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Let There Be a Beam: Highlights from the 2020 IEEE Five-Minute Video Clip Contest

Wei Liu, Mohammad Reza Anbiyaei, Xue Jiang, Lei Zhang, and Lucio Marcenaro

Abstract

The annual 5-Minute Video Clip Contest was launched by the IEEE Signal Processing Society and beamforming was chosen as this year's topic, which has a wide range of applications in radar, sonar, microphone arrays, radio astronomy, seismology, medical diagnosis and treatment, and wireless communications. After two stages of fierce competition, three finalist videos were selected by the organizing committee and placed online for public voting. The first one is about fast beam alignment in mmWave radios, the second one is about co-prime beamforming and its application to speech enhancement, and the third one is about an indoor localization system employing a synthetic aperture-based beamforming approach. Taking into consideration the public voting result, the judge panel made the decision about the final ranking of the three videos. Highlights of the whole event are provided in this article, including a general introduction to beamforming.

I. Introduction

The new 5-Minute Video Clip Contest (5-MICC) was launched by the IEEE Signal Processing Society (SPS) alongside the 45th International Conference on Acoustics, Speech, and Signal Processing (ICASSP) in Barcelona (May 2020). It is an annual event and open for submissions from IEEE SPS members of various backgrounds, such as high school students, undergraduate and postgraduate students, as well as researchers from all over the world. Each participating team must be composed of: (i) one faculty member (the Supervisor), (ii) at most one graduate student (the Tutor), and (iii) at least three but no more than five undergraduates. At least three undergraduate team members must be either IEEE SPS

Wei Liu is with the Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield, S1 3JD, UK (e-mail: w.liu@sheffield.ac.uk).

Mohammad Reza Anbiyaei is with the Faculty of Engineering, Alzahra University, Tehran, Iran (e-mail: mr.anbiyaei@ieee.org).

Xue Jiang is with School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China (e-mail: xuejiang@sjtu.edu.cn.)

Lei Zhang is with the James Watt School of Engineering, University of Glasgow, Glasgow, G12 8QQ, UK (e-mail: lei.zhang@glasgow.ac.uk).

Lucio Marcenaro is with the Department of Electrical, Electronics and Telecommunication Engineering and Naval Architecture, University of Genoa, Italy (e-mail: lucio.marcenaro@unige.it).

student members or SPS members by the time they submit the full 5-minute video. The aim of 5-MICC is to help promote the indispensable role signal processing plays in our everyday life and attract more younger generations to pursue a career in signal processing, by creating video clips that "highlight and convey excitement about signal processing in the broad sense - including fundamentals, image, video, audio, speech, communication, radar, language, knowledge, human and machine learning and other forms of information bearing data and signals."

There are three stages for the contest: submission of 30-second trailers, submission of the full 5-minute video and final contest at ICASSP of the year. The three finalist teams' 5-minute videos will be available on the ICASSP website and voted by the conference participants. The final ranking will be decided by the judging panel, also taking into account the popular vote. It is planned that the finalist teams will also be invited to join the ICASSP Conference Banquet, as well as the Student Career Luncheon, so that they can meet and talk to SPS leaders and global experts.

II. The Topic

As the first time to run this contest, the topic chosen this year was beamforming.

Beamforming is one of the major areas of sensor array signal processing research and has been studied extensively in the past due to its wide range of applications in radar, sonar, microphone arrays, radio astronomy, seismology, medical diagnosis and treatment, and wireless communications [1]–[4]. It involves multiple sensors (microphones, antennas, hydrophones, etc.) placed at different spatial locations to process the received/transmitted signals for enhanced signal reception or transmission, while at the same time achieving effective interference reduction.

