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# Proceedings of

## 2018 5<sup>TH</sup> NAFOSTED CONFERENCE ON INFORMATION AND COMPUTER SCIENCE

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# Table of Contents

Message from the NICS'18 General and TPC Chairs.....	xv
Executive Committee.....	xvii
Technical Program Committee.....	xix
Additional Reviewers.....	xxiv
Keynote Abstracts.....	xxv
Invited Talks.....	xxvii

## Communications and Networking

- Closed-form Analysis of a Decode-and-Forward Scheme under Physical Layer Security over General Fading Channels  
.....  
Ngoc Son Pham (Ho Chi Minh City University of Technology and Education, Vietnam), Van Phu Tuan (University of Ulsan, Korea), Sol Park (University of Ulsan, Korea), Hyung-Yun Kong (University of Ulsan, Korea) 1
- Time-Frequency Distribution for Undersampled Non-stationary Signals using Chirp-based Kernel  
.....  
Yen Thi Hong Nguyen (The University of Danang & University of Science and Technology, Vietnam), Desmond McLernon (The University of Leeds, United Kingdom (Great Britain)), Mounir Ghogho (International University of Rabat, Morocco & University of Leeds, United Kingdom (Great Britain)), Syed Ali Raza Zaidi (University of Leeds, United Kingdom (Great Britain)) 6
- A New Protocol based on Optimal Capacity for Energy Harvesting Amplify-and-Forward Relaying Networks  
.....  
Hung Ha Duy (Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, HCMC, Vietnam, Vietnam), Dac-Binh Ha (Faculty of Electrical and Electronics Engineering, Duy Tan University, Da Nang, Vietnam, Vietnam), Jaroslav Zdralek (Faculty of Electrical Engineering and Computer Science, VSB - Technical University of Ostrava, Ostrava, Czechia, Czech Republic), Miroslav Voznak (Faculty of Electrical Engineering and Computer Science, VSB - Technical University of Ostrava, Ostrava, Czechia, Czech Republic) 11
- Stable low-stretch routing scheme for wireless sensor networks with a large hole of complicated shape  
.....  
Nhan Thai (Hanoi University of Science and Technology, Vietnam), Khanh-Van Nguyen (Hanoi University of Science and Technology, Vietnam) 17
- Reconfigurable Mode Converter Using Two Silicon Y-Junction Couplers for Mode Division Multiplexing Network  
.....  
Ho Duc Tam Linh (Danang University of Science and Technology & Hue University of Sciences, Vietnam), Duong Duy (Posts and Telecommunications Institute of Technology, Vietnam), Cao Dung Truong (Posts and Telecommunications Institute of Technology & Faculty of Electronics Engineering, Vietnam), Hung Nguyen (The University of Danang, Vietnam) 24

## Foundations of Computer Science

- Drug Repositioning by Bipartite Local Models  
Phuong H. Nguyen (Thuyloi University, Vietnam), Duc-Hau Le  
(Thuyloi University, Vietnam) 30
- Hardware Trojan Threat and Its Countermeasures  
Xuan-Thuy Ngo (Secure-IC S.A.S, France), Van-Phuc Hoang (Le Quy Don Technical  
University, Vietnam), Han Le Duc (Le Quy Don Technical University, Vietnam) 35
- Linear time algorithm for maximum distance- $k$  matching in interval graphs  
Viet Hung Tran (Hanoi University of Science and Technology, Vietnam), Nguyen Duc  
Nghia (Hanoi University of Science and Technology, Vietnam, Vietnam), Phan-Thuan  
Do (Hanoi University of Science and Technology, Vietnam) 41
- User's perception on mental health applications: a qualitative analysis of user reviews  
Kong Saoane Thach (Tra Vinh University, Vietnam) 47
- Adding External Features to Convolutional Neural Network for Aspect-based  
Sentiment Analysis  
Nguyen Thi Xuan Huong (HaiPhong Private University, Vietnam), Vo Cong Hieu  
(Ton Duc Thang University, Vietnam), Le Anh Cuong (Ton Duc Thang University,  
Vietnam) 53

## Modern Linguistics

- Response particles: The mysteries of yes and no  
Manfred Krifka (Leibniz-Zentrum Allgemeine Sprachwissenschaft, Germany) 60
- Polarity and the diachronic development of deontic modality in Chinese  
Barbara Meisterernst (National Tsing Hua University, Taiwan) 66
- Towards a Compositional Semantics for  $L+H^*LH\%$   
Marie-Christine Meyer (ZAS, Germany) 70

## Computational Intelligence

- Deep Learning versus Traditional Classifiers on Vietnamese Students' Feedback  
Corpus  
Phu Nguyen (University of Information Technology, VNU-HCM, Vietnam), Tham  
Truong (University of Information Technology, VNU-HCM, Vietnam), Kiet Van  
Nguyen (University of Information Technology, VNU-HCM, Vietnam), Ngan L.T.  
Nguyen (University of Information Technology, VNU-HCM, Vietnam) 75
- A Coevolutionary approach for classification problems: Preliminary results  
Van Truong Vu (Le Quy Don Technical University, Vietnam), Bui Lam (Le Quy Don  
University, Vietnam), Trung Nguyen (Liverpool John Moores University, United  
Kingdom (Great Britain)) 81
- Two new concepts "Picture Fuzzy Rough Soft Sets" and "Picture Fuzzy Dynamic  
Systems" in Picture Fuzzy Systems

Bui Cuong (Institute of Mathematics, Hanoi, Vietnam), Pham Thong (VNU University of Science & Vietnam National University Hanoi, Vietnam) 87

•Text Generation from Abstract Semantic Representation for Summarizing Vietnamese Paragraphs Having Co-references

