Editorial: Intelligent Signal Analysis for Contagious Virus Diseases

COVID-19 infection's recent outbreak triggered by the SARS-CoV-2 Corona virus had already led to more than two million reported infected individuals when we first addressed the community by our call – by now, the number sadly rose to roughly half a billion cases worldwide. The back then many thousand deaths worldwide have increased to six million, and the first author is infected himself while writing these lines.

The immediate health, but also expected financial, political, sociological, and further consequences caused by the pandemic have fueled one of the greatest crises of our time. As a consequence, there is currently an unseen interest in solutions across scientific disciplines to help in the fight against the virus' and potential follow-ups' spread and consequences. While curves of new COVID-19 infections may start to flatten again after repeated waves in some countries, potential oncoming follow-up waves, variants, and future outbreaks of novel mutated highly contagious viruses have to be best prevented by all means. Already, there are more than 40 further known potential highly contagious virus diseases that could lead to new pandemics in the near future. In this light, there is an unusual urgency calling the signal processing community as well as many scientists across disciplines to immediate action. Advanced modelling and intelligent digital and mobile health contributions empowered by intelligent signal processing solutions are just examples of how we might help. In many immediate use-cases, signal processing is already being applied or researched in this context, such as in deep learning-based CT COVID-19 diagnosis, or even audio-based tracking of symptoms and infection as recently also shown in several benchmark challenges.

The outbreak of COIVD-19 has also re-shaped and accelerated the scientific publication landscape in no time. One can observe a massive uprise in interest in work related to the topic of highly contagious virus diseases and potential contributions of digital health including intelligent signal processing. In addition, most publishers have reacted in one or the other way to the crises such as by opening up to pre-prints, waiving publication fees for COVID-19-related research, providing search functions and tools for COVID-19 research, and many more. Here, we gathered 13 carefully selected novel contributions across signal types such as audio, speech, image, video, or symbolic information, as well as their multimodal combination for application in the risk assessment, diagnosis, and monitoring of contagious virus diseases. A focus is thereby put on intelligent processing of the signals, such as by suited and novel deep learning approaches, or other forms of machine learning and general AI. But the topics that we present span a wide range of applications in intelligent medical data and every-day health-related signal processing. These can range from mobile health-ready solutions for sensing and diagnosis or applications for tracking to modelling and forecasting tools of the spread and sources of the viruses.

Below, we will summarise these grouped into two larger clusters, starting with sensing and recognition before moving to modelling and forecasting.

I. SENSING AND RECOGNITION

The first set of six well selected contributions revolves around diagnosis and privacy aspects in the data needed therefore as well as risk assessment.

First, in *"Detection of SARS-CoV-2 in COVID-19 Patient Nasal Swab Samples Using Signal Processing"*, Al Ahmad and colleagues [A2] introduce an opto-electrical method as novel biosensor able to measure the viral nucleocapsid protein and anti-N antibody interactions to decide on SARS-CoV-2 negative or positive nasal swab samples. The samples need to be exposed to light. Then, the method is based on initiating charge transfer transitions. In their experiments, two minutes suffice for the final decision. They conclude that the method appears suited for mobile usage and mass testing at low cost.

In *"Project Achoo: A Practical Model and Application for COVID-19 Detection from Recordings of Breath, Voice, and Cough"* by Ponomarchuk and colleagues [A3], the authors present a variant of the currently heavily researched COVID-19 detection from audio. They include noise reduction and apply deep neural networks for the audio-based diagnosis. The approach is based on ensembling Mel-scale spectrogram and Cochleagram audio representations handled by deep and non-deep solutions. In addition, the authors established a mobile application that combines a symptom questionnaire with the introduced voice, breathing, and coughing analysis. In their experiments, two datasets acquired from the public and additional data from end-users shows robust processing and ternary decision making – positive, unsure, or negative. The authors note that worldwide, many parallel similar efforts are presently made and encourage synergistic bundling of energies and sharing of data.

