Dogancan Temel and Ghassan AlRegib

Traffic Signs in the Wild

Highlights from the IEEE Video and Image Processing Cup 2017 Student Competition

As we witness the fourth industrial revolution, several aspects of our daily lives will soon be impacted beyond recognition. The list includes health care, education, security, transportation, warfare, and entertainment. Transportation, in particular, is undergoing a set of disruptive technologies including electrical vehicles (EVs) and autonomous vehicles (AVs). Although AVs have witnessed a revolution in many aspects over the past 20 years, deploying AVs in the wild remains to be a challenge. One of the basic features of AVs is to understand the surroundings and interpret sensed data. This requires the deployment of recognition algorithms that are expected to operate under all conditions. One of the most researched recognition applications in the literature is traffic sign recognition (TSR). Nevertheless, testing TSR algorithms under challenging conditions has been lagging for a number of reasons. One major factor is the limitation of existing data sets in terms of challenging conditions and metadata. To address such shortcomings, the Challenging Unreal and Real Environments for Traffic Sign Detection (CURE-TSD) data set was recently introduced [1], which was also utilized for TSR in [2].

The CURE-TSD data set was used to host the first edition of the Video and Image Processing (VIP) Cup in 2017 denoted as *Traffic Sign Detection Under Challenging Conditions*. The VIP Cup is a student competition in which undergraduate students form teams to work on real-life challenges. Each team should include one faculty member as an advisor, at most one graduate student as a mentor, and at least three but no more than ten undergraduate students. Formed teams participate in an open competition, and the top three teams are selected to present their work at the final competition, which was held at the 2017 IEEE International Conference on Image Processing (ICIP) in Beijing, China. Travel costs of finalist teams were supported by the IEEE Signal Processing Society (SPS). See "Winners of the VIP Cup 2017" for details.

In this article, we share an overview of the VIP Cup experience including competition setup, teams, technical approaches, statistics, and competition experience through finalist teams members' and organizers' eyes.

TSR under challenging conditions

Traffic signs can be recognized by state-of-the-art algorithms with high precision and accuracy in existing data sets, which are limited in terms of challenging conditions and corresponding metadata. The limited nature of these test sets makes it difficult to estimate the performance of recognition algorithms in nonideal real-world scenarios. Recent studies [3], [4] showed that adversarial perturbations can degrade the performance of existing TSR systems under specific conditions. Even though these studies shed a light on conditions that are intentionally designed to fool existing systems, introduced nonidealities are inherently different from realistic challenging conditions. To perform practical robustness tests for traffic sign detection and recognition systems, we need to test them with realistic mild-to-severe challenges, which is the main objective of the VIP Cup 2017. The challenges in the VIP Cup include multiple levels of rain, snow, haze, brightness, darkness, shadow, blur, decolorization, codec error, dirty lens, and noise; examples are depicted in Figure 1.

VIP Cup 2017 statistics

VIP Cup 2017 started with a global engagement of more than 250 requests from 147 parties to access competition data from all around the world, as shown in Figure 2. At the starting line, the highest engagement was received from Bangladesh, India, China, and the United States. At the registration stage, there were 80 members clustered into 19 teams from ten countries including Australia, Bangladesh (two teams), China (seven teams), Hong Kong (two teams), India, Malta, Pakistan, Sweden, Taiwan, and the United States (two teams). Out of these 19 teams, six teams with a total of 32 members, from Australia, Bangladesh (two teams), China, Hong Kong, Sweden, and Taiwan, made it to the final stage.

FIGURE 1. Examples of challenging conditions in a scene from the 2017 VIP Cup: (a) darkness, (b) brightness, (c) snow, (d) haze, (e) rain, (f) dirty lens, (g) noise, (h) decolorization, and (i) blur.

Tasks in the VIP Cup 2017

VIP Cup 2017 included an open competition stage and a final stage. The call for competition was announced on 15 February 2017, and the open competition started by making data publicly available on 15 March 2017. The video data set was released in the open competition stage, which included processed versions of captured and synthesized traffic videos with challenging conditions spanning a wide range from mild to severe. The competition data set was split into 70% training set and 30% test set. Specifically, 3,978 sequences were provided for model development and 1,755 sequences for final testing. There were 300 frames in each video sequence.

