

Mango Diseases Classification Solutions Using Machine Learning or Deep Learning: A Review

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Abstract

The mango crop suffers from several diseases that reduce both the production and the quality of the mangoes. This also reduces its price on the international market. Diagnosis of these diseases remains difficult in many countries due to poverty and lack of infrastructure. Plant pathologists use several techniques to identify these diseases. But these techniques are time consuming and relatively expensive for mango growers and the solutions proposed are often not very accurate and sometimes biased. In the last decade, researchers have proposed several solutions in the field of automatic diagnosis of mango diseases. Such solutions are based on Machine Learning (ML) and Deep Learning (DL) algorithms. In this paper, we divided these solutions into two groups: solutions based on classical ML algorithms, and those based on DL. In recent years, DL, especially Convolutional Neural Network (CNN) has become the most widely used method by researchers because of its impressive performance. The critical analysis of the proposed solutions has allowed us to identify their limits and potential challenges in mango disease automatic diagnosis.

Keywords

Mango, Diseases, Diagnosis, Image Processing, Machine Learning, Deep Learning

1. Introduction

Mango (*Mangifera Indica* L.) is a lucrative fruit widely grown in tropical countries. This fruit belongs to the anacardiaceous family [1]. It contains significant amounts of vitamin A and vitamin C [2]. It is called the “King of fruits” because of its alluring aroma, flavorful pulp and high nutritional value that attract many mango lovers from around the world [1] [3]. In 2021, mango was the third most traded tropical fruit after pineapple and avocado in terms of quantities exported.

The Asian continent (912.510 tons exported) is the largest producer of mango in the world in 2021. It is followed by, South America (620.745 tons), Central America and the Caribbean (545.428 tons), Africa (202.010 tons), and Oceania (4.254 tons) [4].

However, mango suffers from several diseases at all stages of its life. Such diseases lead to a considerable reduction in both quality and quantity of mango production. In addition, its lead to a reduction of mango price on the local and international markets. Due to poverty and the lack of infrastructure in many parts of the world (e.g.: developing countries), the rapid diagnosis of these diseases remains difficult [5]. Mango growers and plant pathologists use naked eye observation to diagnose mango diseases and make decisions based on their experiences. Such decisions are often not accurate and biased sometimes because many types of mango diseases appear to be the same since their symptoms are similar at the early stage [6] [7]. This approach leads to unnecessary use of pesticides, which results in higher production costs. In addition, techniques used by plant pathologists are time-consuming and relatively expensive for mango growers. Timely and automatic diagnosis of mango diseases is, therefore very critical [8].

In recent years, with the advances in the field of computer vision, researchers have proposed several automatic diagnostic solutions for grading mango and diagnosing its diseases. Such solutions are based on classical Machine Learning (ML) algorithms and Deep Learning (DL) algorithms.

This paper proposes a review of mango diseases identification and automatic quality grading solutions proposed by researchers during the last decade.

The specific contributions of this paper include:

- A critical analysis of recently proposed mango diseases automatic diagnostic and quality grading solutions.
- Identification of limitations of such solutions and potential challenges could help researchers in this area.

The paper is organized as follows: Section 2 identifies the most common diseases of mango treated by researchers in recent years, Sections 3 provides a critical analysis of the proposed solutions based on classical ML and DL algorithms, Section 4 shows the potential challenges in automatic diagnosis of mango diseases and the last section concludes the paper.

2. A Review of the Most Common Mango Diseases

The production of mangoes suffers from several problems. These problems are caused by pests and diseases which kill about 30% - 40% of the crop [2]. Mango diseases are caused by a number of pathogens like bacteria, fungi, virus, algae and insect which attack all the parts of the plant, such as trunk, branch, leaf, twig, petiole, flower and fruit [1] [2] [8]. The causes of these diseases can also be of climatic origin or unfavorable environmental conditions [9] [10]. **Table 1** provides a summary of fourteen mango disease diagnostic solutions proposed by researchers between 2017 and 2022.

Table 1. A list of fourteen treated mango diseases by researchers between 2017 and 2022.

