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University of Adelaide, Australia

Professor with the School of Electrical and Electronic Engineering

Derek Abbott (M'85–SM'99–F'05) was born in South Kensington, London, U.K. He completed his B.Sc. (Hons.) degree in physics (1982) from Loughborough University, Leicestershire, U.K. and the Ph.D. degree in electrical and electronic engineering (1995) from The University of Adelaide, Adelaide, SA, Australia.

From 1978 to 1986, he was a Research Engineer with the GEC Hirst Research Centre, London, U.K. From 1986 to 1987, he was a VLSI Design Engineer with Austek Microsystems, Australia. Since 1987, he has been with The University of Adelaide, where he is currently a full Professor with the School of Electrical and Electronic Engineering. His research interests include multidisciplinary physics and electronic engineering applied to complex systems, networks, game theory, energy policy, stochastics, and biophotonics. He co-edited Quantum Aspects of Life (Imperial College Press, 2008), and co-authored Stochastic Resonance (Cambridge Univ. Press, 2008) and Terahertz Imaging for Biomedical Applications (Springer-Verlag, 2012).

He has served as Guest Editor for IEEE J. Solid-State Circuits (1999) and Associate Editor for IEEE Photonics (2009–2014). He has served on the Editorial Board of Proceedings of the IEEE (2009–2014), the Editorial Board of IEEE Access (2015–Present), and he currently serves on the IEEE Publications Publication Services and Products Board (PSPB).

Prof. Abbott has received a number of awards, including an Australian Research Council Future Fellowship (2012), the David Dewhurst Medal (2015) for biomedical engineering, the Barry Inglis Medal (2018) for measurement science, and the M. A. Sargent Medal (2019) for eminence in engineering.

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Ram Adapa

Electric Power Research Institute

Palo Alto, California, USA

Technical Executive in the Power Delivery and Utilization Sector

About Dr. Adapa

Ram Adapa (S'82-M'85-SM'90-F'12) received the B.S. degree from Jawaharlal Nehru Technological University, India, the M.S. degree from IIT Kanpur, India, and the Ph.D. degree from the University of Waterloo, ON, Canada, all in electrical engineering.

He is a Technical Executive in the transmission and substations area with the Power Delivery and Utilization Sector.

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Anuradha Annaswamy

MIT

Cambridge, Massachusetts, USA

Founder and Director, Active-Adaptive Control

About Dr. Annaswamy

Dr. Anuradha Annaswamy is Founder and Director of the Active-Adaptive Control Laboratory in the Department of Mechanical Engineering at MIT. Her research interests span adaptive control theory and its applications to aerospace, automotive, and propulsion systems as well as cyber physical systems such as Smart Grids, Smart Cities, and Smart Infrastructures. Her current research team of 15 students and post-docs is supported at present by Air-Force Research Laboratory, Boeing, Ford-MIT Alliance, Department of Energy, and NSF.

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Nirwan Ansari

New Jersey Institute of Technology

Newark, New Jersey, USA

Distinguished Professor, Electrical and Computer Engineering

About Professor Ansari

Nirwan Ansari is Distinguished Professor of ECE at NJIT. He authored Green Mobile Networks: A Networking Perspective (IEEE-Wiley, 2017) with T. Han, and co-authored two other books. He has also (co-)authored more than 550 technical publications, over 250 published in widely cited journals/magazines. He has guest-edited a number of special issues covering various emerging topics in communications and networking. He has served on the editorial/advisory board of over ten journals.

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Jun Cai

Concordia University, Canada

Montreal, Quebec, Canada

Professor and the PERFORM Centre Research Chair

About Professor Cai

Jun Cai received the Ph.D. degree from the University of Waterloo, ON, Canada, in 2004. From June 2004 to April 2006, he was with McMaster University, Canada, as a Natural Sciences and Engineering Research Council of Canada (NSERC) Postdoctoral Fellow. From July 2006 to December 2018, he has been with the Department of Electrical and Computer Engineering, University of Manitoba, Canada, where he was a full Professor and the NSERC Industrial Research Chair. Since January 2019, he has joined the Department of Electrical and Computer Engineering, Concordia University, Canada, as a full Professor and the PERFORM Centre Research Chair.

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José Capmany

About Professor Capmany

José Capmany was born in Madrid, Spain, he received the Ingeniero de Telecomunicacion degree from the

Universitat Politecnica de Valencia

València, Spain

Director of the Research Institute of Telecommunications and Multimedia (iTEAM)

Universidad Politécnica de Madrid (UPM) in 1987 and the Licenciado en Ciencias Físicas. He holds a PhD in Electrical Engineering from UPM (1991) and a PhD in Quantum Physics from the Universidad de Vigo. Since 1991 he is with the Departamento de Comunicaciones, Universidad Politecnica de Valencia (UPV), where he started the activities on optical communications and photonics, founding the Photonics Research Labs Group (www.prl.upv.es). Since 1996 he is a Full Professor in Photonics and Optical Communications. From 2005 to 2016, he was the Director of the Research Institute of Telecommunications and Multimedia (iTEAM) at UPV (www.iteam.upv.es).

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Babu Chalamala

Sandia National Laboratories

Albuquerque, New Mexico, USA

Manager of the Energy Storage Systems Department

About Dr. Chalamala

Babu Chalamala (S'96–M'96–SM'00–F'14) is Manager of the Energy Storage Systems Department at Sandia National Laboratories.

Prior to joining Sandia in August 2015, he was a Corporate Fellow at SunEdison (formerly MEMC Electronic Materials) for five years, where he led R&D and product development in grid scale energy storage.

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Kun-Shan Chen

Guilin University of Technology

Guangxi, China

Professor

About Dr. Chen

Kun-Shan Chen (S'86-M'92-SM'98-F'07) received a Ph.D. degree in electrical engineering from the University of Texas at Arlington in 1990. From 1992-2014, he was a professor at the National Central University, Taiwan. Since 2014, he has been with the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, China. In 2019, he joined Guilin University of Technology as a full-time professor, where his research interests include electromagnetic wave scattering and emission, microwave remote sensing theory and modeling, system measurements and calibration, and more recently, intelligent signal processing and data analytics for radar.

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M. Jamal Deen

McMaster University
Hamilton, Ontario, Canada

Distinguished University Professor

About Dr. Deen

Dr. M. Jamal Deen (Fellow '02) is a Distinguished University Professor at McMaster University, Canada. He received the Ph.D. degree in electrical engineering and applied physics from Case Western Reserve University for research work sponsored and used by NASA, Cleveland. He was awarded four honorary doctorate degrees in recognition of his exceptional research and scholarly accomplishments, professionalism and service.

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John W. Evans

NASA
Washington, DC, USA

Program Executive, Office of Safety and Mission Assurance

About Dr. Evans

Dr. John W. Evans is currently a Program Executive at NASA HQ, Office of Safety and Mission Assurance in Washington, DC, where he is leading agency policy development and research programs for Reliability and Maintainability and managing the NASA Electronic Parts and Packaging Program.

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Shaikh Anowarul Fattah

About Dr. Fattah

Shaikh Fattah received Ph.D. degree from Concordia University, Canada and was a visiting Postdoctoral Fellow at Princeton University, USA. He received B.Sc. and M.Sc. degrees from BUET, Bangladesh, where he is now Professor, Department of EEE and Director, INPE.

Bangladesh University of Engineering and Technology (BUET)

Dhaka, Bangladesh

Professor, Department of Electrical and Electronic Engineering

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Aura Ganz

University of Massachusetts

Amherst, Massachusetts, USA

Professor with the Electrical and Computer Engineering Department and Director of the 5G Mobile Evolution Laboratory

About Professor Ganz

Aura Ganz (M'88-SM'90-F'08) is a Professor with the Electrical and Computer Engineering Department and the Director of the 5G Mobile Evolution Laboratory with the University of Massachusetts, Amherst.

She has more than 25 years experience in research and development of wireless and sensor networks, system architecture design, and software on mobile platforms.

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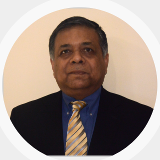
Amitava Ghosh



Nokia Networks

Buffalo Grove, Illinois, USA

Head of North America Radio Systems Research

About Dr. Ghosh

Amitava Ghosh (M'86-SM'06-F'15) received the Ph.D. degree in electrical engineering from Southern Methodist University, Dallas.

He joined Motorola in 1990. Since joining Motorola, he worked on multiple wireless technologies starting from IS-95, CDMA-2000, 1xEV-DV/1XTREME, 1xEV-DO, UMTS, HSPA, 802.16e/WiMAX/802.16m, enhanced EDGE, and 3GPP LTE.

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Dmitry Goldgof

University of South Florida

Tampa, Florida, USA

Distinguished University Professor and Vice-Chair, Department of Computer Science and Engineering

About Professor Goldgof

Dmitry Goldgof is an educator and scientist working in the area of Medical Image Analysis, Image and Video Processing, Computer Vision and AI, Ethics and Computing, Bioinformatics and Bioengineering. Research interests are related to two broad thrusts. First is in the area of biomedical image analysis and machine learning with application in MR, CT, PET and microscopy images, radiomics and bioinformatics. Second thrust is the area of video motion analysis with biometrics, surveillance and biomedical applications.

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Venu Govindaraju

University of Buffalo

Buffalo, New York, USA

Vice President for Research and Economic Development

About Dr. Govindaraju

Venu Govindaraju serves as the Vice President for Research and Economic Development at the University at Buffalo. He is a SUNY Distinguished Professor of Computer Science and Engineering and is the founding director of the Center for Unified Biometrics and Sensors. A recognized authority in the field of Pattern Recognition, Govindaraju has received peer honors such as the IAPR/ICDAR Outstanding Achievements (2015), Distinguished Alumnus Award from IIT Kharagpur (2014), the IEEE Technical Achievement Award (2010), MIT Global Indus Technovator Award (2004), and fellowships from the major professional societies such as AAAS, ACM, IAPR, IEEE, and the SPIE. He is also a member of the National Academy of Inventors (2015).

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Josep M. Guerrero

About Professor Guerrero

Josep M. Guerrero received the B.S. degree in telecommunications engineering, the M.S. degree in electronics engineering, and the Ph.D. degree in power electronics from the Technical University Catalonia, Barcelona, in 1997, 2000 and 2003, respectively. Since

Aalborg University
Aalborg, Denmark

Professor, Department of Energy Technology

2011, he has been a Full Professor with the Department of Energy Technology, Aalborg University, Denmark.

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Melinda Hodkiewicz

University of Western Australia
Perth, Australia

Professor in the School of Mechanical and Chemical Engineering

About Dr. Hodkiewicz

Melinda Hodkiewicz received her Ph.D. Mechanical Engineering from the University of Western Australia in 2004.