Traffic signs within the video sequences included *bicycle, goods vehicles, hump, no entry, no left, no overtaking, no parking, no right, no stopping, parking, priority to, speed limit, stop,* and *yield.* The participants were asked to develop algorithms that can detect these traffic signs under challenging conditions in the test set, which cannot be used in the model development. Participants were allowed to use MATLAB as a coding platform and Python and C++ as coding languages along with any library or toolboxes. Competition rules (which were set to have a fair competition ground, guarantee reproducible research, and obtain practical algorithms) were as follows.

- Any algorithm that utilizes future frames for prediction will be disqualified.
- Any algorithm that utilizes testing labels in the final evaluation will be disqualified.
- Any algorithm that utilizes testing sequences or labels in the training including model training and validation will be disqualified.
- The submissions should include detailed instructions and necessary codes to replicate the results. Otherwise, the participants can be disqualified.
- Reproducing results including training, testing, or any other processes should not exceed a reasonable

First Place: Team Neurons

- Affiliation: Bangladesh University of Engineering and Technology
- Undergraduate students: Uday Kamal, Sowmitra Das, and Abid Abrar
- Supervisor: Md. Kamrul Hassan
- Technical approach: Team Neurons (Figure S1) developed a data-driven system based on convolutional neural networks (CNNs) similar to an existing approach [5] to identify the type of challenging conditions in a scene. Based on the identified challenging condition, they performed a preprocessing operation over video frames to eliminate the effect of challenging conditions and enhance traffic sign visibility. After the preprocessing stage, they trained separate CNNs to localize and recognize traffic signs. In their algorithm development, they used the Keras API with Tensoflow back-end on NVIDIA GeForce GTX 1050 graphics processing unit.

First Runner Up: Team PolyUTS

- Affiliations: The Hong Kong Polytechnic University, the University of Technology Sydney, and the University of New South Wales
- Undergraduate students: Weixi Feng, Aung Min, Jiawei Zhang, Chenhang He, Hardy Zhu, and Wenqi Jia
- Supervisor: Xiangjian He
- Technical approach: Team PolyUTS (Figure S2) utilized two CNNs trained with the competition data set; one is for possible region proposal, and the other is for classification. A region proposal network was based on extracting image

(a)

(b)

(c)

(d)

FIGURE S1. Team Neurons took first place and pose with (a) then IEEE SPS President Dr. Rabab Ward, IEEE Student Services Director Dr. Patrizio Campisi, and VIP Cup 2017 Organizer Dr. Ghassan AlRegib; (b) with judge Dr. Béatrice Pesquet-Popescu; and (c) with judge Dr. Amy R. Reibman. (d) A behind-the-scenes look is captured.

features with a pretrained CNN [6] and regressing these features. To reduce the time consumed during the region proposal procedure, they forward-propagated all possible bounding box coordinates once and used the second CNN architecture to classify proposed regions. In their algorithm development, they utilized Tensorflow and OpenCV on NVIDIA GTX 1080 graphics proceessing unit.

Second Runner Up: Team Markovians
- Affiliation: Bangladesh University of Engineering and Technology
- Undergraduate students: Ahmed Maksud, Jubaer Hossain, Kinjol Barua, Roknuzzaman Rokon, Muhammad Suhail Najeeb, Nahian Ibn Hasan, Shahruk Hossain, Shakib Zaman, and SM Raiyan Chowdhury

- Graduate mentor: Sayeed Shafayet Chowdhury
- Supervisor: Mohammad Ariful Haque
- Technical approach: Team Markovians (Figure S3) trained a recurrent CNN [7] to identify challenging conditions in a scene and detected traffic signs with a faster region-based CNN architecture. They used a Kalman-based approach to track signs with static challenging conditions including dirty lens and shadow whereas they used a Lucas–Kanade-based approach for all other challenge types. They used a CNN architecture to recognize detected and tracked signs. In their algorithm development, they used Keras API with Tensorflow back-end and OpenCV.
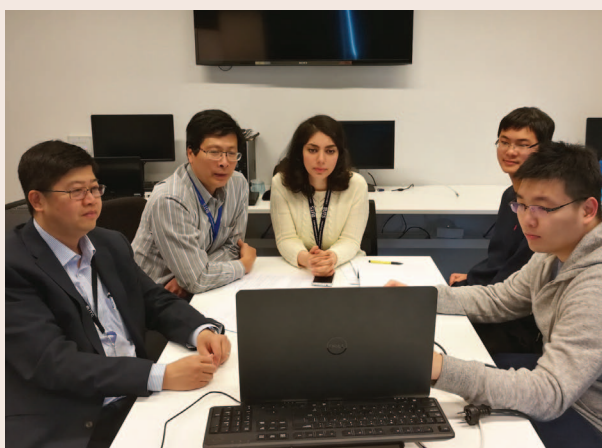
(*continued*)

