Tekhnê

Tecnología al servicio de la sociedad

Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

Universidad Distrital Francisco José de Caldas
Facultad Tecnológica

Vol. 19 No. 2
July - December 2022
ISSN 1692-8407

Tekhnê
Tecnología al servicio de la sociedad
Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

Volumen 19 - Número 2 - 2022

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
FACULTAD TECNOLÓGICA

Cubierta: Monumento a India Catalina, Cartagena de Indias (Colombia)
Autor: Fredy H. Martínez S.

Contracubierta:
- Superior izquierda: ROC curve (Cartagena, C., and Martín, J.)
- Superior derecha: Flowchart of the control scheme (Marin, A., and Reyes, J.)
- Centro: Laboratory prototype (Marin, A., and Reyes, J.)
- Inferior izquierda: Bot messages on Telegam (Marin, A., and Reyes, J.)
- Inferior derecha: Confusion matrix of the ResNet-50 model (Sánchez, K., and Reyes, C.)

Corrección de estilo español
Angélica Viviana Rendón Calderón

Corrección de estilo inglés
Fredy H. Martínez S.

Impresión
Imprenta Universidad Distrital Francisco José de Caldas
Formato 21.5 × 28 cm
Papel Bond 75 g
Tiraje de 70 ejemplares

Revista Tekhnê

La revista **Tekhnê** es una publicación institucional de la Facultad Tecnológica de la Universidad Distrital Francisco José de Caldas. Posee un carácter científico, y atiende a la comunidad nacional e internacional especialista en áreas de ingenierías eléctrica, electrónica, mecánica, de sistemas, industrial y civil. Publica resultados de investigación en inglés (artículos originales e inéditos), y está completamente abierta a especialistas de todo el mundo en calidad de autores y/o lectores. Es arbitrada mediante un proceso doble ciego, con rotación continua de árbitros. La periodicidad de la conformación de sus comités Científico y Editorial está sujeta a la publicación de artículos en revistas indexadas internacionalmente por parte de sus respectivos miembros.

Periodicidad

La revista **Tekhnê** posee una periodicidad semestral, coincidente con los semestres académicos de la Universidad Distrital. La publicación se realiza los meses de julio y diciembre. El primer volumen de la revista se publicó el primer semestre de 2003, manteniendo su regularidad hasta la fecha.

Misión

La revista **Tekhnê** tiene como misión divulgar resultados de investigación realizados en el área de la ingeniería, a través de la publicación de artículos originales e inéditos, realizados por académicos y profesionales pertenecientes a instituciones nacionales o extranjeras del orden público o privado. Propende por la difusión de resultados y su acceso abierto y libre.

Público objetivo

La revista está dirigida a docentes, investigadores, estudiantes y profesionales interesados en la actualización permanente de sus conocimientos y el seguimiento de los procesos de investigación científica en el campo de la ingeniería.

Forma de adquisición

La revista **Tekhnê** se puede adquirir a través de compra o canje.

Reproducción

Dirección postal

Prof. Fredy H. Martínez S.
Editor y director revista Tekhnê
Sala de Revistas, Bloque 5, Oficina 301
Facultad Tecnológica
Universidad Distrital Francisco José de Caldas
Transversal 70B No. 73A-35 sur
Teléfono: (571) 3238400 Ext. 5003
Celular: (57) 3005585481
Bogotá D.C., Colombia
E-Mail: fhmartinezs@udistrital.edu.co
Url: https://revistas.udistrital.edu.co/index.php/tekhne

Tekhnê

Tecnología al servicio de la sociedad

Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

Volume 19 - Number 2 - 2022

UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS
FACULTAD TECNOLÓGICA

Cover picture: India Catalina Monument, Cartagena de Indias (Colombia)
Author: Fredy H. Martínez S.

Back cover picture:
- Top left: ROC curve (Cartagena, C., and Martín, J.)
- Top right: Flowchart of the control scheme (Marin, A., and Reyes, J.)
- Middle: Laboratory prototype (Marin, A., and Reyes, J.)
- Lower left: Bot messages on Telegam (Marin, A., and Reyes, J.)
- Lower right: Confusion matrix of the ResNet-50 model (Sánchez, K., and Reyes, C.)

Style correction in spanish
Angélica Viviana Rendón Calderón

Style correction in english
Fredy H. Martínez S.

Printed by
Imprenta Universidad Distrital Francisco José de Caldas
Format: 21.5 × 28 cm
Paper: Bond 75 g
Printing: 70 copies

Tekhnê Journal

Tekhnê journal is an institutional publication of the Facultad Tecnológica of the Universidad Distrital Francisco José de Caldas (Bogotá D.C. - Colombia). It has a scientific character and serves the national and international community specialized in the areas of electrical, electronic, mechanical, systems, industrial and civil engineering. It publishes research results in English (original and unpublished articles), and is completely open to specialists from around the world as authors and/or readers. It is arbitrated through a double-blind process, with continuous rotation of arbitrators. The periodicity of the formation of its Scientific and Editorial Committees is subject to the publication of articles in internationally indexed journals by their respective members.

Periodicity

Tekhnê journal is published every six months, coinciding with the academic semesters of the Universidad Distrital. It is published in July and December. The first volume of the journal was published in the first semester of 2003, maintaining its regularity to date.

Mission

The mission of **Tekhnê** journal is to disseminate research results conducted in the area of engineering, through the publication of original and unpublished articles by academics and professionals belonging to national or foreign institutions of public or private order. It aims at the diffusion of results and their open and free access.

Target audience

The journal is aimed at professors, researchers, students, and professionals interested in permanently updating their knowledge and monitoring scientific research processes in the field of engineering.

Form of adquisition

Tekhnê journal can be purchased, or exchanged.

Reproduction

Mailing address

Prof. Fredy H. Martínez S.
Editor and director Tekhnê Journal
Sala de Revistas, Bloque 5, Oficina 301
Facultad Tecnológica
Universidad Distrital Francisco José de Caldas
Transversal 70B No. 73A-35 sur
Phone: (571) 3238400 Ext. 5003
Cell phone: (57) 3005585481
Bogotá D.C., Colombia
E-Mail: fhmartinezs@udistrital.edu.co
Url: https://revistas.udistrital.edu.co/index.php/tekhne

Declaración de ética y buenas prácticas

Tekhnê
Tecnología al servicio de la sociedad
Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

Revista Tekhnê
Universidad Distrital Francisco José de Caldas
Facultad Tecnológica

El comité editorial de la revista **Tekhnê** está comprometido con altos estándares de ética y buenas prácticas en la difusión y transferencia del conocimiento, para garantizar el rigor y la calidad científica. Es por ello que ha adoptado como referencia el Código de Conducta que, para editores de revistas científicas, ha establecido el Comité de Ética de Publicaciones (COPE: Committee on Publication Ethics) dentro de los cuales se destaca:

Obligaciones y responsabilidades generales del equipo editorial

En su calidad de máximos responsables de la revista, el comité y el equipo editorial de **Tekhnê** se comprometen a:

- Aunar esfuerzos para satisfacer las necesidades de los lectores y autores.
- Propender por el mejoramiento continuo de la revista.
- Asegurar la calidad del material que se publica.
- Velar por la libertad de expresión.
- Mantener la integridad académica de su contenido.
- Impedir que intereses comerciales comprometan los criterios intelectuales.
- Publicar correcciones, aclaraciones, retractaciones y disculpas cuando sea necesario.