Traditionally, beamforming is mainly designed for line of sight (LoS) transmission and reception such as radar and many speech enhancement scenarios using microphone arrays and physically a beam will be formed in the process pointing to different directions around the sensor array system. However, with the arrival of the age of mobile communications, due to the strong multi-path effect, the result of beamforming between the user equipment and the base station will not necessarily form a real beam in space, but rather an overall enhanced signal transmission link between them. Nowadays, any process achieving enhancement of the desired signal while reducing the effect of interference can be considered as beamforming. One interesting development is, with the introduction of massive MIMO and millimetre wave communications in 5G [5]–[7], the LoS case is becoming more and more important in wireless communications.

In general, beamforming can be classified in different ways. Depending on the array geometry, we can have one-dimensional (linear), two-dimensional (planar) and three-dimensional (volumetric) beamformers. Depending on the format of signal processing, we can have either analogue beamforming or digital beamforming. With the advancement of digital technology, analogue techniques seem to be out of date these days. However, when a large number of sensors working at high frequencies with a wide bandwidth, the extremely high cost associated with the large number of high-speed analogue to digital converters (ADCs) and the high-level power consumption will render a completely digital solution practically infeasible and a hybrid beamforming structure is preferred in this case. Depending on whether the beamforming process is determined by the received specific signals or not, we have either a data-independent/fixed beamformer or a data-dependent/adaptive beamformer [1], [3], [8]. A widely used example for the fixed case is the delay-and-sum beamformer, while the Capon beamformer and the Frost beamformer/generalized sidelobe canceller are well-known for the second case [3], [4].

Depending on the relative bandwidth of the signals, we can have either a narrowband beamformer or a wideband/broadband beamformer. These two classes of beamformers have different signal models and implementation structures. For the narrowband case, only one coefficient is attached to each sensor; as a result, for the receiving mode, the beamformer output will be an instantaneous linear combination of the received sensor signals. For the wideband case, a tapped delay-line (TDL) or sensor delay-line structure (SDL) is needed for effective beamforming [3]. Whether to adopt the narrowband structure or the wideband structure depends on the relative bandwidth of the signals. However, this is not simply a calculation of the ratio between the bandwidth of the signal and its center frequency and it is also related to the array aperture. A further insight is to look at the correlation between the signals received at the two opposite ends of the array [9]. If the correlation value is not high, then a simultaneous linear combination of the multiple sensor signals will not help much in enhancing the signal of interest and a wideband structure can then be employed to improve the performance. One example is adaptive beamforming for distributed unmanned aerial vehicles (UAVs), where each UAV carries a sensor array of its own (a subarray) and together they form a distributed array system. Although the signal is narrowband for each subarray, due to the distributed nature, the signals received by different subarrays are not correlated with each other any more; as a result, a wideband beamforming structure has to be employed for effective beamforming [10]. Another wideband beamforming example is speech enhancement with microphone arrays, which has become even more important in the era of artificial intelligence.

III. The Contest

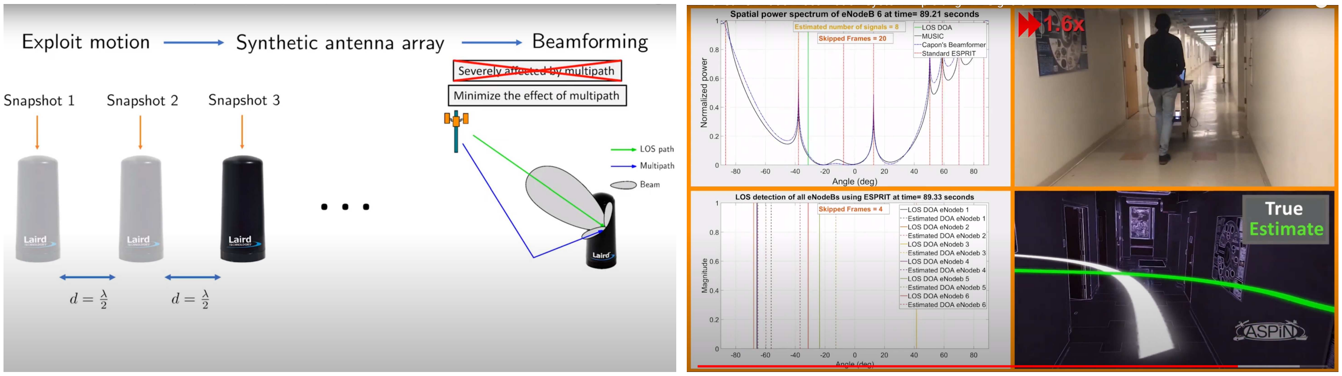
The title of the specific call for this year's 5-MICC was "Let There Be a Beam". The submitted video could cover any aspects of beamforming related areas. For example, it could be a general introduction to beamforming and how it works, one or more specific beamforming techniques, recent developments in beamforming and future directions, one or more specific applications of beamforming, various demonstrations of beamforming devices and systems, and so on. To engage the broad signal processing community to come up with creative ideas, "open topic" video submissions were also accepted, even if they were not related to beamforming.