She is currently the BHP Billiton Fellow for Engineering for Remote Operations at the University of Western Australia and leads the System Health Laboratory.

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Abbas Jamalipour

University of Sydney
Sydney, Australia

Professor of Ubiquitous Mobile Networking

About Professor Jamalipour

Abbas Jamalipour is the Professor of Ubiquitous Mobile Networking at the University of Sydney, Australia, and holds a PhD in Electrical Engineering from Nagoya University, Japan 1996. He is a Fellow of the IEEE (2007), Institute of Electrical, Information, and Communication Engineers (IEICE 2010), and the Institution of Engineers Australia (2004), an ACM Professional Member, and an IEEE Distinguished Lecturer.

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Weihua Jiang

Nagaoka University of Technology

Nagaoka, Niigata, Japan

Professor, Department of Electrical Engineering

About Professor Jiang

Weihua Jiang graduated from National University of Defense Technology, Changsha, China, in 1982, receiving a Bachelor Degree in Applied Physics. He received his Master Degree in Plasma and Nuclear Fusion Engineering from Institute of Atomic Energy, Beijing, China, in 1985 and his PhD in Energy and Environment Engineering from Nagaoka University of Technology, Nagaoka, Japan, in 1991, respectively. He started working for Nagaoka University of Technology in April 1991 where he is now a full Professor on Electrical Engineering.

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Lina Karam

Lebanese American University

Beirut, Lebanon

Dean of Engineering

About Dr. Karam

Dr. Lina Karam, Fellow of the IEEE, is the incoming Dean of Engineering at the Lebanese American University starting January 2020. She is also a Professor in the School of Electrical, Computer & Energy Engineering, and the Director of the Image, Video & Usability Research Laboratory at Arizona State University. She is the President of PICARIS, LLC, a consulting company, and serves as expert consultant in patent litigation. She received the B.E. degree in computer and communications engineering from the American University of Beirut in 1989 and the M.S. and Ph.D. degrees in electrical engineering from the Georgia Institute of Technology in 1992 and 1995, respectively. She served as the Computer Engineering Graduate Program Chair and as Computer Engineering Director for Industry Engagement at ASU. She is the Editor-In-Chief of the IEEE Journal of Selected Topics in Signal Processing.

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Okyay Kaynak

About Dr. Kaynak

Fellow, B.Sc. 1969, Ph.D. 1972, (University of Birmingham, UK). From 1972 to 1979, he held various positions within the industry, both in and outside of Turkey. In 1979, he joined Bogazici University, Istanbul.

Bogazici University
Istanbul, Turkey

Professor, Department of Electrical and Electronic Engineering

He has served as the chair of Computer Engng. and EEE Departments and as the Director of Biomedical Engineering Institute. Currently, he is an Emeritus Professor and the holder of UNESCO Chair on Mechatronics. He has hold long-term visiting professor/scholar positions at various institutions in Japan, Germany, U.S., Singapore and China.

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Joy Laskar

Maja Systems
Milpitas, California, USA

Senior Vice-President and Chief Technology Officer

About Dr. Laskar

Joy Laskar received his B.Sc. in Computer Engineering from Clemson University and the M.Sc. and Ph.D. degrees from the University of Illinois at Urbana-Champaign. Dr. Laskar is currently the Senior Vice President/CTO of Maja Systems and a partner at Anayas360, an advisory group in Silicon Valley.

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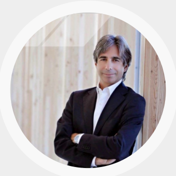
Gianluca Lazzi



University of Southern California
Los Angeles, California, USA

Provost Professor of Ophthalmology and Electrical Engineering

About Dr. Lazzi

Gianluca Lazzi (S'94–M'95–SM'99–F'08) received the Dr.Eng. degree in electronics from the University of Rome "La Sapienza," Rome, Italy, in 1994, and the Ph.D. degree in electrical engineering from the University of Utah, Salt Lake City, UT, USA, in 1998.

He is a Provost Professor of Ophthalmology and Electrical Engineering at University of Southern California.

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Victor Leung

About Dr. Leung

The University of British Columbia

Vancouver, British Columbia, Canada

Professor of Electrical and Computer Engineering

Victor C. M. Leung is a Professor of Electrical and Computer Engineering and holder of the TELUS Mobility Research Chair at the University of British Columbia.

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Shengtao Li

Xi’an Jiaotong University

Xi'an, Shaanxi, China

Professor, State Key Laboratory of Electrical Insulation and Power Equipment

About Professor Li

hengtao Li received the Ph.D. degree in electrical engineering from Xi’an Jiaotong University (XJTU), China, in 1990. He was a Lecturer, Associate Professor, and Professor of XJTU in 1990, 1993, and 1998, respectively. He was a Research Fellow at Waseda University, Japan, in 1996, and was also a Senior Visiting Scholar at University of Southampton, UK, in 2001. From 1993 to 2003, he was a deputy director of the State Key Laboratory of Electrical Insulating and Power Equipment (SKLEIPE) at XJTU. Since 2003, he has been an executive deputy director of SKLEIPE. Since 2013, he has been a deputy dean of the Department of Electrical Engineering at XJTU. He was awarded a Distinguished Young Scholar of China by the National Science Foundation in 2006.

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Qilian Liang

University of Texas at Arlington

Arlington, Texas, USA

About Dr. Liang

Qilian Liang is a Distinguished University Professor at the Department of Electrical Engineering, University of Texas at Arlington. He received his PhD degree from University of Southern California in Electrical Engineering in 2000.

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Director of the Chair on Systems Science and the Energetic Challenge of the Foundation Electricite' de France at CentraleSupélec, France, full professor and President of the Alumni Association at Politecnico di Milano

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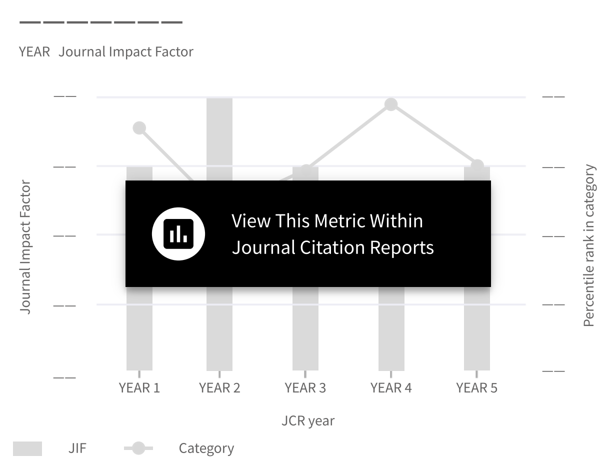

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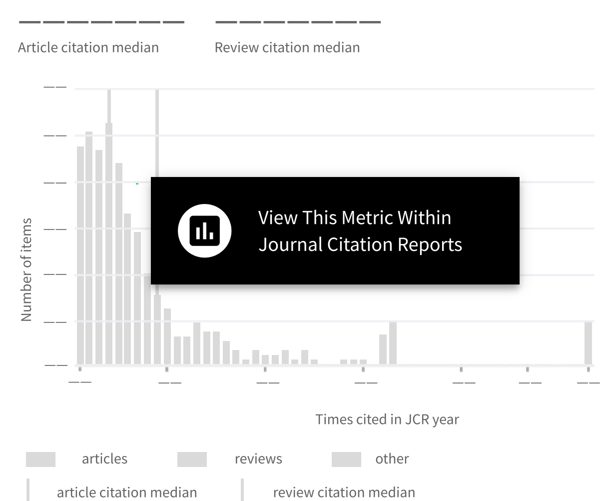

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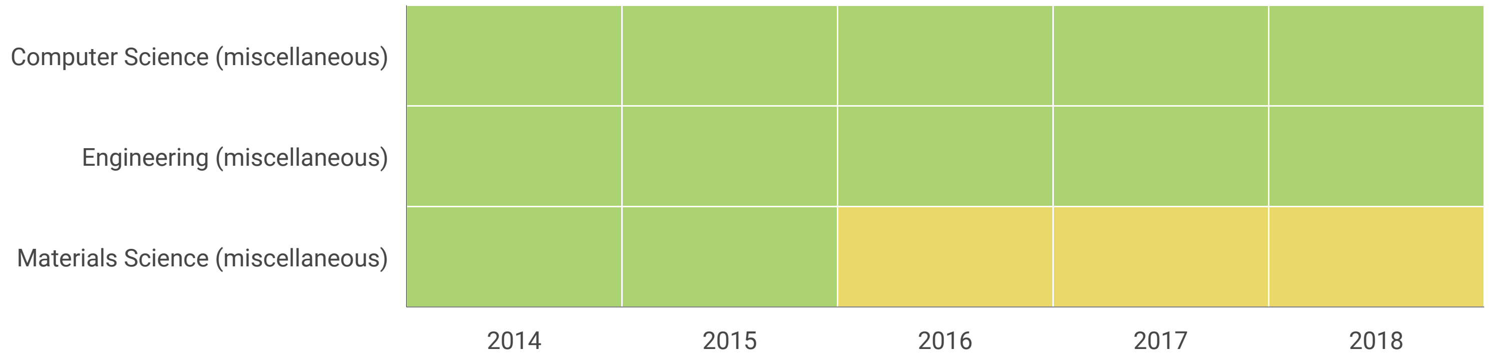

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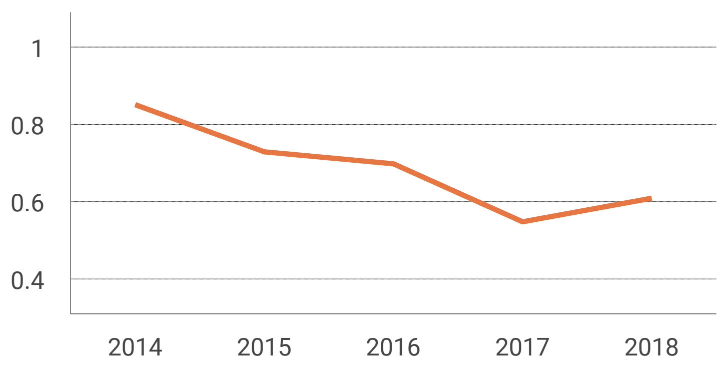