Relaciones con los lectores

Los lectores estarán informados acerca de quién ha financiado la investigación y sobre su papel en la investigación.

Relaciones con los autores

Tekhnê se compromete a asegurar la calidad del material que publica, informando sobre los objetivos y normas de la revista. Las decisiones de los editores para aceptar o rechazar un documento para su publicación se basan únicamente en la relevancia del trabajo, su originalidad y la pertinencia del estudio con relación a la línea editorial de la revista.

La revista incluye una descripción de los procesos seguidos en la evaluación por pares de cada trabajo recibido. Cuenta con una guía de autores en la que se presenta esta información. Dicha guía se actualiza regularmente y contiene un vínculo a la presente declaración ética. Se reconoce el derecho de los autores a apelar las decisiones editoriales.

Los editores no modificarán su decisión en la aceptación de envíos, a menos que se detecten irregularidades o situaciones extraordinarias. Cualquier cambio en los miembros del equipo editorial no afectará las decisiones ya tomadas, salvo casos excepcionales en los que confluyan graves circunstancias.

Relaciones con los evaluadores

Tekhnê pone a disposición de los evaluadores una guía acerca de lo que se espera de ellos. La identidad de los evaluadores se encuentra en todo momento protegida, garantizando su anonimato.

Proceso de evaluación por pares

Tekhnê garantiza que el material remitido para su publicación será considerado como materia reservada y confidencial mientras que se evalúa (doble ciego).

Reclamaciones

Tekhnê se compromete responder con rapidez a las quejas recibidas y a velar para que los demandantes insatisfechos puedan tramitar todas sus quejas. En cualquier caso, si los interesados no consiguen satisfacer sus reclamaciones, se considera que están en su derecho de elevar sus protestas a otras instancias.

Fomento de la integridad académica

Tekhnê asegura que el material que publica se ajusta a las normas éticas internacionalmente aceptadas.

Protección de datos individuales

Tekhnê garantiza la confidencialidad de la información individual (por ejemplo, de los profesores y/o alumnos participantes como colaboradores o sujetos de estudio en las investigaciones presentadas).

Seguimiento de malas prácticas

Tekhnê asume su obligación para actuar en consecuencia en caso de sospecha de malas prácticas o conductas inadecuadas. Esta obligación se extiende tanto a los documentos publicados como a los no publicados. Los editores no sólo rechazarán los manuscritos que planteen dudas sobre una posible mala conducta, sino que se consideran éticamente obligados a denunciar los supuestos casos de mala conducta. Desde la revista se realizarán todos los esfuerzos razonables para asegurar que los trabajos sometidos a evaluación sean rigurosos y éticamente adecuados.

Integridad y rigor académico

Cada vez que se tenga constancia de que algún trabajo publicado contiene inexactitudes importantes, declaraciones engañosas o distorsionadas, debe ser corregido de forma inmediata.

En caso de detectarse algún trabajo cuyo contenido sea fraudulento, será retirado tan pronto como se conozca, informando inmediatamente tanto a los lectores como a los sistemas de indexación.

Se consideran prácticas inadmisibles, y como tal se denunciarán las siguientes: el envío simultáneo de un mismo trabajo a varias revistas, la publicación duplicada o con cambios irrelevantes o parafraseo del mismo trabajo, o la fragmentación artificial de un trabajo en varios artículos.

Relaciones con los propietarios y editores de revistas

La relación entre editores, editoriales y propietarios estará sujeta al principio de independencia editorial. **Tekhnê** garantizará siempre que los artículos se publiquen con base en su calidad e idoneidad para los lectores, y no con vistas a un beneficio económico o político. En este sentido, el hecho de que la revista no se rija por intereses económicos, y defienda el ideal de libre acceso al conocimiento universal y gratuito, facilita dicha independencia.

Conflicto de intereses

Tekhnê establecerá los mecanismos necesarios para evitar o resolver los posibles conflictos de intereses entre autores, evaluadores y/o el propio equipo editorial.

Quejas/denuncias

Cualquier autor, lector, evaluador o editor puede remitir sus quejas a los organismos competentes.

Code of ethics and good practice

Tekhnê
Tecnología al servicio de la sociedad
Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

Tekhnê Journal
Universidad Distrital Francisco José de Caldas
Facultad Tecnológica

The editorial board of **Tekhnê** journal is committed to ethics high standards and good practice for knowledge dissemination and transfer, in order to ensure rigour and scientific quality. That is why it has taken as reference the Code of Conduct, which has been established by the Committee on Publication Ethics (COPE) for scientific journal editors; outlining the following:

General duties and responsibilities of the editorial board

As most responsible for the journal, **Tekhnê** committee and the editorial board are committed to:
- Joining efforts to meet the readers and authors needs.
- Tending to the continuous improvement of the Journal.
- Ensuring quality of published material.
- Ensuring freedom of expression.
- Maintaining the academic integrity of their content.
- Prevent commercial interests compromise intellectual standards.
- Post corrections, clarifications, retractions and apologies when necessary.

Relations with readers

Readers will be informed about who has funded the research and their role in the research.

Relations with authors

Tekhnê is committed to ensuring the quality of published material, informing the goals and standards of the journal. The decisions of publishers to accept or reject a paper for publication are based solely on the relevance of the work, originality and pertinence of the study with journal editorial line.

The journal includes a description of the process for peer evaluation of each received work, and has an authors guide with this information. The guide is regularly updated and contains a link to this code of ethics. The journal recognizes the right of authors to appeal editorial decisions.

Publishers will not change their decision in accepting or rejecting articles, unless extraordinary circumstances or irregularities are detected. Any change in the editorial board members will not affect decisions already made, except for unusual cases where serious circumstances converge.

Relations with evaluators

Tekhnê makes available to reviewers a guide to what is expected from them. Reviewers identity is protected at all times, ensuring anonymity.

