



Vol. XII &amp; Issue No. 6 June - 2019

INDUSTRIAL ENGINEERING JOURNAL

## UNMANNED AERIAL VEHICLE FOR ROAD MONITORING: FULLY CONVOLUTIONAL NETWORKS APPROACH

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### ABSTRACT:

Unmanned Aerial Vehicle (UAV) can be used to monitor road conditions, particularly road survey and inspection of distressed roads. UAVs can collect large amounts of datasets and ease of use made these devices popular in many applications. On the basis of the detailed literature survey, various methods and models of UAV for road monitoring were studied. Lack of consideration of all distresses and inadequate data is the major research limitations. In this paper, a model for the preparation of an extensive collection of data and the classification of this data using semantic segmentation is proposed. The proposed model would efficiently help with huge data collection and the model designed will classify the distresses for maintenance and construction purposes. The model can be modified with neural networks or deep learning algorithms for accuracy and various frameworks can be used for improving speed and training time.

**Keywords-** *Unmanned Aerial Vehicle (UAV), Potholes, Pavement distress, Fully Convolutional Networks (FCN), Semantic Segmentation.*

### 1. INTRODUCTION

Roads play a very crucial role in the socio-economic development of any country. Maintenance of infrastructures is expensive and time-consuming, lack of efficient inspection and maintenance leads to distressed roads. According to analysis almost 3,597 have been killed and 25,000 have been injured in India in 2017 owing to potholes alone which form a major category of road distress. The scope of maintenance can be explored and modified only if there are efficient provisions for inspection. In this research various methods for inspection are studied and a comparison of the same has been made. Traditional methods of inspection included extensive field survey and manual measurements of distressed roads. It also required huge labor and capital investment. With advancements in technology, many other methods have emerged. With proper analysis and data roads can be efficiently repaired or maintained.

Various 3D, 2D techniques can be used to determine the dimensions of the distresses and then classified as follows: laser technologies by Kang and Choi [1], remote sensing by Schnebele et al. [2], 3D imaging by Mathavan et al. [3]. In remote sensing technique, the sensors are attached to various objects such as a vehicle and the data collected is then sent to a centralized system where they are further processed. Dedicated robots were designed to measure and survey the land and give accurate dimensions on the basis of which the classification of distress is done by Tseng et al., [4]. The smartphones are mounted on a vehicle these phones capture the photographs and then these photos are sent for future experiments by Maeda et al. [5]. The images are directly captured using the satellite system, but setting and manufacturing a satellite is quite expensive and needs skilled engineers and consumes a lot of time concluded by Shin and Kim [6]. Video-based distressed pavement screening

was proposed by Yan & Yuan [7]. Instead of taking pictures a video of the pavement is filmed and then this video is broken down into a number of frames by image/video processing and further steps are taken. Recently UAV based imaging system for the 3D audit of rural roads has been presented by Mathavan et al. [3], Zhang and Elaksher [8]. In this paper, the method of inspection of distressed roads with the use of UAVs is proposed.

UAVs are already replacing satellites and other aerial systems. This is mainly due to the ease in building high speed wide data acquisition high safety collection of images small size wide area coverage compared to the field review controllability, manageability in abnormal conditions like snow storm rainfall, low cost maintenance, maneuverability to work in difficult surveying missions by Zakeri et al. [9]. UAVs are more efficient than the methods proposed above since it provides more detailed images of the area that it covers. With the help of UAVs better quality of pictures of the roads can be obtained at different intervals of a day without disturbing the local transportation.

This paper proposes the use of UAVs for road survey and inspection of distressed roads and classifying them into 9 categories. The workflow proposed here is the collection of a large amount of images of the different roads, at various intervals of time, in different lighting conditions. Transmitting these images to the centralized system where they are processed and segmented. After the segmentation, the matrix of these images is classified into different categories by using deep learning algorithms. These classified data can be made public and provisions can be made to make this data easily accessible to vehicle drivers thus warning them about potholes or cracks ahead and avoiding fatal accidents. There is no common dataset available for such research. All proposed methods are evaluated using own datasets. By using UAVs large amount of dataset can be collected and these data can be made public for testing of

various models on different data and accuracy can be evaluated of a particular model.