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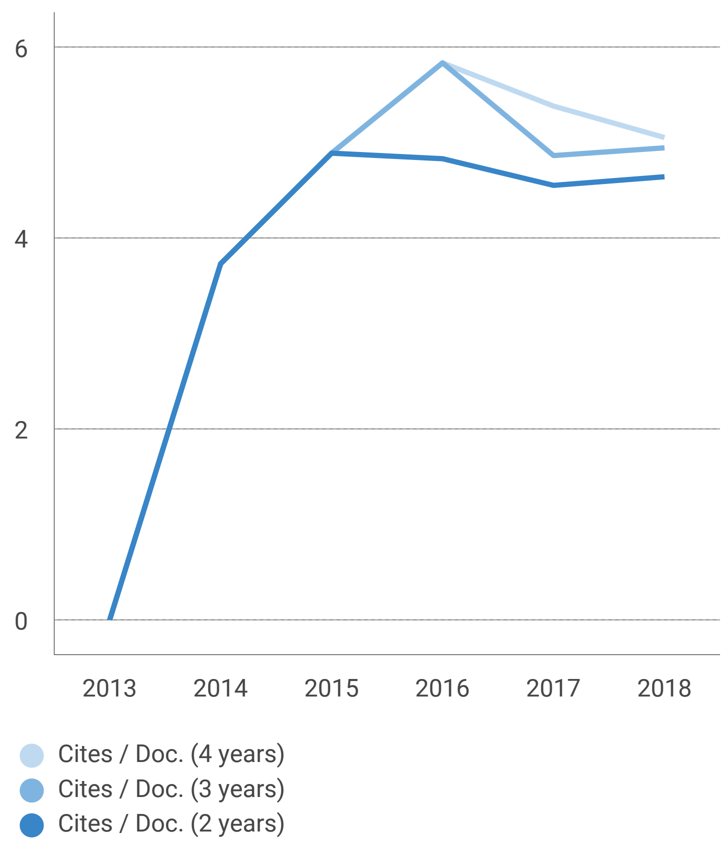

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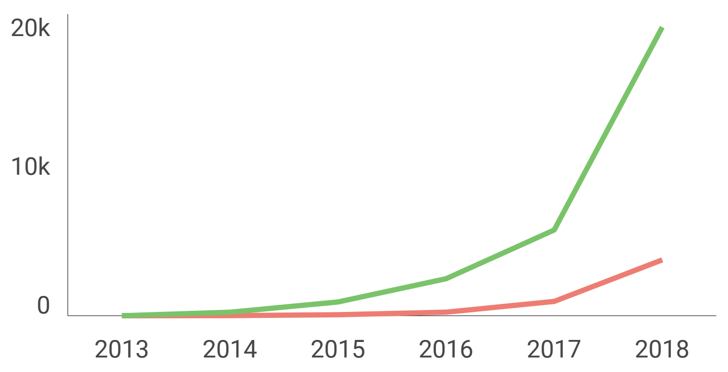

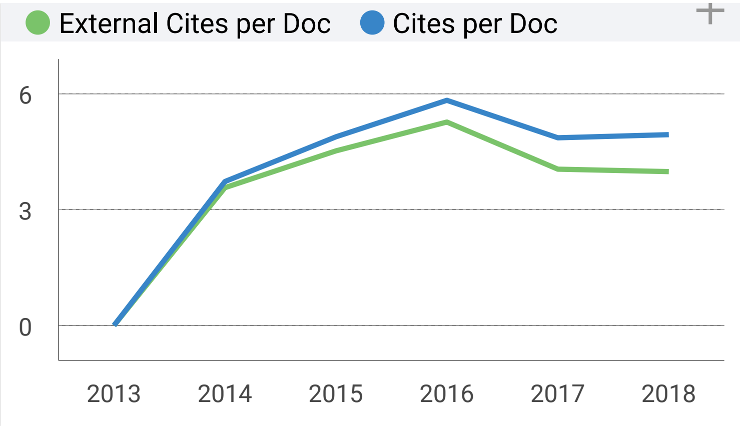

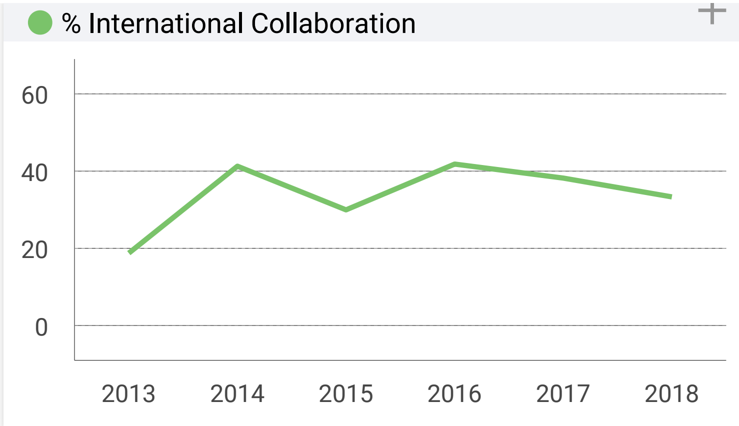

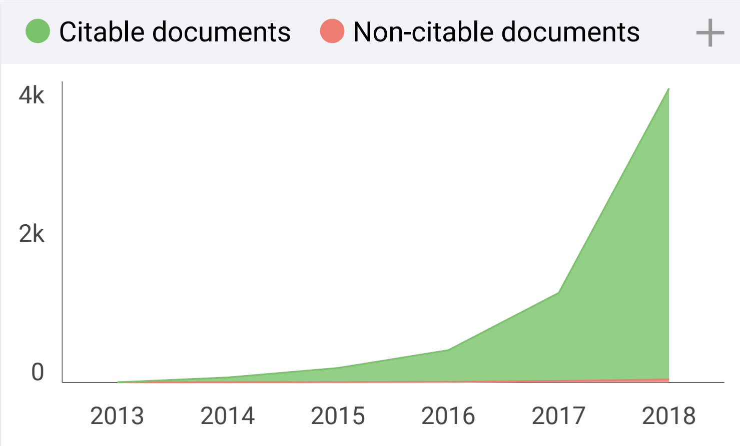

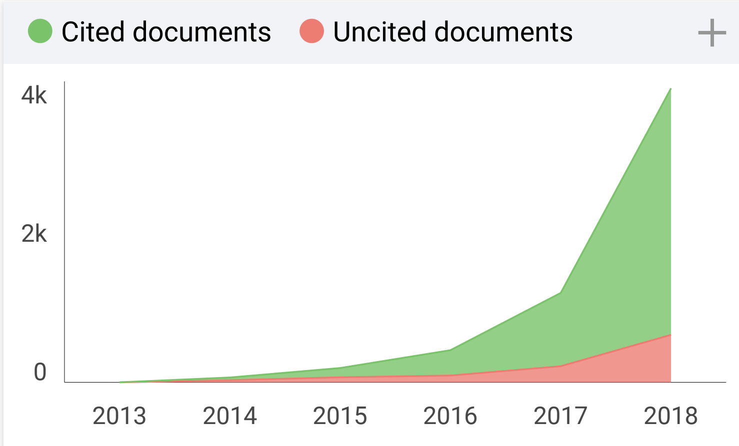

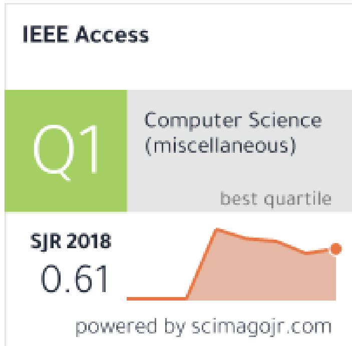

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3D Land Mapping and Land Deformation Monitoring Using Persistent Scatterer Interferometry (PSI) ALOS PALSAR: Validated by Geodetic GPS and UAV

PAKHRUR RAZI[1,2], JOSAPHAT TETUKO SRI SUMANTYO[2], (Senior Member IEEE), DANIELE PERISSIN[3], (Member, IEEE), HIROAKI KUZE[2], MING YAM CHUA[2], (Member, IEEE), AND GOOD FRIED PANGGABEAN[2]

[1]Physics Department, Universitas Negeri Padang, Sumatra 25131, Indonesia
[2]Center for Environmental Remote Sensing, Chiba University, Chiba 236-8522, Japan
[3]Lyle School of Civil Engineering, Purdue University, West Lafayette, IN 47907 USA

Corresponding author: Pakhrur Razi (fhrrazi@fmipa.unp.ac.id)

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ABSTRACT Complex topography and geological formation are the primary causes of frequent land deformation occurrence at Kelok Sembilan area, West Sumatra, Indonesia. This paper presents a research work on land mapping and land deformation monitoring carried out using persistent scatterer interferometry (PSI) synthetic aperture radar (SAR) technique at Kelok Sembilan bridge region. In this paper, 13 ascending Advanced Land Observation Satellite Phased Array L-band Synthetic Aperture Radar (ALOS PALSAR) scenes, taken from July 2007 to November 2010, were processed using PSI-SAR technique. Then, the land deformation analysis was performed in two of the critical landslide areas near the Kelok Sembilan bridge. For validation purpose, the results were compared with *in situ* ground measurement data obtained using both differential global positioning system technique, and 3-D photogrammetry technique based unmanned aerial vehicle. The land deformation analysis showed that both of the investigation areas are suffering a severe land movement of approximately −100 mm every year. In addition to that, the validation results showed erroneousness of less than 0.3%.

INDEX TERMS Persistent scatterer interferometry (PSI), 3D mapping, land deformation, radar interferometry, UAV validation, Kelok Sembilan.

I. INTRODUCTION

Located in West Sumatra, Indonesia, Kelok Sembilan or ‘‘9 curve-climbs’’ is a very famous road that connects West Sumatra province to Riau province. Built by the Dutch in 1914, the road nowadays is essential for transportation, serving as the pillar of Central Sumatra’s economy with more than ten thousand of vehicles passing through the road daily. To cater the high traffic demand in Kelok Sembilan road, a flyover bridge (part of 44 km from Sarilamak to Pangkalan Koto Baru) was built in 2003 at the center for Kelok Sembilan road.

Land deformation problems such as landslides and land subsidence occurring at Kelok Sembilan are frequently mainly due to its complex surface topography and geology formation. Over the past three years, 110 landslide incidents were identified, 35 in 2015, 11 in 2016, and 64 on March 3, 2017 [1]. Thus, to minimize the impact caused by land deformation, it is necessary to map and monitor the land instability in Kelok Sembilan from time to time.

Persistent Scatterer Interferometry–Synthetic Aperture Radar (PSI-SAR) is a well-known surface displacement detection technique that is frequently used to quantify the earth surface movement precisely. It is more advanced than conventional Interferometry Synthetic Aperture Radar (InSAR) technique and had overcome the limitations in temporal decorrelation, geometrical decorrelation and atmospheric disturbance [2], [3]. The technique exploits multiple SAR scenes (slave) over the same area at different acquisition time, concerning one adequately chosen master SAR scene. The master scene is carefully selected based upon several critical criteria such as the atmospheric condition [3], the normal baseline and the temporal baseline, and also the Doppler centroid [4]. After selecting the master scene, many pairs of interferograms were generated by performing complex multiplication of the master scene to each slave scenes. However, not all phase information in the interferograms can be used for surface displacement. In PSI-SAR, several Persistent Scatterer (PS) points are chosen, and analysis is performed only on these satisfied PS points [5]. Typically, the PS points are selected based upon the stability of its amplitude and its phase history over a long time interval for every resolution cell [2]. By doing so, proper millimeter terrain motion can be precisely quantified [6].