N°	Paper	Year	Treated diseases
1	[12]	2017	Anthracnose
2	[13]	2017	Powdery Mildew and Anthracnose
3	[8]	2018	Scab (fungus), Anthracnose (fungus), Red Rust (<i>Cephaleuros virescens</i> , an algal plant pathogen) and Sooty Mold (caused by mealy bug, scale insect and hopper)
4	[10]	2018	Anthracnose, Alternaria leaf spots, Leaf Gall, Leaf webber, Leaf burn of mango plant
5	[14]	2018	Anthracnose, Red rust, Sooty mold and scab
6	[7]	2019	Anthracnose
7	[2]	2019	Mango anthracnose disease, mango powdery mildew disease, red rust and mango Golmich.
8	[6]	2020	Anthracnose, Gall Midge, and Powdery Mildew
9	[11]	2020	Dag disease, Golmachi disease, Shutimold disease and Red Moricha disease
10	[15]	2021	Anthracnose
11	[9]	2021	Anthracnose, Apical Necrosis
12	[16]	2021	Sooty mold and Powdery Mildew
13	[17]	2021	Bacterial Canker, Powdery Mildew and Scab
14	[18]	2022	Mango Anthracnose, Bacterial black spot, and Sooty mold

Based on this table, we can say Anthracnose (**Figure 1(a)**) is the most common mango diseases treated by researchers during this period since losses of mango trees are caused up to 39% worldwide by this disease [11]. It is followed by Sooty Mold (**Figure 1(b)**), Powdery mildew (**Figure 1(c)**), Gall Midge (Golmich, Golmachi or leaf Gall) (**Figure 1(d)**), Scab (**Figure 1(e)**) and Red Rust (**Figure 1(f)**). **Figure 2** shows the number of times these diseases are treated based on fourteen topics in **Table 1**.

3. Automatic Diagnosis of Mango Diseases

In recent years, several solutions for automatic diagnosis of mango diseases have been proposed. These solutions can be divided into two categories: those based on classical ML algorithms on the one hand, and those based on DL on the other.

3.1. Automatic Diagnosis Based on Machine Learning

In the field of automatic plant disease detection and identification, IP techniques combined with classical ML algorithms have obtained excellent results. In the proposed models, IP techniques are used to improve the quality of images used for training and testing, while ML algorithms are used for image segmentation, feature extraction and finally, image classification.

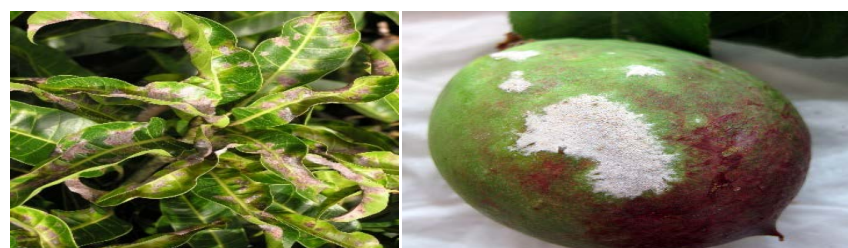
For example, authors of [8] proposed a MLAD (mango leaf ailment detection) based on Neural Network and Support Vector Machine (SVM) classifiers. MLAD can detect and atomically classify four diseases, namely scab, anthracnose, Red Rust and Sooty Mold, with an average accuracy of 80%, although the



(a)



(b)



(c)



(d)



(e)



(f)

Figure 1. Symptoms of the most common mango diseases. Symptoms can appear on leaves, fruit, flowers, stems, ...

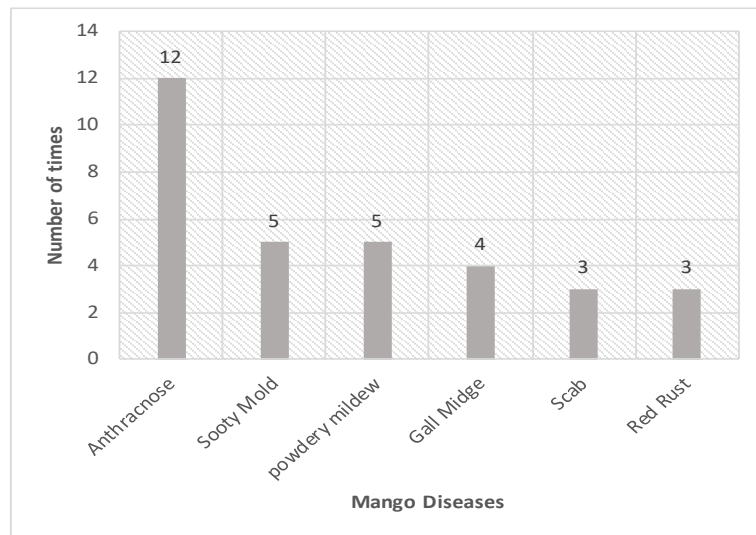


Figure 2. Ranking of the most common and treated mango diseases. The ranking depends on the number of time the disease is present in fourteen considered papers of **Table 1**.