(a)

(b)

(c)

(d)

FIGURE S2. First runner-up team PolyUTS with (a) then IEEE SPS President Dr. Rabab Ward, IEEE Student Services Director Dr. Patrizio Campisi, and VIP Cup 2017 Organizer Dr. Ghassan AlRegib. (b) The VIP Cup 2017 final. (c) and (d) A behind-the-scenes look.
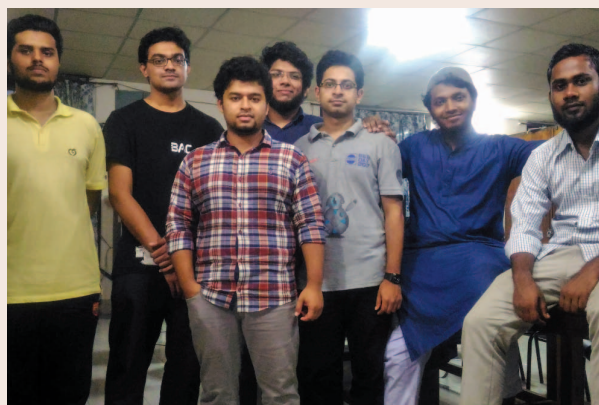
FIGURE S3. Second runner-up team Markovians with (a) then IEEE SPS President Dr. Rabab Ward, IEEE Student Services Director Dr. Patrizio Campisi, and VIP Cup 2017 Organizer Dr. Ghassan AlRegib. A behind-the-scenes look at the competition is shown in (b)–(d).

amount of time that allows the organizers to evaluate all submissions within the given time window.

The open competition stage was completed on 8 July 2017, which was the deadline to receive team submissions that included

- a report in the form of an IEEE conference paper up to six pages, on the technical details of the methods used, programs developed, and results
- estimated detection files for each test sequence
- all codes with detailed comments and README files.

The VIP Cup 2017 organizers evaluated the submissions and announced the three finalist teams: Neurons, PolyUTS,

and Markovians on 15 August 2017. Evaluation was based on the overall precision, recall, and combination of these metrics. Finalist teams were invited to the final competition at the 2017 ICIP, which was held 17–20 September 2017. Finalist teams presented their work on Sunday, 17 September. Each team had 15 min for its presentation and 5 min for questions and answers. After team presentations, the jury had an internal discussion to finalize the ranking. In the opening ceremony of the conference on 18 September, Dr. Rabab Ward, SPS's then president, highlighted the first VIP Cup and publicly announced the winners of the competition. The jury included Dr. Amy R. Reibman, Dr. Béatrice

Pesquet-Popescu, Dr. Patrizio Campisi, and Dr. Ghassan AlRegib.