Over the years, PSI-SAR technique has been widely applied in many remote sensing applications, including, but not limited to, land deformation monitoring [6], [7], sedimentation impact [8], and fault [9]. Conventionally, PSI-SAR results were usually validated with *in situ* ground truth measurement data recorded from geodetic GPS [10]. In this research work, the validation was performed by comparing the results to not only GPS geodetic data but also to 3D orthophoto synthesized using 3D photogrammetry technique based on UAV. 3D photogrammetry is a new technique that can be implemented on validating results obtained from microwave remote sensing technique. The accuracy is comparable to GPS geodetic instruments and has the advantage of broad coverage in observation area through a single scan. Interpreting the PSI-SAR results with 3D orthophoto gives not only a 3D visualization of the study area but also verifies the position and height of the PS points. Also, it keeps an inventory of information related to properties of the study area (e.g., falls, topples, slides flow and spread). Furthermore, high-resolution 3D orthophoto can be used to identify geomorphology features related to mass movements, such as scraps and debris flows.

Thus, this research aims to map and monitor land deformation using PSI-SAR technique. Then, the results from the PSI-SAR analysis were further validated using 3D orthophoto and differential GPS geodetic data. The generated land deformation information then can be beneficial to the local authorities as part of the scientific information in drafting/amending policies to minimize the impacts caused by landslides. Moreover, the outputs of this research can be used to increase awareness to those living in the area.

II. BACKGROUND OF STUDY AREA

The area of study is in the Kelok Sembilan bridge that is located at a latitude of 0° 4' 13.30'' S and longitude of 100° 41' 53.56'' E, in Limapuluh Kota District, West Sumatra, Indonesia. Mountainous areas surround it with many land deformation in the area [1]. Physically, Kelok Sembilan bridge is main interconnects connecting West Sumatra province (Kelok Sembilan) and Riau Province in Indonesia. The bridge was built meandering in the middle of two hilly mountainous areas with the aim to reduce the high traffic loads of the old roads. Today, the area was resolved to a famous tourist attraction destination in West Sumatra, Indonesia.

A. TOPOGRAPHY AND GEOMORPHOLOGY

Regarding regional geomorphology, the study area is in the range of mountainous area known as the Bukit Barisan which is part of the volcanic arc arrangement of tectonics plate in Sumatra Island. It is surrounded by several inactive volcanoes such as Mount Sago (2.261 m), Mount Bungsu (1.253 m) and Mount Sanggul (1.495 m). Based on the latest 30 m resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data, the highest point in the area (after geoid correction) is 961.4 m and the lowest is recorded to be 710.4 m above sea level. The slope values (in degree) is as high as 75° at western and eastern sides of the bridge. Batang Sanipan is a 20 km long river that crosses the two-hilly mountainous area in Kelok Sembilan.

Fig. 1 shows the topography and geomorphology structure of the study area and its contour shape. The study area is highlighted (white box) in Fig. 1. which covers both the left side and the right side of the bridge (positive slope of terrain: blue color and the negative slope of the terrain: yellow-green color). The positive slope of terrain on the study area is foreshortening of satellite's line of sight (LOS) with the high-resolution cell in the range direction. Contrary to the positive slope, the west side has good coherence but with minimum resolution. It is because the terrain of the area is in parallel to the LOS of the satellite [11]. Coherency and resolution cell of images of terrain area is profoundly affected by the topography of the area of interest.

B. GEOLOGICAL STRUCTURE

Geological structures of West Sumatra are folded (anticlinorium), and its fault structure heads from northwest to southeast, following the formation of Sumatra Island. The prominent fault of Sumatra is known as Sumatra fault (Semangko fault), along 1,900 km which is related to the subduction zone on the west coast of Sumatra island.

Fig. 2 depicts the geological structure of Limapuluh Kota District, West Sumatra, Indonesia. The areas have faults in the shape of normal fault structure (fault down) and a strike-slip fault which is part of block faulting system. A normal fault located at 1.1 km North direction from the Kelok Sembilan bridge, namely Kelok Sembilan-Solok Bio-Bio Fault. This fault stretches along 20.73 km from Southwest to Northeast. Another fault close to the area is Koto Alam fault spreading out from Southeast to Northwest with approximately 12.83 km long.

Based on the geological survey, the soil in the study area is majorly composed of marlstone with andesite, and slate varied by quartz. These are metamorphic rocks and

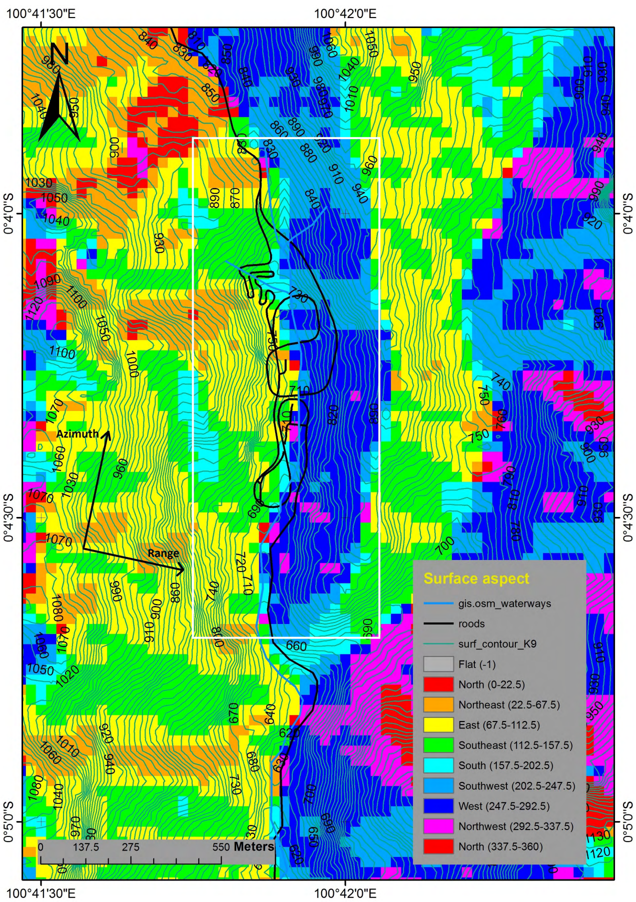

FIGURE 1. Topography and geomorphology structure of Kelok Sembilan region, West Sumatra Indonesia provided by SRTM DEM data with 30 m resolution. White box marks the area of research. Inset picture (right-below) shows surface aspect of Kelok Sembilan area.

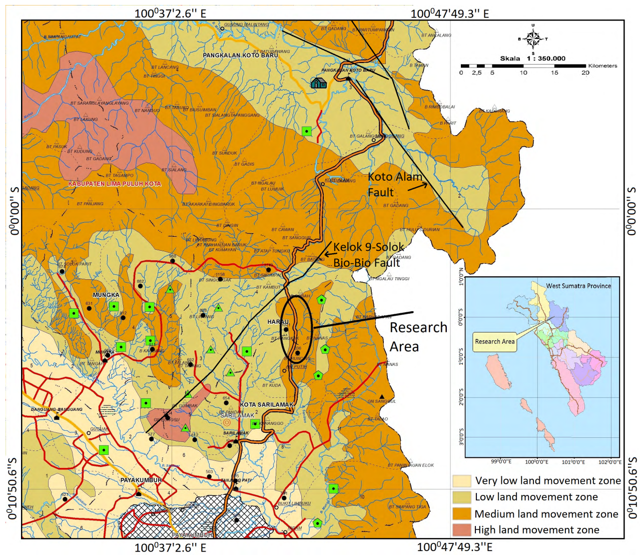

FIGURE 2. Geology structure of land movement level and fault orientation of Limapuluh Kota District, West Sumatra, Indonesia. A black line marks active faults. Inset map presents the location of the research area in West Sumatra Province.

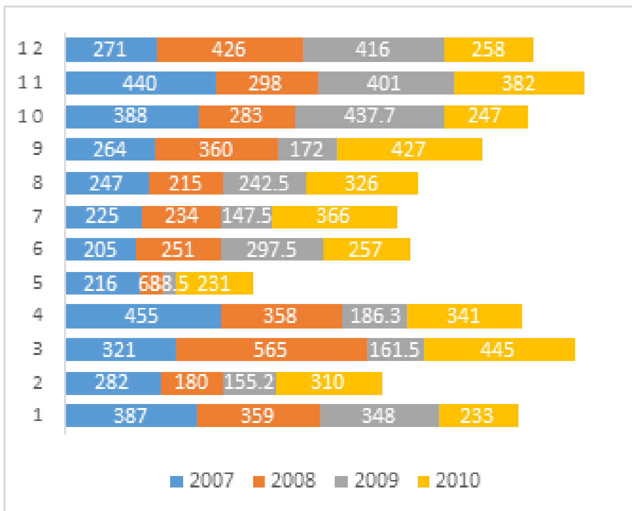

FIGURE 3. Rainfall intensity distribution of Kelok Sembilan region, West Sumatra from 2007-2010 in blue, orange, gray and yellow color respectively (mm) [12].

sedimentary rocks class with shared-joint structure, while in some other area, there is tension-joint structure. The porosities of two type of soil above are 7.6 percent and 3.4 percent, respectively. The complex geological environment of Kelok Sembilan is the primary cause of severe land deformation in that area. According to Indonesia National Agency for Disaster Management (BNPB), the area is categorized as the medium-high level land movement and earthquake.

C. RAINFALL AND TEMPERATURE

The raindrops fall in Kelok Sembilan region throughout the years with high fluctuation in rainfall intensity. Fig. 3 presents the rainfall intensity distribution of Kelok Sembilan from 2007 to 2010 (the 13 ALOS PALSAR scenes were acquired from 2007 to 2010). Statistically, based on the rainfall intensity data collected from 2007 to 2010, heavy raindrops starting at the year-end and slow down after the first quarter of the following year. The average rainfall intensity of the study area is high with rainfall intensity of 3,531 mm/year. The highest recorded rainfall intensity (from 2007 to 2010) is 3,823 mm/year in 2010, and the lowest is 3,003 mm/year in 2009. The highest monthly rainfall intensity is in March 2008 (565 mm), and lowest is in May 2009 (38.5 mm). Moreover, the rain-day is 170-197 days/year. On average, there are at least 14 days -rain every month.

