Volume 15, Issue-1
March, 2025, P10
ISSN: 2319-9253

# NOVEL EMBEDDED SYSTEM FOR REAL TIME FAULT DIAGNOSIS OF PHOTOVOLTAIC MODULES

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**ABSTRACT:** The innovative embedded technology described here can improve the efficiency and dependability of solar energy systems by detecting problems with photovoltaic (PV) modules in real time. To detect, categorize, and foresee problems like discoloration, degeneration, and hotspots, the system employs sophisticated machine learning algorithms and data processing techniques. The suggested technique leads to more efficient power generation, fewer power outages, and lower maintenance costs. An important resource for green power administration, the system has been experimentally validated to prove its rightness and efficacy in actual photovoltaic configurations.

***Keywords:*** Photovoltaic modules, fault diagnosis, embedded system, real-time monitoring, machine learning, signal processing, solar energy, predictive maintenance.

## 1. INTRODUCTION

Solar photovoltaic (PV) systems are expanding in popularity as a result of the rising demand for renewable energy. Shadowing, cell death, and electrical issues are just a few of the long-term issues that might make it difficult to guarantee optimal performance. Finding issues as they arise in real time is crucial for preventing significant energy losses and maintaining optimal performance. Conventional approaches to diagnosis frequently employ inefficient and time-consuming standard testing. In response to these issues, a unique integrated device was developed to detect malfunctions in solar modules in real-time.

Utilizing state-of-the-art sensors, microcontroller designs, and machine learning techniques, this embedded system detects and organizes issues with photovoltaic modules. Unlike previous approaches that depend on passive data analysis or human checks, our system provides continuous, real-time monitoring. The data-driven methods it employs allow it to pinpoint outliers and foretell when things might not work out as expected. By reducing maintenance needs and downtime, this technique makes solar installations more reliable and long-lasting.

One defining feature of this state-of-the-art integrated technology is its independence from human intervention. Monitoring the entire system is made possible by efficiently collecting data from several photovoltaic panels simultaneously. With edge computing, massive volumes of cloud computing are unnecessary, allowing for quicker local decision-making. Problems can be fixed more quickly when operators can receive diagnostic results remotely using wireless communication.

This device represents a significant advancement in photovoltaic defect testing technology because of its expansion. To increase energy production and decrease waste due to invisible issues, an advanced monitoring system can be integrated into the PV system. Making renewable energy production easier, this strategy advances the primary objective of constructing smart infrastructure. The world's energy transitions depend on the reliability and efficiency of photovoltaic setups, which is why real-time integrated defect detection systems are crucial.

## 2. LITERATURE SURVEY

Pandian et al. (2024) A machine learning model that uses Artificial Neural Networks (ANN) and Support Vector Machines (SVM) can quickly figure out what's wrong with solar PV systems. In order to enhance the precision of PV defect detection, this research makes use of SVM for classification and ANN for feature extraction. Both the accuracy of defect detection and the rate of false alarms are enhanced by the suggested model. Datasets collected experimentally from functional solar systems corroborate the research's validity. A considerable enhancement in the efficacy of fault categorization is shown by the results.

Mellit et al. (2023) An embedded system that diagnoses and remotely monitors solar panel issues using the Internet of Things. To enhance the accuracy of fault detection, the approach employs machine learning methods. It detects irregularities in photovoltaic system operation using sensors and real-time data analytics. With this method, problems can be found quickly, which reduces maintenance expenses and system downtime. The research shows that managing renewable energy installations using the Internet of Things has many benefits.

Wang et al. (2023) To account for labeling errors, suggest a method for the real-time detection of photovoltaic array failures. The research applies Distributionally Robust Logistic Regression (DRLR) to enhance defect classification in uncertain settings. By training on a wide variety of PV datasets, the model becomes more resilient. It outperforms conventional logistic regression methods, as shown by the results. Solar power systems might benefit from the method's capacity to detect faults in real time.

Benghanem et al. (2023) To diagnose problems with photovoltaic modules, build an embedded model that combines ML with convolutional neural networks (CNN). In order to identify potential issues, the research used thermographic imaging to spot temperature anomalies. Convolutional neural networks (CNNs) make feature extraction easier, and machine learning approaches classify various defect kinds. The suggested method improves the dependability and precision of PV problem identification. For the purpose of system validation, thermographic data collected in the actual environment is employed.