Staying with audio as information source, Taylor, Keane, and Zigel present *"A Speech Obfuscation System to Preserve Data Privacy in 24-Hour Ambulatory Cough Monitoring"* [A4]. They concern themselves with privacy in continuously recorded

---

Date of current version April 18, 2022.
Digital Object Identifier 10.1109/JSTSP.2022.3160023

audio and base their studies on data collected from a commercial device for cough monitoring. Specifically, they obfuscate intelligible speech while aiming to preserve all cough information in the audio stream. To do so, they detect vowels and replace such regions with synthesised audio that pertains prosody, but removes the dominant spectral maxima, i. e., the formants. In their experiments on five days of recorded audio, they measure above 99 % correct obfuscation of vowels as well as correct preservation of cough events.

"A Multi-Channel Ratio-of-Ratios Method for Noncontact Hand Video Based SpO2 Monitoring Using Smartphone Cameras" by Tian and colleagues [A5] next leads us to video as modality. The aim is to measure blood oxygen saturation (SpO_2) from mobile phones' cameras. The motivation being is that the levels can be dangerously low for COVID-19 patients already considerably before degrading conditions occur. Hence, an early detection of low SpO_2-levels can serve as a warning sign. While common methods for its measurement require contact with the camera such as by the finger tip, a contact-less method avoids sanitary issues and skin irritation. Other than concurrent methods, the authors exploit all three of the RGB colour channels. They further apply heart-rate adaptation in narrow-band filtering to best identify the AC-component per channel. In their tests, they reach close to 1 % mean absolute error in comparison to a pulse oximetre reference.

Canil, Pegoraro, and Rossi next introduce *"milliTRACE-IR: Contact Tracing and Temperature Screening via mm-Wave and Infrared Sensing"* [A6]. The approach combines radar and infrared thermal camera imaging preserving privacy of those scanned. It allows to automatically estimate distancing and body temperature. The face is tracked from the thermal imagery for temperature assessment; the body motion is tracked by the radar for distance measurement. In addition, indoor contact tracing is possible, as individuals with high temperature are re-identified across different rooms. Gait patterns serve as reference for the contact tracing. The modelling is solved by deep and further neural approaches. From a real-world installation, the authors measure accuracy at decimetre level for distances, half a degree Celsius for temperature, and above 95 % for person re-identification.

Adhane, Dehshibi, and Masip then present findings *"On the use of uncertainty in classifying Aedes Albopictus mosquitoes"* [A7]. The motivation behind is the re-emergent mosquito-borne diseases (MBDs), responsible for several hundred thousand of annual mortalities. A frequent approach for mosquito tracking is based on convolutional neural networks for image analysis. Here, the authors suggest a Monte Carlo dropout-based method to provide a measure on the uncertainty during Aedes albopictus mosquitoes recognition. This uncertainty is exploited in active learning to reduce the required amount of human involvement in data labelling for improved learning databases. The experiments presented show a gain over considered competitors and a high reduction in human involvement. The authors also give examples of visual explanations for the uncertainty.

II. MODELLING AND FORECASTING

We now move towards seven hand-picked approaches geared more towards modelling and forecasting of contagious virus diseases.

The first contribution in this cluster comes from Yu, Tan, and Fu dealing with *"Epidemic Source Detection in Contact Tracing Networks: Epidemic Centrality in Graphs and Message-Passing Algorithms"* [A8]. The authors concern themselves with the challenge of the source detection in graph-based tracing networks. The basis of their approach is formed by the susceptible-infected model in epidemiology and the optimal solution of the maximum-likelihood estimator. This forms the basis of an efficient contact tracing exceeding currently used heuristics both for the earlier SARS-CoV 2003 and the currently ongoing COVID-19 pandemic. In particular, super-spreaders are correctly classified in the considered Singapore and Taiwan data samples.

