Automated and Waterless Cleaning of Solar Panels using Unmanned Aerial Vehicle and Machine Learning

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***Abstract*— Energy from the Sun is a very abundant resource, the uses of which are manifold. Water is another essential resource and carries importance for the sustenance of life on Earth. According to a report, the amount of water needed to clean a single solar panel is 3-5 litres per solar panel in normal areas and 7-8 litres per panel in desert areas. While the installation of solar panels has a key role in saving the environment, the wastage of water in its maintenance is undoubtedly a serious concern as the purpose of protecting the environment is not met. Thus, the proposed work introduces a waterless and automated mechanism for selective cleaning of solar panels using unmanned aerial vehicle and machine learning. The term selective indicates that only those panels will be cleaned which are dirty rather than the traditional approach where all the panels are cleaned irrespective of whether they are clean or dirty. The novelty in our approach is data collection using UAV and enabling an automated cleaning mechanism based on machine learning which does not use water. The Unmanned Aerial Vehicle performs the monitoring of solar panels and collects their images from time to time. The collected images are compared to the preloaded dataset and are classified as either clean or dirty. According to the status of the panels, non-abrasive microfibers on a pole mounted on the solar panel are activated for cleaning.**

***Keywords*- UAV, selective cleaning, machine learning, solar panels, automated mechanism**

I. INTRODUCTION

Sustainable energy comes from solar panels because it is a green, inexhaustible, and reliable source of energy. Solar energy can be used to generate electricity for a variety of applications, such as residential, commercial, and industrial uses. Compared to other energy sources, solar energy does not produce harmful emissions and can be used to power the world without relying on fossil fuels. The amount of sunlight that hits the earth in an hour and a half is enough to power the world for a year, according to the US Department of Energy. Fossil fuels have the potential to deplete the earth's resources but solar energy does not have this problem. Solar panels generate electricity from the sun's rays. They consist of semiconductors and can convert solar radiation into direct current. Because solar panels are pollution-free, renewable, and safe, they have been growing in popularity in recent years. Mega solar power plants have already been installed in various countries, such as Australia, the Middle East, the United States, Europe, China. However, there are some onsite issues that need to be taken into account, such as bird droppings, dust accumulation, water stains, and reduced efficiency due to wiring, module soiling, and inverter losses.

Dust settling on solar panels is influenced by a variety of factors, including biological, electrostatic, and chemical properties of the dust, as well as the shape, size, and weight of the dust particles. Today, there are a variety of electrostatic cleaning methods and water-based methods available, and they are all widely used to clean solar panels.

A semi-automatic wiper control system-based cleaning method is proposed in [1]. There is a possibility of achieving a maximum efficiency of 86.7% by this mechanism. Multiple cleaning systems including air, water and vibration are presented in [2] for cleaning in arid zones. The output power of the system is increased by 27% by making use of a water jet spray. In addition to this, an automatic self-cleaning method is proposed in [3]. To design this system, a 50 Wp solar panel is used that has the capability to generate 26%-50% more electricity with the proposed cleaning method than a normal solar panel. The entire system is controlled by a microcontroller. Another wiper control method-based two steps cleaning system is developed in [4] where water is first applied to the surface of the solar panel following which the wiper is triggered. Resultantly, this system’s efficiency becomes 17.55% after cleaning. This is similar to the average efficiency of the system before dust is accumulated. Electrostatic dust removal is another efficient method but it is inappropriate for pole-mounted PV installations. An electrostatic cleaning equipment is proposed in [5] which is suitable and economical for mega solar power plants present in desert areas. The performance of the system is enhanced when the dust is less than 5 g/m^2. An electrostatic travelling wave based self-cleaning technique is proposed in [6] wherein the system consists of transparent dielectric film and parallel electrodes. With this technique, 90% of the dust is removed in about two minutes. An automatic robotic cleaning system is described in [7] which uses a silicon rubber brush and an aluminum core to clean the surface of solar panel. Surface acoustic waves are utilized in [8] such that the spoiling particles are removed from the surface of solar panel. As far as data collection is concerned, the importance of UAV is emerging as an important topic of discussion for researchers and UAV'S can thus serve as an effective tool for data collection in solar panel cleaning as well. As per a research, traditional network data collection is considered to consume a huge amount of energy as data packets are supposed to be routed in a hop-by-hop basis. [9]

In the mechanism proposed in our paper, we introduce a method which integrates the use of Unmanned Aerial Vehicle and Machine Learning to detect the dirt accumulated on the surface of solar panel. Microfibers which are non- abrasive and capable of rotation, automatically get triggered based on analysis of the data collected from the UAV and the dataset from the machine learning model. This helps to clean the particular solar panel found to be unclean. Cleaning costs are saved as energy and resources are spent only on the panel which requires cleaning. Most importantly, the entire process is automated and water is saved to a huge extent.