Finally, the average daily high/low temperature in the study area was recorded as 32.1°C / 19.5°C. During the rainy season, daily high/low temperature can be as low as 23 °C/ 19.5 °C. The processed ALOS PALSAR scenes were acquired in the afternoon at 4.14 PM with average environment temperature of 23 °C.

TABLE 1. ALOS PALSAR data set (part:446; frame 7180).

No	Acquisition Date (DD/MM/YYYY)	Mode	Normal Baseline, B_n (m)	Temporal Baseline Relative B_t,(Days)	Temporal Baseline Series (days)
1	03072007	FBD	74	-460	0
2	18082007	FBD	-24	-414	46
3	03102007	FBD	211	-368	92
4	20052008	FBD	259	-138	322
5	05072008	FBD	155	-92	368
6	20082008	FBD	626	-46	414
7	05102008	FBD	0	0	460
8	08072009	FBD	758	276	736
9	08102009	FBD	-134	368	828
10	11072010	FBD	272	644	1104
11	26082010	FBD	82	690	1150
12	11102010	FBD	120	736	1196
13	26112010	FBD	351	782	1242

III. METHODOLOGY

A. PSI-SAR TECHNIQUE

In this research work, PSI-SAR technique was applied for land deformation mapping and monitoring of the study area. 13 ascending Advanced Land Observation Satellite Phased Array L-band Synthetic Aperture Radar (ALOS PALSAR) scenes acquired from March 2007 to November 2010 (observation part number of 446 and frame of 7180) were used for PSI-SAR processing. In these scenes, the satellite is operating in Fine Beam Dual (FBD) HV (horizontal transmit and vertical receive) [13] with an incident angle of 38,79°, off-nadir angle 34.3° and spatial resolution of 10 m. HV was chosen because our area provides strong HV backscattering due to azimuth slopes [14]. The datasets were in Single Look Complex (SLC) with product level of 1.1.

Table 1 tabulates the parameters distribution of temporal baseline and perpendicular baseline of the scenes. The total acquisition time for all the scenes is 1,242 days. The perpendicular and temporal baseline values of all scenes are as listed in the Table. In selecting an appropriate master scene for PSI-SAR processing, relevant parameters for optimization images combination were employed [2]. In short, minimum normal baseline difference gives better accuracy in elevation, while shorter temporal baseline difference ensures better coherence value [11]. In PSI-SAR processing, the scene acquired on 5 October 2008 was chosen as the master scenes while the rest were assigned to the slave scenes.

Fig. 4 plots the network configuration between the master scenes and each of the slave scenes. The temporal baseline of the master scene is in the middle of the acquisition time. Coherence level indicates a connection between master and slave pair. The distribution value of normal baseline is equitable, where the maximum normal baseline was 758 m (Scene No. 8: 8 July 2009), and the minimum one was 24 m (Scene No. 2: 18 August 2007). Which is the critical baseline for ALOS FBD mode with off-nadir angle 34,3° is 6.5 km [15].

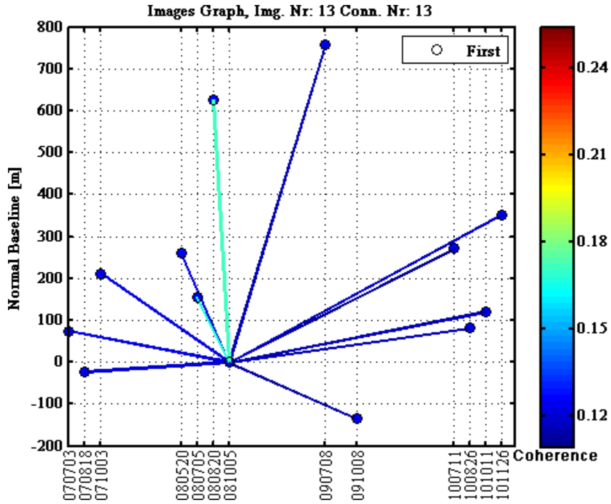

FIGURE 4. Star graph network configuration of master and slave pair images. The color bar in right-side is a coherence level as an indication of master-slave connection.

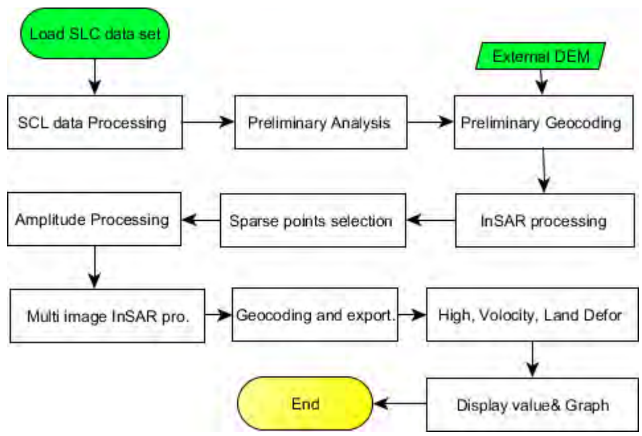

FIGURE 5. PSI-SAR processing chain. External DEM can be linked to USGS database or input manually in Tiff format.

Furthermore, weather condition such as atmospheric disturbance was also another consideration factor in choosing the master scene. In the dataset, the master image was acquired by the sensor after rain. Thus, the distortion due to the cloud in the transmitted and received microwave signal is minimal and will result in better coherence value.

After the appropriate master scene was chosen, the remaining scenes were used as slave scenes in the PSI-SAR processing. Then, the PSI-SAR processing was carried out with the process chain as shown in Fig.5. First, before interferograms were generated, all slave scenes must be appropriately co-registered to the geometry of the master scene. It is a fundamental step to ensures that each ground target has the same azimuth and range geometry for both master and slave images [16]. If co-registration failed, this might be due to the weather condition, the image SNR, and the range pixel of the master scenes.

After SLC data processing, reflectivity map and temporal standard deviation were generated by performing a preliminary analysis of reflectivity index and amplitude stability index. Followed by that, with an external DEM data, preliminary geocoding was applied with the purpose to correct the initial orbit offset. Then, interferograms were generated (InSAR Processing) whereby complex multiplication was performed on the master-slave pairs of the dataset. It was then followed by sparse point selection to obtain scattered point data and amplitude processing in time series analysis. Finally, multi-image InSAR processing was applied with Persistent Scatterer (PS) technique. The processing results were then geocoded and projected to 3D orthophoto map.

The components that contribute to produced interferometric phase follow the equation [3], [17], [18].

$$\Delta\varphi_{m,s}(T) = \Delta\varphi_{m,s}^{flat}(T) + \Delta\varphi_{m,s}^{height}(T) + \Delta\varphi_{m,s}^{disp}(T) + \Delta\varphi_{m,s}^{atm}(T) + \Delta\varphi_{m,s}^{nois}(T) \quad (1)$$

Index m is a master image, and index s is slave image of the dataset. $\Delta\varphi_{m,s}^{flat}(T)$is flat terrain component that can be estimated from orbital data and then removed. $\Delta\varphi_{m,s}^{height}(T)$is topography component due to in accuracy of reference DEM, which is liner with normal baseline and height of the target T and can be written as

$$\Delta\varphi_{m,s}^{height}(T) = \frac{4\pi}{\lambda}\frac{B_n}{R_m}\frac{\Delta h(T)}{sin\theta} \quad (2)$$

where B_n is satellite perpendicular distance between satellite S_m and satellite S_s, R_m is slant range satellite to reference O, $\Delta h(T)$ is height of target T relative to reference point O, θ is off-nadir angle of satellite. $\Delta\varphi_{m,s}^{disp}(T)$is relative displacement of the target T respect to reference point and temporal baseline B_t. The linear model of displacement can be written as

$$\Delta\varphi_{m,s}^{disp}(T) = \frac{4\pi}{\lambda}B_t\Delta v(T) \quad (3)$$

where $\Delta v(T)$ is average displacement at target T, $\Delta\varphi_{m,s}^{atm}(T)$ is component of atmospheric, in the small area processing the component can be neglect. The last term $\Delta\varphi_{m,s}^{nois}(T)$ is noise contribution, which is estimated from the model residuals. Then, the remaining interferometric component can be rewritten as

$$\Delta\varphi_{m,s}(T) = \Delta\varphi_{m,s}^{height}(T) + \Delta\varphi_{m,s}^{disp}(T) \quad (4)$$

$$\Delta\varphi_{m,s}(T) = \frac{4\pi}{\lambda}\frac{B_n}{R_m}\frac{\Delta h(T)}{sin\theta} + \frac{4\pi}{\lambda}B_t\Delta v(T) \quad (5)$$

where λ is wavelength of radar carrier signal used by the radar system.

B. UAV-BASED 3D PHOTOGRAMMETRY TECHNIQUE

Recently, UAV 3D photogrammetry can map the area with very high accuracy. Fig. 8 shows the 3D orthophoto of the study area. The orthophoto was synthesized using Structure from Motion (SfM) technique with the 2D images captured by FC300C digital camera (focal length of 3.61mm) mounted on a UAV. The accuracy of the orthophoto was determined by the relative and absolute accuracy (projected to the ground) [19] of the captured images. Technically,

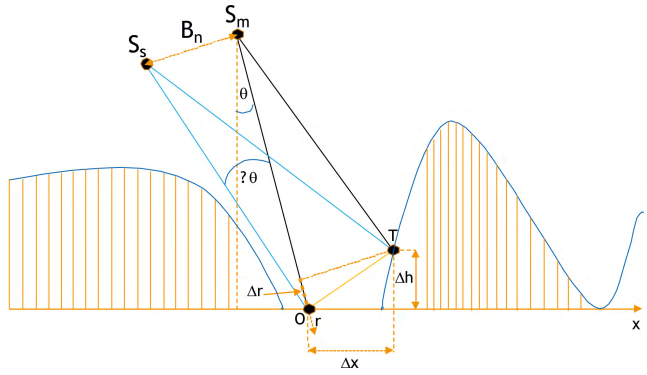

FIGURE 6. Geometry of interferogram generation master-slave pair.

the relative accuracy is the degree of how close the distance between two points on the 3D orthophoto to its actual distance on the ground is. On the other hand, the absolute accuracy is the degree to which a position on the 3D orthophoto corresponds to a fixed coordinate system on the ground survey. It is crucial to ensure the accuracy of the latitude, the longitude, and the elevation of the synthesized 3D orthophoto.