The rest of the paper is organized as follows. Next Section summarizes literature survey. Adopting FCN to perform semantic segmentation of pavement distress detection is proposed in Section 3. Section 4 gives the conclusion and future scope.

## 2. LITERATURE SURVEY

The research papers on 'Use of Drones for Traffic Management' and 'Pothole Detection' were identified. Keywords used for the search were UAVs, cracks, potholes, distressed, traffic. Peer-reviewed journal papers by renowned publishers like Springer, IEEE, Wiley, Taylor and Francis, etc. were studied in detail. After

extensive research and study, only 23 journal papers were shortlisted based on abstract, keywords and title. The problem faced during the survey was lack of research in this domain and subsequently, the lack of papers to study. Conference papers, white papers, thesis were not taken into consideration. The papers studied were very recent (2015-2018). Out of 23 papers shortlisted, only eight papers have been found to be relevant to the purpose of the study. Among these 12 papers 4 papers were on UAVs for Distressed Road inspection, 3 paper on 3D imaging, 1 paper on remote sensing, 1 paper on use of smartphone and vehicle for road distress, 1 paper on use of ABC-ANN for classification, 1 paper on MSVP (Multi-Purpose Survey Vehicle) and 1 paper on VPAD (Video-based Pavement Distress screening) were extensively studied and reviewed. The contribution of each of these papers has been tabulated in Table 1.

**Table 1: Selected literature papers**

| S.N. | Publications         | Journal   | Industry          | Country | Work Done  |
|------|----------------------|---|-------------------|---------|--|
| 1.   | Zakeri et al. [9]    | Archives of Computational Methods in Engineering                            | Computational     | Spain   | Comparison between different models has been made.   |
| 2.   | Schnebele et al. [2] | European Transport Research Review  | Transportation    | USA     | Various remote sensing techniques are compared and discussed.  |
| 3.   | Banharnsaku n [10]   | International Journal of Machine Learning and Cybernetics                   | Machine Learning  | Germany | ABC-ANN model is proposed and the entire working and accuracy is discussed.  |
| 4.   | Pan et al. [11]      | Journal of Selected Topics in Applied Earth Observations and Remote Sensing | Remote Sensing    | China   | The dataset is evaluated on the basis of three features texture, spectral and geometry also classifiers such as ANN(Artificial Neural Network),RF(Random Forest) and SVM(Support Vector Machine) and the accuracy and speed is compared and relevant models for each are proposed. |
| 5.   | Sultani et al. [12]  | Transactions on Intelligent Transportation Systems                          | Transportation    | USA     | Laser imaging system and superpixel method of segmentation have been discussed.  |
| 6.   | Mathavan et al. [3]  | Transactions on Intelligent Transportation Systems                          | Transportation    | UK      | Different approaches in 3D and 2D imaging have been extensively elaborated and experiments on the same are conducted.  |
| 7.   | Maeda et al. [5]     | Computer-Aided Civil and Infrastructure Engineering                         | Civil Engineering | Japan   | Road distress classification using smartphone images.  |

|     |                           |  |                  |          |  |
|-----|---------------------------|--|------------------|----------|--|
| 8.  | Yan & Yuan [7]            | Journal of Intelligent Transportation Systems            | Transportation   | Canada   | Low cost video inspection of road pavement is suggested. Instead of pictures the videos are processed here. And image processing methods are adopted for classification. |
| 9.  | Nasir N. H. M et al.[13]  | Advances in Transportation and Logistics Research        | Transportation   | Malaysia | A comparative study of various road conditions have been studied.  |
| 10. | Leonardi G et al.[14]     | International Symposium on New Metropolitan Perspectives | Transportation   | Italy    | 3-D mapping of various paved and unpaved roads have been studied.  |
| 11. | Li.Z et al. [15]          | ISPRS International Journal of Geo-Information           | Machine Learning | China    | LiDAR technology and machine learning algorithm like Random Forest and SVM have been used for asphalt detection.   |
| 12. | Inzerillo, L., et al.[16] | Automation in Construction                               | Construction     | Italy    | 3D reconstruction of images of obtained from UAVs have been carried out.   |