II. BACKGROUND

A. *Unmanned Aerial Vehicle with a mounted camera*

Data collection through UAV's is highly affordable and images with high resolution are obtained as stated in [10]. In [11], the authors mention that Unmanned Aerial Vehicles are highly advantageous for path and trajectory planning as well as data collection. In [12], a drone- mounted camera, set on video mode at a resolution of 1920 x 1080 px is employed for forensic scene documentation. Moreover, in [13] as well, the authors lay emphasis on the importance of using embedded cameras for object detection. They specify SSD (Single Stage multi-object Detector) and YOLO (You Only Look Once) as extremely beneficial algorithms for this application. Single Stage multi-object detector allows the system to conveniently detect numerous objects in an image by taking only a single shot. In this approach, the output space of bounding boxes is discretised into several default boxes wherein the scales per feature map location and aspect ratios differ. Scores are generated for the presence of each object along with adjustments being made to the box to properly match the shape of the objects.

The YOLO object detector is similar to SSD and faster than methods like Faster R-CNN as specified in [11]. YOLO is a one-time convolutional neural network which enables the prediction and classification of several objects. Region Proposal Generation involves creating a set of candidate boxes which can cover objects, proposal feature extractions and proposal classification [14]. Faster R-CNN is an object detection mechanism which executes region proposal generation accurately and has low time complexity compared to its predecessors, R-CNN and Fast R-CNN [15]. It is observed that out of YOLO and Faster R-CNN, SSD performs its operations at a lesser speed but at the same time, SSD requires a huge amount of data for training purposes. YOLO is the most efficient out of the three algorithms and is also the most appropriate for analysing a live video feed [16].

Hence, after a detailed analysis, it is found that a drone mounted camera on video mode using the YOLO algorithm serves the purpose of analysing a video feed and detecting the presence of solar panels in it in the most effective manner.

B. *Machine Learning and Microcontroller*

In the context of Machine Learning, classification refers to identifying the class in which an item would fit in with reference to the similarity of its characteristics to existing classes. If a classification problem consists of two mutually exclusive classes, it is known as Binary Classification [17]. Binary Classification comprises of a large group of algorithms which are capable of learning prediction rules automatically from the training data [18]. These algorithms primarily include Naïve Bayes Classifier, K-Nearest Neighbors Classifier, Logistic Regression, Decision Tree Classifier and Random Forest Classifier.

In [19], a comparative study was conducted to ascertain the most effective algorithm out of these. It was found that Random Forest Classifier followed by Naïve Bayes Classifier proved to be the best out of all the others. In [20], Kappa values which indicate the similarity between classification and truth values, were used to indicate the accuracy of classification of machine learning algorithms and Random Forest Classifier was assessed as the best with a Kappa value of 0.92. Thus, Random Forest Classifier is the most suitable for the cleaning mechanism suggested by us.

Regarding the integration of the Random Forest Classifier with the microcontroller, implementing TinyML is a suitable technique as per [21]. According to [22], TinyML is a technology used for embedding intelligence in low-power devices. Further, high privacy, low latency along with avoiding data loss and energy costs are some added advantages of using deploying TinyML [23]. In [22], Arduino Nano 33 BLE Sense is specifically mentioned as appropriate for implementing TinyML due to it having 256 kB RAM along with 1 MB of flash memory.

In [24], the paper discusses about the utility of microcontrollers for triggering the cleaning of photovoltaic modules. Here, a microcontroller controls the movement of a motor driver which rotates the motors attached to the cleaning wiper, thus rotating it. As per [25] and [26], if we can accommodate significant volumes of training data, deep learning models can serve the purpose of image classification more efficiently than any usual machine learning model.

Thus, for demonstration of the cleaning mechanism, we have implemented a prototype which makes use of Transfer Learning model which is an important deep learning technique. We took a readily available dataset from Kaggle for training the deep learning model. In the real-world scenario, we suggest using the data collected by UAV's.