Peer review process

Tekhnê ensures that material submitted for publication will be considered private and confidential issue while being reviewed (double blind).

Claims

Tekhnê is committed to respond quickly to complaints and ensure that dissatisfied claimant can process all complaints. In any case, if applicants fail to satisfy their claims, the journal considers that they have the right to raise their protests to other instances.

Promoting academic integrity

Tekhnê ensures that the published material conforms to internationally accepted ethical standards.

Protection of individual data

Tekhnê guarantees the confidentiality of individual information (e.g. participant teachers and/or students as collaborators or subjects of study in the presented research).

Tracking malpractice

Tekhnê accepts the obligation to act accordingly in case of suspected malpractice or misconduct. This obligation extends both to publish and unpublished documents. The editors not only reject manuscripts with doubts about possible misconduct, but they are considered ethically obligated to report suspected cases of misconduct. From the journal every reasonable effort is made to ensure that works submitted for evaluation are rigorous and ethically appropriate.

Integrity and academic rigour

Whenever evidence that a published work contains significant misstatements, misleading or distorted statements, it must be corrected immediately.

In case of any work with fraudulent content is detected, it will be removed as soon as it is known, and immediately informing both readers and indexing systems.

Practices that are considered unacceptable and as such will be reported: simultaneous sending of the same work to various journals, duplicate publication with irrelevant changes or paraphrase of the same work, or the artificial fragmentation of a work in several articles.

Relations with owners and journal editors

The relation between editors, publishers and owners will be subject to the principle of editorial independence. **Tekhnê** will ensure that articles are published based on their quality and suitability for readers, and not for an economic or political gain. In this sense, the fact that the journal is not governed by economic interests, and defends the ideal of universal and free access to knowledge, provides that independence.

Conflict of interest

Tekhnê will establish the necessary mechanisms to avoid or resolve potential conflicts of interest between authors, reviewers and/or the editorial board itself.

Complaints/allegations

Any author, reader, reviewer or editor may refer their complaints to the competent authorities.

Volume 19 - Number 2 - 2022

Index

Editorial

En los últimos años, en muchos países del mundo, entre ellos Colombia, ha disminuido el interés de los jóvenes por las carreras técnicas tradicionales, como la ingeniería. Esta tendencia tiene consecuencias significativas tanto para las instituciones universitarias como para la fuerza laboral.

Una de las principales consecuencias es la disminución de la matrícula en programas de ingeniería en las universidades. Esto tiene un impacto directo en la sostenibilidad financiera de las universidades, ya que menos estudiantes significan menos ingresos. Además, un descenso de las matriculaciones en programas de ingeniería puede conducir a un descenso de la calidad de la enseñanza, puesto que las universidades pueden tener dificultades para atraer y retener a profesores de alta calidad en ausencia de un número suficiente de matriculaciones de estudiantes. Otra consecuencia es la posible escasez de ingenieros cualificados en la población activa. La ingeniería es una profesión crítica esencial para el desarrollo de infraestructuras y tecnología, y una escasez de ingenieros puede impedir el progreso y la innovación en estas áreas. Además, el descenso del interés por la ingeniería también puede provocar una escasez de profesionales en otros campos técnicos, como la construcción y la fabricación, ya que muchos de estos campos dependen de los ingenieros para diseñar y desarrollar nuevos productos y procesos.

Hay varias causas posibles del descenso del interés por las carreras técnicas tradicionales. Una posible causa es la falta de conocimiento de las oportunidades y beneficios que ofrecen estas carreras. Es posible que muchos jóvenes no sean conscientes de la gran demanda de ingenieros y del potencial de carreras bien remuneradas y satisfactorias. Además, la imagen de la ingeniería como una profesión de "nerds" o "poco cool" también puede disuadir a los jóvenes de seguirla. Otra posible causa es la percepción de que estas carreras no son tan flexibles o creativas como otras. Muchos jóvenes pueden estar más interesados en carreras que les permitan expresar su individualidad y creatividad, como las artes o el espíritu empresarial. Además, la falta de flexibilidad de las carreras técnicas tradicionales también puede disuadir a algunos jóvenes de seguirlas, ya que puede que no tengan la posibilidad de cambiar de carrera fácilmente o no tengan las mismas oportunidades de trabajar a distancia que otras carreras.

Prof. Fredy H. Martínez S., Ph.D
Docente Facultad Tecnológica
Universidad Distrital Francisco José de Caldas

Editorial

In recent years, there has been a decline in the interest of young people in traditional technical careers, such as engineering, in many countries around the world, including Colombia. This trend has significant consequences for both university institutions and the workforce.

One of the main consequences is the decline in enrollment in engineering programs at universities. This has a direct impact on the financial sustainability of universities, as fewer students mean less revenue. Additionally, a decline in enrollment in engineering programs can lead to a decline in the quality of education, as universities may struggle to attract and retain high-quality faculty members in the absence of sufficient student enrollment. Another consequence is the potential shortage of qualified engineers in the workforce. Engineering is a critical profession that is essential for the development of infrastructure and technology, and a shortage of engineers can impede progress and innovation in these areas. Furthermore, the decline in interest in engineering can also lead to a shortage of professionals in other technical fields, such as construction and manufacturing, as many of these fields rely on engineers to design and develop new products and processes.

There are several possible causes of the decline in interest in traditional technical careers. One possible cause is a lack of awareness of the opportunities and benefits that these careers offer. Many young people may not be aware of the high demand for engineers and the potential for high-paying and fulfilling careers. Additionally, the image of engineering as a "nerdy" or "uncool" profession may also discourage young people from pursuing it. Another possible cause is the perception that these careers are not as flexible or creative as other careers. Many young people may be more interested in careers that allow them to express their individuality and creativity, such as the arts or entrepreneurship. Furthermore, the lack of flexibility in traditional technical careers may also discourage some young people from pursuing them, as they may not have the ability to change careers easily or have the same opportunities to work remotely as other careers.

Prof. Fredy H. Martínez S., Ph.D
Professor at the Facultad Tecnológica
Universidad Distrital Francisco José de Caldas

Tekhnê
July - December 2022, Vol. 19, No. 2, pp. 13 – 22

ISSN 1692-8407

Visual inspection of transmission tower insulators

Inspección visual de aisladores para torres de transmisión

Camila A. Cartagena B.[1] and John E. Martín L.[2]
[1]Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
cacartagenab@correo.udistrital.edu.co
[2]Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
jemartinl@correo.udistrital.edu.co

One of the most important processes in the maintenance of electrical networks is the detection of faults in the insulators of transmission towers. These prevent an unexpected voltage drop at a point on the line. Therefore, it is necessary to maintain and supervise them in time so that they do not act inefficiently. There are systems to facilitate, streamline, and classify the detection of faults without putting anyone at risk, since the maintenance of electrical systems is one of the most risky and thus requires a quick solution. In this article, a methodology was implemented that facilitates the location of faults in the insulator system by means of an image that is captured by a drone and sent to the database to be analyzed by the code, detecting the possible fault. Thus, allowing in a quick and timely manner to maximize the visibility of the electrical system to generate an optimal solution.

