passive Millimeter Wave Imaging System with an Auto-segmentation Routine
Hakan Isiker (*Mersin University*); *Sevket Demirci* (*Mersin University*); *Betul Yilmaz* (*Mersin University*); *Serhat Gokkan* (*Mersin University*); *Caner Ozdemir* (*Mersin University*);

31 An Analysis of Relationship between Urban Heat Island in the Tropics in Extremely Hot Days with Land Use Using Landsat 8 Image — A Case Study in Hanoi Vietnam
Nguyen Thanh Hoan (*Institute of Geography, Vietnam Academy of Science and Technology*); *Tran Duy Phien* (*Institute of Geography, Vietnam Academy of Science and Technology*); *Dao Dinh Cham* (*Institute of Geography, Vietnam Academy of Science and Technology*);

32 Automatic Sport Fields Detection from China GF-1 Satellite Image Data via Improved SSD Model
Zhengchao Chen (*Institute of Remote Sensing and Digital Earth, CAS*); *Kaixuan Lu* (*Institute of Remote Sensing and Digital Earth, CAS*); *Xuan Yang* (*Institute of Remote Sensing and Digital Earth, CAS*); *Baipeng Li* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Jianwei Gao* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Mufeng Yao* (*Institute of Remote Sensing and Digital Earth, CAS*);

33 Impact of Usage of Multiple-satellite Sensors on Accuracy of Sea Surface Wind Data
Ayumi Koizumi (*Tokai University*); *Masahisa Kubota* (*Tokai University*); *Kunio Kutsuwada* (*Tokai University*);

34 Double Weighted Fourier Transform (DWFT) in Statistical Problems
Sergei I. Knizhin (*Irkutsk State University*); *Mikhail V. Tinin* (*Irkutsk State University*);

35 Experiment and FDTD Simulation of Antenna for the Microwave CT
Tomoya Hanashima (*Nihon University*); *Yoshio Nagayama* (*Nihon University*); *Tomohiko Asai* (*Nihon University*); *Toshifumi Moriyama* (*Nagasaki University*); *Toshiyuki Tanaka* (*Nagasaki University*); *Soichiro Yamaguchi* (*Nihon University*); *Hayato Tsuchiya* (*Nihon University*);

36 The Method of Adaptive Gaussian Decomposition Based Recognition and Extraction of Scattering Mechanisms
Xinyi He (*Science and Technology on Electromagnetic Scattering Laboratory*); *Pengcheng Gao* (*Science and Technology on Electromagnetic Scattering Laboratory*); *Wei Gao* (*Science and Technology on Electromagnetic Scattering Laboratory*); *Xiao Lin Mi* (*Science and Technology on Electromagnetic Scattering Laboratory*); *Yuan Zhang* (*Science and Technology on Electromagnetic Scattering Laboratory*);

37 Using Spectral Residual Method to Identification Buried Objects from GPR B-Scan Image
Yao Qin (*Henan University of Technology*); *Jing Wan* (*Henan University of Technology*); *Jieyi Yang* (*Henan University of Technology*); *Li Hong Qiao* (*Henan University of Technology*); *Chunhua Zhu* (*Henan University of Technology*); *Qifu Wang* (*Henan Academy of Science, Applied Physics Institute Co., Ltd*);

38 A Novel Encoding and Decoding Method for Packaging Goods Based on Grayscale-Information Matrix
Guo Chun Wan (*Tongji University*); *Wen Jing Liu* (*Tongji University*); *Jian Zhou* (*Tongji University*); *Mei Song Tong* (*Tongji University*);

39 Development of Middle-power W-band Gyrotron in IAP RAS
Mikhail Yu. Glyavin (*Federal State Budgetary Scientific Institution "Federal Research Center The Institute of Applied Physics of the Russian Academy of Sciences"*); *Mikhail D. Proyavin* (*Institute of Applied Physics of the Russian Academy of Sciences (IAP RAS)*); *Anton S. Sedov* (*Federal State Budgetary Scientific Institution "Federal Research Center The Institute of Applied Physics of the Russian Academy of Sciences"*); *Evgeni S. Semenov* (*Institute of Applied Physics of the Russian Academy of Sciences*); *Andrey S. Zuev* (*Federal Research Center "Institute of Applied Physics RAS"*); *Alexander I. Tsvetkov* (*Federal State Budgetary Scientific Institution "Federal Research Center The Institute of Applied Physics of the Russian Academy of Sciences"*);