The organizing committee consisted of four members, including Dr Wei Liu (University of Sheffield, UK), Dr Mohammad Reza Anbiyaei (Alzahra University, Iran), Dr Xue Jiang (Shanghai Jiao Tong University, China), and Dr Lei Zhang (University of Glasgow, UK). The contest received submissions from Australia, China, India and United States and after two stages of fierce competition, three finalists were left with two from the US and one from Australia. These three videos were placed online for public voting. Due to the outbreak of the Covid-19 pandemic, ICASSP2020 was transformed into a fully virtual conference. As a result, it was decided that the voting would open not just to the ICASSP participants, but also the general public. To reduce the possibility of getting the voting system abused, information about the name, affiliation and email address of each voter was required for the vote to be valid. The voting system was open from 22 April to 6 May 2020, bringing in about 5500 votes in total.

The final judging panel was composed of seven members, including the four organizing committee members, plus Dr. Lucio Marcenaro (University of Genova, Italy), Prof. K.V.S. Hari (Indian Institute of Science, Bangalore), and Prof. Nikolaos Sidiropoulos (University of Virginia, US). Taking also into consideration the public voting result, the panel made the decision for the final ranking of the three finalist teams as follows. The Grand Prize of US$5000 was awarded to the team from the University of California, Irvine, while the two runner-up prizes with an equal amount of US$2500 each (i.e. two equal second positions) were received by the two teams from the University of Texas at Austin and the University of Wollongong, respectively. The videos are available from the IEEE SPS YouTube channel (https://www.youtube.com/playlist?list=PLcZOnmyqlalaq96E2GyjWZKhdgjAXWp9x) or the IEEE SPS website (https://signalprocessingsociety.org/get-involved/five-minute-video-clip-contest).

A. Grand Prize: An Indoor Localization System Exploiting LTE Signals: A Synthetic Aperture-based Beamforming Approach to Mitigate Multipath

- *Affiliation*: University of California, Irvine, CA, USA.
- *Undergraduate Students*: Zainab Ashai, Xinyi Zhong, Qitai Meng
- *Tutor*: Ali A. Abdallah
- *Supervisor*: Prof. Zaher M. Kassas
- *Description*: This video presented an approach for indoor localization using long-term evolution (LTE) carrier phase measurements. In order to mitigate the non-LoS (NLoS) multi-path effect for localization of time-of-arrival (TOA) estimation based algorithms [11], a so-called synthetic aperture navigation (SAN) beamforming approach was presented [12]. The four steps of SAN are 1) estimate