III. METHODOLOGY

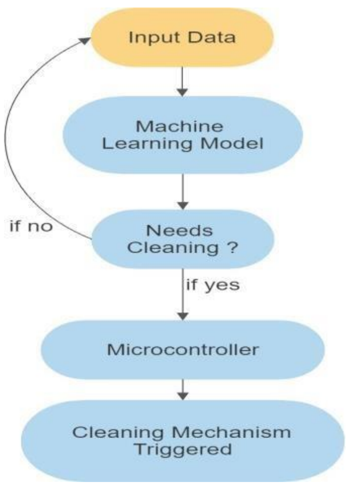

Fig. 1- Flowchart of the cleaning system

As per the suggested mechanism, firstly an Unmanned Aerial Vehicle is deployed to monitor the cleanliness of solar panels. It captures a video feed of the solar panels and immediately sends it to the machine learning model for processing. Thereafter, the machine learning model compares the video feed with the available trained dataset. This is followed by a microcontroller receiving the signal to trigger the rotating microfibers attached to one end of the solar panel, if the panel is found to be dirty. In case the panel is clean, the triggering mechanism does not take place. For the demonstration of results, we use a servomotor instead of rotating microfibers in this paper.

IV. PSEUDOCODE

Input:
Video feed from the drone

Output:
Probability whether the solar panel is clean/dirty

Definitive output:

Step 1: **Deploy the drone and collect the video feed on the solar panels.**

Step 2**: Run the video through the trained algorithm for evaluation.**

1. Get the dataset of images form the drone / the deployment scenario.
2. Categorize the dataset as clean and dirty.
3. Give the dataset for training to the algorithm.
4. Calculate the parameters per epoch for verification.
5. Verify the accuracy of the model and make corrections accordingly.
6. Deploy.

Step 3: **Use binary classification of images.**

Step 4: **Figure out whether the panel is clean/dirty based on the classification algorithm.**

Step 5**: Trigger the cleaning mechanism.**

V. SYSTEM MODEL

Following is the system model which depicts the working of the proposed work. In [27], a monitoring technique for solar panels was dependent on three different sources for collecting data. One of the sources out of the three included weather stations. The authors in [28] emphasise on the importance of image processing, pattern recognition and machine learning in UAV based computer vision. Thus, in the proposed work, data collection is considered to be enabled by the Unmanned Aerial Vehicle and is subsequently sent to the machine learning model for binary classification. It is conveniently analysed if the solar panel is clean or not. Furthermore, it depicts how the cleaning mechanism is triggered due to the indication provided by the microcontroller when the solar panel is detected as unclean. Moreover, when the solar panel is clean, capturing the video feed and image processing begins again. Cleaning of photovoltaic panels using a robotic arm has been proposed in [29]. Spraying a nanomaterial, Surfashield-G on solar panels has been put forth in [30] and the improvement in their efficiency of the solar panels is highlighted. Though these mechanisms offer a highly advanced approach to cleaning solar panels, they may not be affordable by all stakeholders of solar energy. In [31], it is identified that a microfiber - based wiper cloth is the most appropriate while considering the cost and the performance of cleaning solar panels. Therefore, rotation of soft and non-abrasive microfibers mounted on a pole on the solar panels are deployed for cleaning. In this paper, we observe the rotation of a servo motor when a particular solar panel is detected as clean or dirty. This is facilitated by a machine learning model based on binary classification. Hence, the prototype presented in this paper illustrates the manner in which the system model can be executed.