Highlights of technical approaches

All of the finalist algorithms are based on state-of-the-art data-driven methods. Specifically, baseline methods used by finalist algorithms rely on convolutional neural networks (CNNs) that directly learn visual representations from examples with labels in a supervised fashion. In the VIP Cup, CNNs were utilized for various tasks including challenge type classification, preprocessing, localization, and recognition. The contribution of finalist algorithms to the literature can be considered as fourfold. First, challenging conditions in video sequences
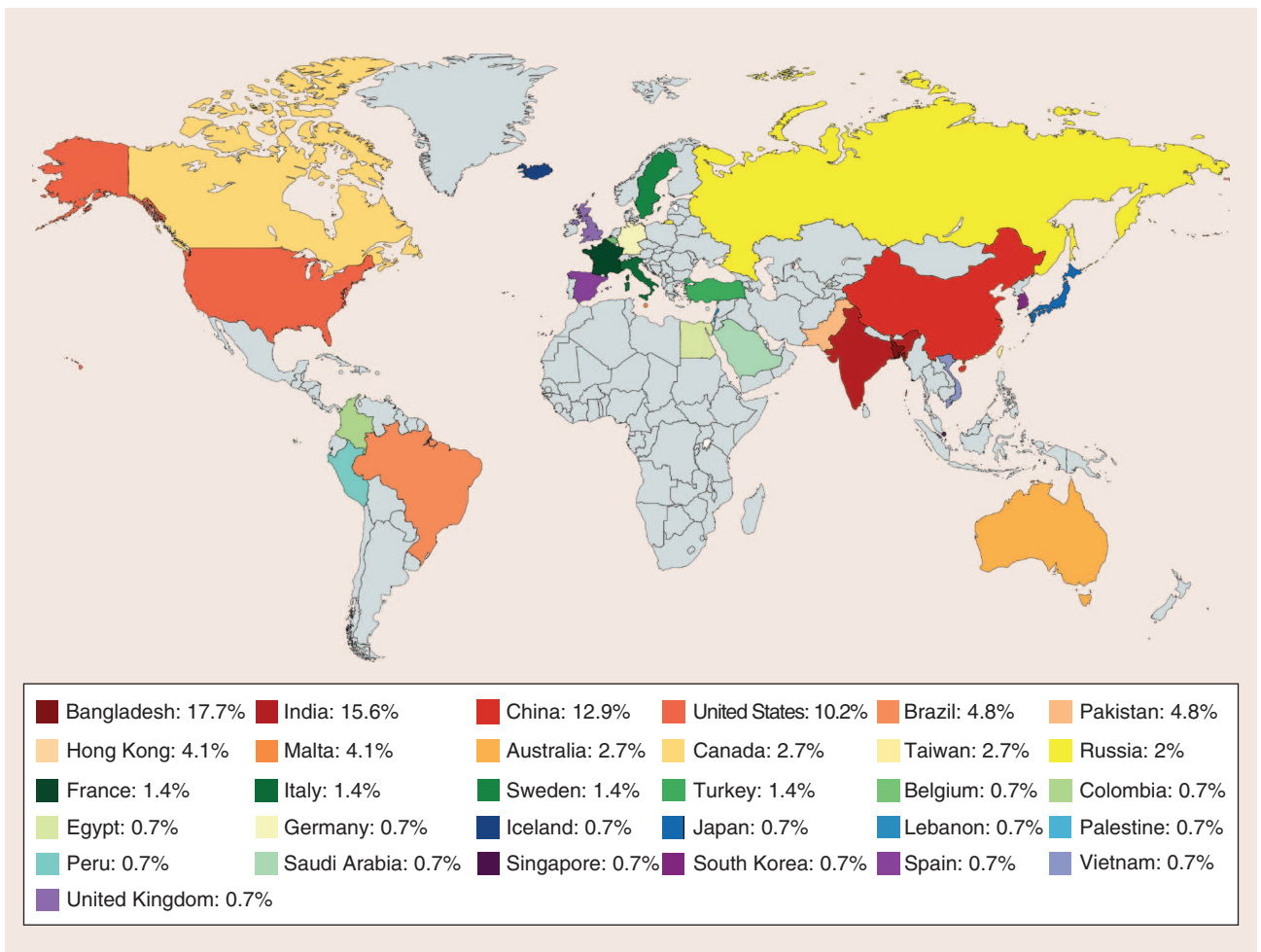
FIGURE 2. A global engagement map of the VIP Cup 2017.

were identified by teams Markovians and Neurons. Second, video sequences were processed with challenge-specific operations to enhance traffic sign visibility. Third, team Markovians tracked signs through temporal information, which is overlooked by majority of the state-of-the-art architectures in the literature. Fourth, a challenge-aware tracking mechanism was used by team Markovians, which alternated a tracking mechanism based on the dominant challenging condition in video sequences. The best-performing method achieved a precision of 0.550 and a recall of 0.320 in the overall test set, which is an indicator of the competition difficulty and a sign of room for improvement. To achieve top performance, finalist teams used open-source deep-learning libraries that were commonly supported with graphics processing units.