Trung Tran (University of Information Technology, VNU - HCMC, Vietnam), Dang Tuan Nguyen (University of Information Technology, VNU-HCM, Vietnam) 93

## Computational Intelligence

•Relation Extraction in Vietnamese Text via Piecewise Convolution Neural Network with Word-Level Attention

Nhat Nguyen (University of Engineering and Technology, VNU, Vietnam), Thanh Ha Nguyen (University of Engineering and Technology, VNU, Vietnam), Hieu Vo (University of Engineering and Technology, VNU, Vietnam), Nguyen Le Minh (Jaist, Vietnam) 99

•Deep Learning for Aspect Detection on Vietnamese Reviews

Dang Van Thin (University of Information Technology, VNU-HCM, Vietnam, Vietnam), Vu Duc Nguyen (University of Information Technology, VNU-HCM, Vietnam), Kiet Van Nguyen (University of Information Technology, VNU-HCM, Vietnam), Ngan L.T. Nguyen (University of Information Technology, VNU-HCM, Vietnam) 104

•A Hybrid Feature Selection Approach for Applying to Patients with Diabetes Mellitus: KNHANES 2013-2015

Huilin Zheng (Chungbuk National University, Korea), Hyun Woo Park (Chungbuk National University, Korea), Dingkun Li (Chungbuk National University, Korea), Kwang Ho Park (Chungbuk National University, Korea), Keunho Ryu (Chungbuk University, Korea) 110

## Communications and Networking

•Repeated Index Modulation with Coordinate Interleaved OFDM

Le Huyen (Le Quy Don Technical University, Vietnam), Vu-Duc Ngo (Hanoi University of Science and Technology, Vietnam), Minh-Tuan Le (MobiFone R&D Center, MobiFone Corporation, Vietnam), Nam Xuan Tran (Le Quy Don Technical University, Vietnam) 114

•Implementation of IDMA System with Multiple Access Channel and non-Gaussian Noise

Bao Quoc Vuong (International University, VNUHCM, Vietnam), Hung Ngoc Do (International University, Vietnam) 119

•Performance Comparison of Indoor Positioning Schemes Exploiting Wi-Fi APs and BLE Beacons

Younguk Yun (Kwangwoon University, Korea), Jeongpyo Lee (Kwangwoon University, Korea), Dukhyun Ann (Kwangwoon University, Korea), Sangsoo Kim (Hoseo Telnet, Korea), Youngok Kim (Kwangwoon University, Korea) 124

## Modern Linguistics

- Some observations on Vietnamese demonstratives  


---

Phan Thi Huyen Trang (Vietnam National University, Vietnam), Dylan Tsai (National Tsing Hua University, Taiwan) 128
- The Asymmetry of Topicalization: a View from Mandarin Chinese  


---

Wei-wen Roger Liao (Academia Sinica, Taiwan) 132

## Software Engineering

- Modelling Dynamic Information Flows: Extensions of LINQ with Norms  


---

Nguyen Hoang Thuan (Can Tho University of Technology, Vietnam), Tran Anh Tri (Can Tho University, Vietnam), David Swann (LINQ Ltd, Vietnam), Huu-Hoa Nguyen (Can Tho University, Vietnam) 138
- Electroencephalography Analysis Using Neural Network  


---

Ngan Vuong Thuy Nguyen (University of Science, VNU-HCM, Vietnam), Tuan Van Huynh (University of Science, VNU-HCM, Vietnam), Hanh Thi Hong Nguyen (VNU-University of Science Ho Chi Minh city, Vietnam) 144
- The Influence of Icon Background Colors and Icon Symbols on Menu Item Selection for Smartphone  


---

Lumpapun Puchoojit (Thammasat University, Thailand), Nuttanont Hongwarittorn (Thammasat University, Thailand) 148

## Computational Intelligence

- An Efficient Parallel Algorithm for Mining Both Frequent Closed and Generator Sequences on Multi-core Processors  


---

Hai Duong (University of Dalat, Vietnam), Tin Truong (University of Dalat, Vietnam), Bac Le (University of Science. VNU HCM, Vietnam) 154
- Building mathematical models applied to UTXOs selection for objective transactions  


---

Nguyen Huy (University of Technology, Vietnam), Hong-Son Trang (Hoa Sen University, Vietnam), Thinh Nguyen (Ho Chi Minh City University of Technology, Vietnam), Nguyen Huynh Tuong (Faculty of Computer Science & Engineering, Ho Chi Minh city University of Technology, Vietnam), Thanh Van Le (Ho Chi Minh City University of Technology, Vietnam) 160
- An Ensemble of Shallow and Deep Learning Algorithms for Vietnamese Sentiment Analysis  


---

Nguyen Quan (Le Quy Don Technical University, Vietnam), Uy Nguyen (Le Quy Don Technical University, Vietnam) 165
- On Temporal Cluster Analysis for Early Identifying In-trouble Students in an Academic Credit System  


---

Chau Le (Ho Chi Minh City University of Technology, Vietnam), Chau Thi Ngoc Vo (Ho Chi Minh City University of Technology, Vietnam), Phung Hua Nguyen (Ho Chi Minh City University of Technology, Vietnam) 171

## Communications and Networking

- A role-based statistical mechanism for DDoS attack detection in SDN  


---

Phan The Duy (University of Information Technology, VNU-HCM, Vietnam), Do Thi Thu Hien (University of Information Technology, VNU-HCM, Vietnam), Van-Hau Pham (University of Information Technology, Vietnam) 177

• Hardware Implementation of a MIMO Channel Emulator for high speed WLAN 802.11ac

Van Tien Tran (University of Information Technology, Vietnam), Manh Tien Tran (University of Information Technology, Vietnam), Duc Khai Lam (University of Information Technology, VNU-HCM, Vietnam) 183