Parsafar & Qaderi Baban (2023) Showcase an embedded system-based technology for the real-time diagnosis of electrical panel problems. Integrating sensors for real-time monitoring of electrical issues is crucial, according to the research's findings. This system can identify and categorize potential issues in real-time, allowing it to head them off at the pass. Improving safety and reducing maintenance costs are the goals of the proposed strategy. The research's actual application in industrial settings validates its efficacy.

Parsafar & Qaderi Baban (2023) Investigate the detection of electrical panel problems in real-time in the same manner. The results show that the algorithm accurately identified different types of mistakes. This approach makes use of embedded technology to provide continuous monitoring. According to the research, it helps reduce unplanned wait times. Additional evidence that the model can be used for electrical system management is provided by the results.

Mehmood et al. (2023) An approach is suggested that makes use of the IoT, cloud computing, and artificial neural networks (ANN) to evaluate the soiling ratio in photovoltaic (PV) systems. As dust accumulates on photovoltaic panels, this technique can foretell when their efficiency may decrease. This method allows for the automatic suggestion of cleaning products and the real-time identification of soiling. Soiling levels can be more accurately determined with the help of the ANN model. This research shows that optimal photovoltaic maintenance requires cloud computing.

Ledmaoui et al. (2022) Make a deep learning model that can detect defects in solar modules using thermographic imaging and integrate it into such modules. Automatic feature extraction is achieved by means of Deep Convolutional Neural Networks (DCNN) by means of the system. The suggested technique uses infrared imaging to enhance the precision of defect classification. Testing is done using thermographic data taken from the actual world. The results show that AI has the potential to help with PV problem diagnosis.

Mellit & Kalogirou (2022) Find out which ensemble and machine learning approaches are best for identifying PV problems. Random Forest, SVMs, and deep learning models are some of the categorization techniques that are compared in the research. An investigation is conducted to determine the best machine learning technique for detecting solar faults. The results provide light on how to improve solar system diagnostics. Ensemble learning is shown to be effective in defect categorization in this experiment.

Sairam et al. (2022) Construct a perceptible AI system for use at the edge that can identify defects in solar panels. Rolling out machine learning models to edge devices is the program's primary objective. This approach lessens reliance on cloud services while improving real-time diagnostics. By enhancing response speed and simultaneously protecting data privacy during problem identification, the technology is truly remarkable. Evidence from real-world solar applications shows that the model works.

Hong & Pula (2022) An advanced 3D Convolutional Neural Network (CNN) capable of accurately identifying and categorizing solar array flaws. To enhance accuracy, the research employs a three-dimensional feature extraction technique. The method accurately identifies a wide range of errors. Large PV datasets are used to train the model. Results show that our approach outperforms conventional methods for fault categorization.

Hojabri et al. (2022) A method for detecting solar breakdowns using network-integrated supervised learning. Machine learning algorithms and smart sensors are part of the system. The importance of real-time monitoring in improving the reliability of solar systems is emphasized by the research's findings. Downtime is minimized by the method's early problem detection. The results of the field tests are confirmed in the report.

Mellit et al. (2021) Make your platform available that can remotely detect solar panel faults using blockchain and AI. The investigation integrates cloud computing with defect detection driven by artificial intelligence. The dependability of solar systems is enhanced by this method, which enables predictive maintenance. The technology analyzes data in real-time to identify errors with pinpoint accuracy. The research demonstrates how the IoT may be used to effectively control renewable energy sources.

Zhang et al. (2021) Using Extreme Gradient Boosting (XGBoost), find a way to diagnose issues with photovoltaic arrays. This investigation uses decision trees to enhance classification accuracy. By analyzing historical photovoltaic data, the model is able to forecast and detect issues. This approach outperforms state-of-the-art ML techniques. Putting the research to the test in real-world scenarios validates its efficacy.

