Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 133 (2018) 585–593

Procedia Computer Science

www.elsevier.com/locate/procedia

International Conference on Robotics and Smart Manufacturing (RoSMa2018)

On the technologies empowering drones for intelligent monitoring of solar photovoltaic power plants

Nallapaneni Manoj Kumar[a,*], K. Sudhakar[a,b], M. Samykano[a], V. Jayaseelan[c]

[a]*Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia*
[b]*Energy Centre, Maulana Azad National Institute of Technology Bhopal, M.P., India*
[c]*Department of Mechanical Engineering, Prathyusha Engineering College, Tiruvallur-602025, Tamil Nadu, India*

Abstract

Monitoring of solar photovoltaic power plants is an essential task that could enable efficient operation and maintenance. Active control and regular maintenance will enhance the photovoltaic plant's output performance and helps in reasonable or better returns on the investments made. The process of monitoring is done by conducting manual inspections, but due to technological advancements, the manual checks were replaced by intelligent systems, centralized control, and monitoring systems, surveillance cameras, robotics, drones, etc. Drones are becoming more suitable for the solar industry due to a wide range of surveillance capability, long range inspection, efficient data logging capability, easy to control and access from the central level, etc. In this paper, the role of drones in solar photovoltaic power plants, and scope for enabling intelligence and automation in drones for the active monitoring and data logging is discussed. Various types drones and their configurations along with the dynamics are also considered. A study on the technologies behind the drone intelligence and automation were identified and discussed. From this study, it was found that Recognition Technologies (RT), Artificial Intelligence (AI), and Machine Learning (ML) could empower the drones and make the monitoring of large-scale solar power plants easier. This study could help the developers and researcher who are working on intelligent drones for specialist care of massive solar parks, unaccessible remote solar plants, etc.

Keywords: Drones; solar power plants; monitoring of solar plants; drones in the solar industry; intelligent drones; autonomous drones.

1. Introduction

In line with the population growth over the nations led to the expansion of industries and various utility level projects serving the needs of humanity for better living on this earth[1]. This expansion led to the exponential increase in energy demands across the globe contributing the significant share of electricity. It is a noted fact for all of us that

* Corresponding author. Tel.: +91 9491925258, +60 14 6335006
E-mail address: nallapanenichow@gmail.com

1877-0509
10.1016/j.procs.2018.07.087

most of the electricity we are utilizing today is from fossil fuels and the process of electricity generation from fossil fuels is complex and more intensive towards the release of greenhouse gas emission. On the other side, the resource availability of fossil fuel is becoming diminished due to the unceasing and excessive consumptions over the long periods[2]. With the increased greenhouse gas emissions and lessened fossil fuel resources, the demand for meeting energy needs becoming quite difficult with fossil fuel-based power sector. This creates a gap between the energy demands and energy production constraining to the limits of the environment[3]. Hence, the gap must be filled with the alternative energy source which is environmentally friendly. When we talk about the alternative energies, options are many, but all the technologies may not viable hence a specific energy source needs to be selected based on the site, availability, utility integration, etc. Among the alternative energy sources, solar energy seems to be rising and shining on a global level due to market development, abundant availability, ease of operation, and the possibility of generating energy at load centers[4]. All those factors gave the scope for broad acceptance of solar photovoltaics across the globe. However, the PV systems are widely accepted, they further need a specific focus on the performance aspects[5]. In PV systems, we encounter issues related to the underperformance, system component failure, and weather parameter influenced performance, etc. These issues lower the PV plant energy yields causing energy losses, but in most cases, the reasons for energy loss is not identified, and limits of a parameter affecting this loss are not efficiently quantified. And such influential parameters could be many in the solar power plants[6]. Hence, there is a need for tackling the issues associated with solar PV plants, and one needs a single solution rather than having multiple solutions. As we are more interested in the single solution for solving or identifying issues in solar, the first one that would come to our mind is the continuous monitoring of the PV plant. That would enable us to have comprehensive knowledge of the weather parameters of the site location. With this knowledge, the operator can analyze and come out with a conclusion how the climatic parameters are affecting the energy performance[7]. Apart from weather data, the operator can also monitor the well-being of the PV plant or the health of PV system components, etc. can be observed, this could allow to have regular maintenance of the system and address the issues related to component failure[8]. The single solution that could help the PV system to perform well and in delivering better returns on investment would be the monitoring of PV systems.