Keywords: Artificial intelligence, drone, electricity, isolators, transmission tower

Uno de los procesos más importantes en el mantenimiento de redes eléctricas es la detección de fallas en los aisladores de las torres de transmisión. Estos evitan que exista una caída de tensión no esperada en un punto de la línea. Por ello, es necesario el mantenimiento y supervisión a tiempo para que no actúe de manera ineficiente. Existen sistemas para facilitar, agilizar y clasificar la detección de fallas sin poner en riesgo ninguna persona, ya que el mantenimiento de los sistemas eléctricos son uno de los más riesgosos y así buscando una rápida solución. En este artículo se implementó una metodología que facilita la ubicación de fallas en el sistema de aisladores por medio de una imagen que es capturada por un dron, enviada a la base de datos para ser analizada por el código, detectando la posible falla. Así, permitir de manera rápida y oportuna maximizar la visibilidad del sistema eléctrico para generar una óptima solución.

Palabras clave: Aisladores, dron, electricidad, inteligencia artificial, torre de transmisión

---

Article typology: Research

Received: December 14, 2022
Accepted: December 23, 2022

Research funded by: Universidad Distrital Francisco José de Caldas (Colombia).

How to cite: Cartagena, C., Martín, J. (2022). *Visual inspection of transmission tower insulators*. Tekhnê, 19(2), 13 -22.

Introduction

According to (Sampedro et al., 2019) the inspection of the insulators are an important part to have the good functioning of the electrical system and the transmission of energy through these lines. The parameters and standards lead us to give importance to isolating each transmission line to ensure the transport of that energy from one point to another. But it projects to us that each one of them must work according to the regulation, that it does not present cracks, nor dusting of them. Therefore, it is said that any failure of this would lead to low power usage and processing power outages of sectors especially benefited by the power supply of these transmission lines (Guo et al., 2018a).

Based on (Sampedro et al., 2019) the inspection of insulators for power transmission lines is an important process in the supply of electricity to power grids, we can detect faults in the insulators of the transmission lines, presenting economic losses at the time of the supply of energy through one of the lines in failure (Odo et al., 2021). This proceeds to keep the transmission and distribution systems working satisfactorily being necessary to have accurate information on the service performance of the insulators, over time these tend to fail due to various factors such as cracks, vandalism, bird nests, or accumulation of dust (Mohana et al., 2021).

The maintenance of transmission towers can present several challenges and hazards for those involved (Ochoa & Penagos, 2021). One such issue is the risk of accidents during the process of preventive maintenance (Romero et al., 2019). This can occur when personnel is required to change out elements that have accumulated energy, or when deploying the lines of the transmission tower. These difficulties underscore the importance of proper training and safety protocols for those working on transmission tower maintenance.

In addition to the safety risks, some logistical challenges can arise during the maintenance of transmission towers. For example, the equipment and tools needed for the job may be difficult to access, or the location of the tower may be remote and difficult to reach (Khanna, 2021). Furthermore, the size and scale of transmission towers can make it difficult to carry out necessary repairs or upgrades.

Despite these difficulties, it is important to maintain transmission towers in good working condition to ensure the reliability and stability of the power grid. This requires a combination of proper planning, training, and resources to effectively address the various challenges and risks associated with transmission tower maintenance.

According to (Belitsyn et al., 2021; Gao et al., 2019), the use of artificial intelligence to predict or detect faults in the electrical system is a promising and innovative alternative, as it can improve the quality of electric power by reducing the possible failures, these can be implemented in the power transmission system automatic inspection based on aerial platforms with unmanned vehicles such as drones: (Belitsyn et al., 2021), since with its image detection method that could evidence the problem presented by the transmission line, detected the influence of weather, network infrastructure or nearby vegetation, thus maintenance teams are properly prepared and take action as planned by AI's previously (Guo et al., 2018b).

Based on (Guo et al., 2018b) the importance of insulators and the different types of failures that these can present, this article will relate how the different types of neural networks can interact according to the detection of failures at the exact time of this event and how they interpret the situation to not incur in over maintenance and its costs when repairing the damage. Thus, visualizing the damage of this insulator material and the prompt repair for the supply of the affected line in the electrical system (Sopelsa et al., 2021).

Based on (López et al., 2021) it is said that the preventive maintenance at the time of the first failure presented in the electrical system using the supply of electrical energy to the industrial sectors and the residential Zones. Based on the corrective maintenance, it is presented a diagnosis that has been visualized in the previous maintenance, detailing what should be fixed at the point of the line and its insulator. Therefore, the maintenances are essential for the supply of the service of electric energy employing the passage of the line and its corresponding insulator in the transmission towers, of transporting that energy until the substation is distributed to the residential and industrial zones of the cities (Odo et al., 2021; Sampedro et al., 2019; Yin et al., 2020).

Therefore, the development of this paper is organized as follows. In section two we will see the formulation of the problem, how the idea and problem arose in which the approach was given, and the solution method that is considered to be the most optimal, Experimental results of various conditions and the corresponding analysis are presented in Section three, Section four concludes the results and also discusses future improvement methods.

Problem statement

The installation of a transmission line requires a series of procedures to verify and ensure proper electrical operation of the transmission towers. One crucial aspect of this is proper maintenance of the system of insulators implemented. Insulators play a vital role in the transmission of electricity by preventing the flow of current from the transmission line to the ground, and it is important to ensure that they are functioning properly.

Proper maintenance of insulators includes regular inspections to detect faults, which can occur due to a variety of factors such as weathering, mechanical damage, or contamination. However, inspecting for faults in the electrical sector is one of the most dangerous tasks in transmission line maintenance, as it requires personnel to work near high-voltage equipment. Therefore, it is crucial to have different methods of analysis and visual monitoring in place to detect faults in the insulators, as undetected faults can lead to leakage currents and an increased risk of fire or loss of continuity in the electrical system. This can result in costly repairs and unexpected expenses.

One of the methods used for visual monitoring of insulators is the use of drones equipped with cameras, which can safely and efficiently inspect hard-to-reach areas of the transmission line. Additionally, the use of infrared thermography technology can detect hot spots on insulators caused by faults, which can be indicative of a problem.