model suffers from a lack of training data. In [16] authors proposed a novel segmentation approach to segment the diseased part by considering the vein pattern of the mango diseased leaf. Diseases treated in this study are sooty mold and powdery mildew. The leaf's features were extracted on the basis of color and texture using canonical correlation analysis (CCA)-based fusion. They used ten different classifiers to identify leaf diseases but the best results were obtained with cubic SVM classifier (95.5% of accuracy). However, the amount of data used is very small and the time needed to identify diseased leaves is significant. Moreover, the proposed architecture does not allow for real-time identification of treated diseases. In the study of [14], a method for automatic mango leaf diseases recognition and classification is developed. Authors used k-means clustering for image segmentation, GLCM (gray level color co-occurrence metrics) for feature extraction and SVM for diseases classification. SVM classifier gets accuracy up to 96%. But one of the proposed model's limits is that the presence of several diseases in the same region of a leaf makes image segmentation difficult. Similarly, the variation in leaf color, texture, and shape made the feature selection phase difficult. Authors of [11] used K-means clustering for image segmentation and SVM and Neural Network Ensemble (NNE) to automatically detect and identify the symptoms of mango leaf diseases namely Dag disease, Golmachi disease, Shutimold disease and Red Moricha disease. The proposed system could detect and classify the diseases with average accuracy up to 80%. However, the authors believe that by increasing the training data, the model would perform better. In [12] authors proposed an Artificial Neural Network (ANN) combined with a Modified Rotation Kernel Transformation (MRKT) system based on directional feature (shape, color or other deceptive features) extraction for recognition and classification of mango disease named anthracnose. They obtained an

accuracy of 98% using the proposed MRKT. The performances obtained are very significant but the proposed system is only limited to anthracnose disease. [13] is an improvement of [12] in order to recognize diseases with more accuracy. Authors introduce an enhanced Wavelet-PCA based Statistical Feature Extraction technique with MRKT based directional features for plant disease recognition. They used an ANN to diagnose both Powdery Mildew and Anthracnose disease. They obtained 98.50%, 98.70% and 98.75% of accuracy respectively for flowers, leaves and fruits.

Several solutions have been proposed for grading the quality of mangoes according to their defects, shape, size and maturity.

For example, authors of [18] implemented a real time automated mango fruit grading scheme according to maturity level and quality attributes like shape, size and surface defect. They used Support Vector Regression (SVR) for maturity prediction, Multi Attribute Decision Making (MADM) system for quality estimation and a fuzzy incremental learning algorithm for mangoes grading. Nearly 87% of accuracy has been achieved by the proposed system. In [19] authors developed an image processing algorithm capable to identify defects and detect maturity of mango fruits based on shape, color and size features using digital images. Such method is useful since it allows automatic sorting of mango fruits. However, it is only able to identify visible defect on mango fruit. Authors of [20] developed a method based on segmentation techniques namely thresholding, K-means clustering, watershed and region growing and a multilayered back propagation neural network (BPNN) classifier for detection and grading of fruits (mango, grape and pomegranate) affected by Anthracnose fungal disease. Experimental results show that classification accuracies are 84.65% and 76.6% respectively for normal and affected anthracnose fruit. In the study of [21], authors designed and developed an efficient algorithm for detecting and sorting the mango fruit with an accuracy more than 80% in grading, compared to human expert sorting. They used Fuzzy inference to extract size, color and skin features on mango RGB images and fuzzy classification to perform the mango classification. **Table 2** summarizes proposed models based on classical ML algorithms used for automatic diagnosis of mango diseases and mango quality grading.