The primary objective of this paper is to discuss the technologies behind the intelligent and automated drones used for monitoring of photovoltaic power plants. Before going to the details of the technologies behind the drones, a brief study on monitoring of the PV systems is taken up with two broad classifications as physical inspection by human workforce (PI-HWF), and inspection by remote monitoring (I-RM). A comparison over PI-HWF and I-RM is dealt focusing on ten aspects in the view of small-scale PV plants and large-scale PV plants. The scope for drones in remote monitoring and how could drones become a part of intelligent monitoring systems for solar were analyzed and studied. Various technologies that could make drones more intelligent and allow autonomous task handling capabilities were identified and discussed.

2. Monitoring of Solar PV Plants

Developing solar power plant design in simulation beds, procuring system components, executing the installation, and commissioning does not mean the shifting to a sustainable solar energy option. It becomes sustainable only when it is operated at optimal performance with reasonable returns on the investment made by the project owner. To observe this, we should monitor the performance of solar power plants continuously focusing on the identification of under operating conditions and required maintenance is to be carried out to match the performance to an optimal level. The continuous monitoring will enable us to report the data on the maximum possible energies at the site, energy generations, ambient weather parameters, PV system component temperatures, fault occurrence frequencies, faulty prone components in a system, any other external influence[7,8]. With this reported data we can easily quantify and analyze the energy losses associated, reliability aspects, climate influence, early measures as per the operational issues, etc.

Monitoring of solar PV plants can be done in both traditional ways of using human workforce and the current trend of using remote monitoring systems. However, the monitoring methods to be adopted could vary depending upon the size of the power plant, the site at which the plant is located, etc. Monitoring of PV plants is explained here in two broad categories, namely Physical Inspection by Human Work Force (PI-HWF), and Inspection by Remote Monitoring (I-RM). These two inspection methods were discussed below in section 2.1 and section 2.2.

Whatever may be the monitoring method employed, the typical function of it was explained in five steps. These five steps could vary depending upon the policy and monitoring systems adopted, However, the conceptual process and flow behind every monitoring method would be similar. The five steps were given below:

Step-1: Collection of information on the plant site and PV system components.

Step-2: Reporting the data in prescribed formats and storing in different means.

Step-3: Analysis of the data depending on the monitored parameters and frequency of the monitoring.

Step-4: Generating analysis reports on the performance indices and effects on performance indices,
Highlights of the reasons for underperformance, and
Suggestions for improving the performance thereby providing effective operation and maintenance.

Step-5: Execution of suggested operation and maintenance strategies for improving the PV plant performance.

An evaluation is made here to understand the performance abilities of both the methods. Table 1 shows the comparison of the human workforce and remote monitoring facilities for inspecting solar power plants either small scale or large scale focusing on ten aspects.

Table 1. Comparison of monitoring ability with the human workforce and remote monitoring

Focused parameter	A physical inspection by the human workforce		Inspection by remote monitoring	
	Small scale PV plant	Large scale PV plant	Small scale PV plant	Large scale PV plant
Quality of the inspection	Moderate	Poor	Better	Better
Duration of inspection	Moderate	Very long	Very less	Less
Reliability of inspection	Moderate	Very poor	Very high	High
Data collection frequency	Possible on hourly scale	Possible on daily/monthly scale	Possible on minutes scale	Possible on minutes scale
The accuracy of the monitored parameters	Moderate	Very poor	Very high	High
Identifying the cause of faults	Easy and takes little time	Difficult and takes time	Very easy	easy
A prior information-based fault occurring frequency	Possible as data can be monitored effectively	Not possible because it's quite difficult to inspect large-scale plant with a human workforce	Possible as data is completely monitored and analyzed using various predictive tools	Possible as data is completely monitored and analyzed using various predictive tools
Data filing and storage	Easy	Quite difficult	Very easy	Very easy
Protocol for service and maintenance	Quick	Takes time	Very quick	Quick
Cost involved in the inspection	Very less	High	High	Very high