Kapucu & Cubukcu (2021) Present a supervised ensemble learning approach for defect detection in photovoltaic strings. The research evaluates and combines various machine learning techniques to enhance accuracy. This method enhances the accuracy of classification in intricate photovoltaic datasets. The results of the experiment show that ensemble learning is beneficial. The photovoltaic diagnostics model is reliable for use in real-time.

Li et al. (2020) Offer an improved defect diagnostic tool that makes use of decision trees and genetic algorithms. Using evolutionary computation, the research improves the classification of photovoltaic array defects. Picking the right features improves the diagnosis

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accuracy. To ensure the accuracy of the model, it is tested on a wide range of PV datasets. Genetic algorithms are quite good at improving machine learning, according to the results.

Zhu et al. (2020) Create a feature-selection-based decision tree model to detect PV issues. The research enhances the accuracy of classification by removing irrelevant data. The model streamlines computations without compromising on efficiency. The methodology is evaluated using records from industrial solar systems. Extensive research has confirmed its efficacy in real-world scenarios.

Liu & Sun (2019) Using Random Forest classification techniques, build the best solar power forecasting model. Predictions of photovoltaic electricity generation are made more accurate by the research. To improve the accuracy of its projections, the model incorporates operational data and weather forecasts. Solar power projections are made more accurate with this method. The research proves that it's good for managing energy.

Li et al. (2019) In order to identify issues with solar arrays, create a state-of-the-art Deep Belief Network (DBN). Using deep learning, the model aspires to enhance defect categorization. This method examines massive PV databases and generates very accurate diagnoses. Results show that DBN is more effective than traditional ML techniques. The model is supported by empirical data.

Ma et al. (2019) The diagnosis of issues in solar systems is accomplished with the help of a Support Vector Machine (SVM) that has been optimized using a Genetic Algorithm. The model's classification accuracy is enhanced through the use of evolutionary computing. With this method, we can pick the best features to boost performance. The findings of the analysis are backed by evidence from a wide variety of PV systems. Its ability to accurately identify photovoltaic issues has been validated by the investigation.

Afifi et al. (2018) Create a system that can identify photovoltaic array irregularities in real time using FPGAs. The research speeds up the defect classification process by using hardware acceleration. The strategy enhances the system's dependability and detection speed. The accuracy of the model has been confirmed by field experiments. This article explains why field-programmable gate arrays (FPGAs) are a good choice for renewable energy diagnostics.

## 3. PROPOSED SYSTEM

A proposed integrated system for real-time failure detection in photovoltaic (PV) modules combines machine learning (ML) with the Internet of Things (IoT). By collecting and analyzing data in real-time utilizing state-of-the-art sensors and edge computing, it facilitates the rapid discovery of faults.The goal of creating a hybrid model is to improve the accuracy of classification by combining SVMs with CNNs.

Temperature, voltage, and current are just a few of the electrical parameters that the system constantly monitors for potential issues. The solution lowers energy waste and enhances predictive maintenance with real-time alarms and data stored in the cloud.

The decision-making algorithm of the embedded platform has been enhanced to reduce noise and false positives. As a further step toward improved defect classification, thermal imaging and current-voltage (I-V) characteristic analysis are employed.The machine is powered by an inbuilt low-power CPU, which ensures that it needs minimal power. In order to facilitate remote supervision, a wireless connection module transmits diagnostic data to a central tracking system. This technique is ideal for extensive photovoltaic installations because to its adaptability to various weather conditions.

Users can more easily access the system because of its graphical user interface, which allows them to view errors as they occur in real time. Using a coherent self-learning strategy improves the

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International Journal of Advanced Research & Innovations
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accuracy of fault prediction. Automatic flaw categorization with minimal human intervention is now a reality, all thanks to deep learning algorithms. The system's capacity to be expanded in a modular fashion facilitates better energy management and facilitates integration with other smart systems. This state-of-the-art embedded technology improves the efficiency and dependability of photovoltaic power generation through the acceleration and precision of defect detection.