Zhu and colleagues next present an *"Early Detection of COVID-19 Hotspots Using Spatio-Temporal Data"* [A9] based on a Bayesian framework. The lieu of testing are the United States. The underlying modelling assumption is that the observed cases and hotspots number depends on a class of latent random variables that underlie a zero-mean Gaussian process and a covariance of a non-stationary kernel function. These variables then encode the spatio-temporal dynamics of the disease's spread. A key feature of the presented work is that deep learning is injected while preserving the kernel's interpretability. For efficiency reasons, the model is derived in a sparse manner allowing for processing of bigger data. In an evaluation, the methods are found superior to other baseline approaches.

Bai, Safikhani, and Michailidis subsequently suggest the *"Hybrid Modeling of Regional COVID-19 Transmission Dynamics in the U.S."* [A10] taking into account spatio-temporal information. The approach relies on a piecewise susceptible-infected-recovered (SIR) model. In this model, significant changes in transmission or recovery rates are nominated as break points. These points are then identified based on fused lasso and thresholding. For smoothing and improved development estimation, spatial smoothing covariates and a vector auto-regressive (VAR) model are added. The tests on data from the US and other countries as well as synthetic data show good results in break point identification super-seeding amongst others deep learning approaches.

In *"Predicting the Epidemics Trend of COVID-19 Using Epidemiological-based Generative Adversarial Networks"*, Wang and colleagues [A11] also combine epidemiological theories and deep learning. Their approach equally relies on the SIR model. Here, it is used to generate epidemiological simulation data. This data is then forwarded for augmentation of data to a generative adversarial network (GAN) as adversarial examples. Finally, transformers provide the estimates of COVID-19 trends based on this data. The method proved superior on actual data. The authors further elaborate on vaccine effectiveness by the delta of reported and predicted infection cases.

"Modeling Social Distancing and Quantifying Epidemic Disease Exposure in a Built Environment" is next discussed by Chaitra and colleagues [A12]. They introduce a new risk of exposure metric dependent on the number of people in an indoor environment and the distances. They further incorporate individual data, virus-specific data, and the ventilation rate in the built environment. While the parameters have been chosen for the COVID-19 situation, the authors believe they apply also

for other contagious virus diseases. The approach was tested with real-world data and a tool was realised that also features visualisation of risk areas in buildings.

"Mathematical Modeling of COVID-19 and Prediction of Upcoming Wave" by Arti [A13] then considers practical scenarios in India, and four other countries. She employs a Gaussian mixture model fed by daily novel COVID-19 cases. The author further makes the assumption of N waves with the information being present in adjacent waves. The analyses between modelling and observed real data support the model's validity and usefulness.

Finally, Sameni introduces *"Model-based Prediction and Optimal Control of Pandemics by Non-pharmaceutical Interventions"* [A14]. Based on finite-horizon optimal control, and exploiting extended Kalman filtering, the author presents a framework in the context of optimal non-pharmaceutical interventions. The exploited parameters thereby stem both from epidemiological facts known from the literature and from machine learning. Encouraging results are presented based on the Oxford COVID-19 Government Response Tracker project including over 300 countries and regions. Implementations of the algorithm are available online.

III. CONCLUSION

The selected contributions effectively demonstrate the usefulness of intelligent signal processing methods in the combat against the spread of contagious virus diseases and their modelling. A variety of possibilities has been shown in impressive ways. However, a number of challenges beyond increased robustness of these methods and first steps towards increased privacy, efficiency, and explainability as were shown are left for oncoming efforts, including, but not being limited to factors of crucial practical relevance to assure working solutions in the real world. Examples are trustable and responsible solutions, potentially increasingly multimodal in their nature. In addition, the constant mutations of such diseases require for further databases and techniques for dealing with drifting targets while at the start of mutation often only having little data available.

Overall, we feel that intelligent signal processing is well equipped to provide substantial aid in the oncoming challenges given by contagious virus diseases – we need to make our best efforts to assure their best possible performance at most responsible processing of often highly sensitive and private data to be prepared.