• Enhanced Spread Spectrum OFDM-IM with Rotated Zadoff-Chu Sequences

Thien Van Luong (Queen's University Belfast, United Kingdom (Great Britain)), Youngwook Ko (Queen's University Belfast, United Kingdom (Great Britain)), Vu-Duc Ngo (Hanoi University of Science and Technology, Vietnam), Minh-Tuan Le (MobiFone R&D Center, MobiFone Corporation, Vietnam), Le Huyen (Le Quy Don Technical University, Vietnam), Nam Xuan Tran (Le Quy Don Technical University, Vietnam) 189

• Nonnegative Tensor Decomposition for EEG Epileptic Spike Detection

Nguyen Thi Anh Dao (University of Technology and Logistics, Vietnam), Le Trung Thanh (Vietnam National University, Hanoi, Vietnam), Nguyen Linh-Trung (Vietnam National University, Hanoi, Vietnam), Vu Ha Le (UET, Vietnam) 194

## Computer Vision and Intelligent Systems

• Occluded Image Recognition with Extended Nonnegative Matrix Factorization

Viet-Hang Duong (BacLieu University, Vietnam), Manh-Quan Bui (National Central University, Taiwan), Jia-Ching Wang (National Central University, Taiwan) 200

• Region-based deformation transfer

Phong Khac Do (Vietnam National University, Hanoi, Vietnam), Chau Ma Thi (VNU University of Engineering and Technology, Vietnam), Giang Cao (Can Tho University, Vietnam), An Thi Thu Nguyen (Can Tho University, Vietnam) 205

• Planar Object Recognition For Bin Picking Application

Đức Hạnh Lê (Supervisor, Vietnam), Le Minh Duc (Ho Chi Minh City University of Technology, Vietnam) 211

• A Frame-work assisting the Visually Impaired People: Common Object Detection and Pose Estimation in Surrounding Environment

Le Hung (International Research Institute MICA - HaNoi University Science and Technology, Vietnam), Hai Vu (International Research Institute MICA, Hanoi University of Science and Technology, Vietnam), Nguyen T. Thuy (Vietnam National University of Agriculture, Vietnam) 216

## Modern Linguistics

• Bilingualism and the Lifespan: Young Adult Heritage Speakers of Spanish

Sandra Pucci (University of Wisconsin, Milwaukee, USA) 222

• Onset consonant clusters in Phu Quy dialect

Dung Hoang (University of Education, Ho Chi Minh City, Vietnam), Mai Le Nguyen  
Hoang (University of Education, Vietnam) 237

• Assessing the Readability of Literary Texts in Vietnamese Textbooks

An-Vinh Luong (HoChiMinh city University of Science, Vietnam), Diep Nguyen  
(SaiGon Technology University, Vietnam), Dinh Dien (University of Natural Sciences,  
Vietnam) 231

## Computational Intelligence

• An Efficient Hardware Implementation of Artificial Neural Network based on  
Stochastic Computing

Duy-Anh Nguyen (VNU University of Engineering and Technology, Vietnam), Huy-  
Hung Ho (VNU University of Engineering and Technology, Vietnam), Duy-Hieu Bui  
(VNU University of Engineering and Technology (VNU-UET), Vietnam), Xuan-Tu  
Tran (VNU University of Technology and Engineering, Vietnam) 237

• Integrating Grammatical Features into CNN Model for Emotion Classification

Thi-Thanh-Thuy Huynh (Ton Duc Thang University, Vietnam), Le Anh Cuong (Ton  
Duc Thang University, Vietnam) 243

• An Effective Similarity Measure for Neighborhood-based Collaborative Filtering

Tan Nghia Duong (Hanoi University of Science and Technology, Vietnam), Viet Duc  
Than (Hanoi University of Science and Technology, Vietnam), Trong Hiep Tran (Hanoi  
University of Science and Technology, Vietnam), Quang Hieu Dang (Hanoi University  
of Science and Technology, Vietnam), Nguyen D. Minh (HUST, Vietnam), Pham Manh  
Hung (VNPT Technology, Vietnam) 250

• Speech perception based on mapping speech to image by using convolution neural  
network

Nguyen Quang Trung (Human Machine Interaction Laboratory, University of  
Engineering & Technology, VNU Ha Noi, Vietnam), The Duy Bui (Human Machine  
Interaction Laboratory, Vietnam) 255

• Collecting Chinese-Vietnamese Texts From Bilingual Websites

Minh Trinh (Ton Duc Thang University, Vietnam), Phuoc Tran (Faculty of IT, TDTU  
& NLP-KD, Vietnam), Nhung Tran (Ton Duc Thang University, Vietnam) 260

## Communications and Networking

• Energy-Efficient and Low Complexity Channel Coding for Wireless Body Area  
Networks

Hieu T. Nguyen (University in Southeast Norway, Norway), Thuy V. Nguyen (Posts  
and Telecommunications Institute of Technology, Vietnam) 265

• Fully Digital Background Calibration Technique for Channel Mismatches in TIADCs

Van-Thanh Ta (Le Quy Don Technical University, Vietnam), Yen Hoang Thi (Le Quy  
Don Technical University, Vietnam), Han Le Duc (Le Quy Don Technical University,  
Vietnam), Van-Phuc Hoang (Le Quy Don Technical University, Vietnam) 270