40 Wavelength-dependent Terahertz Wave Modulation in Organic/Si Hybrid Structures
Joong Wook Lee (*Chonnam National University*);

41 Topological Propoties and Edge State in Parity-time Symmetrical Waveguide Array
Qi Dong Fu (*Shanghai Jiaotong University*);

14:20 Automatic Building Extraction Based on Deep Convolutional Neural Networks from High-resolution Remote Sensing Images
Jianwei Gao (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Zhengchao Chen* (*Institute of Remote Sensing and Digital Earth, CAS*); *Xuan Yang* (*Institute of Remote Sensing and Digital Earth, CAS*); *Qun Ma* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*); *Baipeng Li* (*Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences*);

14:40 Handheld Bistatic Subsurface Radar Using Accelerometer
Kazutaka Kikuta (*Tohoku University*); *Motoyuki Sato* (*Tohoku University*);

15:00 Investigation for the Measurement Accuracies of Silica Waveguide Sidewall Angles with Confocal Laser Scanning Microscope
Hongpeng Shang (*Changchun University of Science and Technology*); *De Gui Sun* (*Changchun University of Science & Technology; University of Ottawa*); *Jinzhu Gao* (*Institute of Metal Research, Chinese Academy of Sciences*); *Peng Yu* (*Changchun University of Science & Technology*); *Qingyu Sun* (*Changchun University of Science and Technology*); *Peng Liu* (*University of Ottawa*); *Trevor J. Hall* (*University of Ottawa*);

15:20 An Experimental Study of Foliage Penetrating Radar with Coherent Change Detection
Sevket Demirci (*Mersin University*); *Betul Yilmaz* (*Mersin University*); *Hakan Isiker* (*Mersin University*); *Serhat Gokkan* (*Mersin University*); *Caner Ozdemir* (*Mersin University*);

15:40 **Coffee Break**

Session 4P1b
Electromagnetic Modeling and Inversion and Applications

Saturday PM, August 4, 2018
Room T1
Organized by Jianhua Li, Ganquan Xie
Chaired by Shigu Cao, Ganquan Xie

16:00 Plane Wave Coupling to Overhead Lines over Stratified Earth
Zeyneb Belganche (*Mohammed V University*); *Abderrahman Maaouni* (*Mohammed V University*); *Ahmed Mzerd* (*Mohammed V University*); *Ayoub Lahmidi* (*Universite Mohammed V*);

16:20 Metasurface Design by Surrogate-assisted Optimization
Binbin Zhu (*Kuang-Chi Institute of Advanced Technology*); *Yang Yang* (*Tsinghua University*); *Yiqi Liu* (*Kuang-Chi Institute of Advanced Technology*); *Xiao Guo* (*Kuang-Chi Institute of Advanced Technology*); *Ke Deng* (*Tsinghua University*); *Chunlin Ji* (*Kuang-Chi Institute of Advanced Technology*);

16:40 Multiphysics Modeling for Ferroelectric Materials
Shigu Cao (*Shenzhen Inequation Technology Co. Ltd.*);

17:00 GL Full Wave Modeling and Ray Tracing Method for Cloak
Jianhua Li (*GL Geophysical Laboratory*); *Lee Xie* (*GL Geophysical Laboratory*); *Feng Xie* (*GL Geophysical Laboratory*); *Ganquan Xie* (*GL Geophysical Laboratory*);

17:20 r Can Be Negative in a New Negative World on Acoustic, EM, and Seismic Modeling and Inversion
Jianhua Li (*GL Geophysical Laboratory*); *Feng Xie* (*GL Geophysical Laboratory*); *Lee Xie* (*GL Geophysical Laboratory*); *Ganquan Xie* (*GL Geophysical Laboratory*);

17:40 A New GLHUANPII-3 Electromagnetic Invisible Cloak
Jianhua Li (*GL Geophysical Laboratory*); *Feng Xie* (*GL Geophysical Laboratory*); *Lee Xie* (*GL Geophysical Laboratory*); *Ganquan Xie* (*GL Geophysical Laboratory*);