In generating 3D orthophoto, a commercial software, Agisoft Photoscan Professional, was used to process 157 aerial photos with an image resolution of 4000 × 3000 pixels. Firstly, after loading the aerial images, camera calibration was first performed so that the software can accurately estimate the intrinsic parameters of the camera such as the image resolution, the pixel size of the images and the focal length of the camera. Secondly, in the 3D orthophoto construction process, the aerial photos were aligned and projected to WGS 84/UTM zone 47S (EPSG:32747) coordinate system. Then, the software will find the matching points in the overlapping area between the images, estimate the position of the camera and create a Sparse Point Cloud Model (SPCM). Based on SPCM, dense point cloud was built to obtain a detailed image and to do further image analysis. Using the dense point cloud model, Digital Terrain Model (DTM) and 3D orthophoto were generated (texture). Finally, a tile model was created from the generated 3D orthophoto for high resolution 3D responsive visualization.

Several Ground Control Point (GCP) was used to get a better absolute accuracy during the construction of 3D orthophoto. In the synthesized 3D orthophoto, the spatial resolution is 2.99 cm/pixel measured in Ground Sampling Distance (GSD) meanwhile, the horizontal relative resolution is 5.97 cm, and vertical relative resolution is 8.95 cm. The workflow SfM technique is shown in Fig. 7.

C. DIFFERENTIAL GLOBAL POSITIONING SYSTEM (DGPS) TECHNIQUE

In the research, Differential Global Positioning System (DGPS) technique was adopted to enhance the accuracy

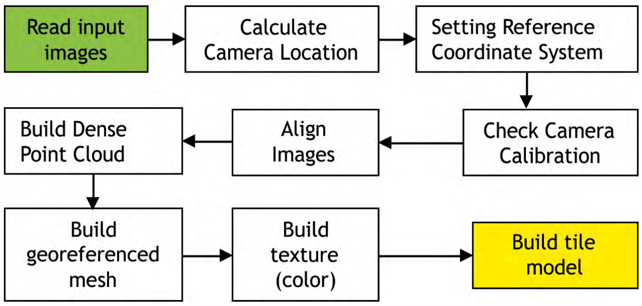

FIGURE 7. Structure from Motion (SfM) technique workflow.

FIGURE 8. 3D orthophoto map of the study area in the WGS84 coordinate system.

(up to sub-centimeter) of the position measurement [20]. During the acquisition of the GPS geodetic data, a base-rover network configuration as shown in Fig. 9 was proposed. In the setup, several GPS receivers (Leica 1200+) were installed in the study area, whereby, one of the receivers (yellow point) is assigned as the base station / GCP while the others (P1, P2, P3, P4, and P5) as the rover (moving). The configuration was chosen to maintain the network stability and to improve the accuracy and quality of the acquired data. To record the position information, the GPS receiver must receive the signal (locked) from at least four [21] out of the 29 operating GPS satellites [22]. For sub-centimeter resolution position measurement, the GPS receivers were locked to 12-16 of GPS satellites.

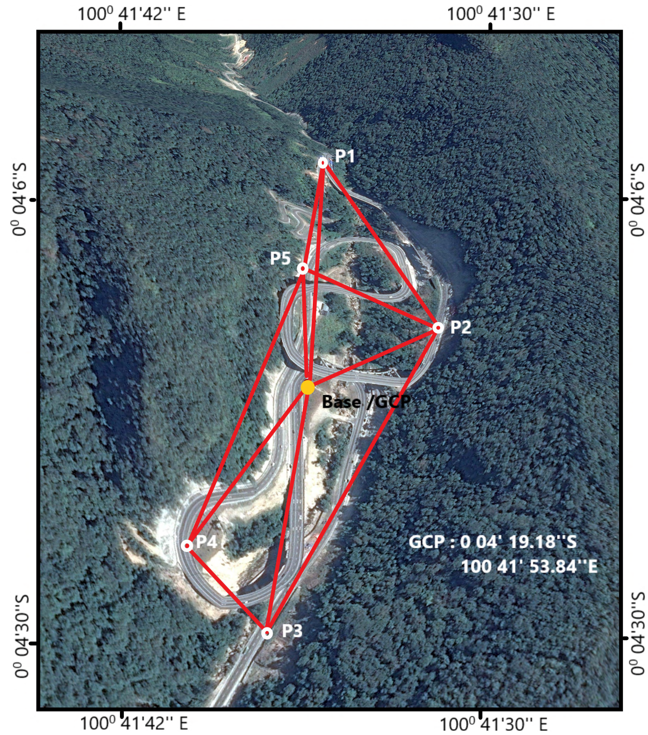

FIGURE 9. Base-rover network configuration for three-dimensional calculation position using DGPS technique at Kelok Sembilan area. In the center of connection, GPS receiver installed a base station where P1, P2, P3, and P4 as rover position.

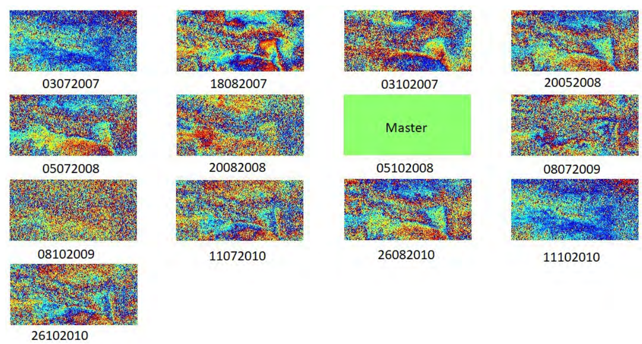

FIGURE 10. Interferograms of the study area (12 master-slave images pairs). Every interferogram is labeled by date acquisition (DDMMYYYY).

IV. RESULTS AND DISCUSSION

Based on PSI-SAR processing on the study area, 12 interferograms were generated from the 12 master-slave pairs of ALOS PALSAR SLC images acquired either between July 2007 and November 2010. Fig. 10 shows the generated interferograms.

The normal baseline maximum of master-slave pairs is 758 m with total time interval 1,242 days. Short normal baseline and temporal baseline can guarantee the quality of interferogram. To minimize phase noise related to vegetated and high mountainous areas, Goldstein modification filtering and the multi-look operation applied.

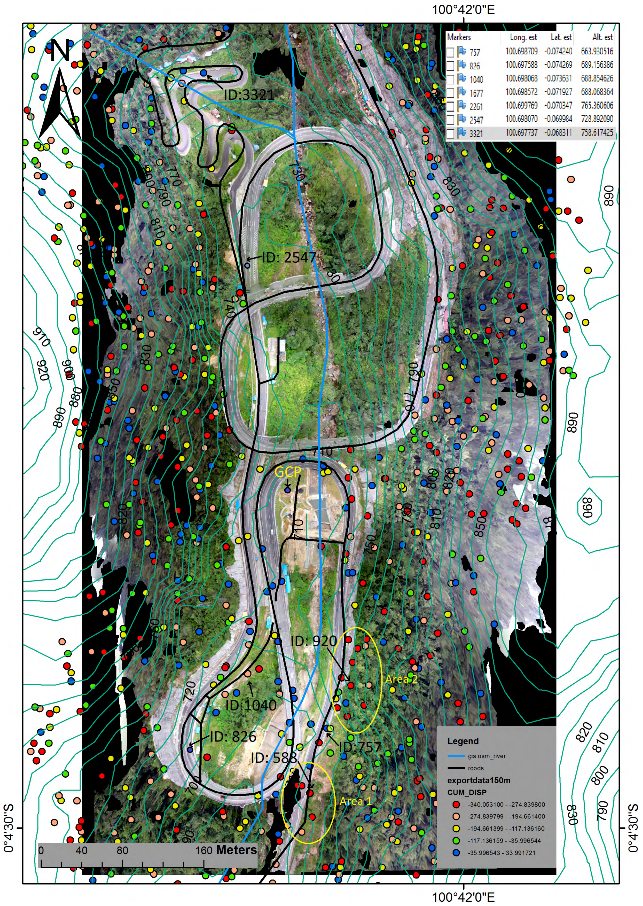

FIGURE 11. Geocoded PS points on the 3D orthophoto land mapping in the WGS84 coordinate system. The black line is a road on Kelok Sembilan. The blue line is a Sanipan river in a valley, crosses the research area. A yellow circles mark area of research concern. Inset picture above is a position (latitude, longitude, and height) of PS point selected for PSI technique validation. Inset picture below-right is cumulative displacement for each PS.

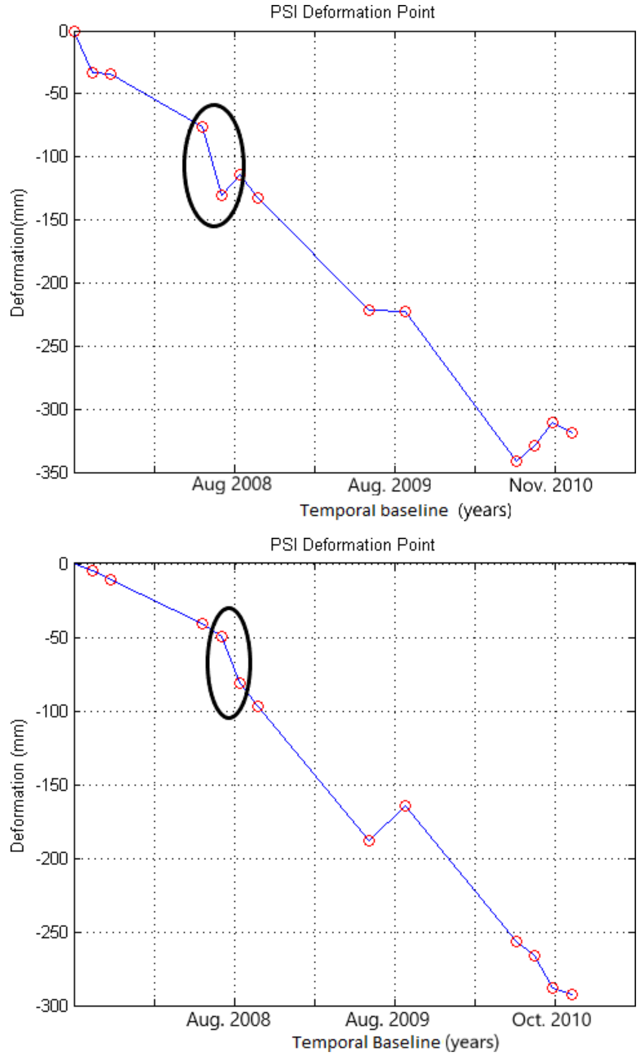

FIGURE 12. Time Series Land Deformation starting from July 2007 to November 2010 represented by PS point: (a) PS Point in Area 1 (ID 588), (b) PS Point in Area 2 (ID 920). Both graphs exhibit linear deformation trend faraway to the line of sight of the satellite. Black circles indicate high acceleration term of land movement.