## Computer Vision and Intelligent Systems

- Machine Learning Based-distributed Optimal Control Algorithm for Multiple Nonlinear Agents with Input Constraints  
.....  
Luy Tan Nguyen (Industrial University of Ho Chi Minh City, Vietnam), Dang Nguyen (Industrial University of Ho Chi Minh City, Vietnam), Minh Dang (Industrial University of Ho Chi Minh City, Vietnam), Vinh Tran (Industrial University of Ho Chi Minh City, Vietnam) 276
- An Intelligent Support System for the knowledge evaluation in high-school mathematics by multiple choices testing  
.....  
Thanh Mai (Ho Chi Minh city Open University, Vietnam), Hien Nguyen (University of Information Technology, Vietnam), Trung Le (Vinh Long College of Economics and Finance, Vinh Long, Vietnam), Vuong Pham (University of Information Technology, VNU-HCM, Vietnam) 282
- A new ensemble approach for hyper-spectral image segmentation  
.....  
Le Cam Binh (Academy of Military Science and Technology, Vietnam), Pham Van Nha (Academy of Military Science and Technology & Le Quy Don University, Vietnam), Long Thanh Ngo (Le Quy Don University, Vietnam), Pham The Long (Le Quy Don University, Vietnam) 288
- Preliminary Result of 3D City Modelling For Hanoi, Vietnam  
.....  
Anh Phan (VNU University of Engineering and Technology, Vietnam), Vu Chu (Center of Multidisciplinary Integrated Technology for Field Monitoring, Vietnam), Hung Bui (VNU University of Engineering and Technology, Vietnam), Thanh Nguyen (VNU University of Engineering and Technology, Vietnam), Nguyen Viet Ha (VNU Ha Noi, Vietnam) 294
- Vision-based Inspection System for Leather Surface Defect Detection and Classification  
.....  
Hoang-Quan Bong (Kiengiang Vocational College, Vietnam), Truong Quoc Bao (CanTho University, Vietnam), Huu-Cuong Nguyen (Can Tho University, Vietnam), Minh Triet Nguyen (CanTho University, Vietnam) 300

## Modern Linguistics

- Linguistic barriers to syllogistic reasoning  
.....  
Andreas Haida (The Hebrew University of Jerusalem, Israel), Luka Crnić (The Hebrew University of Jerusalem, Israel), Yosef Grodzinsky (The Hebrew University of Jerusalem, Israel) 305
- Parsing out in English and Vietnamese  
.....  
Nigel Duffield (Konan University, Japan) 311
- The Participant-Pronoun Restriction: English and Vietnamese  
.....  
Tue Trinh (University of Wisconsin-Milwaukee, USA), Hubert A Truckenbrodt (Leibniz-Zentrum Allgemeine Sprachwissenschaft, Germany) 317

## Poster Session

- Improving Phonetic Recognition with Sequence-length Standardized MFCC Features and Deep Bi-directional LSTM  
.....



Pham Van Toan (Framgia Inc, Vietnam), Nguyen Thanh Hau (Framgia Inc, Vietnam), Minh Thanh Ta (Le Quy Don University, Vietnam)	322
<hr/>	
• Improving the 3D model classification based on selecting proper features	
Nong Thi Hoa (Thai Nguyen University of ICT, Vietnam), Nguyen Van Tao (University of Information & Communication Technology, Vietnam), Dinh Thi Thanh Uyen (Thai Nguyen University of Agriculture and Forestry, Vietnam)	326
<hr/>	
• Towards An Educational Music Processor for Folk and Popular Musics	
Anh-Thu G. Phan (Columbia University & Temple University, USA), Nhan T Ngo (New York University & Temple University, Center for Vietnamese Philosophy, Culture and Society, USA)	330
<hr/>	
• Study on Cloud computing and Emergence of Internet of the Thing in Industry	
Symphorien Yoki Donzia (South Korea, Korea), Haeng Kon Kim (Daegu Catholic University, Korea), Bo Yeon Shin (Seoul, Korea)	334
<hr/>	
• FVI: An End-to-end Vietnamese Identification Card Detection and Recognition in Images	
Liem Hoang (FPT Technology Research Institute, FPT University, Vietnam), Hoang Vu Dang (FPT Technology Research Institute, Vietnam)	338
<hr/>	
• A Practical Solution to the ACM RecSys Challenge 2018	
Tan Nghia Duong (Hanoi University of Science and Technology, Vietnam), Viet Duc Than (Hanoi University of Science and Technology, Vietnam), Trong Hiep Tran (Hanoi University of Science and Technology, Vietnam), Thi Hong Anh Pham (Hanoi University of Science and Technology, Vietnam), Van Hoang Anh Nguyen (Hanoi University of Science and Technology, Vietnam), Hoang Nam Tran (Thanglong High School, Hanoi, Vietnam)	341
<hr/>	
• A Reconfigurable Multi-function DMA Controller for High-Performance Computing Systems	
Hung K. Nguyen (VNU University of Engineering and Technology, Vietnam), Khoi Dong (VNU University of Engineering and Technology, Vietnam), Xuan-Tu Tran (VNU University of Technology and Engineering, Vietnam)	344
<hr/>	
• A Deep Learning Model for Extracting User Attributes from Conversational Texts	
Pham Quang Nhat Minh (Alt Vietnam Co., Ltd., Vietnam), Tuan-Anh Nguyen (Alt Vietnam Co., Ltd., Vietnam), Tuan Duc Nguyen (Alt Vietnam Co., Ltd., Vietnam)	350
<hr/>	
• Building Vietnamese Linguistic Resources for Social Network Text Analysis	
Tuyen Nguyen (FPT Corporation, Vietnam), Luong Vu (Vietnam Lexicography Center, Vietnam), Phuong Le-Hong (Vietnam National University, Hanoi & FPT Technology Research Institute, FPT Corporation, Vietnam)	354
<hr/>	
• Lead Engagement by Automated Real Estate Chatbot	
Quan Thanh Tho (HCMUT, Vietnam), Trung Trinh (Ho Chi Minh City University of Technology, Vietnam), Dang Ngo (Ho Chi Minh City University of Technology, Vietnam), Hon Pham (Ho Chi Minh City University of Technology, Vietnam), Long Hoang (Atomic Vietnam Co., LTD, Vietnam), Hung Hoang (Atomic Vietnam Co., LTD, Vietnam), Thanh Thai (Ho Chi Minh City University of Technology, Vietnam),	