BJÖRN W. SCHULLER, *Guest Editor*
University of Augsburg
86159 Augsburg, Germany
bjoern.schuller@uni-a.de

YONINA ELDAR, *Guest Editor*
Weizmann Institute of Science
Rehovot 7610001, Isreal
yonina.eldar@weizmann.ac.il

MAJA PANTIC, *Guest Editor*
Imperial College London
SW7 2AZ London, U.K.
m.pantic@imperial.ac.uk

SHRIKANTH NARAYANAN, *Guest Editor*
University of Southern California
Los Angeles, CA 90007 USA
shri@ee.usc.edu

TUOMAS VIRTANEN, *Guest Editor*
Tampere University of Technology
33720 Tampere, Finland
tuomas.virtanen@tuni.fi

JIANHUA TAO, *Guest Editor*
Nanjing University
Nanjing 210093, China
jhtao@nlpr.ia.ac.cn

ACKNOWLEDGMENT

This special issue came to live thanks to the efforts of many, ultimately across the entire research community. First, we thank the IEEE Journal of Selected Topics in Signal Processing team, in particular the Editor-in-Chief, Xiao-Ping Zhang, as well as Mikaela Langdon and Shannon Campos for helping with the organisation and production of this issue. Most notably, we also thank the manifold reviewers for their great work during the repeated revision rounds. Without greatest quality review, which often comes at bigger sacrifice in time, it seems impossible to reach the great quality of articles the situation requires. Finally, we thank all the authors for their great contributions.

APPENDIX: RELATED ARTICLES

[A1] B. W. Schuller *et al.*, "Editorial: Intelligent signal analysis for contagious virus diseases," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 159–163, Feb. 2022.

[A2] M. A. Ahmad *et al.*, "Detection of SARS-CoV-2 in COVID-19 patient nasal swab samples using signal processing," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 164–174, Feb. 2022.

[A3] A. Ponomarchuk *et al.*, "Project Achoo: A practical model and application for COVID-19 detection from recordings of breath, voice, and cough," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 175–187, Feb. 2022.

[A4] T. E. Taylor, F. Keane, and Y. Zigel, "A speech obfuscation system to preserve data privacy in 24-hour ambulatory cough monitoring," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 188–196, Feb. 2022.

[A5] X. Tian, C.-W. Wong, S. M. Ranadive, and M. Wu, "A multi-channel ratio-of-ratios method for noncontact hand video based SpO_2 monitoring using smartphone cameras," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 197–207, Feb. 2022.

[A6] M. Canil, J. Pegoraro, and M. Rossi, "milliTRACE-IR: Contact tracing and temperature screening via mmwave and infrared sensing," *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 208–223, Feb. 2022.

[A7] G. Adhane, M. M. Dehshibi, and D. Masip, “On the use of uncertainty in classifying *aedes albopictus* mosquitoes,” *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 224–233, Feb. 2022.

[A8] P.-D. Yu, C. W. Tan, and H.-L. Fu, “Epidemic source detection in contact tracing networks: Epidemic centrality in graphs and message-passing algorithms,” *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 234–249, Feb. 2022.

[A9] S. Zhu *et al.*, “Early detection of COVID-19 hotspots using spatio-temporal data,” *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 250–260, Feb. 2022.

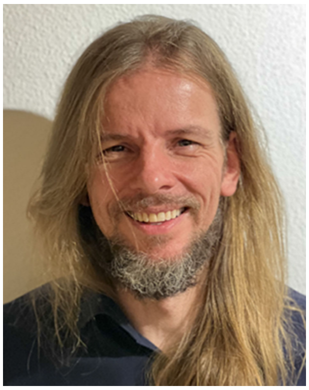
[A10] Y. Bai, A. Safikhani, and G. Michailidis, “Hybrid modeling of regional COVID-19 transmission dynamics in the U.S.,” *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 261–275, Feb. 2022.

[A11] H. Wang *et al.*, “Predicting the epidemics trend of COVID-19 using epidemiological-based generative adversarial networks,” *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 276–288, Feb. 2022.