As mentioned in the earlier section, only the coherence information of PS points can be used for land deformation analysis. In PSI-SAR, PS points were selected according to the amplitude of its stability index [2], [4]. In the 1,450 × 1, 550 km2 study area (most are covered by vegetation), 5,787 PS points were detected with coherence value is in the range of 0.5-0.91. 15.3% of the PS points has the coherence value higher than 0.7 while the rest, 84.6 % were within 0.5-0.69. The number of PS decreases with the increases in the threshold value.

Fig. 11 shows the PS distribution of the study area. The PS point only covers the area within 150 m on the left-side of the bridge to 150 m on the right-side of the bridge. The result of PSI processing was then geocoded and overlaid with the 3D orthophoto land mapping for validation and ground visualization. In the figure, the land movement of the PS points is represented by RGB color scale while red indicates high land movement. The result shows that 39.6% PS points have cumulative movement of greater than 200 mm in four years, with a movement velocity up to -100 mm/year in the point of view of the satellite.

With the interferograms, some smaller areas with critical land deformation issues are then further analyzed. The analysis was carried out by small area land deformation processing. As indicated in Fig. 11, the areas (Area 1 and Area 2) are located on the positive slope, the southern part of Kelok Sembilan Bridge. In the past, some landslide incidents are occurring in Area 1 and Area 2. The remaining areas were not included in this analysis as ground truth data were not available due to the dangerous geography condition in the area. From PSI-SAR processing, the coherence values of the PS points in these areas are in the range of 0.6–0.65. It is because the regions are foreshortening with a slope range of 32°-48°. Moreover, the vegetation covers decrease the coherence value.

Measuring the position and height of selecting points that are used as validation data was carried out by using markers

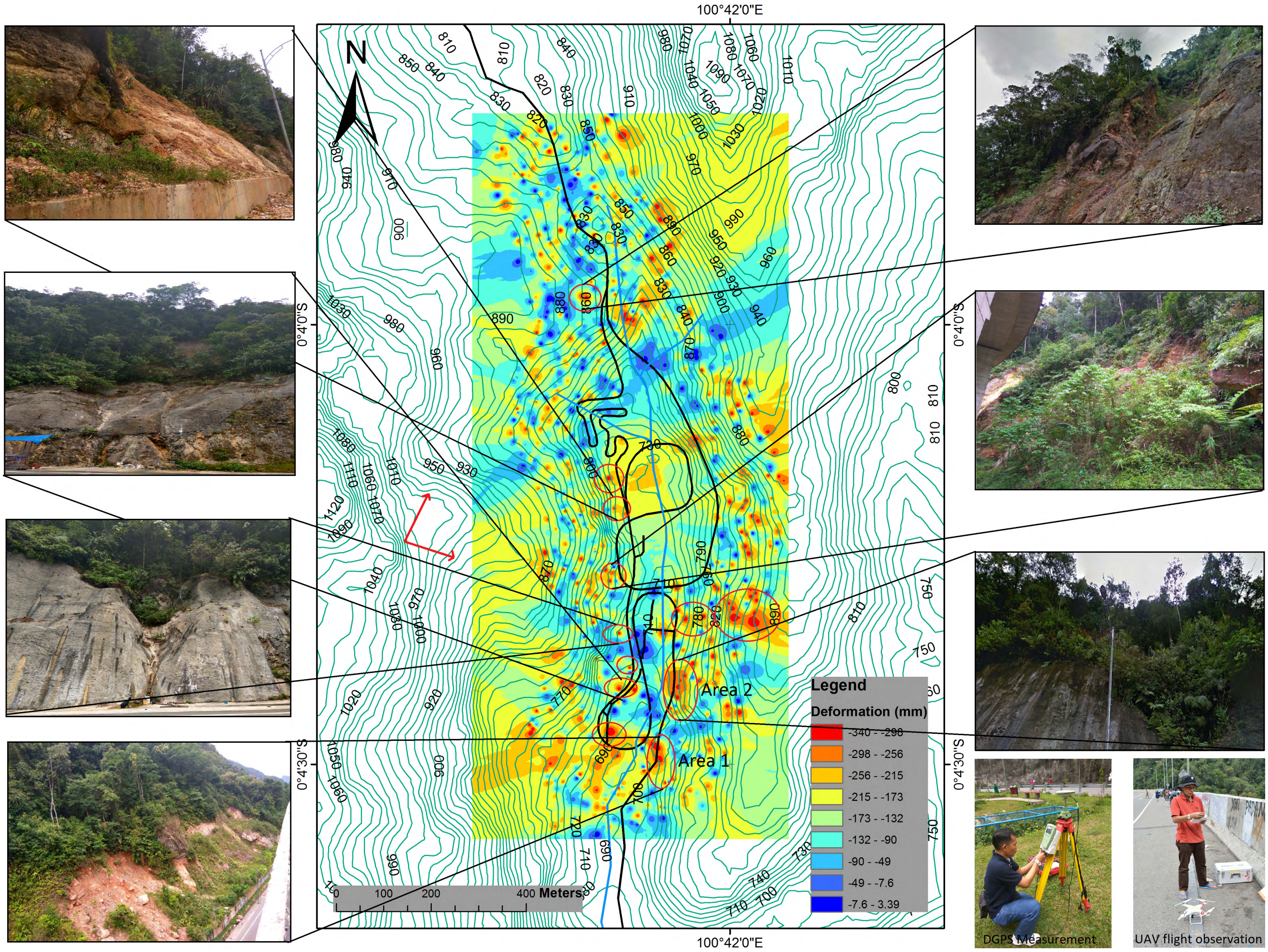

FIGURE 13. **Land deformation map and contour shape of the study area in the WGS84 coordinate system. The red circle indicates deformation area, proved by ground survey photo which presented on left and right side. Inset picture below is deformation displacement in millimeter unit. Left-middle arrow line is the line of sight (range) satellite direction and the satellite movement (azimuth) direction.**

in 3D orthophoto land map. The marked location has displayed the position (longitude and latitude), and height of the area in ellipsoid coordinate.

Fig. 12 presents the time series- deformation for a PS point from each of the areas. In the figure, the X-axis is temporal baseline in days (dated from July 2007 to November 2010) while the Y-axis is deformation value in millimeters. At a glance, the deformation exhibits linear motion trend with the displacement at about 90 mm/year far away to a line of sight of the satellite. For PS point ID 588, the highest slope of the graph was between May 20, 2008, and July 05, 2008 while for PS point ID 920, the highest slope is from July 05, 2008 to August 20, 2008. High slope indicates a high acceleration of land movement. From the analysis, the acceleration values are -23.06 mm/month^2 and -5.4 mm/month^2 respectively. During the time, the rainfall intensity in Area 1 and Area 2 was high, 251 mm/month and 215 mm/month, respectively [23].

Fig. 13. shows the land deformation map and contour shape of Kelok Sembilan areas produced by PSI processing and geographic information system (GIS). In this case, the PS point converted to raster using Inverse Distance Weighted (IDW) interpolation technique. The cumulative land movement in Area 1 and Area 2 is -318.6 mm and -329 mm, respectively. The red circle represents landslide areas with a cumulative displacement of greater than 300 mm. Average land movement velocity of the regions is -100mm/year from the LOS of the satellite. Different color of the image corresponds to a different displacement value of PS. A ground survey confirms these results. Deformation areas around Kelok Sembilan bridge depicted on left-side and right-side of Fig. 13. Consequently, preventing or minimizing land deformation impact in Kelok Sembilan region is a necessity.

An *in-situ* ground truth measurement campaign to validate the results obtained from PSI-SAR processing was arranged in that time. During the measurement campaign, ground truth data were collected using both GPS geodetic instrument Leica GPS 1200 plus and UAV Phantom 3 professional for some selected high coherence level PS points.

TABLE 2. In situ ground truth measurement results for validation using GPS Geodetic and UAV 3D photogrammetry.

PS ID	PSI Technique			GPS Geodetic			UAV			Height Error	
	LAT	LON	Height (m)	LAT	LON	Height (m)	LAT	LON	Height (m)	% GPS	%UAV
826	-0.074281	100.69759	687.61	-0.074278	100.697520	688.30	-0.074269	100.697588	689.15	0.10	0.22
1040	-0.073636	100.69809	686.92	-0.073632	100.697960	687.62	-0.073631	100.698068	688.85	0.10	0.28
2547	-0.070005	100.69808	726.72	-0.070009	100.697890	727.71	-0.069984	100.698070	728.89	0.14	0.30
3321	-0.068322	100.69770	758.12	-0.068237	100.697610	760.01	-0.068311	100.697737	758.61	0.25	0.06
757	-0.074240	100.69870	662.41	-0.074060	100.698630	662.72	-0.074240	100.698709	663.93	0.05	0.23
1677 (GCP)	-0.071926	100.69858	687.13	-0.071921	100.698470	687.51	-0.071927	100.698572	688.06	0.06	0.14
								Average Height Error		0.12	0.21

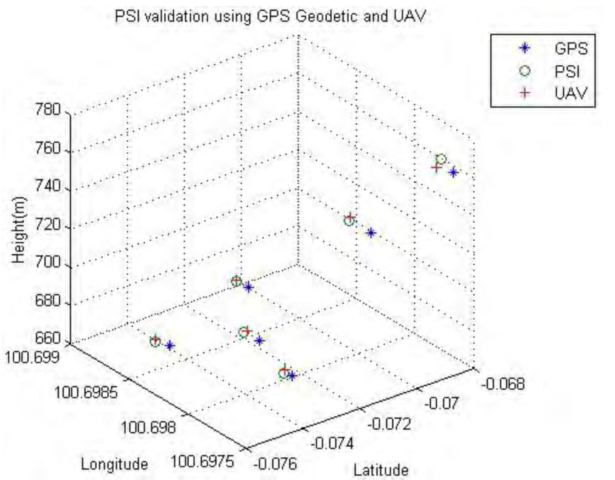

FIGURE 14. 3D visualization of *in situ* ground truth measurement results for validation using GPS geodetic and UAV 3D photogrammetry compare to PSI result.

The recorded results are tabulated in Table 2 which compare the latitude (LAT), longitude (LON), and the elevation level extracted from PSI-SAR analysis and the instruments. It shows that the elevation level difference between the techniques is less than 0.3%, with its RMSE of PSI-GPS and PSI-UAV are 0.97 m and 1.5 m, respectively. In 3D visualization, the result of measurement is shown in Fig.14.

V. CONCLUSION

In this study, the authors have mapped and monitored past land deformation condition in Kelok Sembilan area using PSI-SAR technique. Thirteen ascending scenes acquired by the ALOS PALSAR sensor over four years were used for the analysis. From the PSI-SAR processing, temporal land deformation information such as velocity and displacement were obtained. From the analysis, several landslide areas were successfully identified. For better result in map visualization, the geocoded land deformation contour map was overlaid by the 3D photogrammetry of the study area.