Session 4P2a
SC5: Advances in PolSAR/PolInSAR Analysis and Applications

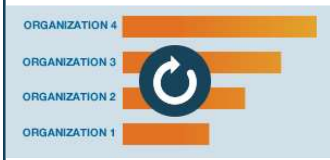
Saturday PM, August 4, 2018
Room T2
Organized by Hiroyoshi Yamada, Ryoichi Sato
Chaired by Hiroyoshi Yamada, Ryoichi Sato

13:00 Detection of Landslides of the 2016 Kumamoto Earthquake by Using Two Single-pass Cross-track Interferometry Airborne SAR Data
Toshifumi Moriyama (*Nagasaki University*); *Fumiaki Jitsufuji* (*Nagasaki University*);

13:20 Monitoring Permafrost Environments with Polarimetric SAR and Optical Remote Sensing Data
Sang-Eun Park (*Sejong University*);

An Experimental Study of Foliage Penetrating Radar with Coherent Change Detection

5 Author(s) S. Demirci ; B. Yilrnaz ; H. Isiker ; S. Gokkan ; C. Ozdemir **View All Authors**



Abstract

Document Sections

1. Introduction
2. Detection of Movements in Forests
3. Experimental Results
4. Conclusion

Authors

Figures

References

Keywords

Metrics

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Abstract: In this study, we designed and built a prototype foliage penetrating radar (FPR) system for real-time detecting and imaging of moving objects in forestlands. The system w... **View more**

Metadata

Abstract:
In this study, we designed and built a prototype foliage penetrating radar (FPR) system for real-time detecting and imaging of moving objects in forestlands. The system was composed of a handheld VNA, two log-periodic antennas, a 1 W RF amplifier, a LNA and a computer. Two different change detection procedures namely complex subtraction and wavelet-based semblance analysis were employed for the detection of electromagnetic impedance changes due to human movement in slightly dense forest camouflage conditions. Both techniques are based on the comparison of the 1D range profiles of the scene acquired at consecutive time instants. The results demonstrate the successful detection and tracking of the change signals occurring at up to 100 m range.

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Contents

SECTION 1.
Introduction

An Experimental Study of Foliage Penetrating Radar with Coherent Change Detection

S. Demirci[1], B. Yilmaz[1], H. Isıker[2], S. Gokkan[2], and C. Ozdemir[1]

[1]Department of Electrical-Electronics Engineering, Mersin University, Mersin, Turkey
[2]Vocational School of Technical Sciences, Mersin University, Mersin, Turkey

Abstract— In this study, we designed and built a prototype foliage penetrating radar (FPR) system for real-time detecting and imaging of moving objects in forestlands. The system was composed of a handheld VNA, two log-periodic antennas, a 1 W RF amplifier, a LNA and a computer. Two different change detection procedures namely complex subtraction and wavelet-based semblance analysis were employed for the detection of electromagnetic impedance changes due to human movement in slightly dense forest camouflage conditions. Both techniques are based on the comparison of the 1D range profiles of the scene acquired at consecutive time instants. The results demonstrate the successful detection and tracking of the change signals occurring at up to 100 m range.

1. INTRODUCTION

The detection and tracking of moving ground targets within a foliage terrain environment is vital in various surveillance missions of defense, border guarding and homeland security applications. Among these missions are; detection and identification of terrorist activities in forested areas of mountainsides and locating people or animals those are lost in severe environmental conditions of forested regions. For this purpose, foliage penetrating radars (FPR) have been developed thanks to their ability in seeing through visually opaque forest medium via detecting and locating small changes in the reflected signals' amplitudes and phases as an indicator of movement.