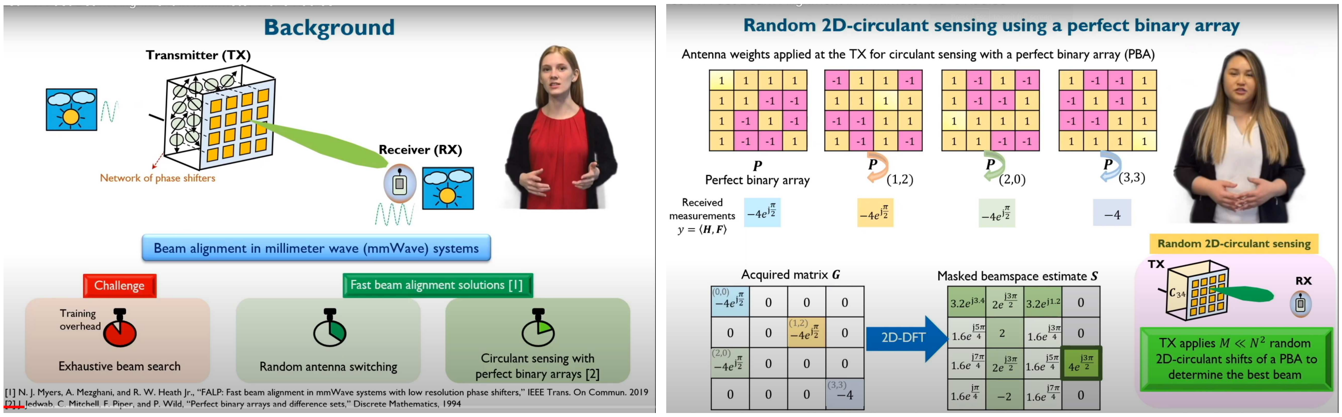
(a) Synthetic aperture based array for beamforming. (b) The experimental validation process of SAN.

Fig. 1. Two snapshots of the video for indoor localization exploiting LTE signals.

all LoS and NLoS paths in the received signals, 2) select the LoS among all identified paths, 3) beamform towards the direction of LoS while minimizing the NLoS effect, 4) process the received LoS signal and estimate the parameters of interest with the aid of the Kalman filter (EKF). The video used animations vividly showing the principle of synthetic aperture beamforming (Fig. 1(a)). More impressively, an experimental validation was carried out with step-by-step technical and visual presentations through four sub-videos, as shown in a snapshot in Fig. 1(b). National Instrument (NI) universal software radio peripheral (USRP)-2955 equipped with four consumer-grade cellular omnidirectional Laird antennas was used as the receiver mounted on a cart (top right) to listen to six LTE eNodeBs from three U.S. cellular providers. Signals were then sampled and transferred to a laptop for post-processing, where the real-time direction of arrival (DOA) estimation results were shown in the left half of the video of the snapshot. At the bottom right, the ground truth was provided, and overall the proposed LTE-SAN framework outperformed the LTE standalone solution with a position RMSE of 3.93 m versus 7.19 m.

B. Runner Up: Fast Beam Alignment in Millimeter Wave Radios

- *Affiliation*: The University of Texas at Austin, TX, USA
- *Undergraduate Students*: Juliet M. Leger, Frida K. Maldonado, Kayla N. Tran
- *Tutor*: Nitin J. Myers
- *Supervisor*: Prof. Robert W. Heath Jr.
- *Description*: The video explained the concept of beamforming of mmWave radios used in 5G and IEEE 802.11ad/ay devices and pointed out that the conventional exhaustive search over the 2D discrete Fourier transform (DFT) codebook would result in a substantial training overhead [7]. In order to implement fast beam alignment in mmWave radios (Fig. 2(a)), the team proposed the compressive beam alignment method by utilizing the sparsity of the beamspace matrix. In this way, the best



(a) Background of the beam alignment problem.