Phong Vo (Ho Chi Minh City University of Technology, Vietnam), Dang Pham  
(University of Science, Vietnam), Trung Mai (Bach Khoa University, Vietnam) 357

## Computational Intelligence

- A Comparative Study of Neural Network Models for Sentence Classification  
Phuong Le-Hong (Vietnam National University, Hanoi & FPT Technology Research  
Institute, FPT Corporation, Vietnam), Le Anh Cuong (Ton Duc Thang University,  
Vietnam) 360
- A Hybrid Approach to Paraphrase Detection  
Phuc H. Duong (Ton Duc Thang University, Vietnam), Nguyen Thanh Hien (TDT,  
Vietnam), Hieu Duong (Ho Chi Minh City University of Technology, Vietnam), Khoa  
Ngo (NewAI Research, Vietnam), Dat Ngo (NewAI Research, Vietnam) 366
- A review of feature indexing methods for fast approximate nearest neighbor search  
The-Anh Pham (Hong Duc University, Vietnam), Van-Hao Le (Hong Duc University  
(HDU) Thanh Hoa, Vietnam), Dinh-Nghiep Le (Hong Duc University (HDU), Thanh  
Hoa, Vietnam) 372
- Building a Spelling Checker for Documents in Khmer Language  
Trần Văn Nam (Trường Đại học Trà Vinh, Vietnam), Nguyen Thi Hue (Tra Vinh  
University, Vietnam), Huy Khanh Phan (Danang College of Technology, Vietnam) 378

## Computer Vision and Intelligent Systems

- A solution based on combination of RFID tags and facial recognition for monitoring  
systems  
Hoang Van Dung (Quang Binh University, Vietnam), Van-Dat Dang (Quang Binh  
University, Vietnam), Tien-Thanh Nguyen (Science and Technology Department of  
Quang Binh, Vietnam), Diem-Phuc Tran (Duy Tan University, Vietnam) 384
- An effective implementation of Gaussian of Gaussian descriptor for person re-  
identification  
Thuy-Binh Nguyen (Hanoi University of Science and Technology, Vietnam), Duc-Long  
Tran (MICA, HUST, Vietnam), Thi-Lan Le (MICA, HUST, Vietnam), Pham Thanh  
Thuy (MICA Institute (HUST - CNRS/UMI 2954 - INP Grenoble), Vietnam), Huong-  
Giang Doan (MICA, HUST, Vietnam) 388
- Hybrid discriminative models for banknote recognition and anti-counterfeit  
Hoang Van Dung (Quang Binh University, Vietnam), Hoang-Thanh Vo (Quang Binh  
University, Vietnam) 394
- Total Variation L1 Fidelity Salt-and-Pepper Denoising with Adaptive Regularization  
Parameter  
Dang N. H. Thanh (Hue College of Industry, Vietnam), V. B. Surya Prasath (Cincinnati  
Children's Hospital Medical Center & University of Cincinnati, USA), Le Thi Thanh  
(Ho Chi Minh city University of Transport, Vietnam) 400

## Computational Intelligence

- Semi-supervised method with Spatial weights based Possibilistic fuzzy C-means clustering for Land-cover Classification  
Dinh-Sinh Mai (Le Quy Don Technical University, Vietnam), Thanh Long Ngo (Le Quy Don University, Vietnam) 406
- Vietnamese Keyword Extraction Using Hybrid Deep Learning Methods  
Hung Thanh Bui (Thu Dau Mot University & Data Analytics & Artificial Intelligence Laboratory, Vietnam) 412
- Empirical Evaluation of Link Prediction Methods in Social Networks  
Ba-Hien Tran (John von Neumann Institute, Vietnam National University, Ho Chi Minh City, Vietnam) 418

## Computer Vision and Intelligent Systems

- A Predictive Model for ECG Signals Collected from Specialized IoT Devices using Deep Learning  
Duy Tran (Ho Chi Minh City University of Technology, Vietnam), Thanh Vo (Ho Chi Minh City University of Technology, Vietnam), Dung Nguyen (Ho Chi Minh City University of Technology, Vietnam), Quan Nguyen (Ho Chi Minh City University of Science, Vietnam), Liem Huynh (GTOPIA Joint Stock Company, Vietnam), Ly Le (International University, USA), Hai Do (Ho Chi Minh City International University, Vietnam), Tho Quan (Bach Khoa University, Vietnam), Trung Mai (Bach Khoa University, Vietnam) 424
- Joint Image Deblurring and Binarization for License Plate Images using Deep Generative Adversarial Networks  
Van-Giang Nguyen (Le Quy Don Technical University, Vietnam), Duy Long Nguyen (Le Quy Don Technical University, Vietnam) 430
- Deep Learning-based Multiple Objects Detection and Tracking System for Socially Aware Mobile Robot Navigation  
Do Nam Thang (Le Quy Don Technical University, Vietnam), Nguyen Lan Anh (Le Quy Don Technical University, Vietnam), Trung Dung Pham (Military Technical Academy, Vietnam), Truong Dang Khoa (Le Quy Don Technical University, Vietnam), Nguyen Huu Son (Le Quy Don Technical University, Vietnam), Pham Van Nguyen (Le Quy Don Technical University, Vietnam), Nguyen Hiep (Le Quy Don University, Vietnam), Vu Duc Truong (Le Quy Don Technical University, Vietnam), Dinh Hong Toan (Le Quy Don Technical University, Vietnam), Nguyen Manh Hung (Le Quy Don Technical University, Vietnam), Trung Dung Ngo (University of Prince Edward Island, Canada), Xuan-Tung Truong (Le Quy Don Technical University, Vietnam) 436