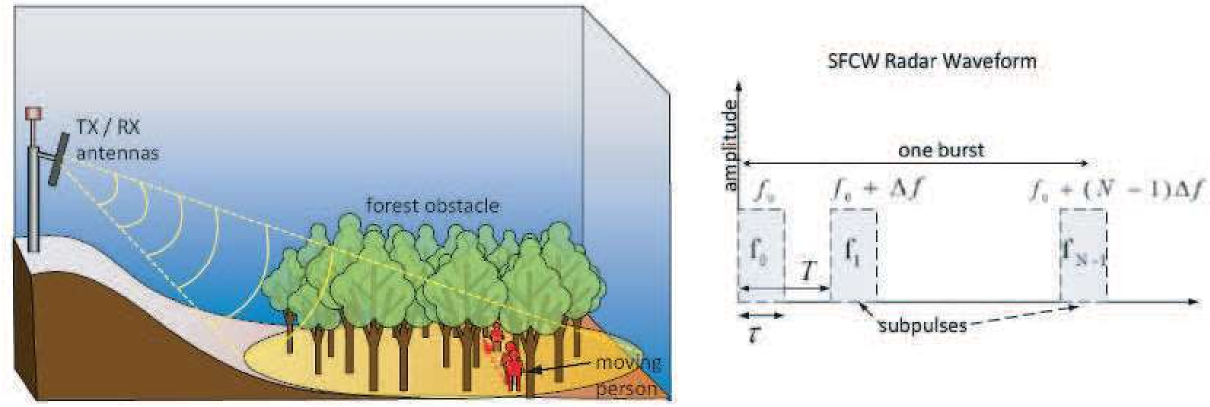
The most common use of FPR has been in airborne/satellite-based moving target detection within large forest regions through repeat-pass SAR images [1, 2]. There are also other applications that exploit the information contained in time-series SAR images to fulfill the goals such as; characterization of different forest types and deforestation and carbon monitoring [3]. Ground-based systems; on the other hand, provide less coverage area within the sensors' fields of view and hence they have been less deployed. One example is The Camp Sentinel Radar which was used during the Vietnam War [4]. Some border security systems aimed to detection of immigrants and smugglers have also been demonstrated [5–9]. But these systems were designed to operate mostly in open area environments and hence the account of the electromagnetic wave attenuation due to vegetation obstacles was considered to a certain degree.

With today's increasing security issues, ground-based FPRs can be of great importance in practically monitoring the illegal activities within small scale foliage regions. In this study, an experimental ground-based FPR system capable of real-time tracking of moving ground targets is investigated and evaluated under slightly dense forest camouflage condition. Since the goal of this application is just to locate the positions of moving objects, high resolution imaging and use of array antennas are not needed. Indeed, one transmit and one receive antenna would suffice to be able to detect the movements of targets and their ranges to the radar. The data processing step, however, involves challenges due to encountered low signal-to-clutter-ratio conditions. The traditional approach to this change detection problem, still potentially useful for most cases, is subtracting the signals consecutively measured for the same scene. Other techniques have also been proposed by taking into account the employed radar systems [10–14]. In this study, we applied two coherent change detection procedures namely; the simple subtraction technique and a wavelet-based semblance analysis approach which has shown promise by our previous water-leak detection application [15].

2. DETECTION OF MOVEMENTS IN FORESTS

2.1. System Geometry

Figure 1(a) shows the schematic diagram of our TFR system used for the detection of movements in forests. The radar platform at some stand-off distance is elevated to a certain height and the quasi-monostatic transmitter (TX) and receiver (RX) antennas are inclined from the vertical direction



(a) (b)

Figure 1: (a) Schematic diagram of our TFR system, (b) SFCW radar waveform.

to illuminate the investigated area of the forest with a desired range of local incidence angles. With transmission of a single modulated/pulse signal, the radar records part of the scattered wave directed backwards to the RX antenna. Then, one range profile data of the illuminated region is gathered through proper signal acquisition routines. To detect the changes due to movements of the objects, a continuous scanning of the same region is needed. The collected time-series data are then processed by using change detection techniques to able to retrieve the electromagnetic impedance change information that shows whether a target is present and moving. As a consequence, the real time tracking of the objects is achieved by displaying the resulted change signal.

It is well known that the characterization of the electromagnetic wave propagation through a forest medium is complex depending on several factors. Transmission and reflection properties of forests considerably differ for different data collection topologies, radar systems/waveforms, polarizations, frequency ranges as well as weather conditions. In this work, we employed a suitable combination of these parameters (center frequency, bandwidth, beam width of the antenna, antenna gain, radiated power, incidence angle, maximum range and etc.) to detect movements behind trees.