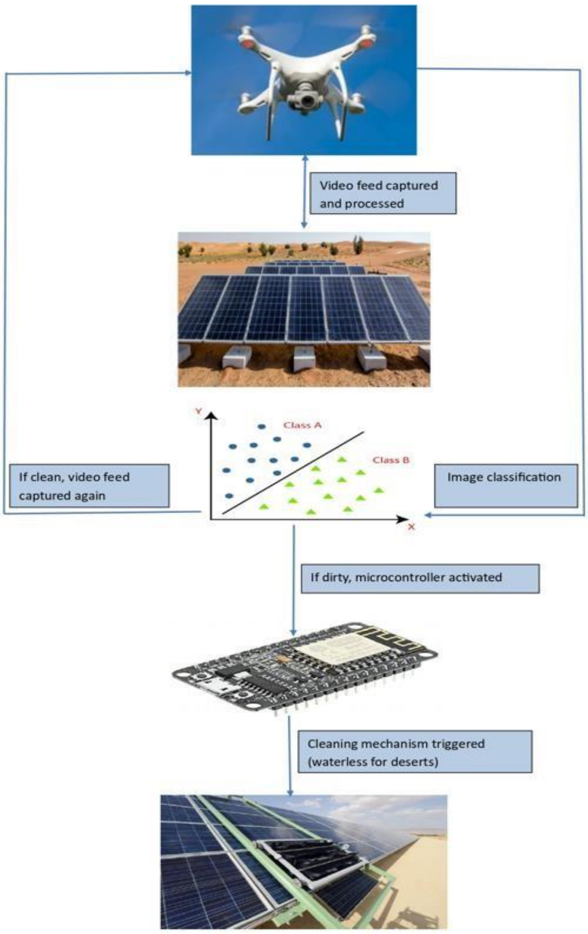

Fig. 2- System Design of the cleaning system

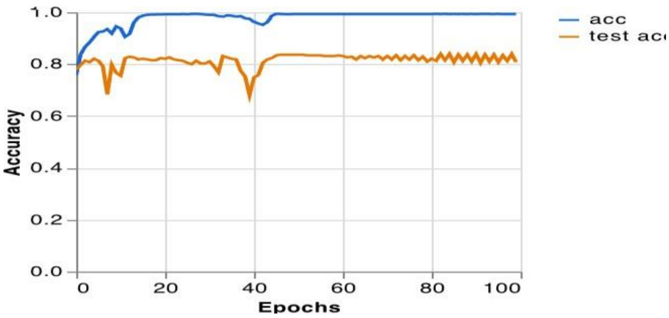

Fig. 5. Accuracy per epoch: - Accuracy is the percentage of classifications that a model gets right during training.

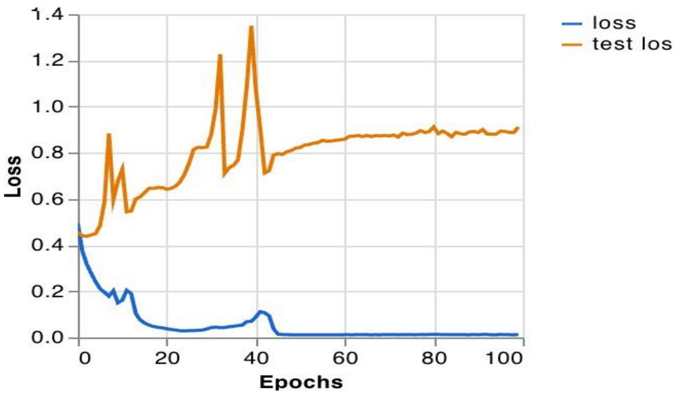

Fig. 6. Loss per epoch: - Loss is a measure to evaluate how well a model has learned to predict the right classifications for a given set of samples.

VI. PERFORMANCE ANALYSIS

[1] *Analysis of the Machine Learning Model*

CLASS	ACCURACY	#SAMPLES
Clean	0.88	224
Dirty	0.70	161

Fig. 3. Accuracy per class is obtained using the test samples.

X/Y	Clean	Dirty
Clean	198	26
Dirty	48	117

Fig. 4. Confusion Matrix: The column (Class) represents the class of the samples considered. The row (Prediction) represents the class that the model, after learning, guesses those samples belong to.

[2] *Hardware Description*

The hardware comprised of 8GB DDR4 Random Access Memory, 256 GB Solid State Drive and a M1 - Apple Silicon, an ARM based chip. It had an 8-core CPU with 4 performance cores, 4 efficiency cores, 7 Core GPU and a 16 Core Neural Engine which runs at a maximum clock speed of 3.2 GHz.

VII. RESULTS AND DISCUSSION

The demonstrated results validate the idea of using machine learning algorithms along with efficient cleaning mechanisms for solar panels. The video feed captured allows the images of solar panels to be compared with the existing dataset based on binary classification. Eventually, appropriate action is initiated as a response to the decision made by the algorithm. The accuracy of a machine learning model must generally be greater than or equal to 0.70. The accuracy per class of the demonstrated results in this paper satisfies this condition as it is 0.88 and 0.70 for clean and dirty solar panels respectively. From Figure-4, it can be noted that the number of True Positives and True Negatives is the maximum which implies that the model is accurate. From Figure-5 and Figure-6, the accuracy and loss per epoch is understood in training and testing phases.