2.1. Physical Inspection by Human Work Force

Physical inspection of the solar power plants is done by sending the workforce to the plant site and ask them to monitor the possible parameters manually or using measuring instruments. This process of inspection is quite difficult to execute and monitor. Depending on the plant size and site the difficulty and monitoring accuracy will vary. Fig. 1. Shows the clear execution of PI-HWF in systematic view considering the stepwise power. Human workforce monitors the data related to the PV array/module/cell, weather parameter, dust accumulation on the PV system, and careful investigation of the mounting structures used for installation. All these monitored data were reported either in the printed papers or the tablet devices. The data can be analyzed, and possible operation and maintenance strategies could be evaluated. Sometimes without much analysis, the operation and maintenance can be carried out. However, physical inspection can be made appropriately when PV plant size is smaller, and moderate accuracies can be achieved. Usually, chances are more for human errors causing the unaccountability of few parameters; this is possible in the case of large-scale PV plants. The human inspection takes the lengthy process for large-scale plants, and re-occurrence of various issues are possible before monitoring cycle finishes.

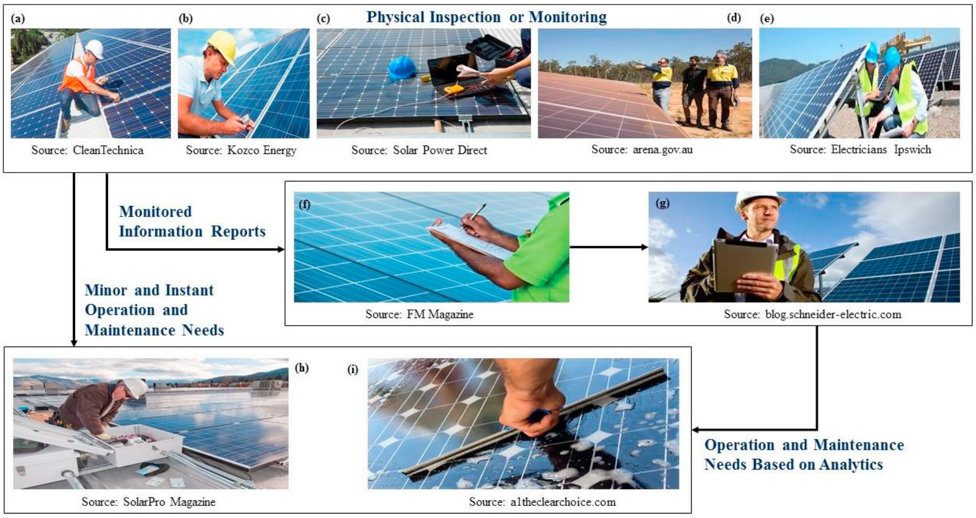


Fig. 1. (a) String electrical parameter monitoring; (b) array output monitoring; (c) array monitoring and feeding the data to laptop; (d) dust accumulation inspection on the PV array; (e) installation structure monitoring; (f) making note of monitored data on paper; (g) making note of monitored data in Tablet; (h) operation and maintenance execution; (i) manual dust cleaning process.