2.2. SFCW Design

In our prototype TFR system, we have adopted stepped-frequency continuous wave (SFCW) operation due to its high performance in low SCR environments. Fig. 1(b) shows one burst of a transmit signal of SFCW radar for the generation of a single range profile. Each burst consists of N subpulses with constant-frequencies that are incremented linearly in discrete steps, attaining a larger effective bandwidth of B. τ is the pulse width and T is the pulse repetition interval which determines the desired unambiguous range R_u. After a subpulse is transmitted, the frequency response of the illuminated scene is sampled and stored for the corresponding stepped-frequency. Each sample is called as a range bin since it represents the return from a range window of $c\tau/2$ where c is the speed of light in free space. To perform any processing, all the samples (amplitudes and phases) due to N pulses of the burst should be acquired for any one bin.

Denoting the starting carrier frequency as f_0, the step size as Δf and the pulse index as $k\,(0 \leq k \leq N-1)$, the transmit signal for the kth subpulse can be expressed as $E_1 \cos 2\pi(f_0 + k\Delta f)$. Then, the phase lag of the return signal for a stationary target at a range R_0 can be written as

$$\phi_k = 2\pi(f_0 + k\Delta f)\frac{2R_0}{c} \quad (1)$$

Taking the IDFT of N complex samples corresponding to a specific range bin produces the range profile which represents the range bin in the slant range with N finer subdivisions. When the target is moving at a constant velocity v, the phase for the kth echo signal becomes

$$\phi_k = 2\pi(f_0 + k\Delta f)\frac{2}{c}(R_0 + vkT) \quad (2)$$

which can be rewritten as

$$\phi_k = \frac{4\pi f_0 R_0}{c} + 2\pi\frac{\Delta f}{T}\frac{2R_0}{c}kT + 2\pi\frac{2v}{c}f_0 kT + 2\pi\frac{\Delta f}{T}\frac{2vkT}{c}kT \tag{3}$$

For stationary targets only the first two terms of Eq. (3) are valid whereas for moving targets the last two terms related to Doppler frequency shifts are also added to the signal phase. In range profile generation process, these Doppler frequency shifts result in shifting of target range from its actual range, known as range-Doppler coupling. For our TFR waveform parameters and velocity ranges, this range spread was found to be very lower than the range bin size, thus no additional signal processing was required in our application. The two important waveform design equations are related with the range resolution ΔR and unambiguous range R_u which are given as $\Delta R = c/2N\Delta f$ and $R_u = T\cdot(c/2)$, respectively. Finally, in our application, we chose single range bin which implies $\tau = T$ together with $\tau\Delta f = 1$ (or $B(NT) = N^2$).

2.3. Change Detection Techniques

Two change detection procedures were used namely; complex subtraction and wavelet-based semblance analysis. The former is the most straightforward change detection scheme wherein the "difference signals" between two consecutive range profiles are displayed in real time and exploited as an indication of the movement. The latter is based on the phase correlations between the wavelet decompositions of two consecutive range profile signals. The operation of this cross-wavelet transform based technique can be briefly explained as follows:

i) Take any sequential two raw range profiles $e_1(r)$ and $e_2(r)$ that are measured at different time instants.
ii) For a chosen mother wavelet ψ (or analyzing function), obtain the continuous wavelet transform (CWT) of each range profile, W_ψ^1 and W_ψ^2 for a discrete grid of scales and translations.
iii) Calculate the cross-wavelet spectrum by using $W_\psi^{12} = W_\psi^1 W_\psi^2$.
iv) Compute the phase angle θ of the complex signal W_ψ^{12} via $\theta = \tan^{-1}(\Im(W_\psi^{12})/\Re(\Im(W_\psi^{12}))$.
v) Calculate the semblance defined as $S = \cos^n(\theta)$, $S \in [-1,\ 1]$.