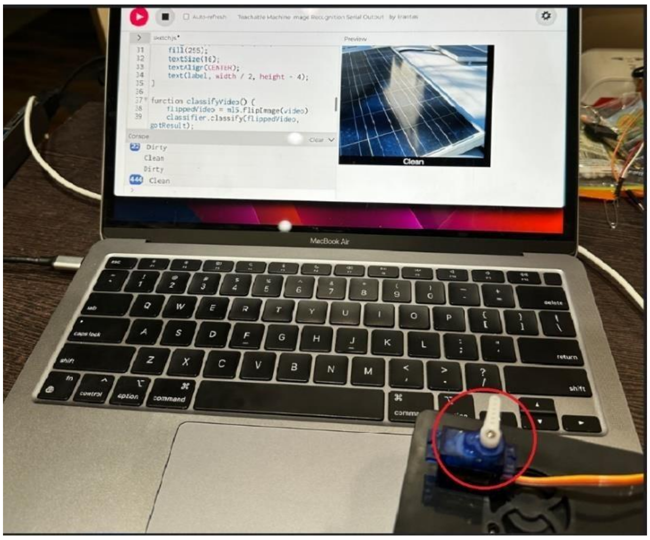

Fig.7 Cleaning Mechanism not triggered as the solar panel is clean.

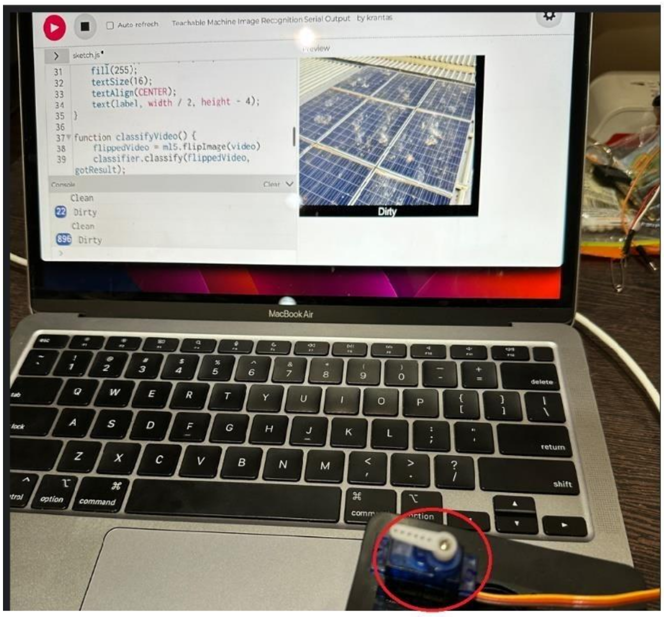

Fig.8 Cleaning mechanism triggered as the solar panel is dirty.

Rotating microfibers (cleaning mechanism) getting automatically triggered is an effective method of cleaning specifically for conserving water in arid zones.

Figure-7 depicts the solar panel being detected as clean by the deployed machine learning method. Hence no cleaning is required and the servomotor is in its initial position when the algorithm ascertains it to be clean.

Figure-8 depicts the rotation of the servomotor by 90 degrees. This movement is in response to the dirty solar panel detected by the machine learning algorithm.

In this paper, the relevant response generated as per the machine learning algorithm is indicated by the rotation of a servomotor.

Here we have considered only one solar panel for the scope of this paper. Furthermore, a Solar panel tracking system can be implemented to identify a dirty solar panel incase of multiple solar panels.

VIII. CONCLUSION

Hence, we have successfully devised the mechanism for cleaning solar panels using UAV (Unmanned Aerial Vehicle) and machine learning. A detailed analysis of the existing researches enabled us to introduce a novel mechanism for an environment friendly and extremely efficient cleaning system of photovoltaic panels. The system thus enables the necessary action to ensure the cleanliness of solar panels and is not responsible for depletion of any important natural resource. As a proof of concept, firstly, a binary classification model was prepared which could distinguish between the clean and dirty panels. Eventually, the rotation of a servo motor was tested which indicated that the servo motor rotated only when the solar panels were observed to be dirty.