3.2. Automatic Diagnosis Based on Deep Learning

In the last decade, in the field of automatic plant disease detection and identification, models based on DL algorithms are the most proposed by researchers. These models have achieved state-of-the-art performance on ImageNet and other benchmark datasets [22]. The latest generation of Convolutional Neural Networks (CNNs) has achieved impressive results in image classification and is considered as the leading method for object detection in computer vision [22] [23].

For example, in [2], authors proposed ResNet-CNNs (ResNet18, ResNet34 and ResNet50) coupled with Transfer Learning (TL) for automatic detection and identification of four mango leaf diseases namely, anthracnose, powdery mildew,

Table 2. Models based on ML algorithms.

Paper	Year	Objectives	Algorithms	Data used	Results
[21]	2012	Automatic detection and grading of mango fruit according to size, color and skin of the mango.	Fuzzy image clustering algorithm	Dataset of self-collected mango images.	80%
[20]	2013	Grading of mango, grape and pomegranate affected by anthracnose.	Thresholding, region growing, K-means clustering and watershed + ANN classifier	Dataset of 600 fruits' image samples collected by a color Digital Camera.	Normal fruits: 84.65% affected fruit: 76.6%
[18]	2016	Automated grading of mango (<i>Mangifera Indica L.</i>) according to maturity and quality.	SVR + MADM	Mango video images captured by a CCD camera.	87%
[12]	2017	Mango diseases recognition.	K-Means Clustering + MRKT + ANN	500 images of mango leaves and fruits from a Nikon 16 MP digital camera.	98%
[13]	2017	Mango diseases recognition.	K-Means Clustering + MRKT + ANN + Wavelet-PCA	500 images of mango leaves and fruits from a Nikon 16 MP digital camera.	Flower: 98.50%; Leaf: 98.70%; Fruit: 98.75%
[19]	2017	Defect identification and maturity detection of mango fruits.	Proposed image processing algorithms	Dataset of 28 mango images, including 14 defected mangos and 14 did not defected others.	Not specified
[8]	2018	Mango Leaf Ailment (disease) Detection (MLAD).	ANN (Neural Network Ensemble) + SVM	Own dataset.	Mean accuracy of 80%
[14]	2018	Mango leaf unhealthy region detection and classification.	K-means + GLCM and Multiclass SVM	The dataset contains images divided into 5 classes as follows: 61 images for anthracnose, 50 for red rust, 55 for black rot, 75 for scab and 45 for healthy mango leaf.	96%
[11]	2020	Mango leaf disease detection and identification.	Neural Network Ensemble (SVM) + K-means clustering	Self-collected images.	Average accuracy of 80%
[16]	2021	Mango leaf disease detection and identification.	CCA + cubic SVM	29 self-collected RGB images using different types of gadgets and from different areas. 135 images after pre-processing.	95.50%

This table indicates, chronologically, for each article considered, the year of publication, the objectives, the segmentation and classification algorithms used and the performances obtained.

red rust and golmich. Results show that ResNet50 gives better performance with an accuracy of 91.50%. Authors of [6] implemented a Feed-Forward Neural Network (FFNN) with Hybrid Metaheuristic Feature Selection (HMFS) for classifying 3 mango diseases named Anthracnose, Gall Midge, and Powdery Mildew. The proposed model achieved an accuracy of 89.41% more than comparative CNN such as AlexNet (78.64%), VGG16 (79.92%) and ResNet (84.88%). In the study of [7] a Multilayer Convolutional Neural Network (MCNN) model for the classification of mango leaves infected with anthracnose fungal disease is used.