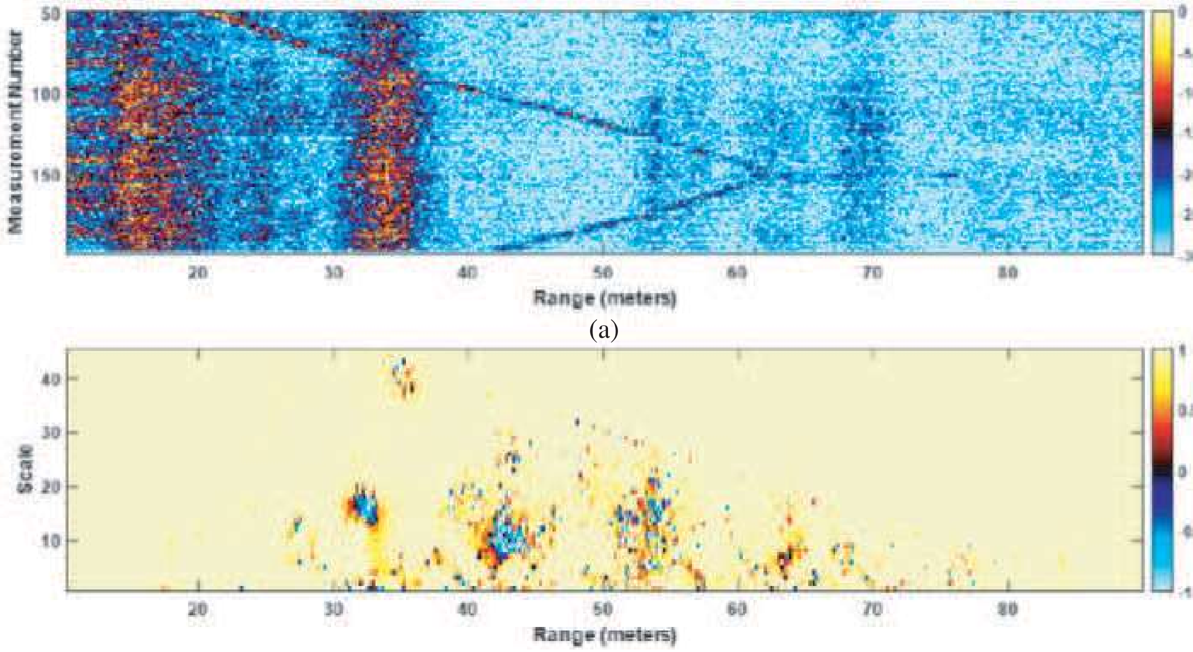
where n is an odd integer greater than zero. The calculated semblance values S will then give a measure of the phase correlation between the two range profiles for the different scales of the used wavelet where values close to "-1" indicate high negative correlation, "0" indicate no correlation and "1" indicate high positive correlation [16].

3. EXPERIMENTAL RESULTS

The goal of our study was the experimental detection of the movement of a person within trees against up to 100 m operating ranges. The photographs of the implemented TFR set-up and test field are shown in Fig. 2. The system consists of a handheld VNA, two log-periodic antennas, an RF amplifier (1 W), a LNA and a computer. The frequency range was selected to be 1 GHz to 2 GHz with 601 sampling points due to the tradeoff between foliage penetration and resolution. The transmission of continuum series of burst signals through the forest was performed for a desired

Figure 2: Sample photographs of the system and test field.

time duration. The measured back-scattered data for each burst was recorded to a computer via VNA's GPIB port and processed into range profiles by real-time processing. The change detection procedures were then applied to consecutive range profiles and the results are continuously monitored. The top image in Fig. 3 shows the whole tracking result of a moving person where each row represents the amplitude difference between the consecutive range profiles measured at a specific time instant. The movement manifests itself as some straight-line segments; however, the clutter signals due to windblown trees also show up at fixed ranges. The application of a semblance-based detection procedure to this data results in the bottom image. The technique was implemented using 40 scales of complex Morlet wavelet and applied to each range profile pairs measured at consecutive time instants. The blue signatures represent the high negative correlations between the range profiles which further validates the change locations due to windblown and human movement within the scene.



(b)

Figure 3: Results for (a) subtraction method and (b) semblance analysis based method.

4. CONCLUSION

We investigated the capabilities of an experimental TFR system in detecting and localizing the movements in forest regions. For this electromagnetic impedance change problem, a simple principle of differencing the consecutive range-profiles and a spectral-based change detection procedure namely semblance analysis were used and tested on field data. The results indicate the feasibility of the techniques in discriminating electromagnetic impedance changes. As a future work, identification and classification algorithms will be investigated to ascertain whether the movement is by human beings or animals, or is simply a movement of the vegetation due to wind.

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