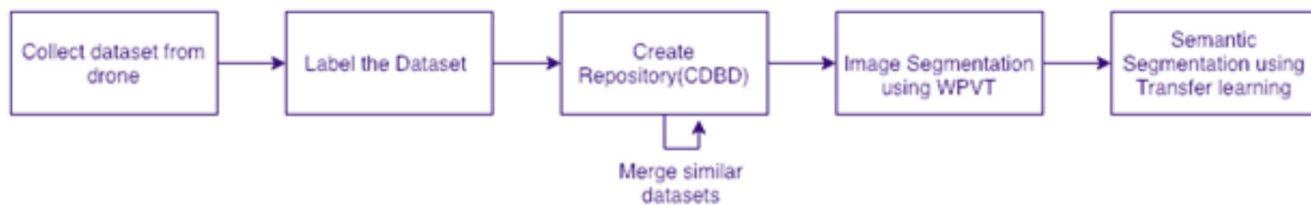
*Research gap*

- Almost all papers use their own datasets which are not comprehensive and do not include images at different times of a day or varying weather conditions.
- Although some public datasets now exist for pavement distress, none of them contain images captured by UAVs.
- In many papers, features have been manually selected based on the localized dataset and hence their model cannot be used for datasets from another region.

- Due to the absence of a unified dataset of reference, accuracy presented by these papers cannot be compared.
- Research article presents different ways in which the distress is classified and sometimes do not cover all possible distresses.
- A standard classification of distress covering all types is not available.

**3. PROPOSED MODEL**

Figure 1 shows the proposed model.



**Fig.1 Flowchart for proposed model [Source author]**

The hardware required for the experiment is Brushless Motors, ESC Speed Controller, Quadcopter Frame, Main controller, power distribution unit, LEDs, GPS module, Wi-Fi module, flight control, telemetry system, MCA camera, Multi-Rotor, and LCD for monitoring, transmitter, receiver for data transfer, radio controllers and relevant sensors.

The images must be collected by flying the drone at different times of day and in different regions. The regions that are

selected must have high variance in weather conditions so as to cover all types of pavement images. Maeda et al. [5] noticed that the accuracy is reduced in when certain categories have fewer than 1000 instances in the dataset hence the dataset needs to be expanded till at least 1000 instances of each distress type is found. The classification of distress used by Maeda et al. [5]. is quite thorough but leaves out a few types of distresses. Also, they put crosswalk blur and white-line blur into different

categories which can be generalized into one category for road marker blur. We propose dividing the distress into these 9 categories. Construction joint part, longitudinal crack, lateral crack, alligator crack, road marker blur, patch, bleeding, joint reflex crack, and pothole. If there are any other such datasets, collected by drones, which are publicly available they can be merged into one large Comprehensive Dataset for Pavement Distress (CDPD). In order for a merge to be possible the dataset should have classified distress into a subset or superset of the 9 categories listed above.

Since the UAV captures images from a great distance above the surface we get a lot of unnecessary objects in them like cars and trees. Such objects may increase computation of the Fully Convolutional Network (FCN) we are about to apply. To counter this problem image segmentation using thresholding is done before-hand to separate out the road from the rest of the image. This can be done using Weighted Peak-Valley Thresholding (WPVT) Method as proposed by Kanungo et al. [17]. Thresholding does not give 100% accuracy but is the fastest method of image segmentation. After segmentation is complete, the image is then used for the next step.

Features extracted from localized datasets may not apply to distress images from other regions. Hence manual feature selection proves to be inefficient for distress classification. Neural networks are capable of learning features of an image on their own; however, using a fully connected neural network is not feasible for high-resolution images because a corresponding weight is required for each individual pixel. Using such a large

number of parameters eventually leads to overfitting. Convolutional Neural Network (CNN) is a state of the art method for solving image classification problems. In CNN multiple filters are passed through the image and corresponding feature maps are obtained. After this, pooling is done to reduce the size of the matrix hence the overall computation is greatly reduced. Feature extraction is also done by convolution and pooling layers and thus must not be done separately. After this, the Rectified linear Unit (ReLU) function is applied element-wise which can be written as  $f(x)=\max(x,0)$ . It removes the negative values from the matrix which prevents the following convolutions from adding up to zero and further reduces computational complexity. Finally after reducing the size of the matrix sufficiently a fully connected layer carries out the task of classification. CNN has been successfully used for pothole detection with up to 99.8% accuracy by Pereira et al [18].