Furthermore, regular cleaning of insulators is also an important aspect of maintenance as insulators that are dirty or contaminated can also cause leakage currents and reduce the insulator's effectiveness. For this reason, it is important to establish a regular cleaning schedule and to use appropriate cleaning methods and materials.

In summary, proper maintenance of the system of insulators in a transmission line is crucial for ensuring proper electrical operation and preventing costly repairs. This includes regular inspections and visual monitoring to detect faults, as well as regular cleaning to prevent contamination. Adequate methods and tools, such as drones and infrared thermography are important to ensure the safety of the personnel involved and the effectiveness of the maintenance process.

Methods

The inspection of insulators on transmission towers can present several difficulties, and as a result, it is important to have a well-planned and organized approach to ensure that all necessary inspections are carried out effectively. Based on this consideration, we have decided to follow up and analyze the towers and the different problems that may occur in the insulators.

To accomplish this, we have taken into account some factors that can affect the inspection process. For example, the number of towers to be inspected, the types of insulator material used, the voltage levels in Colombia, and the types of damage that have been classified into different categories. Based on these considerations, we have developed a staged approach to the inspection process.

The staged approach is designed to ensure that all necessary inspections are carried out efficiently and effectively. This allows us to focus on specific areas of concern, while also ensuring that all necessary inspections are completed promptly. It also enables us to prioritize areas of higher risk and allocate resources accordingly.

Additionally, classifying the types of damage into different categories, makes it easier to identify patterns and areas of concern. This information can be used to develop targeted maintenance and repair plans, which can help to prevent similar issues from arising in the future.

- **Stage 1** Determine the area to be inspected and make a detailed survey of the information obtained by drone (photos, videos).
- **Stage 2** Segmentation and classification of the images and videos obtained taking into account the categories to be studied.

Class definition

Category A: Voltage levels

Some examples are shown in Fig. 1.

Figure 1

Voltage levels

- Level 1: Systems with rated voltage less than 1 kV.
- Level 2: Systems with rated voltage greater than or equal to 1 kV and less than 30 kV.
- Level 3: Systems with rated voltage greater than or equal to 30 kV and less than 57.5 kV.
- Level 4: Systems with rated voltage greater than or equal to 57.5 kV and less than 220 kV.

Category B: Insulator material

- Porcelain insulators (Fig. 2).
- Glass insulators (Fig. 3)
- Composite insulators (Fig. 4).

Figure 2

Porcelain insulators

Figure 3

Glass insulators

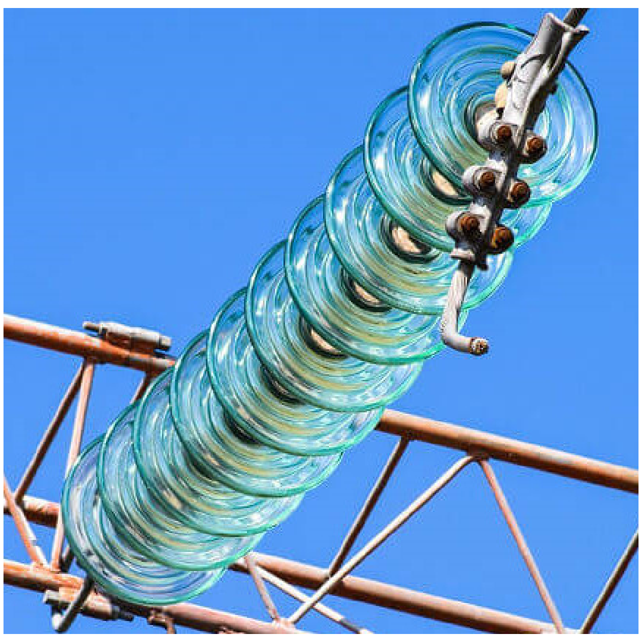


Figure 4

Composite insulators

Figure 5

Cracks

Category C: Types of damage

- Cracks (Fig. 5).
- Bird nests (Fig. 6).
- Corrosion (Fig. 7).
- Dust accumulation (Fig. 8).

The classes defined for this design according to the condition of the insulator were: fair, bad and critical.

Fair class

The images are classified in this category when there are problems that can be quickly solved, narrow and discontinuous leakage lines in the element (Fig. 9).

Bad class

Images are classified in this category when part of their section has been lost (Fig. 10).

Critical class

Images are classified in this category when more than 50% of the element is lost (Fig. 11). In the case of porcelain

Figure 6

Bird nests

Figure 7

Corrosion

Figure 8

Dust accumulation

insulators, it occurs when breakage or cracking is observed on the insulating surface. In the case of glass insulators, when there is a lack of the insulating part.

- **Stage 3** Once the images have been categorized and the problems detected, the information is sent for the respective maintenance.

The use of drones in the inspection of insulators on transmission towers has proven to be an efficient way to identify and categorize possible faults (Cadena et al., 2016). The high-resolution images taken by the drones allow for a detailed examination of the insulators, which is crucial for identifying and classifying the type of damage (Martınez et al., 2017).

The classification process begins by determining the voltage level of the tower, as different voltage levels may have different requirements and potential issues. This information is used to determine the type of insulator that is being inspected and to identify the type of damage that has occurred.

Once the type of damage has been identified, the next step is to subcategorize the dimension of the fault. This information is crucial for providing an appropriate solution for the fault. For example, a small crack in an insulator may be repaired with a simple patch, while a large crack may require a complete replacement of the insulator.

The use of drones in the inspection process is a cost-effective and efficient way to identify and classify faults in the insulators. The high-resolution images taken by the drones are used to determine the voltage level of the tower, the type of insulator, and the type and dimension of the damage. This information is used to provide an appropriate solution for the fault, which can help to prevent more serious issues from arising in the future.

Results

To determine the best neural network for detecting faults in electrical insulators, three different networks were trained and their performance was analyzed using our database. These networks were Dataset, ResNet, and Densenet. After a thorough evaluation, we found that the network that best fits

Figure 9

Insulator in fair condition

Figure 10

Insulator in bad condition

our problem is ResNet. This network presents better training and validation results when compared to the other networks.

The implementation of the detection system algorithm using ResNet allows for the location comparison search of possible faults that can be found in the electrical insulators. The network is trained to visualize images that are in the database, which are then compared with the data in its deep environment. This process allows for the analysis of the accuracy, error, quadratic mean, and final categorization of the images.

Figure 11

Insulator in critical condition

One of the main advantages of using ResNet is its ability to handle a large amount of data, which is essential when dealing with a large number of insulators in a transmission line. The multilayer system of ResNet allows it to extract features from images at different levels of abstraction, which makes it more robust to variations in the images. This improves the performance of the neural network when it comes to identifying faults in the insulators.