Participants' opinions

The VIP Cup 2017 created an opportunity for students to work on a real-world problem related to disruptive autonomous vehicle technologies. Even though participants had limited experience, time, and resources, they delivered promising algorithms, had successful presentations, and, most importantly, showed unceasing dedication during the competition. Bangladesh University of Engineering and Technology has had a finalist team or honorable mention in every SP Cup organized since 2014. Impressively, but not surprisingly, two of the finalists were from the Bangladesh University of Engineering and Technology. In this section, we share the inspirational stories and opinions of finalist teams about the 2017 VIP Cup experience.

Team Neurons

Team Neurons was formed by third-year undergraduate students in the Department of Electrical and Electronic Engineering at Bangladesh University of Engineering and Technology. Their team supervisor, Prof. Md. Kamrul Hasan, was also the supervisor of a team finalist in the first SP Cup in 2014, which is a great example of success when mentorship is combined with dedicated students. Team Neurons' experience can best be described through their own words as follows:

■ "It was quite exciting when we heard the news of the IEEE VIP Cup being organized this year. We decided to participate, as we thought that it would be an excellent opportunity to test our new skill set and gain some valuable experience doing real-world research… We had quite a lot of

hardware limitations… Nevertheless, we went on with our simulations in spite of the difficulties. Before our Ramadan vacation started, we got access to a PC with a decent CPU and GPU configuration… After that, there was no holding us back. We worked round the clock, often 15–16 hours a day, for three whole weeks. A few days before submission, we decided to add another network to our pipeline, as some of the test results were not satisfactory. It was a hectic time. Even after submission, the battle wasn't over. We spent hours on end, in the middle of the night, exchanging e-mails with our reviewer and providing clarifications for different parts of our submission package. We had to do all of this in the midst of our term final, handling a lot of academic pressure at the same time. So, it was a great feeling of triumph, when we were selected as one of the finalists and, finally, the champions of the IEEE VIP Cup 2017—a feat none of us thought we could achieve when we started off in this journey. It was one of the happiest moments of our lives."

—Team Neurons

■ "The first edition of the IEEE VIP CUP was full of 'first-ever' experiences for me—first-ever participation in any global competition, first-ever research project, first-ever international conference, and so on. Participating in this competition helped me to learn a lot not only about video and image processing, but also about machine learning. The challenge itself was very complex. To process this huge amount of given data set was also a tremendous challenge for us. But above all, it was definitely a very exciting and rewarding experience!"

—Uday Kamal

■ "Participating in the VIP Cup was a very enriching experience. I learned about cutting-edge image processing and machine-learning techniques like neural networks; I learned how to read research papers and write one, give a technical presentation, collaborate with fellow team members,

and, stay focused and motivated even in adverse situations, all of which are extremely valuable for doing any kind of research work. Besides, this is the first time I attended an international conference, where I met researchers and industry representatives leading the field of image processing. But, most of all, I got the opportunity to represent my country at a global stage and compete on par with students from around the world. This really gives you a sense of confidence that, if you are willing to put in the effort, all of us could achieve things we wouldn't even dare to think of."

—Sowmitra Das

■ "It was really a unique experience for me. ICIP 2017 was the first international conference that I've joined, and VIP Cup 2017 was the first international competition I've participated in my undergraduate life. I've also learned a lot of new things throughout this journey."

—Abid Abrar

■ "The problem was interesting and quite challenging at least for the students of undergraduate level. I was hesitating in the beginning because of the team members level in the UG program….limited hardware resources in the lab for machine learning….but the team relieved me within a few weeks. It was enjoyable to see the spirit of the team."

—Kamrul Hasan, faculty mentor.

Team PolyUTS

Team PolyUTS is an international project team formed by junior and senior undergraduate students from the Hong Kong Polytechnic University, the University of Technology Sydney, and the University of New South Wales. Team members expressed their opinions about the VIP Cup experience as follows.

■ "The collaboration between us broke the limitation of time and geology. It was through different social platforms that we consistently communicated with each other. Finally, we

were truly delighted that our teamwork was such a great success."

—Team PolyUTS

■ "This competition taught me not just a lot of technical related stuff but also let me experience in how these competitions are conducted. That experience is something I will not forget and remember for the rest of my life."

—Aung Min

■ "Detecting traffic signs in the given conditions is really a tough task. Although I had learned something about object detection before, I found it was still hard to solve the problem at the beginning. The competition taught me that standing on the shoulders of giants was always a good starting point. By testing and evaluating algorithms proposed in others papers, I gradually knew which methods work for this task. Investigating why and how they work finally instructed me what I should do. I think knowing how to overcome such a difficult problem is the most valuable reward for me. I do appreciate the opportunity provided by the match."