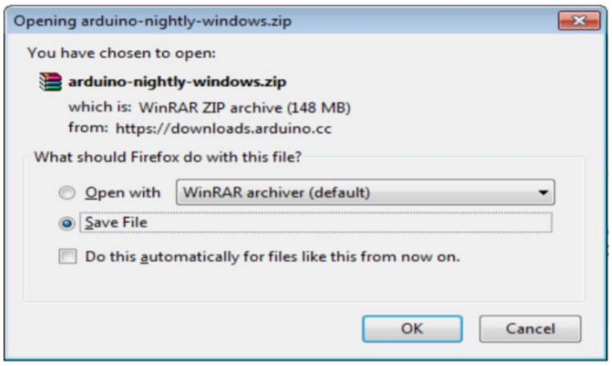
**BENEFITS:**

- **Real-Time Fault Detection** – The PV panels are constantly monitored, allowing for the rapid detection of any issues and subsequent improvement in system performance and reduction in energy loss.
- **High Diagnostic Accuracy** – Finding faults, reducing false positives, and increasing reliability are all made easier with the use of modern machine learning methods like CNN and SVM.
- **Predictive Maintenance** – The system is able to anticipate potential errors by analyzing both historical and current data, which facilitates the resolution of issues prior to their escalation.
- **Remote Monitoring & Control** – There is no longer a need for on-site inspections thanks to the addition of IoT devices, which allow for remote monitoring and problem fixing.
- **Energy Efficiency** – Reliability and low energy consumption are two goals of the embedded system.
- **Scalability & Adaptability** – The system's modular expansion capabilities make it suitable for solar projects of varying sizes.
- **Cost Reduction** – Compared to manual methods, automated fault diagnostic systems save maintenance costs, increase PV module lifespans, and save labor expenses.
- **Improved System Reliability** – The system's overall efficiency and power output are enhanced by continuous health monitoring, which ensures that it always operates at its best.
- **Environmental Sustainability** – Early problem detection allows us to reduce energy waste and improve the performance of renewable resources. These two factors contribute to the energy transition being more long-term viable.
- **Seamless Integration with Smart Grids** – Energy management, grid stability, and distribution efficiency can all be improved with the help of technology in conjunction with smart grids.

## 4. DESCRIPTION OF TOOLS

**Arduino IDE:**

The Arduino IDE displays the software for programming. One location to acquire the most recent version of the Arduino IDE is the official Arduino website. Check the software's compatibility with your current OS to be sure it's compatible with Windows, Linux, or iOS. You will be able to view the contents of the file once the download is complete.




To launch the Arduino IDE, turn on the power. After downloading the Arduino IDE software is complete, remove the folder from the packaging. The "infinite" software's (application.exe) icon might be located here. Simply open the integrated development environment (IDE) by double-clicking the button.

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International Journal of Advanced Research & Innovations
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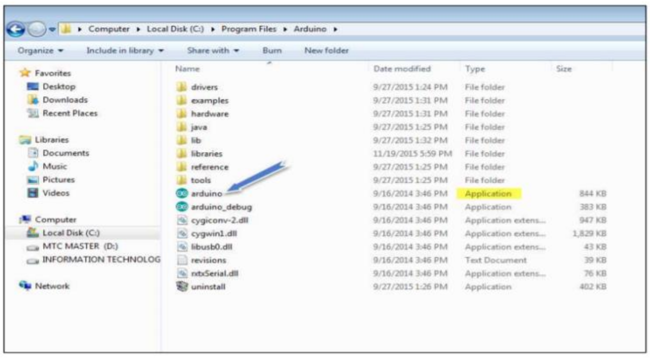
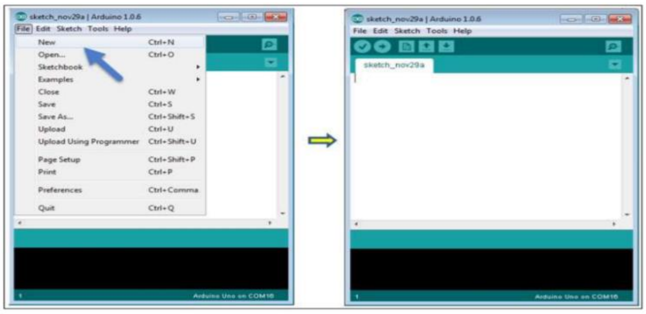
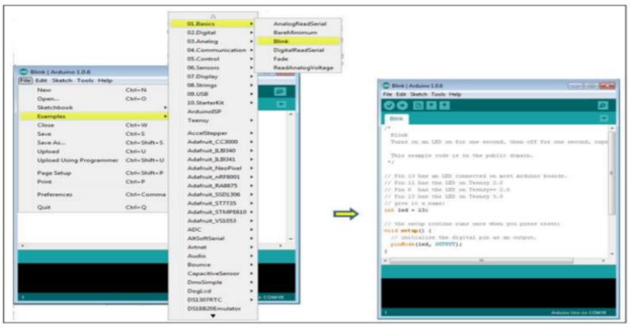