The problem with CNN is that as the last few layers are fully connected, the input size is fixed. We cannot use CNN for working with a CDPD that can contain images with varying resolution. To solve this problem we propose an FCN that performs semantic segmentation. FCN is a CNN without any fully connected layers. Semantic segmentation refers to the partitioning of an image into semantically meaningful parts and classifying each part into one of the predetermined classes. The model proposed is similar to the model presented by Badrinarayan et al (In Press) [19]. Transfer learning will be carried out to modify the pre-trained VGG16 model into an FCN based on encoder/decoder architecture similar to one shown in Figure 2.

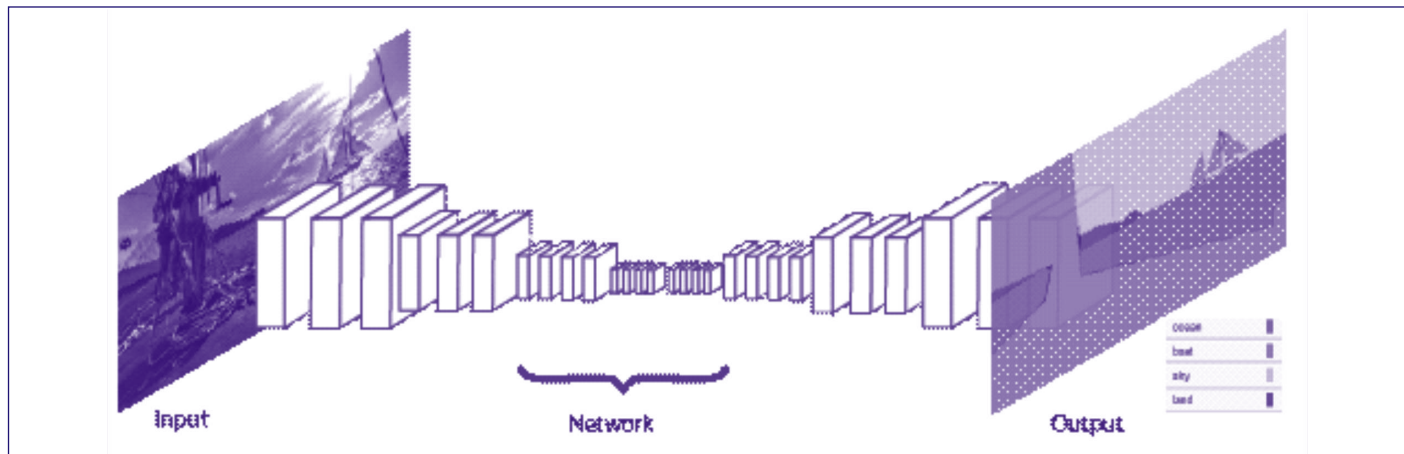


Fig. 2. A typical encoder decoder architecture for semantic segmentation using FCN [20]

The white boxes to the left represent the convolutional and pooling layers whereas the ones to the right represent the up-sampling layers

The workflow of transfer learning is shown in Figure 3. The VGG16 acts as the encoder network. The terminal fully connected layers of VGG16 are converted into fully convolutional layers using  $1 \times 1$  convolutions. Each encoder

layer has a corresponding decoder layer that up-sample the image by transposed convolutions or max-pooling based on memorized indices. Converting VGG16 gives better results than converting its counterparts like AlexNet and GoogLeNet. After the model is set up the collected dataset is used to train it and its accuracy is tested. The advantage of this proposed model is that it extracts the features from the training dataset without the need for human supervision. Also, it can take images of varying resolution and hence can adapt to the periodically updated CDPD proposed in this study.

