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2019 IEEE GRSS Data Fusion Contest: Large-Scale Semantic 3D Reconstruction

For more than a decade, the Image Analysis and Data Fusion Technical Committee (IADF TC) of the IEEE Geoscience and Remote Sensing Society (GRSS) has been organizing the Data Fusion Contest (DFC). Through a series of scientific challenges, participants must solve remote sensing problems using multimodal data, leveraging new sensors and big data, and applying emerging methods to extract geospatial information [1]–[13].

THE 2019 DFC

The 2019 GRSS DFC aimed to take a step toward solving the task of scene understanding from the sky. In particular, it addressed 3D modeling and automated cartography, tools that can feed 3D geospatial information systems and open the path for new levels of analysis, with applications for smart cities, environment monitoring, and disaster response. To encompass the complexity of the problem, different and complementary data were distributed in the community. They included multiview, multiband satellite images; airborne lidar data; and semantic geospatial information about roads, bridges, buildings, trees, and water. Several specific tasks were defined: 3D reconstruction and stereo, semantic mapping in 2D, and semantic labeling of 3D point clouds. One of the overall goals was to sort out how a given task can be approached best, given various inputs, and how different tasks can contribute to each other and result in a precise model.

The contest made use of Urban Semantic 3D data, a large-scale public data set (Figure 1) [15]. More than 320 GB of data have been released for training and evaluation, covering approximately 20 km^2 over the urban areas of Jacksonville, Florida, and Omaha, Nebraska. Precisely, it comprised the following.

- *Multidate satellite images*: WorldView-3 panchromatic and eight-band visible and near-infrared images were provided (courtesy of DigitalGlobe), with ground-sampling distances of 35 cm and 1.3 m, respectively.

Digital Object Identifier 10.1109/MGRS.2019.2949679
Date of current version: 18 December 2019

FIGURE 1. A bird's-eye view of the DFC 2019 data displaying color composites and semantic labels for (a) Jacksonville, Florida, and (b) Omaha, Nebraska.

- *Airborne lidar data*: These are made publicly available by the U.S. Homeland Security Infrastructure Program. They were provided as point clouds or digital surface models (DSMs), with an aggregate nominal pulse spacing of approximately 80 cm.
- *Semantic labels*: These labels (buildings, elevated roads and bridges, high vegetation, ground, and water) were given for each geographic tile, as either semantic maps or point labels for point clouds.

The 2019 DFC had four parallel and independent tracks, each addressing different tasks:

- *Track 1*: In the single-view semantic 3D challenge, the objective was to predict semantic labels and normalized DSM above-ground heights from a single image.
- *Track 2*: The pairwise semantic stereo challenge aimed at predicting semantic labels and stereo disparities using a pair of epipolar rectified images as input.
- *Track 3*: In the multiview semantic stereo challenge, the goal was to predict semantic labels and a DSM, given multiple images for each geographic tile.
- *Track 4*: The last challenge dealt with 3D point-cloud classification and required predicting labels for each input point.

Performances for tracks 1–3 were assessed using the pixel-wise mean intersection over union (mIoU), for which true positives must have both the correct semantic label and a height error less than a given threshold of 1 m. We call this metric *mIoU-3*. Track 4 was evaluated using standard mIoU. For all tracks, baseline approaches were made available as open-source code, thus providing participants a workable solution to start with.

The actual competition was divided into three phases. First, on 7 January 2019, the training data (with reference labels) and evaluation data (without reference) were released using various channels, including torrents. One month later, on 7 February 2019, the evaluation services, hosted on the CodaLab platform [16], were opened. Thus, participants were able to evaluate their approach against an undisclosed reference and rank themselves with respect to other teams on a public leaderboard. On 7 March 2019, the test data (still without reference) were made public, and the test phase was opened on the evaluation server. This phase lasted only 15 days, with a limited number of possible attempts to avoid overfitting on the test data.

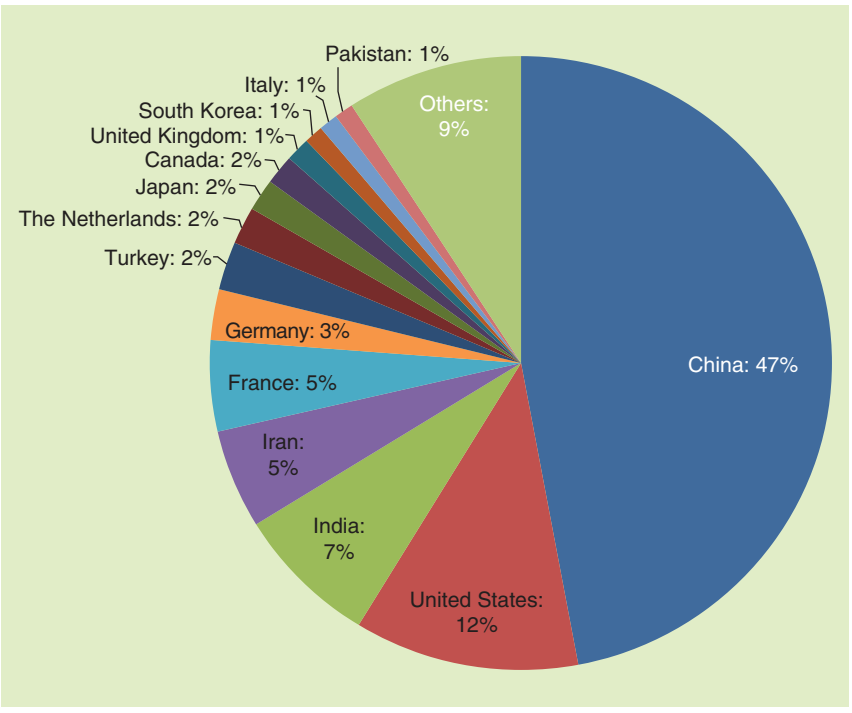

FIGURE 2. The 2019 GRSS DFC participants by country.