We kindly request that you initiate the process without delay. There are two options shown to you when you launch the application for the first time:

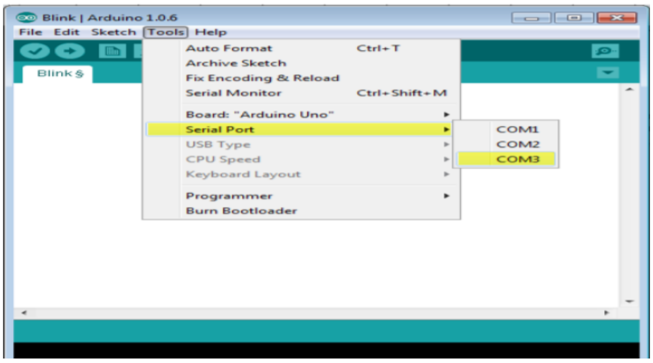
- Create a new project.
- Open an existing project example

To initiate a fresh project, choose "New" from the "File" menu.





Our decision to choose Blink as our model was made not long ago. The light will turn off after a specific period of time has elapsed. Out of the available cases, pick the one that suits your needs the most. This is why you need to use extreme caution when choosing a machine. Selecting the USB driver associated with the Arduino board is now possible. Click on "Serial Port" in the "Tools" menu. Because other hardware is using COM1 and COM2, you can utilize COM3 or a later version. Once you remove the Arduino board, you can utilize the configuration tool to locate the solution. Remove the component that rests on the Arduino wiring. After you've linked the two devices, be sure to use a stable USB port.

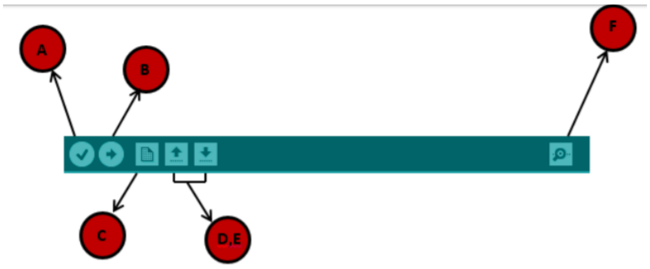



Ensure that the components in the Arduino IDE menu are working properly before sending the code to the board.

- ➢ In order to identify potential issues.
- ➢ This allowed the Arduino board to execute programs.
- ➢ A fresh picture can start only by hitting a button on a computer.
- ➢ A broad overview was much easier to come by in bygone days.
- ➢ Rest certain, you will secure employment.
- ➢ On the circuit board or other device you'll find the instructions for setting up serial links.

After a list appears, choose "Upload" from it.

After a brief blinking period, the RX and TX LEDs of the device should switch off completely. The progress bar will display "Done uploading" once the upload is complete.




In this section, we will go over the structure of the Arduino program and define various words used by the Arduino community. The Arduino software is available for free download and can be used on any computer. You can use the Java environment and the C/C++ microcontroller tools' source code for free under both the LGPL and the GPL.