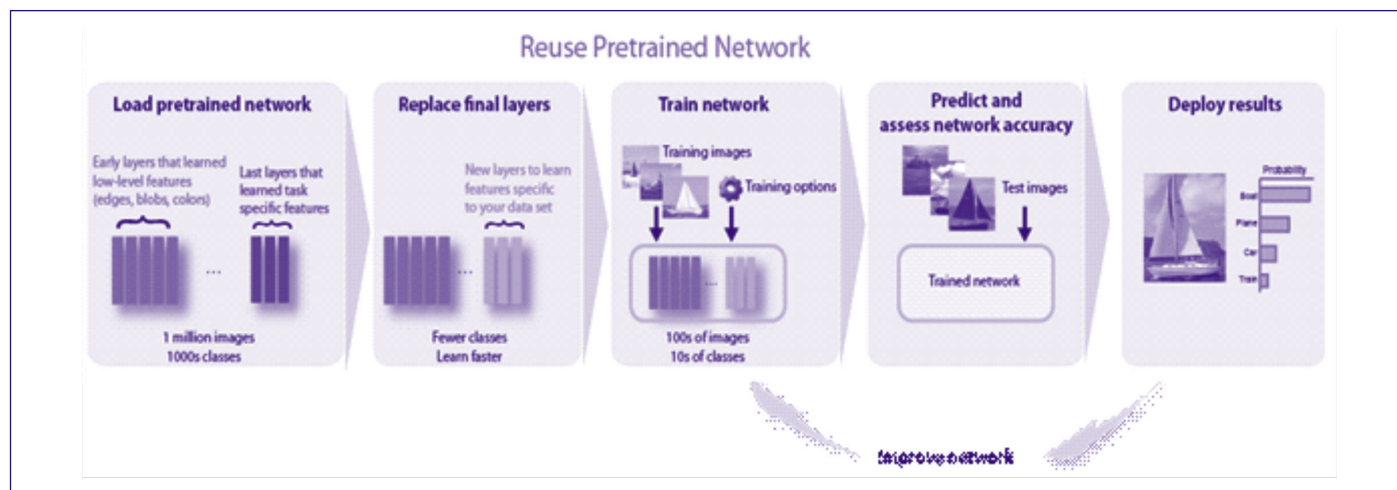


Fig. 3 Workflow for transfer learning [21]

#### 4. CONCLUSION AND FUTURE SCOPE

The study proposes an approach to study the road pavement distresses more efficiently with the help of UAVs and deep learning algorithm. Research gaps can be bridged by implementing the proposed model. UAVs provide a large platform and flexibility in extracting the desired features. Also, the study of all kinds of distresses can help in the improvement of the technical methods used for construction and maintenance.

With the help of the images collected of different roads and at various intervals of time, a huge amount of data can be made available to train other deep learning algorithms with more layers and accuracy can be validated. Also if this data is collected from other parts of the world and made available for training purposes, road conditions of other countries can also be studied for betterment in the civil engineering and for the advancement in technologies used. The accuracy of different models can be compared and the best model can be evaluated. Even the highest resolution cameras used in UAVs cannot capture small dimensions (distresses of size below 20mm). With the development of more digital cameras, this can be overcome. Also with many deep learning, machine learning and transfer learning methods emerging every day the entire system can be used efficiently and improved. Development of other software and frameworks can also speed up the entire training, testing procedure. Other methods like remote sensing, Lidar, Radar, 3D imaging in collaboration with UAVs have great potentials in the future.

#### REFERENCES

1. B. H. Kang, & S. I. Choi, (2017, July). *Pothole detection system using 2D LiDAR and camera. In Ubiquitous and Future Networks (ICUFN), 2017 Ninth International Conference on* (pp. 744-746). IEEE.
2. E. Schnebele, B. F. Tanyu, G. Cervone, & N. Waters, *Review of remote sensing methodologies for pavement management and assessment. European Transport Research Review*, 7(2), 7, 2015.
3. S. Mathavan, K. Kamal, & M. Rahman, *A review of three-dimensional imaging technologies for pavement distress detection and measurements. IEEE Transactions on Intelligent Transportation Systems*, 16(5), pp. 2353-2362, 2015.
4. Y. H. Tseng, S. C. Kang, J. R. Chang, & C. H. Lee, *Strategies for autonomous robots to inspect pavement distresses. Automation in Construction*, 20(8), pp. 1156-1172, 2011.
5. H. Maeda, Y. Sekimoto, T. Seto, T. Kashiyama, & H. Omata, *Road damage detection and classification using deep neural networks with smartphone images. Computer Aided Civil and Infrastructure Engineering*, 33(12), 1127-1141, 2018.
6. S. Shin, & W. Y. Kim, (2018, January). *Fast satellite streak detection for high-resolution image. In Advanced Image Technology (IWAIT), 2018 International Workshop on* (pp. 1-4). IEEE.
7. W. Y. Yan, & X. X. Yuan, *A low-cost video-based pavement distress screening system for low-volume roads. Journal of Intelligent Transportation Systems*, 22(5), 376-389, 2018.
8. C. Zhang, & A. Elaksher, *An Unmanned Aerial Vehicle Based Imaging System for 3D Measurement of Unpaved Road Surface Distresses I. Computer Aided Civil and Infrastructure Engineering*, 27(2), 118-129, 2012.
9. H. Zakeri, F. M. Nejad, & A. Fahimifar, *Image based techniques for crack detection, classification and quantification in asphalt pavement: a review. Archives of Computational Methods in Engineering*, 24(4), 935-977, 2017.
10. A. Banharnsakun, *Hybrid ABC-ANN for pavement surface distress detection and classification. International Journal of Machine Learning and Cybernetics*, 8(2), 699-710, 2017.
11. Y. Pan, X. Zhang, G. Cervone, & L. Yang, (2018). *Detection of Asphalt Pavement Potholes and Cracks Based on the Unmanned Aerial Vehicle Multispectral Imagery. IEEE Journal*