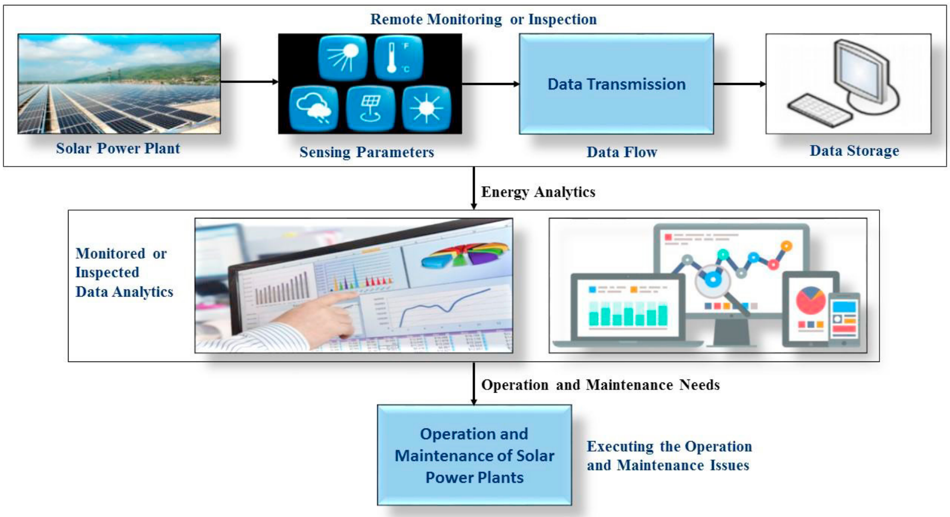


Fig. 2. Remote monitoring of solar photovoltaic power plant.

2.2. Inspection by Remote Monitoring

Remote monitoring of solar photovoltaic plants is more important as the physical inspection by human workforce is not giving an appropriate monitoring ability to perform better operation and maintenance service for improving the output performance of the PV plants. Fig. 2. Shows the schematic view of remote monitoring of PV plants. Here, the monitoring system is equipped with the sensors, signal processing unit, data transmission, data storage and logging facilities, and cloud-integrated data analytics. Here, the remote monitoring system collects various data related to the electrical, ambient, energy, losses, occurrence of faults and time of outages, etc. These monitored data were stored and further analyzed for evaluating the performance of the system. This would allow us to have a stable and need-based operation and maintenance strategies[7-9]. This sought of inspection could be easy compared to the conventional inspection carried out using human workforce. Accuracies in monitoring the data are higher than to the human work face one. Irrespective of the PV plant size and location, the remote monitoring would help to achieve reliable operation. Significant drawbacks are the cost and complexity, and this makes more difficult and economically intensive for commercial and large-scale PV plants. Latest trends in remote monitoring include the use of drone system.

3. Drones as Intelligent Remote Monitoring Systems for Solar PV Plants

The exponential growth seen in photovoltaic markets led to the development of large-scale power plants and ultra-solar parks. While, developing PV plant, many issues arise at different stages of the solar PV systems, these include the site selection stage, PV plant installations stage, operating stage, monitoring stage, and maintenance stage. Most of the things in the solar power plant were executed using help-seeking from the workforce. With the physical inspection, reliable and stable operations may not be obtained, and better yields on the return on investments cannot estimate. Remote monitoring also seems to be quite expensive and complicated way for monitoring especially for large-scale photovoltaic plants.