IX. REFERENCES

[1] N. Sugiartha et al., “Preliminary design and test of a water spray solar panel cleaning system,” J. Physics: Conf. Series, vol. 1450, 012108, Feb. 2020.

[2] A. S. Alghamdi, A. S. Bahaj, L. S. Blunden, and Y. Wu, “Dust removal from solar PV modules by automated cleaning systems,” Energies, vol. 12, pp. 121, 2019.

[3] K. P. Amber et al., “A self-cleaning device for pole mounted solar photovoltaic installations,” Thermal Science, vol. 23, no. 2A, pp. 739- 49, 2019.

[4] Syafaruddin, F. A. Samman, Muslimin, and S. Latief, “Design of automatic control for surface cleaning system of photovoltaic panel,” ICIC Express Letters, Part B: Appl., vol. 8, no. 11, pp. 1457-64, 2017.

[5] H. Kawamoto, “Electrostatic cleaning equipment for dust removal from soiled solar panels,” J. of Electrostatics, vol. 98, pp. 11-16, 2019.

[6] M. Mazumder et al., “Characterization of electrodynamic screen performance for dust removal from solar panels and solar hydrogen generators,” IEEE Trans. Ind. Appl., vol. 49, no. 4, pp. 1793-1800, 2013.

[7] B. Parrott, P. C. Zanini, A. Shehri, K. Kotsovos, and I. Gereige, “Automated, robotic dry-cleaning of solar panels in Thuwal, Saudi Arabia using a silicone rubber brush,” Solar Energy, vol. 171, pp. 526- 33, 2018.

[8] S. Alagoz and Y. Apak, “Removal of spoiling materials from solar panel surfaces by applying surface acoustic waves,” J. Cleaner Production, vol. 253, 2020, 119992.

[9] Goudarzi, S., Kama, N., Anisi, M. H., Zeadally, S., & Mumtaz, S. (2019). Data collection using unmanned

aerial vehicles for Internet of Things platforms. Computers & Electrical Engineering, 75, 115.

[10] Anitha Ramachandran, Arun Kumar Sangaiah, A review on object detection in unmanned aerial vehicle surveillance, International Journal of Cognitive Computing in Engineering,Volume 2, 2021, Pages 215-228, ISSN 2666-3074, https://doi.org/10.1016/j.ijcce.2021.11.005.

[11] Ahmed, F., Mohanta, J.C., Keshari, A. et al. Recent Advances in Unmanned Aerial Vehicles: A Review. Arab J Sci Eng 47, 7963–7984 (2022) https://doi.org/10.1007/s13369-022-06738-0

[12] Urbanová P, Jurda M, Vojtíšek T, Krajsa J. Using drone-mounted cameras for on-site body documentation: 3D mapping and active survey. Forensic Sci Int. 2017 Dec;281:52-62. doi:10.1016/j.forsciint.2017.10.027. Epub 2017 Oct 26. PMID: 29101908.

[13] P. Nousi, I. Mademlis, I. Karakostas, A. Tefas and I. Pitas, "Embedded UAV Real-Time Visual Object Detection and Tracking," *2019 IEEE International Conference on Real-time Computing and Robotics (RCAR)*, Irkutsk, Russia, 2019, pp. 708-713, doi: 10.1109/RCAR47638.2019.9043931.

[14] Tang, P. et al. (2018). Weakly Supervised Region Proposal Network and Object Detection. In: Ferrari, V., Hebert, M., Sminchisescu, C., Weiss, Y. (eds) Computer Vision – ECCV 2018. ECCV 2018. Lecture Notes in Computer Science(), vol 11215. Springer, Cham. https://doi.org/10.1007/978-3-030-01252-6_22

[15] M. Maity, S. Banerjee and S. Sinha Chaudhuri, "Faster R-CNN and YOLO based Vehicle detection: A Survey," 2021 5th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 2021, pp. 1442-1447, doi: 10.1109/ICCMC51019.2021.9418274.