In contrast, the other two networks, Dataset and Densenet, did not show the same level of efficiency when compared to ResNet (Montiel et al., 2021). The reason for this is that the database used for these networks to work effectively must be much larger than the one presented in the current research. Therefore, ResNet is the best option for our specific problem as it presents better training and validation results, and its ability to handle a large amount of data and extract features from images at different levels of abstraction.

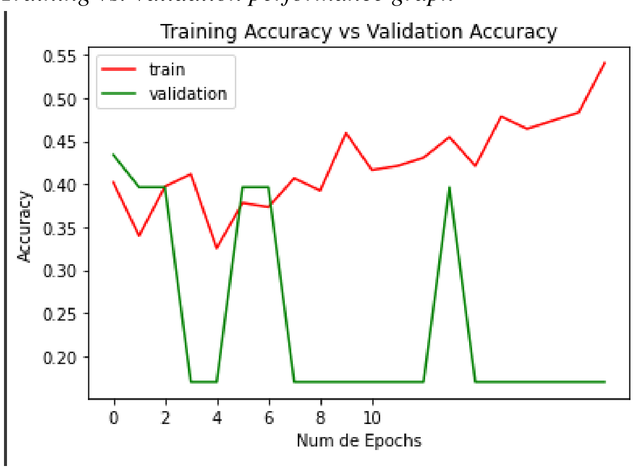
The neural network that was trained for detecting faults in electrical insulators is designed to visualize images that are in the database, and compare them with the data in its deep environment. This process allows for the analysis of the accuracy, error, and quadratic mean of the images. The main goal of this analysis is to identify any discrepancies or faults in the images and categorize them based on their level of severity.

The network begins by analyzing the images in the database and comparing them to the data in its deep environment. The deep environment of the network is composed of multiple layers of artificial neurons, which are designed to extract features from the images. These features are then used to identify patterns and anomalies in the images, which can indicate the presence of a fault.

The accuracy, error, and quadratic mean are important metrics that are used to evaluate the performance of the network (Figs. 12 and 13). The accuracy measures the proportion of correctly classified images, while the error measures the proportion of incorrectly classified images. The quadratic mean, also known as the Root Mean Squared Error (RMSE), is a measure of the average distance between the predicted values and the true values (Rodríguez & Buitrago, 2022). After the analysis is complete, the images are categorized based on their level of severity (Martínez et al., 2020). This process allows for the prioritization of repairs and maintenance, as well as the identification of patterns and trends in the data. This information can be used to improve the overall performance of the network and to develop targeted maintenance and repair plans.

Figure 12

Training vs. validation performance graph



Our confusion matrix, which is used to evaluate the performance of our models in classifying the images, is not showing adequate categorization (Fig. 14). The main issue is the coupling of the database and the codification of the Resnet, DenseNet, and NasNet models. The performance of these models is only 35 percent, indicating that there is a problem when comparing the database with the new images presented by our database.

This issue in the categorization of the images can be attributed to several factors. One potential cause is the lack of diversity in the images in the database. This means that the models are not exposed to a wide range of images, which can result in poor performance when dealing with new images. Additionally, the codification of the models may not be optimal for the specific problem at hand, which can also contribute to the poor performance of the models.

Figure 13

Training error vs. validation error graph

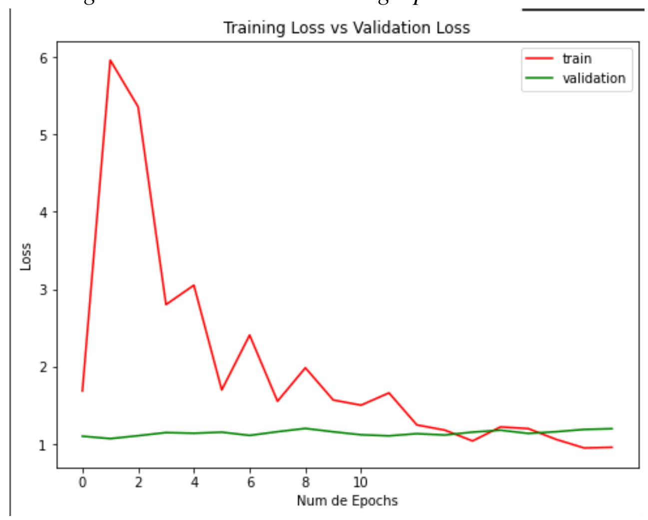
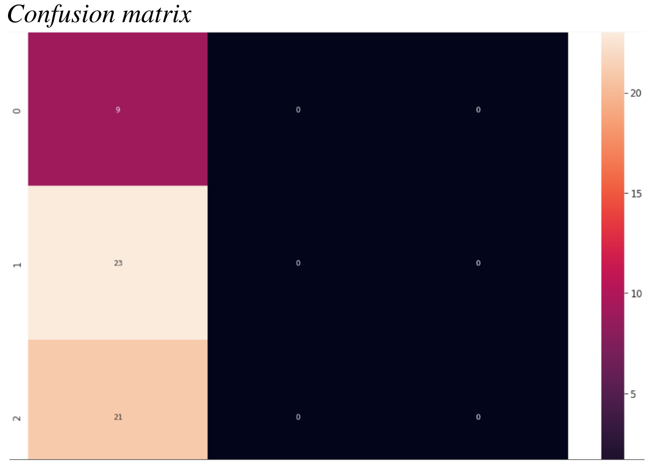


Figure 14

Confusion matrix



Another possible cause is that the data in the database is not properly labeled, which can lead to errors in the classification of the images. This can be due to human error in the labeling process or a lack of consistency in the labeling criteria. This can result in the models being unable to accurately identify and classify the images, which can contribute to the poor performance of the models.

To improve the performance of the models, it is necessary to address these issues. This can include increasing the diversity of the images in the database, improving the codification of the models, and ensuring that the data in the database is properly labeled. Additionally, it is important to consider other models.

We have compiled a table of metrics that compares the performance of the model we have focused on the most, to the performance of the other two models (Fig. 15). However, we have found that the categorization is not accurate in all three models. The first model presents acceptable results, while the other two models have issues with their coding and comparison within the database.

Figure 15

Performance metrics by category

	precision	recall	f1-score	support
0	0.17	1.00	0.29	9
1	0.00	0.00	0.00	23
2	0.00	0.00	0.00	21
accuracy			0.17	53
macro avg	0.06	0.33	0.10	53
weighted avg	0.03	0.17	0.05	53

This lack of accuracy in the categorization can be attributed to several factors. One possible cause is the lack of diversity in the images in the database. This can result in poor performance when dealing with new images as the models have not been exposed to a wide range of images. Additionally, the codification of the models may not be optimal for the specific problem at hand, which can also contribute to the poor performance of the models.