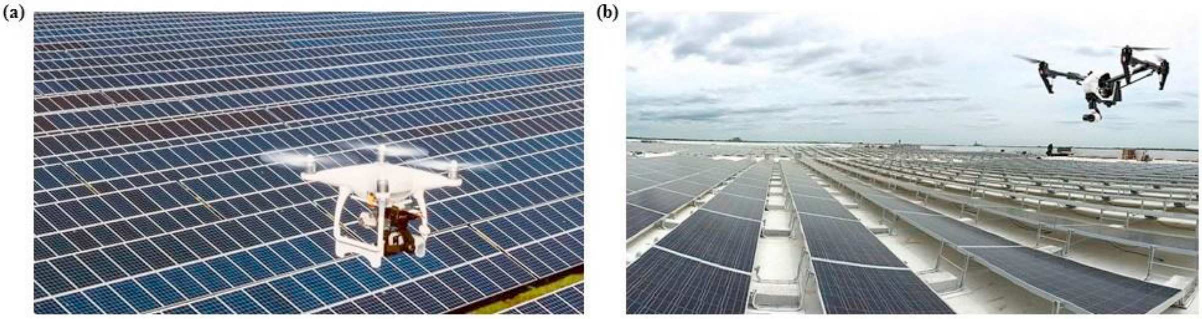


Fig. 3. (a) Quadcopter drone for monitoring solar PV plant; (b) Tri-copter drone for monitoring solar plant (Source: Gregory Zeller, 2015 http://www.innovateli.com/at-rotor-air-cams-hovering-over-the-future/)

In recent years, drones have emerged their services in the solar energy sector also focusing on the needs of monitoring and surveillance services. Drones are capable of monitoring large-scale solar parks even in less time when compared to human inspection and other remote monitoring methods. Drones are the small-scale flying vehicles that are equipped with the sensing elements required for monitory aspects of the designated site. With the help of sensing elements, drones efficiently capture the data and send back to the cloud for the analysis with less time and in more accurate form. Fig. 3. (a), and Fig. 3. (b) shows the typical monitoring application of Quadcopter drone and Tri-copter drone for solar power plant assets. The flying drones are easily capable of capturing high resolution visual and thermal image of the photovoltaic modules and other components in the PV plant. From these images, the analysts can interpret the condition of the PV plant. Drones make the process of monitoring intelligent and more accessible. These offer broad range services that could be a benefit for the solar industry owners[10,11].

3.1. Offered Services for Solar Industry

Various services provided by the intelligent drone systems in photovoltaic power plants were given as follows:

- Enables asset security over the site with the visual monitoring.
- The thermal image captures to identify the faults in the PV module or array.
- Dust accumulation information.
- Monitoring of possible shadows on the PV array.
- Allowing and maximizing the reliability of the inspection.
- Lesser time-consuming monitoring facility.
- Site inspection for the preliminary productivity analysis.
- Provides service of ‘continuous eyesight’ during the construction phase of the solar power plant
- Provides service on the inspecting and identifying the possible string layouts in remote sites.
- Can quickly identify the threats or theft of the equipment enabling safety.

3.2. Potential Benefits in Solar Industry

Various benefits offered by the intelligent drone systems in photovoltaic power plants were given as follows:

- Better operation and maintenance of the PV plant.
- Time-saving during the inspection visits.
- Improved energy productivity.
- Accuracy in the fault identification.
- Helps in improving the returns on investment.
- Improves the efficiency of inspection.
- Wide integration and multi-tasking ability.
- Long-term data maintenance.

Table 2. Design configurations and features of drones.