Authors used on the one hand, mango leaves images from Plant Village dataset and on the other hand real-time captured mango leaf images. Experimental results showed an accuracy of 97.13% in the classification of diseased leaves. However, images taken in real condition majorly suffers from the problem of Variation in Temperature, Shadowing, overlapping of leaves, and presence of multiple objects. Authors of [9] developed a model based CNN and named FrCNnet to segment and identify the diseases (Anthracnose and apical necrosis) on the mango leaves. They used TL technique in their model. To evaluate the model, they compare it with state-of-art models like VGG16, VGG19 and Unet. The proposed model's accuracy is 99.2% with a false negative rate (FNR) of 0.8%, which is much higher than the other models. In [10] authors implemented a CNN with three hidden layers inspired by VGG-16, VGG-19 and AlexNet capable to identify five different diseases in mango leaves. These ones are Anthracnose, Alternaria leaf spots, Leaf Gall, Leaf webber and Leaf burn. The proposed model achieved an accuracy of 96.67% classifying diseased images. But the classification accuracy can be further increased by providing more images in the dataset and tuning the parameters of the CNN model. Authors of [15] proposed a CNN model based on AlexNet architecture for detecting anthracnose mango leaf disease. The system is developed using Tensor Flow framework and a dataset of mango images captured in real condition with a CDD camera. The developed system was more than 70% accurate to isolate the diseased mango leaves. The model uses data taken under real field conditions but is specific to anthracnose. In the study of [24], authors developed a CNN based on AlexNet architecture and using TL to detect and classify Mango and Grapes leaf diseases. They achieved an accuracy rate of 89% and 99% respectively for mango and grapes leaves. They implemented this model as an Android app named JIT CROPFIX. However, disease identification in real-time condition is a very challenging task compared to laboratory conditions. Another limitation of the proposed model is that the model ignores tiny or invisible defects on the fruit, which reduces the accuracy. In [17] authors proposed a novel framework for mango leaves disease classification namely Anthracnose, Bacterial black spot, and Sooty mold. They used a CNN with crossover-based levy flight distribution for better feature selection, MobileNetV2 model for the learning stage and SVM for diseases classification. The experimental results show classification performances over other state-of-art methods. Authors of [25] implemented a computer vision algorithm for defect detection on the surface of to Indian mango fruits varieties named Chausa and Dashehari. The overall efficiency and accuracy of proposed algorithm were 93.3% and 88.6%, respectively. However, multiple small defects or single large defect around the edge decreases the accuracy. Efficiency and accuracy of the proposed algorithm decrease when the severity of defect (blemishes or disease infected area) on the surface of fruit increased.

Several DL based solutions have been proposed for automatic sorting or grading mangoes. In [3] for example, combined and studied several DL models based on AlexNet, VVGs, and ResNet to see which one performs best in clas-

sifying mangoes by quality. The results showed that the VGG16 model, combined with the Mask R-CNN algorithm (for image background removal) and the use of TL (on ImageNet) gave the best performance for this task (accuracy: 83.5%). Authors of [26] designed and implemented a system using non-destructive thermal imaging by deep learning technique for mango sorting and grading according to their quality. The proposed system is based on SqueezeNet deep CNN. Mango quality grading is performed by using parameters such as shape, defects, maturity and size. They used TL technique based pretrained SqueezeNet model and achieved 93.33% and 92.27% of accuracy for RGB and thermal images respectively, with the training time of 30.03 and 7.38 minutes for RGB and thermal images. Results show that the training time is lower with the thermal images (by factor of 4X). **Table 3** summarizes proposed models based on DL and used for automatic diagnosis of mango diseases and mango automatic quality grading.

Table 3. Models based on DL algorithms.

Paper	Year	Objectives	Algorithms	Data used	Results
[10]	2018	Identification of leaf diseases in Mango plant species.	CNN with three hidden layers inspired by VGG-16, VGG-19 and Alexnet.	Dataset consisting of 1200 mango leaf images (captured by a digital camera) of diseased and healthy leaves.	96.67%
[7]	2019	Automatic and an early diagnosis of a disease and its severity in mango leaves.	Multilayer Convolutional Neural Network (MCNN) based on AlexNet architecture.	Dataset of 1070 mango tree leaves images captured on real-time and 1130 images from PlantVillage Dataset.	Accuracy: 97.13%; Missing Report rate: 2.87; False report rate: 0
[2]	2019	Detection and identification of mango leaf diseases.	ResNet-CNN (ResNet18, ResNet34 and ResNet50) + Transfer Learning.	Original mango dataset comprises 8853 images captured infield; and Mango leaflet dataset of 8852 images after data augmentation.	ResNet18: 91%; ResNet34: 90.88% and ResNet50: 91.50%
[25]	2019	Defects detection on the surface of mango fruit.	LabView.	180 mango fruits images of two indian categories (Chausa and Dashehari) with various degrees of defects acquired using color (RGB) camera.	accuracy: 88.6% efficiency: 93.3%
[3]	2020	Mangoes quality grading.	The deep learning models selected for our classification task are AlexNet, VGGs, and ResNets + Transfer Learning.	Dataset of 6400 images (AICUP2020) of single mangos each labeled with a quality grade of either A, B, or C based on the evenness of color and severity of defect or diseases.	accuracy: 83.5%
[6]	2020	Detection of early disease on plant leaves with small disease blobs, which can only be detected with higher resolution images.	ANN (Feed-Forward Neural Network) and Hybrid Metaheuristic Feature Selection in comparison with CNN models (AlexNet, VGG16, ResNet-50).	Dataset of 450 images of mango leaves, which belong to four different types (three diseases and one healthy). The images are captured using a camera in the resolution of 3096×3096 pixels with no background under different lighting conditions in a chamber.	FFNN proposed: 89.41%