[16] Srivastava, S., Divekar, A.V., Anilkumar, C. et al. Comparative analysis of deep learning image detection algorithms. J Big Data 8, 66 (2021). https://doi.org/10.1186/s40537-021-00434-w

[17] Ayça Deniz, Hakan Ezgi Kiziloz, Tansel Dokeroglu, Ahmet Cosar,Robust multiobjective evolutionary feature subset selection algorithm for binary classification using machine learning techniques, Neurocomputing, Volume 241, 2017, Pages 128-146, ISSN0925-2312, https://doi.org/10.1016/j.neucom.2017.02.033

[18] Jingyi Jessica Li, Xin Tong, Statistical Hypothesis Testing versus Machine Learning Binary Classification: Distinctions and Guidelines, Patterns, Volume 1, Issue 7,2020,100115, ISSN 2666-3899, https://doi.org/10.1016/j.patter.2020.100115

[19] V. Bahel, S. Pillai and M. Malhotra, "A Comparative Study on Various Binary Classification Algorithms and their Improved Variant for Optimal Performance," 2020 IEEE Region 10 Symposium (TENSYMP), Dhaka, Bangladesh, 2020, pp. 495-498, doi: 10.1109/TENSYMP50017.2020.9230877.

[20] V. Rodriguez-Galiano, M. Sanchez-Castillo, M. Chica-Olmo, M. Chica-Rivas, Machine learning predictive models for mineral prospectivity: An evaluation of neural networks, random forest, regression trees and support vector machines, Ore Geology Reviews, Volume 71, 2015, Pages 804-818, ISSN0169-1368, https://doi.org/10.1016/j.oregeorev.2015.01.001.

[21] S, A. Potluri, S. M. George, G. R and A. S, "Indian Sign Language Recognition Using Random Forest Classifier," 2021 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT), Bangalore, India, 2021, pp. 1-6, doi: 10.1109/CONECCT52877.2021.9622672.

[22] Ioannis Katsidimas, Thanasis Kotzakolios, Sotiris Nikoletseas, Stefanos H. Panagiotou, and Constantinos Tsakonas. 2022. Smart Objects: Impact localization powered by TinyML. In Workshop on Challenges in Artificial Intelligence and Machine Learning for Internet of Things (AIChallengeIoT) (SenSys '22), November 6–9, 2022, Boston, MA, USA. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3560905.3568298

[23] H. Han and J. Siebert, "TinyML: A Systematic Review and Synthesis of Existing Research," 2022 International Conference on Artificial Intelligence in Information and Communication (ICAIIC), Jeju Island, Korea, Republic of, 2022, pp. 269-274, doi: 10.1109/ICAIIC54071.2022.9722636.

[24] M. R. Habib *et al*., "Automatic Solar Panel Cleaning System Based on Arduino for Dust Removal," *2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS)*, Coimbatore, India, 2021, pp.1555-1558,doi: 10.1109/ICAIS50930.2021.9395937.

[25] S. Sharma and K. Guleria, "Deep Learning Models for Image Classification: Comparison and Applications," *2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*, Greater Noida, India, 2022, pp. 1733-1738, doi: 10.1109/ICACITE53722.2022.9823516.

[26] Alzubaidi, L., Zhang, J., Humaidi, A.J. *et al.* Review of deep learning: concepts, CNN architectures, challenges, applications, future directions. *J Big Data* 8, 53 (2021). https://doi.org/10.1186/s40537-021-00444-8

[27] C. -G. Haba, "Monitoring Solar Panels using Machine Learning Techniques," *2019 8th International Conference on Modern Power Systems (MPS)*, Cluj-Napoca, Cluj, Romania, 2019, pp. 1-6, doi: 10.1109/MPS.2019.8759651

[28] Akbari, Y., Almaadeed, N., Al-maadeed, S. et al. Applications, databases and open computer vision research from drone videos and images: a survey. Artif Intell Rev 54, 3887–3938 (2021). https://doi.org/10.1007/s10462-020-09943-1

[29] A. K. Mondal and K. Bansal, ‘‘Structural analysis of solar panel cleaning robotic arm,’’ Current Sci., vol. 108, pp. 1047–1052, Mar. 2015

[30] Homam Al Bakri, Wejdan Abu Elhaija, Ali Al Zyoud, Solar photovoltaic panels performance improvement using active self-cleaning nanotechnology of SurfaShield G, Energy,Volume 223,2021,119908, ISSN 0360-5442 https://doi.org/10.1016/j.energy.2021.119908.

[31] M. Al-Housani, Y. Bicer, and M. Koç, "Assessment of Various Dry Photovoltaic Cleaning Techniques and Frequencies on the Power Output of CdTe-Type Modules in Dusty Environments," *Sustainability*, vol. 11, no. 10, p. 2850, May 2019, doi: 10.3390/su11102850.