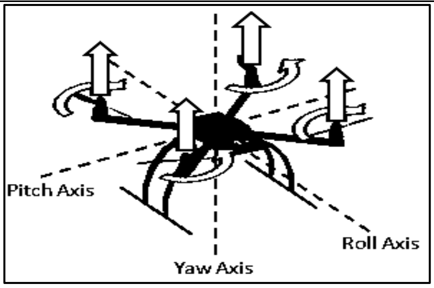
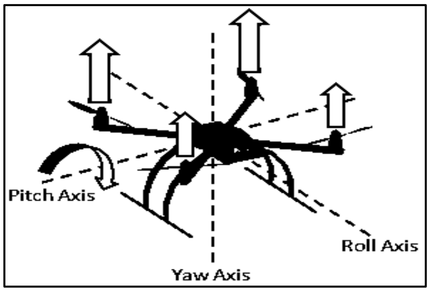
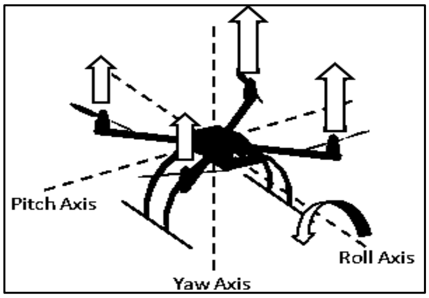
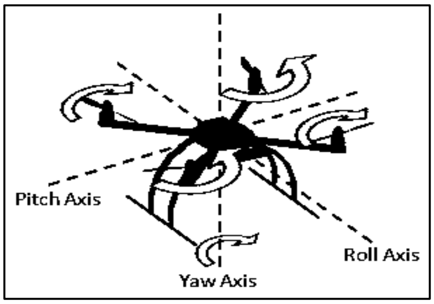
Drone copter type	Configuration	Design complexity	Cost	Implications in solar	Remarks
Bi-copter	I-2 or I —2 or —	More complex	Less cost	Better for small-scale PV plants	Economically better but skilled operator is needed
Co-axial bi-copter	O-2 or O	More complex	Less cost	Better for small-scale PV plants	Economically better but skilled operator is needed
Tri-copter	Y-3 or Y IY-3 or IY	Intermediate	Less cost	The scope is very high for small and medium scale PV plants	Economically better but skilled operator is needed
Quad-copter	X-4 or X I-4 or + H-4 or H	Less complex	Medium Cost	The scope is very high for medium and large-scale PV plants	Economically better and can be operated efficiently.
Hexa-copter	Y-6 or Y IY-6 or IY X-6 or X I-6 or I H-6 or H	Intermediate	High cost	The scope is very high for large-scale PV plants	Economically not viable and can be operated efficiently.
Octo-copter	1-8 or + V-8 or V X-8 or X	More complex	Cost is very high	The scope is very high for large-scale PV plants	Economically not viable for a PV plant owner instead can be approached a third-party drone service supplier and can be operated efficiently.

3.3. Types of Drones and its Dynamics

Drones are classified into various types based on the possible copter configurations. Presently, six types of drones were available in the markets. These include the Bi-copter, Co-axis bi-copter, Tri-copter, Quad-copter, Hexa-copter, and Octo-copter[12]. In Table 2. Various possible configurations and implications in solar along with the potential remarks are shown. From the study on multiple drones, it is understood that the multi-copter design as well their configurations have superior functionality when compared to the others. In multi-copters, the complexity of the rotor design mechanism is eliminated making it be a simple design. This option made the multi-copter to be the best solution provider for various issues[12].

Dynamics is another critical factor to be considered when drones were designed. Easy and effective controllability and stable operation are the primary elements to be considered for the dynamics. Dynamics of any selected drone for the solar industry should fall under the categories of hovering, pitching, rolling and yaw. Table 3. Describes the brief about the dynamics along with the visual representation[12].

Table 3. Dynamics of the drone[12].

Type of dynamics	Description	Visual representation
Hovering	Hover control is achieved when all the propellers of drones are made to function with similar speeds. This will allow generating a thrust force and the torque maintaining same values for all the propellers of the drone.	
Pitch control	In a drone, when it is monitoring the solar power plant, there is a need for drone rotation around the pitch axis. When drone rotates around its pitch axis, a differential thrust is created. In this case, both the front and rear propellers spin at some different speeds.	
Roll control	In a drone, the roll control is quite simpler compared to others. This is achieved by creating variation in the propeller speeds. When the propeller speeds were decreased on one side and increased on another side. .	
Yaw control	Yaw control is achieved in the drones when there is a substantial difference in speeds between the clockwise and anticlockwise propellers. In this case, thrust balance takes place by not allowing the net torque to be completely zero.	

4. Technologies Empowering Intelligence and Automation in Drones

Even though drones were proven to show a wide range of services and benefits in various sectors especially in solar, there is not much market for it. The demand for drones in solar is still underway. Drones perform to be proven technology for monitoring of the large-scale PV plants and remotely located PV plants. However, the deployment of drones in solar sector is quite limited due to the cost factor, intricate design, and handling the functionalities. Apart from these, few more challenges that need to be explored are instant processing and analyzing the monitored data, automatic flight planning of drones based on the need, autonomous protocols, integration with a wide range of sensors, wireless connectivity with the receiver at drone and sensors at the PV site[13].