Other than that, the results from PSI-SAR analysis were validated using the data collected from *in situ* ground truth measurement from both Geodetic GPS instrument and 3D photogrammetry technique. Thus, it can be concluded that 1) PSI-SAR technique can be used to map and monitor land deformation, 2) UAV-based 3D photogrammetry can be used as an alternative validation tool for the precision of ground survey.

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REFERENCES

[1] BNPB. (2017). *Data and Disaster Information of Indonesia*. [Online]. Available: http://dibi.bnpb.go.id/data-bencana/lihat-data

[2] A. Ferretti, C. Prati, and F. Rocca, "Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry," *IEEE Trans. Geosci. Remote Sens.*, vol. 38, no. 5, pp. 2202–2212, Sep. 2000.

[3] B. M. Kampes, *Radar Interferometry*, vol. 12. Dordrecht, The Netherlands: Springer, 2006.

[4] V. B. H. G. Ketelaar, *Satellite Radar Interferometry: Subsidence Monitoring Techniques*. vol. 14. Dordrecht, The Netherlands: Springer, 2009.

[5] M. Crosetto, O. Monserrat, M. Cuevas-González, N. Devanthéry, and B. Crippa, "Persistent scatterer interferometry: A review," *ISPRS J. Photogram. Remote Sens.*, vol. 115, pp. 78–89, May 2016.

[6] A. Ferretti, C. Prati, and F. Rocca, "Permanent scatterers in SAR interferometry," *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 1, pp. 8–20, Jan. 2001.

[7] D. Perissin, T. Wang, and F. Novali, "Monitoring terrain motion in China by means of spaceborne SAR images," in *Proc. Joint Urban Remote Sensing Event*, May 2009, pp. 1–5

[8] J. T. S. Sumantyo *et al.*, "Analysis of coastal sedimentation impact to Jakarta giant sea wall using PSI ALOS PALSAR," *IEEE Geosci. Remote Sens. Lett.*, vol. 13, no. 10, pp. 1472–1476, Oct. 2016.

[9] C. Colesanti, A. Ferretti, F. Ferrucci, C. Prati, and F. Rocca, "Monitoring known seismic faults using the permanent scatterers (PS) technique," in *Proc. IEEE Int. Geosci. Remote Sens. Symp. (IGARSS)*, vol. 5. Jul. 2000, pp. 2221–2223.

[10] V. Tofani, F. Raspini, F. Catani, and N. Casagli, "Persistent scatterer interferometry (PSI) technique for landslide characterization and monitoring," *Remote Sens.*, vol. 5, no. 3, pp. 1045–1065, 2013.

[11] A. Ferretti, A. Monti-guarnieri, C. Prati, and F. Rocca, "InSAR principles: Guidelines for SAR interferometry processing and interpretation," ESA Publications, Dordrecht, The Netherlands, Tech. Rep. TM-19, Feb. 2007.

[12] BMKG. *Rainfall Intensity, 2007–2010*. Accessed: Mar. 3, 2017. [Online]. Available: http://dataonline.bmkg.go.id/mcstation_metadata

[13] *ALOS/PALSAR Level 1.1/1.5 Product Format Description*, JAXA, Tokyo, Japan, 2017.

[14] J.-S. Lee, D. L. Schuler, T. L. Ainsworth, E. Krogager, D. Kasilingam, and W. M. Boerner, ''On the estimation of radar polarization orientation shifts induced by terrain slopes,'' *IEEE Trans. Geosci. Remote Sens.*, vol. 40, no. 1, pp. 30–41, Jan. 2002.
[15] D. T. Sandwell, D. Myer, R. Mellors, M. Shimada, B. Brooks, and J. Foster, ''Accuracy and resolution of ALOS interferometry: Vector deformation maps of the Father's day intrusion at Kilauea,'' *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 11, pp. 3524–3534, Nov. 2008.
[16] A. Ferretti, A. Monti-Guarnieri, C. Prati, and F. Rocca, ''InSAR principles: Guidelines for SAR interferometry processing and interpretation,'' *ESA Publ.*, vol. 19, pp. 1–40, 2007.
[17] D. Perissin, ''Interferometric SAR multitemporal processing: Techniques and applications,'' in *Multitemporal Remote Sensing, Remote Sensing and Digital Image Processing*. Cham, Switzerland: Springer, Apr. 2016, pp. 145–176.
[18] A. Ferretti, *Satellite InSAR Data Reservoir Monitoring From Space*. Dordrecht, The Netherlands: EAGE, 2014.
[19] *ASPRS Positional Accuracy Standards for Digital Geospatial Data*, ASPRS, Denver, CO, USA, 2015, pp. 1–26.
[20] M. Matosevic, Z. Salcic, and S. Berber, ''A comparison of accuracy using a GPS and a low-cost DGPS,'' *IEEE Trans. Instrum. Meas.*, vol. 55, no. 5, pp. 1677–1683, Oct. 2006.
[21] M. Chivers. *Differential GPS Explained*. Accessed: Feb. 02, 2018. [Online]. Available: http://www.esri.com/news/arcuser/0103/differential1of2.html
[22] J. N. S. Policy. *List of Positioning Satellites*. Accessed: Feb. 2, 2018. [Online]. Available: http://qzss.go.jp/en/technical/satellites/index.html#GPS
[23] P. Razi, J. Tetuko, S. Sumantyo, D. Perissin, and A. Munir, ''Persistent scattering interferometry SAR based velocity and acceleration analysis of land deformation: Case study on kelok sembilan bridge,'' in *Proc. TSSA IEEE Conf.*, Oct. 2017, pp. 9–12.

PAKHRUR RAZI was born in Kerinci, Indonesia, in 1979. He received the B.S. degree in physics science from the Universitas Negeri Padang and the M.S. degree in physics science from the Bandung Institute of Technology, Indonesia, in 2005. He is currently pursuing the Ph.D. degree with the Center for Environmental Remote Sensing, Department of Information Processing and Computer Sciences, Graduate School Advanced Integration Science, Chiba University, Japan, with a focus on synthetic aperture radar (SAR) remote sensing processing. Since 2006, he has been with the Physics Department, Universitas Negeri Padang, as a Lecturer, where he became an Associate Professor with the Physics Department eight years later. His research interests are SAR remote sensing, especially PSI and DInSAR, image processing, electronic instrumentation, and ICT.

JOSAPHAT TETUKO SRI SUMANTYO was born in Bandung, Indonesia, in 1970. He received the B.Eng. and M.Eng. degrees in electrical and computer engineering (subsurface radar systems) from Kanazawa University, Japan, in 1995 and 1997, respectively, and the Ph.D. degree in artificial system sciences (applied radio wave and radar systems) from Chiba University, Japan, in 2002. He was with the Center for Frontier Electronics and Photonics (Venture Business Laboratory), Chiba University, as a Lecturer (Post-Doctoral Fellowship Researcher) from 2002 to 2005. He was an Associate Professor (permanent staff) with the Center for Environmental Remote Sensing (CEReS), Chiba University, from 2005 to 2013, where he is currently a Full Professor (permanent staff). His research interests are theoretically scattering microwave analysis and its applications in microwave (radar) remote sensing, especially synthetic aperture radar (SAR) and subsurface radar (VLF), including DInSAR and PS-InSAR, analysis and design of antennas for mobile satellite communications and microwave sensors, development of microwave sensors, including SAR for unmanned aerial vehicle and microsatellite development.

DANIELE PERISSIN was born in Milan, Italy, in 1977. He received the master's degree in telecommunications engineering and the Ph.D. degree *(cum laude)* in information technology from the Politecnico di Milano in 2002 and 2006, respectively. In 2002, he joined the Signal Processing Research Group, Polytechnic di Milano, where he has been involved in the permanent scatterers technique in the framework of radar remote sensing. In 2009, he joined the Institute of Space and Earth Information Science, The Chinese University of Hong Kong, as Research Assistant Professor. Since 2013, he has been holding a position as an assistant professor at School of Civil Engineering, Purdue University, USA. He has authored a patent on the use of urban dihedral reflectors for combining multi-sensor interferometry synthetic aperture radar (InSAR) data, and he has published about 80 research works in journals and conference proceedings, receiving the JSTARS Best Paper Award in 2012. He is the developer of the software Sarproz for processing multi-temporal InSAR data.

HIROAKI KUZE received the Ph.D. degree in physics in the field of quantum electronics from the Graduate School, The University of Tokyo, in 1982. He was a Post-Doctoral Researcher with the Institute for Physical and Chemical Research (RIKEN). In 1984, he became a Research Assistant and in 1986, an Associate Professor with the Physics Department, Faculty of Liberal Arts, Shizuoka University. During 1987–1988, he stayed at the Institute for Quantum Optics, Max-Planck Institute, Germany, as a Visiting Scientist. From 1995 to 2004, he was involved in Center for Environmental Remote Sensing (CEReS) PPI lidar system that can be seen at the top of the building, as an Associate Professor with the CEReS, Chiba University, and in 2004, he became a Full Professor. From 2010 to 2014, he served as the Director of CEReS. From 2014 to 2016, he was the President of the Remote Sensing Society of Japan. His primary research field is the optical remote sensing of the atmosphere.

MING YAM CHUA was born in Malacca, Malaysia, in 1980. He received the B.Eng. degree (Hons) in electronics from the Multimedia University, Malaysia, in 2003, the M.Eng.Sc. and Ph.D. degrees in engineering with a focus on passive microwave components design and radar waveform synthesis techniques from Multimedia University, Malaysia, in 2007 and 2016, respectively. He was a Researcher from 2003 to 2009, a Lecturer from 2009 to 2012, and a Senior Lecturer from 2012 to 2016 with Multimedia University. He is currently an Assistant Professor with the Center for Environmental Remote Sensing, Chiba University, Japan, undergoing his two years post-doctoral research leave from Multimedia University. His research interests are in the areas of synthetic aperture radar system development, with emphasis on radar waveform synthesis and field programmable gate array applications on the radar system.

GOOD FRIED PANGGABEAN received the B.S. degree in electrical engineering from the Bandung Institute of Technology, Indonesia, in 1999, and the M.S. degree in software engineering from the Bandung Institute of Technology in 2010. He is currently pursuing the Ph.D. degree in remote sensing with the Josaphat Microwave Remote Sensing Laboratory, Center for Environmental Remote Sensing, Chiba University, Japan. From 2002, he was a Lecturer with the Faculty of Informatics and Electrical Engineering, Institute Technology Del, Toba Samosir, Indonesia. His research interest includes the SAR image signal processing and the application of FPGAs to implementing SAR image processing algorithms.