of Selected Topics in Applied Earth Observations and Remote Sensing, (99), 1-12.

12. W. Sultani, S. Mokhtari, & H. B. Yun, Automatic pavement object detection using superpixel segmentation combined with conditional random field. *IEEE Transactions on Intelligent Transportation Systems*, 19(7), 2076-2085, 2018.

13. N. H. M. Nasir, W. M. W. Mohamed, & K. N. Tahar, A Review on Road Distress Detection Methods. *Advances in Transportation and Logistics Research*, 1(1), 230-241, 2018.

14. G. Leonardi, V. Barrile, R. Palamara, F. Suraci, & G. Candela, (2018, May). 3D Mapping of Pavement Distresses Using an Unmanned Aerial Vehicle (UAV) System. In *International Symposium on New Metropolitan Perspectives* (pp. 164-171). Springer, Cham.

15. Li, Z., Cheng, C., Kwan, M. P., Tong, X., & Tian, S. (2019). Identifying Asphalt Pavement Distress Using UAV LiDAR Point Cloud Data and Random Forest Classification. *ISPRS International Journal of Geo-Information*, 8(1), 39.

16. L. Inzerillo, G. Di Mino, & R. Roberts, Image-based 3D reconstruction using traditional and UAV datasets for analysis of road pavement distress. *Automation in Construction*, 96, 457-469, 2018.

17. P. Kanungo, S. K. Mishra, S. Mahapatra, U. R. Sahoo, U. S. K. Sah, & V. Taunk, Road Scene Segmentation Using Thresholding.

18. V. Pereira, S. Tamura, S. Hayamizu, & H. Fukai, (2018, July). A Deep Learning-Based Approach for Road Pothole Detection in Timor Leste. In *2018 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)* (pp. 279-284). IEEE.

19. V. Badrinarayanan, A. Kendall, & SegNet, R. C. A Deep Convolutional Encoder-Decoder Architecture for Image Segmentation. *arXiv preprint arXiv:1511.00561*

20. Webreference:

<https://in.mathworks.com/help/vision/ug/semantic-segmentation-basics.html> (retrieved on 25 January, 2019)

21. Webreference :

<https://in.mathworks.com/help/deeplearning/examples/get-started-with-transfer-learning.html> (retrieved on 25 January, 2019)

22. W. Feng, W. Yundong, & Z. Qiang, (2009, May). UAV borne real-time road mapping system. In *Urban Remote Sensing Event, 2009 Joint* (pp. 1-7). IEEE.

23. J. Long, E. Shelhamer, & T. Darrell, Fully convolutional networks for semantic segmentation. In *Proceedings of the IEEE conference on computer vision and pattern recognition* (pp. 3431-3440) 2015.

24. Y. Pan, X. Zhang, M. Sun, & Q. Zhao, (2017). Object-Based and Supervised Detection of Potholes and Cracks from the Pavement Images Acquired by UAV. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42.

25. J. Tang, & Y. Gu, (2013, October). Automatic crack detection and segmentation using a hybrid algorithm for road distress analysis. In *Systems, Man, and Cybernetics (SMC), 2013 IEEE International Conference on* (pp. 3026-3030). IEEE.

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