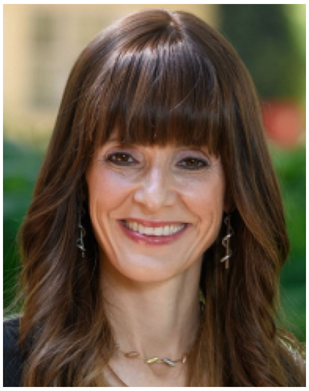
[A12] C. Hegde, A. B. Rad, R. Sameni, and G. D. Clifford, “Modeling social distancing and quantifying epidemic disease exposure in a built environment,” *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 289–299, Feb. 2022.

[A13] Arti M.K., “Mathematical modeling of COVID-19 and prediction of upcoming wave,” *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 300–306, Feb. 2022.

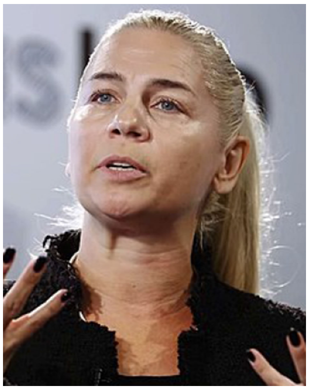
[A14] R. Sameni, “Model-based prediction and optimal control of pandemics by non-pharmaceutical interventions,” *IEEE J. Sel. Topics Signal Process.*, vol. 16, no. 2, pp. 307–317, Feb. 2022.



Björn W. Schuller (Fellow, IEEE) received the Doctor and Habilitation degrees from The Technical University of Munich, Munich, Germany. He is currently a Professor of artificial intelligence and the Head of GLAM with Imperial College London, London, U.K., a Full Professor and the Chair of the Embedded Intelligence for Health Care and Wellbeing with the University of Augsburg, Germany, and also the co-founding CEO and CSO of audEERING providing speech emotion recognition technology. He is also the Independent Research Leader with The Alan Turing Institute – Royal Statistical Society Lab, U.K. Health Security Agency, leading research on COVID-19. He has coauthored five books and more than 1100 publications. He is the Field Chief Editor of the *Frontiers in Digital Health*, Former Editor-in-Chief of IEEE TRANSACTIONS ON AFFECTIVE COMPUTING, President-emeritus and a Fellow of AAAC, Golden Core Awardee of the IEEE Computer Society, a Fellow of BCS, ISCA, and ELLIS, and a Senior Member of ACM. He frequently consults including Barclays, GN, Huawei, Informetis, and Samsung.



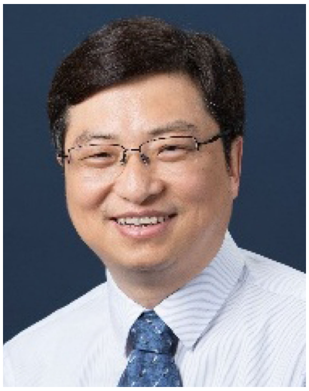
Yonina Eldar (Fellow, IEEE) is a Professor in the Department of Math and Computer Science at the Weizmann Institute of Science, Rehovot, Israel, where she heads the center for Biomedical Engineering and Signal Processing. She is also a Visiting Professor at MIT and at the Broad Institute and an Adjunct Professor at Duke University, and was a Visiting Professor at Stanford University. She is a member of the Israel Academy of Sciences and Humanities, an IEEE Fellow and a EURASIP Fellow. She has received many awards for excellence in research and teaching, including the IEEE Signal Processing Society Technical Achievement Award, the IEEE/AESS Fred Nathanson Memorial Radar Award, the IEEE Kiyo Tomiyasu Award, the Michael Bruno Memorial Award from the Rothschild Foundation, the Weizmann Prize for Exact Sciences, and the Wolf Foundation Krill Prize for Excellence in Scientific Research. She is the Editor in Chief of Foundations and Trends in Signal Processing, and serves the IEEE on several technical and award committees. She is currently involved in several national COVID19 efforts in Israel and is Co-Chair of the InterAcademy Partnership’s COVID-19 Advisory Group.