# Towards an Educational Music Processor for Folk and Popular Musics

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**Abstract**—This paper describes an educational musical processor that takes spectrographic data of a sonic object and turns them into a series of meaningful layers associated with different musical knowledge representations, in such a way that it can be understood, reproduced, played, compared, and taught by everyone across cultures, regardless of their musical backgrounds. Any music audio file can be used as input. Within the scope of this paper, the authors focus on processing of musical audio files onto common graphic platform of physical sound properties, in Hertz, Decibels, and milliseconds, so that culturally dependent musical units such as notes, beats, measures, phrases, chords, and sections can be viewed in separate layers. Syntactic techniques, such as frequency of occurrences, and adjacency are applied to musical units, such as pitches and musical chords. They are key pitches in context and key chords in context. The results are then mapped onto circles of fifths which reveal distinct patterns of each song, each section of one song, of each artist, each genre, and each culture. Semi-automatic generation of layers of annotations on top of the spectrogram helps teachers to quickly discover and/or compare distinctive features of a song, while preparing lessons. Learners of all levels can choose the most prominent patterns of the song to learn. This can also advance methods for preservation for further studies of sonic objects in the future.

**Keywords**—*music processor, music representation, audio files, frequency, pitch, melody, chord, harmonic progression, musical form, circle of fifths, frequency of occurrence, distinctive feature, key words in context, key pitches in context, key chords in context.*

## I. INTRODUCTION

For years, social sciences and humanities rarely involve the study of music. With the advent of artificial intelligence, especially an extensive understanding of natural language processing, and the massive use of digitized sonic objects, it is possible to imagine a platform to present, preserve, and analyze musical and linguistic elements using string grammar, as in [1]. Music and songs can be thought of as linear strings of pitches or syllables from performers to listeners. Music and linguistic units, such as pitches and syllables, are inherently not well-tempered. Notating human music in western notation has stripped away many essential music features, as in [2].

Adding these once-lost features back to their context (adjacent pitches and syllables) reveals culturally dependent characteristics of sonic artefacts, as in [3]. In this paper, natural and well-tempered pitches are presented in different layers or superimposed on each other to help further analysis and comparison, as in [4] and [5]. Linearity, adjacency, regularity, structure, and unit-oriented properties of music from pitches, phrases, sections are similar enough, to that of natural language processing (NLP), as in [6]. This NLP processor helps sketch major components of this educational music processor (EMP).

This paper is largely divided into two parts, one part using technologies to convert musical objects into physical data, measured by Hertz (Hz), Decibels (dBs), and milliseconds (ms). From these units, a layer of musical clefs and layers of interpretive manual insertion of beats, measures, phrases, sections, lyrics, and chords, are overlaid laid. The second part is dedicated to describing an EMP via a test case. It displays frequencies of occurrences of pitches and chords, and strings of adjacent pitches and adjacent key chords. The results expose the unprecedented characteristics of the test song.

## II. OBTAINING DATA

Data of this paper can be divided into two categories: phenomenal and conventional (or knowledge). Phenomenal data are physical signals such as time, frequency, and intensity. Conventional data are interpretive symbols and knowledge that have been used in music and languages in different cultures. Examples of conventional data in this paper are musical beats, pitches, phrases, sections, quarter notes, measures, treble and bass clefs, and chords, which exist only in culturally learned contexts.

## III. TECHNOLOGIES USED

Top-of-the-art technologies are tested and chosen based on three criteria: user-friendliness, cost, and standardization.

### A. Sound Analysis Software

1) *Sonic Visualiser*, is a free software [7] that allows visualized representations of audio input such as soundwaves and spectrograms. It allows manually or plug-in overlaid annotations on top of one another. For examples: *Chordino Chord Estimation*, generates an SVL output<sup>1</sup> containing frames (defined in IV.A. below) associated with the chord labels [8]. *Melodia Melody Extraction* generates an SVL output containing frames associated with the melodic pitches [9]. *Queen Mary Note Onset Detector/Percussive Onset Detector* generates an SVL output containing frames associated with an onset of a percussive sound [10]. *BBC Intensity* generates an SVL output containing frames associated with an intensity value [11].

2) *MuseScore (offline)* is a free standalone open-source software for music notation [12]. The companion *MuseScore (online)*, is an online platform allowing users to share and edit sheet music, and connect to other websites, or through YouTube videos [13]. *MuseScore* offline and *MuseScore* online versions are used *in tandem* by the EMP to create a panel of western musical notation.

3) *AnthemScore* is a standalone which suggests a transcription of an audio file (MP3, WAV, etc.) into sheet music using western notations [14]. It suggests pitches based dominant frequencies' amplitudes of the song's spectrogram.

### B. The educational musical processor (EMP)

1) The EMP is coded in PHP 7.2 with SVG 1.1<sup>2</sup>, follows the international, world wide web, archival, librarian and multilingual standards, Unicode and ISO/IEC 10646 [15], world wide web standards are HTML [16], XML [17], URI and MusicXML.<sup>3</sup> The EMP also adheres to the Open Archive Initiative/Object Reuse and Exchange (OAI/ORE) [18] with Dublin Core Metadata Initiative (DCMI) [19].

2) The EMP runs about 6,000 lines of codes on a Dell T1650 workstation, with Ubuntu 18.04.1.