Continued

[26]	2020	Mango sorting and grading according to their quality.	SqueezeNet deep CNN.	Nearly 10,000 mango fruits self-collected using smart phone, normal camera and a SEEK Thermal camera.	RGB images: 93.33%; Thermal images: 92.27%
[15]	2021	Metetection of mangoes infected with anthracnose.	proposed CNN based on AlexNet architecture.	Dataset of images captured by a CDD camera in real conditions.	70%
[9]	2021	Segment and identify the diseases (Anthracnose and apical necrosis) on the mango leave.	CNN based Fully-convolutional-network (FrCNnet) model.	Real-time self-collected 2286 images captured using different types of image capturing gadgets.	Accuracy: 99.2%; FNR: 0.8%
[24]	2021	Mango and grape diseases detection and identification.	AlexNet CNN.	7,222 and 1,266 images of diseased and healthy mango and grape leaves collected from the PlantVillage dataset and acquired locally respectively.	Grape: 99% Mango: 89%
[17]	2022	Mango leaf disease identification and classification.	CNN with crossover-based levy flight distribution, MobileNetV2 model and SVM.	380 mango images self-captured from a mango cultivating land in India.	Not specified

This table presents, chronologically, for each article considered, the year of publication, the objectives, the CNN algorithms used and the performances obtained.

4. Potential Challenges in Automatic Diagnosis of Mango Diseases

Classical ML and DL algorithms have achieved excellent results in automatic detection and classification of mango diseases. However, the following challenges must be addressed:

- The models proposed so far suffer from a lack of training data, which increases the time to identify diseases and reduces the performance of these models [8] [10] [11] [16].
- The proposed models do not provide real-time diagnosis of mango diseases. This would be very beneficial for mango growers and plant pathologists [16].
- The presence of several diseases in the same region of a leaf makes segmentation difficult. This reduces the accuracy of the model [14].
- Images taken in real condition majorly suffers from the problem of the variation in leaf color, texture, shape, temperature, shadowing, overlapping of leaves and presence of multiple objects. This makes the feature extraction phase difficult. Compared to laboratory conditions disease identification in real-time condition is a very challenging task [7] [14] [24].
- Detection of tiny (or invisible) defects (disease infected area or blemishes) and single large defect around the mango leaf or mango fruit edge is also a challenge [24] [25].
- Mango diseases such as Anthracnose, Sooty Mold, Powdery mildew, Gall Midge, Scab, Red Rust, etc., can affect leaves as well as panicles, stem, flow-

ers, leaves, twigs and fruits. But so far, researchers have focused on leaf-based diagnosis.

5. Conclusion

This paper is a review of mango's most common diseases treated and solutions proposed for automatic diagnosis of such diseases during the last decade. We divided these solutions into two categories: classical ML based solutions and DL based solutions. During the last five years, DL-based solutions, especially CNNs, have been the most widely used since this technology requires less or no preprocessing of images compared to other techniques and offers excellent performances. In this study, a critical analysis of the proposed solutions allowed us to know their limitations and then to identify potential challenges that could be of interest to researchers in automatic diagnosis of mango diseases. We aim, for future work, to propose a dataset of mango diseases whose images will be captured in mango orchards of a Sahelian country like Senegal. Then we will use the CNN model (e.g. VGG16, Unet, AlexNet, MobileNet, ...) which will give the best performances on this dataset and finally deploy this model in a mobile application to allow mango growers to be able to diagnose diseases in their mango orchards without the intervention of plant pathologist. We will focus on anthracnose and peduncular rot diseases which causes significant damage to mango production in Senegal.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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