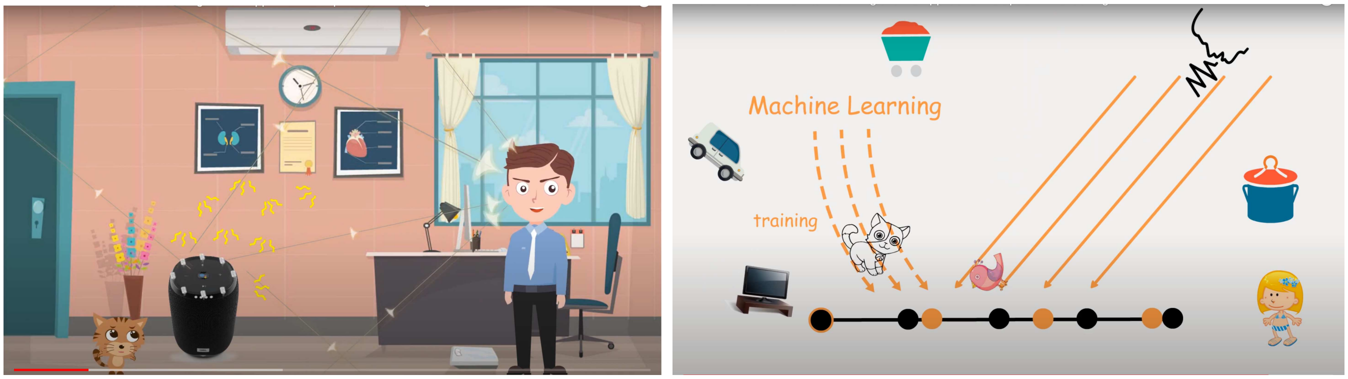
(b) Random 2D-circulant sensing using a perfect binary array.

Fig. 2. Two snapshots of the video for fast beam alignment in mmWave radios.

beam can be estimated by random antenna switchings with much lower overhead than that of the exhaustive search. One-bit phased arrays are promising in terms of the hardware complexity, cost and power consumption for large-scale systems [13]. Therefore, by noticing that the antenna switching is equivalent to 2D-circulant sensing of a Dirac matrix, the team addressed the fast beam alignment issue with low-resolution phase shifters, i.e., random 2D-circulant sensing using a prefect binary array (Fig. 2(b)) [14]. The team utilized 100 LoS channels from the NYU simulator [15] to evaluate the effectiveness of the proposed algorithms. It was demonstrated that the overhead of the proposed random antenna switching and circulant sensing is only 7% and 3% of that of exhaustive search, respectively.

C. Runner Up: Co-Prime Beamforming and Its Applications to Speech Processing

- *Affiliation*: The University of Wollongong, Wollongong, Australia
- *Undergraduate Students*: Hualin Ren, Zishan Gao, Hantao Zeng
- *Tutor*: Jiahong Zhao
- *Supervisor*: Prof. Christian Ritz
- *Description*: This video introduced a new concept called co-prime beamforming and its applications in speech processing (Fig. 3(a)), in a coherent and easy to understand way. The co-prime array (CPA) was proposed in 2010 [16] (Fig. 3(b)), and has been a very active field of research in recent years. Two structures of the co-prime arrays were reviewed in this video, namely, co-prime circular microphone arrays (CPCMAs) and semi-co-prime microphone arrays (SCPMAs). The CPCMA is formed by interleaving two uniform circular sub-arrays with a shared reference microphone [17], while the SCPMA is the product of interleaving three uniform sub-arrays [18]. The signals received from sub-arrays are aggregated using a processor to generate the output of the whole beamformer.



(a) A speech processing context. (b) The co-prime array concept and application.

Fig. 3. Two snapshots of the video for co-prime array beamforming and its applications.

As an advantage, the SCPMA has lower side lobes than the CPCMA. In addition to beamforming, the DOA application of co-prime arrays using conventional steered response power-phase transform (SRP-PHAT) was also described in the video. In the SRP-PHAT method, the angle corresponding to the peak SRP value was calculated and used to estimate the DOA of the source signal. The estimation was then further improved using a histogram-based stochastic algorithm.