## IV. A TEST CASE: DESPACITO BY LUIS FONSI 2017

The video version of *Despacito* by Luis Fonsi ft. Daddy Yankee (hereafter, simply *Despacito*)<sup>4</sup> was chosen to guide the design of our folk and popular music processor. The song is the most viewed YouTube video.

### A. Frame

Frame is a common feature that pairs all data collected. Each frame is 1/44,100 second or 10/441 millisecond. 44,100 Hz is one of the standard digital sample rates.

### B. Spectrographic data plotted as the background layer

*Despacito* is 4 minutes and 42 seconds long. *AnthemScore* reads *Despacito* and generates a spreadsheet of spectrographic data. Data can either be obtained from every 1 ms to every 10

ms, in time, and from every 5 cents to every 25 cents, in pitch. The authors chose to test two sets of data: (a) a fine set of 1 ms by 25 cents in a spreadsheet of 351 pitch columns by 281,522 one-ms rows; and (b) a crude set of 10 ms by 25 cents in a spreadsheet of 351 pitch columns by 28,153 ten-ms rows. Each cell contains an intensity value in dBs. The former spreadsheet is 774 MB and the latter, 94 MB, in size.

The EMP reading of the fine spreadsheet took 130 ms, with a pitch range from 26.7171 to 4,308.66 Hz, and intensity range from 0 to 17,872 dBs. The crude spreadsheet took 15.5 ms to read, with the intensity range from 0 to 4,246.1 dBs.

### C. Musical grand staff and piano keyboard as SVG Layer 1

The 351 pitch values are set on the vertical axis of *Despacito* spectrographic graph, *Layer 0* (Fig. 1), ranging from C<sup>0</sup> (0 cent at 26.7171 Hz) to B<sup>8</sup> (10,700 cents at 4,366.08 Hz). The pixel colors, from deep blue, lowest, to white, strongest, represent the intensity in dBs of the song. This allows a treble and a bass clef, *Layer 1*, with a piano 88 keys from A<sup>0</sup> (900 cents) to C<sup>8</sup> (9,600 cents) to be drawn on top of *Layer 0*. The staff lines run along the horizontal time axis.

### D. Layer 2: Labelling of Beats, Measures, Chords, Phrases and Sections on *Despacito* spectrogram

These data are generated by *Sonic Visualiser* in frames with manual inputs, in SVL format. They are superimposed on *Layer 0* and *Layer 1* to show how human perception paired with the physical data.

On top of each panel of spectrogram, a bar graph of dB values at each frame in the song is drawn in red with white dots underfoot representing the percussive onsets (Fig. 2).

The beats are shown in yellow arrows inside red transparent measure boxes and the chords, in cyan, at their onset time positions (Fig. 3).

At the bottom of *Layer 0*, the phrase boxes in orange contain their lyrics in black, while the lowest light brown bars represent sections in the song (Fig. 4).

Manual markings of *Despacito* result in 83 phrases, 113 lyric expressions, 22 chords, and 26 sections (representing 11 music forms labelled from A to L).

### E. Layers for collections of pitch intensity of each beat, measure, chord, phrase and section.

Specifically, *Layer 3* shows dBs by measures, *Layer 4*, dBs by beats, *Layer 5*, dBs by chords, *Layer 6*, dBs by phrases and *Layer 7*, dBs by sections. Fig. 5 (left) shows *Layer 5*.

### F. Layer 8, music sheet of *Despacito* according to *AnthemScore*

This is an estimate by *AnthemScore*. The notes are displayed over *Layer 0*, *Layer 1* and *Layer 2* to pair the estimates with the spectrographic data and other manual data.

The sums of all pitch dB values within a beat, a measure, a chord, a phrase and a section, reveal the strongest pitches within, evidence of played notes, marked on the vertical axis.

<sup>1</sup> SVL is an XML Sonic Visualiser data exchange format.

<sup>2</sup> At <https://www.w3.org/TR/2011/REC-SVG11-20110816/>.

<sup>3</sup> MusicXML 3.0, in XML format for exchanging digital sheet music, see <https://www.w3.org/2017/12/musicxml31/>.

<sup>4</sup> At <https://www.youtube.com/watch?v=kJQP7kiw5Fk>.

These layers are intended to reveal also differences in the manual perception against the raw spectrographic data.

*G. Layer 9, AnthemScore estimation is displayed through MuseScore applications.*

This layer is the most interactive, by *AnthemScore*. Viewers can play portions of *Despacito*, section by section. They can also play back the sheet music, section by section.

*Layer 0 to 9*, takes about 235 seconds to produce by the EMP, viewed at <http://mlp.cs.nyu.edu/vietmusic/au2spec.php>.

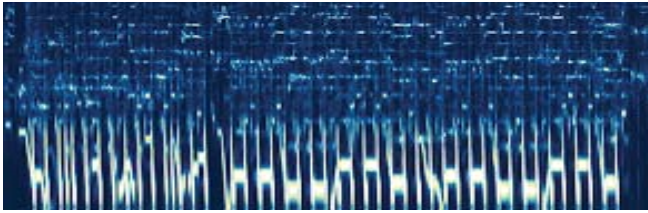


Fig. 1. A segment of spectrogram of *Despacito*'s recording.



Fig. 2. An example of *Despacito* intensity and percussive onsets.



Fig. 3. An example of *Despacito* markings: down arrows for beats, rectangular boxes for measure, cyan letters for chord symbols.



Fig. 4. An example of *Despacito* markings: orange rectangular boxes for lyrics and light brown rectangular boxes for sections.