CONTEST OUTCOME

Teams with various backgrounds (universities, national laboratories, space agencies, and companies) from 45 countries participated (Figure 2). There is an increasing globalization of the DFC, with participants from more diverse countries than usual. Over 710 teams registered for accessing and

downloading the data, and more than 430 participants registered on CodaLab to compete. In the end, over 1,280 results were submitted during the test phase over all tracks.

Seven teams were recognized with awards at the 2019 IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2019) in Tokyo, Japan, based on the excellent results they obtained. The winning teams were as follows:

- *First place for track 1*: Saket Kunwar from NestAI (Nepal), with an mIoU-3 of 0.5571
- *Second place for track 1*: Zhuo Zheng, Yanfei Zhong, and Junjue Wang from Wuhan University, China, with an mIoU-3 of 0.534
- *First place for track 2*: Hongyu Chen, Manhui Lin, Hongyan Zhang, Guangyi Yang, Guisong Xia, Xianwei Zheng, and Liangpei Zhang from Wuhan University, China, with an mIoU-3 of 0.7775
- *First place for track 3*: Pablo d'Angelo, Daniele Cerra, Seyed Majid Azimi, Nina Merkle, Jiaojiao Tian, Stefan Auer, Miguel Pato, Raquel de los Reyes, Xiangyu Zhuo, Ksenia Bittner, Thomas Krauss, and Peter Reinartz from the German Aerospace Center, Cologne, with an mIoU-3 of 0.7461
- *Second place for track 2 and second place for track 3*: Rongjun Qin, Xu Huang, Wei Liu, and Changlin Xiao from The Ohio State University, Columbus, with mIoU-3 values of 0.7724 and 0.7300, respectively
- *First place for track 4*: Lian Yanchao, Feng Tuo, and Zhou Jinliu from Xidian University, China, with an mIoU of 0.9455
- *Second place for track 4*: Jia Meixia, Wu Zhaoyang, and Li Aijin from Xidian University, China, with an mIoU of 0.9454.

At the end of the contest, all winning teams were asked to write a four-page paper describing their approach; these were reviewed by the awards committee, included in the IGARSS 2019 technical program, and presented during an oral invited session about the DFC during the symposium. Moreover, an awards ceremony took place during the TC and Chapter chairs dinner during the symposium. All of these teams were invited, thanks to the GRSS, and awarded an IEEE Certificate of Recognition for their winning participation (Figure 3). The four first-place winners of each track also received a graphics card (NVIDIA RTX 2070 Super), thanks to the support of the IGARSS 2019 Local Organizing Committee. Two extended articles will be written to discuss the successful approaches: the first will focus on height and DSM estimation, corresponding to tracks 1, 2, and 3, while the second will focus on 3D point-cloud classification, corresponding to track 4. These articles will be submitted for peer review to the open-access *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*.

As with previous editions, the 2019 DFC attracted a wide audience that extended beyond the remote sensing community. Therefore, it can be expected that new

Contest Data

The data of the 2019 GRSS Data Fusion Contest will remain available to the GRSS community for benchmarking algorithms and publishing research works. The data are usable free of charge for scientific purposes, but the contest terms and conditions on the contest website remain applicable (http://www.grss-ieee.org/community/technical-committees/data-fusion/2019-ieee-grss-data-fusion-contest/). Please read them carefully.

Join the GRSS IADF TC

You can contact the Image Analysis and Data Fusion Technical Committee (IADF TC) chairs at iadf_chairs@grss-ieee.org. If you are interested in joining the IADF TC, please complete the form on our website (http://www.grss-ieee.org/community/technical-committees/data-fusion/) or send an email to the chairs including your

- first and last name
- institution or company
- country
- IEEE membership number (if available)
- email address.

Members receive information regarding research and applications on image analysis and data fusion topics as well as updates concerning the annual Data Fusion Contest and all other IADF TC activities. Membership in the IADF TC is free! You may also join the LinkedIn IEEE GRSS Data Fusion Discussion Forum: http://www.linkedin.com/groups/IEEE-GRSS-Data-Fusion-Discussion-3678437.

FIGURE 3. The IGARSS 2019 award ceremony honored (front row, from left) Zhuo Zheng, Aijin Li, Meixia Jia, and Changlin Xiao; (second row, from left) Hongyu Chen, Rongjun Qin, and Tuo Feng; (third row, from left) Hongyan Zhang, Zhaoyang Wu, Yanchao Lian, and Saket Kunwar; and (fourth row, from left) Seyed Majid Azimi, and Pablo d'Angelo. In the back row (from left) are organizers Myron Brown, Gary O'Brien, Ronny Hänsch, Bertrand Le Saux, and Naoto Yokoya.

perspectives will be offered on topics of interest and that novel interdisciplinary methods and solutions will emerge. The educational trend of previous years also continued: half of the winning teams were student teams, who developed original approaches with imagination and tireless determination. This is a sign of the vitality of the field of Earth observation and remote sensing data processing. To further nurture this creativity and keep track of new developments, the data will remain freely available, and the evaluation servers are again open to new submissions (see "Contest Data"). See "Joining the GRSS IADF TC" for details about becoming a member.

ACKNOWLEDGMENTS

The 2019 Data Fusion Contest was organized in collaboration with the Applied Physics Laboratory (APL) at Johns Hopkins University (JHU). The IADF TC chairs would like to thank JHU/APL for providing the data and coorganizing the competitions and the IEEE GRSS for continuously supporting the annual DFC through funding and resources.

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