IV. Summary

As a new event launched by our IEEE Signal Processing Society, the 5-Minute Video Clip Contest has proved to be a success in terms of both public engagement and quality submissions, as can also be seen from the large number of public votes attracted by the three finalist videos. The only regret was that the participants and especially the finalist teams and the organizing committee and judging panel members could not meet in person at ICASSP2020 due to the outbreak of Covid-19. Moreover, there were some delays at different stages of the contest, which could be avoided with a better plan and understanding of the time required for preparing for the submission/voting platform and processing the submissions. Built on the success and experience of the 2020 5-MICC, we very much look forward to even more successful contests next year (SPS has decided that there will be two 5-MICC contests in 2021, one with ICASSP and one with ICIP).

V. Acknowledgments

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VI. AUTHORS

Wei Liu (w.liu@sheffield.ac.uk) received his BSc and LLB degrees from Peking University, China, in 1996 and 1997, respectively, MPhil from the University of Hong Kong in 2001, and PhD from the School of Electronics and Computer Science, University of Southampton, UK, in 2003. He then worked as a postdoc first at Southampton and later at Imperial College London. Since September 2005, he has been with the Department of Electronic and Electrical Engineering, University of Sheffield, UK, first as a Lecturer and then a Senior Lecturer. He has published more than 300 journal and conference papers and two research monographs in the area of signal processing, with a focus on sensor array signal processing and its various applications. He is a member of the IEEE Digital Signal Processing Technical Committee (Chair-designate from 2020) and the IEEE Sensor Array and Multichannel Signal Processing Technical Committee (Vice-Chair from 2019).

Mohammad Reza Anbiyaei (mr.anbiyaei@ieee.org) received the M.Sc. (Distinction) and Ph.D. degrees from the Electronic and Electrical Engineering department of the University of Sheffield in 2012 and 2018, respectively. He was a Research Associate with the same department from April 2018 until March 2019. He is currently a Postdoctoral Research Fellow with the Faculty of Engineering, Alzahra University, Tehran, Iran. His current research interests include anomaly detection of communication systems using machine learning and AI, software defined radio, reconfigurable concurrent multiband transceivers and array signal processing. He is a member of the IEEE.

Xue Jiang (xuejiang@sjtu.edu.cn) received the Ph.D. degree from McMaster University, Canada, in 2014. She held the Postdoctoral Fellow position with McMaster University, in 2014-2015, and Arizona State University, Tempe, USA, in 2015-2016. She is an associate professor in the School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China. Her research interests include array processing, robust beamforming, target recognition, image processing, data science and numerical optimization, with applications to radar, sonar, and remote sensing. She was one of the finalists of the Best Student Paper Award of the 2013 IEEE Radar Conference. She is a Senior Member of the IEEE and is the secretary of the IEEE SPS Shanghai Chapter. She is an associate editor for IEEE Transactions on Signal Processing and serves as the Editorial Board Member of IET Radar, Sonar & Navigation.

Lei Zhang (Lei.Zhang@Glasgow.ac.uk) received the Ph.D. degree from the University of Sheffield, U.K. He is currently a Lecturer at the University of Glasgow, U.K. His research interests include wireless communications and networks, blockchain, radio access network slicing (RAN slicing), the Internet of Things (IoT), multi-antenna signal processing, and MIMO systems. He has 19 patents granted/filed in 30+ countries/regions including US/UK/EU/China/Japan/Singapore on wireless communications and published two books, and more than 100 peer-reviewed papers and book chapters. Dr Zhang received the IEEE Communication Society TAOS Best Paper Award in 2019. He is the Technical Program Chair of 5th UK-China Emerging Technologies (UCET) in 2020. Dr Zhang is an Associate Editor of the IEEE Internet of Things Journal, the IEEE Wireless Communications Letters, and IEEE ACCESS.

Lucio Marcenaro (lucio.marcenaro@unige.it) received his degree in electronic engineering and his Ph.D. degree in computer science and electronic engineering from the University of Genova, Italy, in 1999 and 2003, respectively. He is an assistant professor in the Department of Electrical, Electronics and Telecommunication Engineering and Naval Architecture, University of Genoa, Italy. He chairs the Student Service Committee of the IEEE Signal Processing Society. He is a Member of the IEEE.

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