—Jiawei Zhang

■ "Participating in VIP Cup 2017 was a great experience for me to learn more about machine learning and how it is implemented. Although it was a really challenging task, we still managed to complete a whole system. There were lots of struggles and confusion during the process, but overcoming them was also delightful. I'm very happy to spend my summer time on this competition."

—Weixi Feng

Team Markovians

Team Markovians was formed by junior undergraduate students from Bangladesh University of Engineering and Technology. A common interest in video and image processing as well as automation formed strong bonds between team members. As electrical engineering students and technology enthusiasts, team members were thrilled to contribute

toward the research and development of a traffic sign detection system, which might be able to aid autonomous vehicles. Team Markovians briefly expressed their opinions about their VIP Cup experience as follows:

■ *"Although we had no prior expertise in the field, we did not stop short. We started out from zero and constantly found ourselves at an impasse. However, the support from our supervisor and mentor and the relentless efforts from all the team members was animating. We spent countless hours, group sessions in weekends, through holidays, and even before exams for the project. The huge amount of data we needed to process required powerful hardware which wasn't available to us. However, our perseverance allowed us to proceed with what we had and, at the end, we came up with a working solution."*

—Team Markovians

Organizers' opinions

It has been very inspiring to meet the team members in person and hear their stories. Their experience demonstrated that, with dedication, one can compete at the global level despite hardship, lack of resources, and limited support. In addition, this experience showed the importance of mentorship exerted here by professors who lead these undergraduate teams to excel. The dedication of competing teams motivated the organizers to work tirelessly throughout the competition.

Upcoming VIP Cup

The second edition of the VIP Cup will be held at the 2018 ICIP in Athens, Greece, 7–10 October 2018. Visit https://signalprocessingsociety.org/get-involved/video-image-processing-cup for more information.

In addition to the VIP Cup, the SPS announced the fifth edition of the SP Cup. The final competition will be held at the IEEE International Conference on Acoustics, Speech, and Signal Processing 2018 in Calgary, Alberta, Canada,

15–20 April 2018. The theme of the competition is "Forensic Camera Model Identification." For details, visit https://signalprocessingsociety.org/get-involved/signal-processing-cup.

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Authors

Dogancan Temel (cantemel@gatech.edu) received his B.S. degree in electrical and electronics engineering from the Middle East Technical University, Ankara, Turkey, in 2011. He received his M.S. and Ph.D. degrees in electrical and computer engineering from the Georgia Institute of Technology (Georgia Tech) in 2013 and 2016, respectively, where he is currently a postdoctoral fellow. He was the recipient of the Best Doctoral Dissertation Award from the Sigma Xi honor society, the Graduate Research Assistant Excellence Award from the School of Electrical and Computer Engineering, and the Outstanding Research Award from the Center for Signal and Information Processing at Georgia Tech.

Ghassan AlRegib (alregib@gatech.edu) received his B.S. degree in electrical engineering from King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, in 1997 and his Ph.D. degree in electrical and computer engineering from the Georgia Institute of Technology (Georgia Tech) in 2003, where he is a professor in the School of

Electrical and Computer Engineering. In 2012, he was named the director of Georgia Tech's Center for Energy and Geo Processing. He is a faculty member in the Center for Signal and Information Processing. He served as area editor of *IEEE Signal Processing Magazine* (2007–2009), technical program (TP) cochair for IEEE GlobalSIP 2014, special sessions chair for the IEEE International Conference on Image Processing (ICIP) in 2006, tutorial chair for ICIP 2009 and ICIP 2016, and TP chair for ICIP 2020. He is a member of the IEEE Image, Video, and Multidimensional Signal Processing Workshop and the IEEE International Workshop on Multimedia Signal Processing Technical Committees (2015–2020). He was awarded the Electrical and Computer Engineering Outstanding Junior Faculty Member Award in 2008 and the Steven A. Denning Faculty Award for Global Engagement in 2017. He was the organizer and host of the first IEEE Signal Processing Society Video and Image Processing Cup competition in 2017. He is a Senior Member of the IEEE.

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