Another possible cause is that the data in the database is not properly labeled. This can lead to errors in the classification of the images, which can be due to human error in the labeling process or a lack of consistency in the labeling criteria. This can result in the models being unable to accurately identify and classify the images, which can contribute to the poor performance of the models. To improve the performance of the models, it is necessary to address these issues.

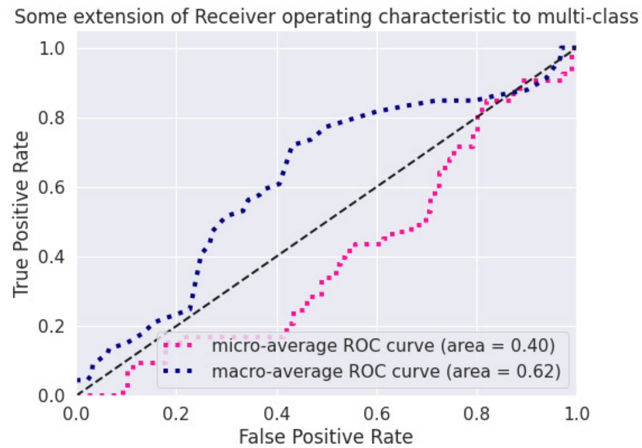
The ROC curve is a powerful tool that allows us to evaluate the performance of a model by plotting the True Positive Rate (TPR) against the False Positive Rate (FPR). This gives us a clear picture of the positive and negative aspects of the model's performance, as well as its accuracy within the database. By analyzing the ROC curve, we can gain insight into how well the model can distinguish between positive and negative examples.

In our analysis, we have used the ROC curve to compare the performance of three different models simultaneously. The models that we have compared include ResNet, DenseNet, and NasNet. The results of this comparison show that the ResNet model is one of the best models when it comes to accuracy and performance (Fig. 16). However, its performance would depend on the database that we manage.

The ROC curve also allows us to determine the optimal threshold for the model, which is the point at which the trade-off between TPR and FPR is most favorable. This is particularly useful when working with imbalanced datasets,

Figure 16

ROC curve



where one class is significantly more prevalent than the other. By adjusting the threshold, we can improve the performance of the model and achieve better results.

Conclusion

In this paper, we present an analysis of the performance of three convolutional models for the task of classifying electrical insulator damage from images captured by a drone. The three models that we have trained and compared include ResNet, DenseNet, and NasNet. Our objective is to evaluate the performance of these models in identifying and classifying different types of damage in electrical insulators. The process of training these models involves feeding them a large dataset of images of electrical insulators, along with their corresponding labels indicating the type of damage present in the image. The models are then trained to learn to recognize and classify the different types of damage based on the patterns and features present in the images. Once the models have been trained, we evaluate their performance using a variety of metrics, such as accuracy, precision, recall, and F1-score. We also use the ROC curve to evaluate the trade-off between the true positive rate and the false positive rate of the models. The results of our analysis show that the ResNet model performs the best among the three models, with the highest accuracy, precision, and F1-score. However, the performance of the models also depends on the database that is used.

In conclusion, it was determined that the best neural network to implement for our database is ResNet. The reason for this is due to its complex algorithm, which is capable of determining the type of damage and categorizing it effectively. The ResNet architecture is designed with a multilayer system, which makes it easier to identify faults in the insulators. This is particularly useful when it comes to tracking and identifying issues in the electrical transmission system.

One of the key advantages of using ResNet is its ability to handle large amounts of data, which is essential when dealing with a large number of insulators in a transmission line. The multilayer system of ResNet allows it to extract features from images at different levels of abstraction, which makes it more robust to variations in the images. This improves the performance of the neural network when it comes to identifying faults in the insulators.

Another important aspect of ResNet is its ability to prevent overfitting. Overfitting is a common problem in neural networks, which occurs when a model is trained too well on the training data but performs poorly on the test data. ResNet uses a technique called residual learning, which helps to prevent overfitting by allowing the network to learn the residuals between the input and the desired output.

In comparison to other neural networks, ResNet has been shown to have the best performance when it comes to the follow-up and search for failure in the insulators. This is due to its ability to handle large amounts of data, its multilayer system, and its ability to prevent overfitting. In light of these advantages, ResNet is the optimal choice for implementing in our database to monitor and identify faults in the insulators of the transmission lines.

References

Belitsyn, I. V., Pestov, M. I., Pavlichenko, I. A., & Belitsyn, A. I. (2021). Fault simulation in networks with isolated neutral to find the fault location in power transmission lines. *Journal of Physics: Conference Series*, *2131*(3), 032045. https://doi.org/10.1088/1742-6596/2131/3/032045

Cadena, A., Peña, E., & Martínez, F. (2016). Desarrollo de prototipo de quadrotor con sistema de comunicación inalámbrica bidireccional. *Tekhnê*, *13*(1), 13–30.

Gao, Q., liu, S., Yang, Y., & Zhang, C. (2019). Study on the influence of insulator on the coupling effect of transmission tower-line system. *Journal of Physics: Conference Series*, *1187*(2), 022030. https://doi.org/10.1088/1742-6596/1187/2/022030

Guo, L., Liao, Y., Yao, H., Chen, J., & Wang, M. (2018a). An electrical insulator defects detection method combined human receptive field model. *Journal of Control Science and Engineering*, *2018*(1), 1–9. https://doi.org/10.1155/2018/2371825

Guo, L., Liao, Y., Yao, H., Chen, J., & Wang, M. (2018b). An electrical insulator defects detection method combined human receptive field model. *Journal of Control Science and Engineering*, *2018*(1), 1–9. https://doi.org/10.1155/2018/2371825

Khanna, J. (2021). Performance evaluation of two basic controls over the boost powerregulator: Pid and fuzzy controllers. *Tekhnê*, *18*(1), 37–49.

López, R., Batista, M., & Jimenez, M. (2021). Autonomous uav system for cleaning insulators in power line inspection and maintenance. *Vol. 21*(8488), 10–50. https://doi.org/10.3390/s21248488

Martínez, F., Martínez, F., & Montiel, H. (2020). Low cost, high performance fuel cell energy conditioning system controlled by neural network. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, *18*(6), 3116–3122.