Table 4. Technologies and their potential roles in the view drone-assisted solar power plants.

Technology	Potential Roles
Recognition technologies	To extract the data and interpret the thermal image and visual image of the photovoltaic module and other system components, Authentication, and authorized entry
Artificial intelligence	Fault identification, quick data processing, interpretation and data analytics, predictive analytics-based fault identification based on the historical data, facilitates the communication between the drones and operation and maintenance team.
Machine learning	Allows the drone to learn about the process happening based on historical data, Allows strategic monitoring plan with preprocessed algorithms.

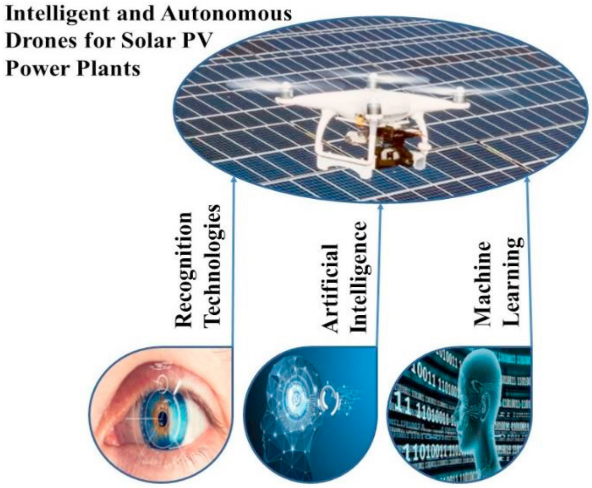


Fig. 4. Technologies empowering intelligence in drones

The above challenges in drones can overcome with the use of three advanced technologies shown in Fig. 4. These three technologies would empower the drone capability and allow to act intelligently with an automated action plan as per the instant data processing. Potential roles of the discussed techniques are shown in Table 4.

4.1. Recognition Technologies

Recognition technologies (RT), are referred as the tracking or capture based emerging techniques used to monitor the physical identification of the things in their original form and compare with subsequent changes happen to the things. This would allow the interpretation very easily and helps in identifying the causes for it. Recognition technologies include the image recognition, face recognition, voice recognition, gesture recognition, etc. Demand for such techniques is very high in the modern era, especially in the industrial, medical, manufacturing sectors. Recently drones have emerged into the solar industry, and to encounter the challenges faced by the drones, we need to opt for the recognition technologies[14]. In solar power plants, the following recognition technologies have scope: voice, facial, iris recognition enabled drones for authentication for authorized entry. Gesture, image recognition enabled drones for monitoring the PV system components and interpret them. From the gesture or the image, authorized persons can analyze the data and functioning of the PV systems. This will allow us to compile substantial possible interpretations of the monitored images and gestures (visual and thermal images) by the industrial, operation and maintenance experts. With RT enabling the drones would become more intelligent. Hence the scope of such things should be explored further.

4.2. Artificial Intelligence

Artificial Intelligence shortly referred as AI, and it functions mostly based on the computer simulated intelligence requiring very less support from the human workforce. The function of AI would be in similar to the human brain. Unlike the capabilities possessed by the human brain, the AI also capable doing computing models, prediction, pattern identification, learning abilities. AI serves as a potential service provider in many fields such as engineering, medicine, transport, industrial, economics, agriculture, etc. The primary reason behind the diversified applications is the highly capable skill on the solving the problems[14,15]. Typical and most common AI applications include the data analysis, data processing, robotics, drones, energy sector, etc. AI could enable the intelligence in the drones used for solar power plant monitoring. Drones enabled with AI analytics platform could support in identifying the faults in the power plant. Drones with AI will allow data processing to be done in less time and increases the quality of inspection. This intern enables having quick operation and maintenance. It facilitates the communication between the drone itself and the person who oversees operation and maintenance. AI will also help the drones to assist the operation and maintenance team for possible fault occurrence and remedies based on the historic monitored data. In this way, AI could make the drone more intelligence making the work much more straightforward for the humanity.