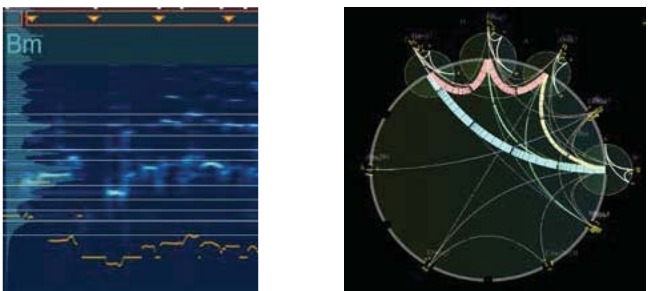


Fig. 5. Left, an example of Layer 5: sum of dBs by Chords B minor over *Despacito* spectrogram image. Right, the chord procession  $kcic(2)$  with their frequencies of occurrences in thickness of over the circle of fifths.

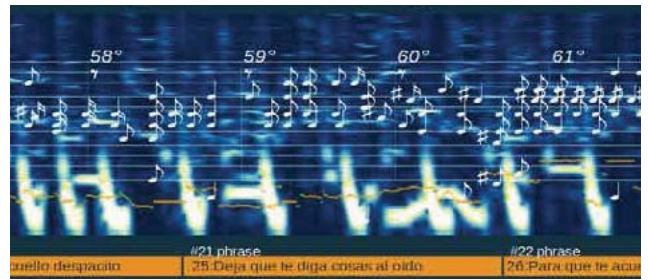


Fig. 6. An example of music notation on top of the spectrogram

*I. Pitch and chord frequencies of occurrences, and key chords in context  $kcic(n)$ , and their visual representations on the Circles of Fifths.*

*AnthemScore* estimates that *Despacito* has a range of 47 pitches, from  $B^0$  to  $C\#^7$ :  $D^4$  occurs 508 times,  $B^3$ , 353 times,  $F\#^4$ , 241 times,  $A^3$ , 201 times,  $E^4$ , 173 times, and so on. They are drawn on the music clefs, as well as on a circle of fifths with their frequencies as radii. This shows that even though the song has all 12 pitch classes, they strongly lean on 4 central pitches (highest frequencies of occurrence), while others are just decorative. Further analysis confirms this observation.

If the song is estimated section by section, it turns out that *AnthemScore* now produces a range of 60 pitches, from  $B^0$  to  $D^7$ . The same 4 notes are still central to the song:  $D^4$ , occurs 612 times,  $B^3$ , 433 times,  $F\#^4$ , 292 times, and  $A^3$ , 243 times, and so on. Their class positions are more prominent in the circle of fifths. The same analysis on frequencies of occurrences of pitches done between sections shows the tendencies of section movements towards each other, serving as clues to identification of musical forms.

Here the concept of key pitches in context  $kpic(n)$  and key chords in context  $kcic(n)$ ,  $1 < n < m$ , where  $m$  is the total number of pitches or chords in a section, are applied.  $kpic(n)$  and  $kcic(n)$  are modeled after *key words in context*,  $kwic(n)$ , that helps show regular pitch and chord strings in the song.

A sample of  $kcic(2)$ ,  $n = 2$ , is shown in Fig. 6 (right) on the circle of fifths with their frequencies of occurrences. It is immediately obvious that *Despacito* has 4 prominent chords, D major, G major, A major and B minor. Chord progressions B minor to G major appears 22 times, G major-D major (18 times), D major-A major (18 times), and finally A major-B minor (10 times). While B minor-G major is most frequent, there is no G major-B minor progression.

Twenty-six song sections are displayed with frequencies of pitches on the music clefs and their proper positions, as well as their pitch classes on the circle of fifths, together with their music forms. Changes in the circles of fifths visualize the class content shifts in forms of song progression by sections.

*H. Lyrics in phrase bars*

In this final panel, for now, another way of data presentation can be viewed in a familiar manner, in a phrase

by phrase layout, containing lyrics with chords associated with their proper lyric syllables. This presentation is a shorthand way for viewers to sing along without being bothered with music clefs and music pitch notes, measures or beats.

Items J. to L. currently take about 20 seconds by the EMP, can be viewed at <http://mlp.cs.nyu.edu/vietmusic/au2ana.php>.

### I. Current Issues

At the moment, the music processor adopts temporarily the use of the best spectrogram analysis by current leading software. This decision creates discrepancies in data units, and requires data unification into *milliseconds* and *cents*. There are other practical issues such as the best approaches for data presentation in layers, as the EMP for *Despacito* currently transfers a massive 330MB of graphic data to browsers.

The EMP begins to modestly scale up to over 4 minutes with 281,522x351 spectrogram of 99 million data points. The first spectrographic and all manual onsets of 9 layers took too long, 235 seconds of processing time. However, they are intended to be processed each separately according to the preference of viewers. The second analysis now takes 20 seconds to produce all 5 subparts, which can also be presented separately based on the viewer preference.

## V. EDUCATIONAL IMPLICATIONS

The main goal of this paper is to work toward a model of music teaching and learning that would be more generally accessible, while not sacrificing the contents and quality of musical experiences.

The use of digital technologies to facilitate teachers and students to develop musical skills and knowledge, most efficiently in the following ways. First, the EMP provides a graphical analogue of music that bypasses the need for specialized musical notation and symbols. Graphical representation is especially suited for teaching musics whose tonalities do not often fit well with the western chromatically-based tonal system. In this sense, these graphs help describing the music inputs faithfully with visual aids. After that, the EMP proceeds to calculate prevailing rhythmic and melodic patterns of a songs by constantly comparing units of data based on the theory of string grammar and deep learning. These patterns serve as basic blocks for improvisation and stylistic recognition. Finally, it allows any teachers to analyze and device lesson plans on any songs suggested by the students. The lessons are automatically tailored to match the student's ability. Teachers are then able to have more time focusing on accommodating other peculiar student needs, encouraging individual interpretations, and providing contextual knowledge.

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