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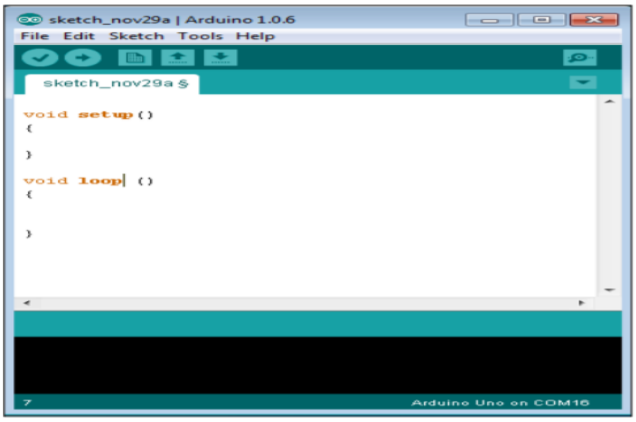
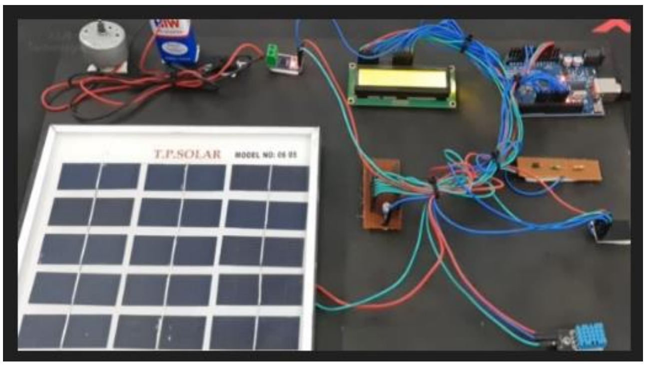
Arduino views the code as nothing more than a "sketch." The structure, including of variables, constants, values, and functions, is an integral aspect of each Arduino program. Learn all the ins and outs of programming in accordance with the guidelines of the Arduino program with this comprehensive course. Our conversations will be structured around the Structure. Two primary responsibilities fall on the shoulders of the program management team:

- Setup( ) function
- Loop( ) function




A fundamental knowledge for any C programmer should be the "data types" that outline the syntax for defining variables and functions. How can we best manage and store data? The features of the variable determine this. You can see what kinds of data types the Arduino code utilizes in the table below.

## 5. RESULTS AND DISCUSSION





## 6. CONCLUSION

To sum up, current integrated technology greatly improves solar energy management by facilitating the real-time detection of photovoltaic module issues. The answer improves efficiency and decreases energy waste by using machine learning algorithms and remote monitoring based on the internet of things to detect issues early on. This method has improved predictive maintenance, reduced downtime, and extended the life of photovoltaic modules in real time. Consequently, solar power systems offer greater dependability and affordability.

The capacity to scale allows for the seamless integration of various photovoltaic systems, spanning from large-scale solar farms to residential solar panels. It is compatible with smart infrastructure and uses less power, making it ideal for sustainable energy management. System performance and operational expenses are both enhanced by its self-diagnostics capabilities, which also decrease the necessity for human inspections.

Making solar panels becomes easier with this built-in gadget, which contributes to the global transition to renewable energy. Maximum energy output is guaranteed, eco-friendly practices are encouraged, and grid stability is improved. For photovoltaic power generation to remain viable and effective in the long run, automated methods for discovering and addressing faults will become increasingly vital as solar technology advances.

## FUTURE SCOPE:

Improving the integration of artificial intelligence (AI) is necessary for embedded systems that detect issues with solar (PV) modules in real time. Utilizing state-of-the-art deep learning techniques, self-learning systems are able to adjust to various module types and environmental conditions, resulting in more precise defect detection. Photovoltaic maintenance will become more efficient and cost-effective with the use of AI-powered automation, which will also reduce the need for human intervention. By integrating 5G with edge computing, we can speed up data processing and analytics in real time while simultaneously decreasing the time it takes to identify issues. The ability to make judgments and implement fixes more swiftly depends on the overall reliability of PV systems. Reducing the need to keep critical operating data in the cloud is another way edge-based fault diagnostics would increase security.

Solar cells that are equipped with intelligent embedded systems have a strong chance of fixing themselves. In order to prevent issues, photovoltaic panels could autonomously adjust their settings or activate backup systems using predictive maintenance algorithms. More research into blockchain-based defect tracking might lead to more trustworthy, transparent, and secure distributed solar energy networks. Solar power generation relies on embedded fault detection solutions to ensure its efficacy and longevity in the increasingly prevalent smart infrastructures and green energy systems.

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