Maja Pantic (Fellow, IEEE) is currently a Professor of affective and behavioral computing and the Leader of i · BUG Group and was the Research Director of Samsung AI Centre, Cambridge (SAIC), MA, USA, working on machine analysis of human non-verbal behaviour and its applications to human-computer, human-robot, and computer-mediated human-human interaction. She has authored or coauthored more than 250 technical papers in the areas of machine analysis of facial expressions, machine analysis of human body gestures, audiovisual analysis of emotions and social signals, and human-centered machine interfaces. She has more than 40 000 citations to her work, and was the Keynote Speaker, Chair and Co-Chair, and an organization/ program committee member with numerous conferences in her areas of expertise. She was the Editor-in-Chief of the *Image and Vision Computing Journal*.

Shrikanth Narayanan (Fellow, IEEE) is currently an University Professor and the Niki & C. L. Max Nikias Chair of engineering with the University of Southern California (USC), Los Angeles, CA, USA, and holds appointments as a Professor of electrical and computer engineering, computer science, linguistics, psychology, neuroscience, otolaryngology-head and neck surgery, and pediatrics, the Research Director of Information Science Institute, and the Director of Ming Hsieh Institute. Prior to USC, he was with AT&T Bell Labs and AT&T Research. He founded and directs the Signal Analysis and Interpretation Laboratory (SAIL) focused on human-centered signal processing and machine intelligence and their societal applications. He has authored or coauthored more than 900 papers and has been granted 18 U.S. patents. He is a Fellow of the Acoustical Society of America, ISCA, American Association for the Advancement of Science, Association for Psychological Science, American Institute for Medical and Biological Engineering, and National Academy of Inventors. He is the inaugural VP for Education for the Signal Processing Society and was previously Editor-in-Chief of IEEE JOURNAL OF SELECTED TOPICS IN SIGNAL PROCESSING.

Tuomas Virtanen (Fellow, IEEE) received the M.Sc. and Doctor of Science degrees in information technology from Tampere University of Technology, Finland, in 2001 and 2006, respectively. He is currently a Professor Faculty of Information Technology and Communication Sciences, Tampere University, Finland, where he is leading the Audio Research Group. He has also been a Research Associate with Engineering Department, Cambridge University, U.K. He is known for his pioneering work on single-channel sound source separation using non-negative matrix factorization based techniques, and their application to noise-robust speech recognition and music content analysis. Recently, he has done significant contributions to sound event detection in everyday environments. He has authored more than 200 scientific publications, which have been cited more than 14 000 times. He was the recipient of the IEEE Signal Processing Society 2012 Best Paper Award and also three other best paper awards. He is a Member of the Audio and Acoustic Signal Processing Technical Committee of IEEE Signal Processing Society, and recipient of the ERC 2014 Starting Grant.



Jianhua Tao (Senior Member, IEEE) received the B.S. and M.S. degrees from Nanjing University, Nanjing, China, and the Ph.D. degree from Tsinghua University, Beijing, China. He is currently a Professor with the NLPR, Institute of Automation, Chinese Academy of Sciences, Beijing. He has authored or coauthored more than 100 papers in main journals. His current research interests include speech synthesis, speaker characters analysis, affective information processing, and multimedia integration. He was the recipient of manifold awards from main conferences. He was elected as the chair or program committee member for several main conferences, including ICPR, ACII, ICMI, EUROCON, or ISCSLP. He is a Steering Committee Member of IEEE TRANSACTIONS ON AFFECTIVE COMPUTING, the Vice Director of the Speech Information Processing Committee of Chinese Information Processing Society, the Vice Chairperson of a special interest group of Chinese Spoken Language Processing in ISCA, a Secretary-General of the Chinese Linguistic Data Association, an Executive Committee Member of AAAC, a Board Member of Chinese Acoustic Society, a Committee Member of Chinese Virtual Reality Committee and Chinese Phonetic Association. He is also the General Chair of INTERSPEECH 2020.