4.3. Machine Learning

Machine learning is otherwise referred as a profound, deep learning technique. It is mostly represented using the mathematical algorithms that help in improving the learning process with a wide range of realistic experiences. Machine learning is of three types: one is unsupervised learning which means having the ability to find different patterns (ability to detect patterns). The second one is supervised learning in which the learning and classification are done based on the previous algorithms, and third would be the reinforcement learning where the use of booties and chastisements were followed for strategic monitoring of PV plants. Using machine learning the drones can be made intelligent and autonomous by preprogramming the drone with the algorithm and mathematical tools[15].

5. Conclusion

A study on the monitoring of PV plants using human workforce and remote monitoring is described highlighting their pros and cons concerning the small and large-scale PV plants. The role of drones in monitoring small-scale and large-scale PV systems were discussed. Various types of drones and their configuration were studied from which one can select the appropriate drone for their requirement. Three technologies that could empower the intelligence and automation capabilities of the drone monitoring system is discussed and identified the potential roles of them in PV plants.

References

[1] MK Nallapaneni. (2015) "Impact of clean development mechanism on eco-friendly energy recovery technology." *Procedia Technology* **21**: 54-58.

[2] N. M. Kumar and G. H. K. Kumar. (2015) "Power generation using Green Technology in Iron and Steel industry." *2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO)*, Coimbatore, pp. 1-6.

[3] Singh GK. (2013) "Solar power generation by PV (photovoltaic) technology: a review." *Energy* **53**:1–13.

[4] Kumar, N. M., Reddy, P. R. K., and Praveen, K. (2017). "Optimal energy performance and comparison of open rack and roof mount mono c-Si photovoltaic Systems." *Energy Procedia* **117**:136-144.

[5] Nallapaneni Manoj Kumar, K. Sudhakar & M. Samykano (2017) "Techno-economic analysis of 1 MWp grid connected solar PV plant in Malaysia." *International Journal of Ambient Energy* DOI: 10.1080/01430750.2017.1410226

[6] Kumar, N. M., Kumar, M. R., Rejoice, P. R., and Mathew, M. (2017) "Performance analysis of 100 kWp grid connected Si-poly photovoltaic system using PVsyst simulation tool." *Energy Procedia* **117**:180-189.

[7] Madeti, S.R. and Singh, S.N. (2017) "Monitoring system for photovoltaic plants: A review." *Renewable and Sustainable Energy Reviews* **67**: 1180–1207

[8] Tejwani, R., Kumar, G., and Solanki, C. (2014) "Remote monitoring for solar photovoltaic systems in rural application using GSM voice channel." *Energy Procedia* **57**:1526-1535.

[9] Benlebna S., Kumar N.M., Tahri A. (2018) "Data acquisition system: On the solar photovoltaic module and weather parameters monitoring." *In Proceedings of International Conference on Computational Intelligence and Data Science (ICCIDS)*, Gurugram, India, April 7-8. (to be published in Procedia Computer Science).

[10] Jennifer Delony (2017) "5 Reasons Why Drones Are Going to Work for Solar Asset Managers." Renewable Energy World.

[11] Dronegird (2017) "The Current Challenges of Solar Site Inspections and How Drones Can Help You." https://www.dronegrid.com/blog/the-current-challenges-of-solar-inspections-and-how-drones-can-help-you

[12] Multi-copter. "The UAV Guide." http://wiki.theuavguide.com/wiki/Multicopter.

[13] Kevin O'Donovan (2017) "Technologies empowering the mobile worker – part 1: drone automation." IT Peer Network.

[14] C. Krittanawong (2018) "The rise of artificial intelligence and the uncertain future for physicians." *European Journal of Internal Medicine* **48**:13–14.

[15] Pavel Hamet, Johanne Tremblay (2017) "Artificial intelligence in medicine." *Metabolism Clinical and Experimental* **69**:36-40.