Martınez, F., Martınez, F., & Jacinto, E. (2017). Visual identification and similarity measures used for on-line motion planning of autonomous robots in unknown environments. In Y. Wang, T. D. Pham, V. Vozenilek, D. Zhang, & Y. Xie (Eds.), *Eighth international conference on graphic and image processing (ICGIP 2016)*. SPIE. https://doi.org/10.1117/12.2266997

Mohana, K., Hussain, A., Kavya, B., J., B., & Kaliappan. (2021). Deep learning for fault diagnostics in bearings, insulators, pv panels, power lines, and electric vehicle applications—the state-of-the-art approaches. *IEEE*, *Vol. 9*(20657183), 41246–41260. https://doi.org/10.1109/ACCESS.2021.3064360

Montiel, H., Jacinto, E., & Martínez, F. (2021). A double-loop hybrid approach for the recognition of fissures in bone structures. *ARPN Journal of Engineering and Applied Sciences*, *16*(11), 1151–1156.

Ochoa, Y., & Penagos, C. (2021). Traveling wave method for analysis of faults in a high voltagetransmission line. *tekhnê*, *18*(2), 13–18.

Odo, A., McKenna, S., Flynn, D., & Vorstius, J. B. (2021). Aerial image analysis using deep learning for electrical overhead line network asset management. *IEEE Access*, *9*(2021), 146281–146295. https://doi.org/10.1109/access.2021.3123158

Rodríguez, A., & Buitrago, X. (2022). How to choose an activation function for deep learning. *tekhnê*, *19*(1), 23–32.

Romero, D., Sánchez, B., & Garzón, N. (2019). Conserving water is conserving your life. *Tekhnê*, *16*(1), 23–34.

Sampedro, C., Rodriguez-Vazquez, J., Rodriguez-Ramos, A., Carrio, A., & Campoy, P. (2019). Deep learning-based system for automatic recognition and diagnosis of electrical insulator strings. *IEEE*, *Vol. 7*(18880601), 101283–101308. https://doi.org/10.1109/ACCESS.2019.2931144

Sopelsa, N., Frizzo, S., & Meyer, L. (2021). A study of multilayer perceptron networks applied to classification of ceramic insulators using ultrasound. *Vol. 11*(1592), 50–150. https://doi.org/10.3390/app11041592

Yin, F., Liu, P., Mei, H., Wang, L., Li, L., & Farzaneh, M. (2020). The shed hole influence on the electrical performance of composite insulator. *IEEE*, *Vol. 8*(20184521), 217447–217455. https://doi.org/10.1109/ACCESS.2020.3042245

Tekhnê
July - December 2022, Vol. 19, No. 2, pp. 23 – 28

ISSN 1692-8407

Visual inspection of architectural faults and cracks

Inspección visual de fallas y fisuras arquitectónicas

Andrea Y. Triana C.
Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
aytrianac@correo.udistrital.edu.co

Civil constructions move, age, and breathe. Their movement is something that cannot be seen with the naked eye, but it is constant. At all times there are small changes in the same due to humidity, temperature, or movements in the ground, reaching the point where the materials with which the buildings are composed do not resist these movements and begin to appear cracks and fissures, which are considered important to examine to ensure the safety, durability, and viability of construction. For the inspection of this structural change, the training of a neural network will be used to inspect using images the appearance of cracks and classify them according to the stipulated categories.

Keywords: Categories, cracks, durability, fissures, images, inspection, materials, movements, neural network, safety

Las construcciones civiles se mueven, envejecen y respiran. Su movimiento es algo que a simple vista no se puede apreciar, pero es constante. En todo momento se producen cambios pequeños en la misma a causa de la humedad, temperatura o por movimientos en el terreno, llegando al punto donde los materiales con los cuales están compuestos los edificios no resisten estos movimientos y empiezan aparecer las grietas y fisuras, las cuales se consideran importantes de examinar para garantizar la seguridad, durabilidad y viabilidad de una construcción. Para la inspección de este cambio estructural se hará uso del entrenamiento de una red neuronal para inspeccionar por medio de imágenes la aparición de las grietas y clasificarlas según las categorías estipuladas.

Palabras clave: Categorías, durabilidad, fisuras, imágenes, inspección, grietas, materiales, movimientos, red neuronal, seguridad

Article typology: Research

Received: December 14, 2022
Accepted: December 23, 2022

Research funded by: Universidad Distrital Francisco José de Caldas (Colombia).

How to cite: Triana, A. (2022). *Visual inspection of architectural faults and cracks*. Tekhnê, 19(2), 23 -28.

Introduction

Crack detection is a crucial aspect of civil engineering infrastructure management, as it plays a vital role in ensuring the durability, integrity, and safety of structures (Carrasco et al., 2021). These structures are exposed to a wide range of factors that can cause partial or complete collapse, making it imperative to quickly identify the direction, location, and extent of any cracks that may develop.

The early detection of cracks allows for prompt repairs to be made, preventing further damage and ensuring the continued safe operation of the structure. Additionally, identifying the cause of the crack, whether it be due to poor construction, overloading, or exposure to extreme weather conditions, can help prevent similar issues from arising in the future (Ercolani et al., 2018).

There are a variety of methods that can be used to detect cracks in structures, including visual inspections, ultrasonic testing, and x-ray imaging. Each method has its strengths and weaknesses, and the choice of which method to use will depend on the specific structure and the type of crack being sought. In addition to traditional crack detection methods, there has been an increasing interest in the use of advanced technologies such as artificial intelligence and machine learning to aid in crack detection. These technologies can help automate the process, reducing the time and cost of inspections, and allowing for more accurate and efficient detection of cracks.

The process of detecting failures in structures has undergone significant evolution over time, with the initial method being manual inspections using a crack width comparator gauge (CWCG). However, this technique had several limitations, including being time-consuming and prone to a high level of error. To overcome these limitations, research and development in crack detection technology have been ongoing, to automate the process and improve its accuracy (Orozco R & Mendoza P, 2017). A variety of different analysis techniques have been explored, some of which include:

- Non Destructive Testing (NDT).
- Resistivity test (Shamsudin et al., 2021).
- Incremental dynamic analysis, considered a powerful tool for assessing vulnerability and seismic risk of buildings (Barbat et al., 2016).
- 3D visualization by means of a climbing robot with sensors that send the information to a ground station in real time (La et al., 2019).
- Inspection in unmanned aerial vehicles (UAV) (Woo et al., 2022), among others.

These studies and tests were carried out on concrete structures analyzing aspects of fracture propagation in concrete (Zárate & Oñate, 2018), cracks in low permeability structures (Donini, 2016), comparisons between preconstructed and constructed (Bernat et al., 2014), and column reinforcement (Naom & Mohammad, 2022); because it is a self-repairing material that can heal itself when cracked, protecting the interior matrix as well as the reinforcing steel, resulting in a longer service life (Mullem et al., 2020).

In the last ten years, advances in photogrammetry and image processing have begun to change the construction industry, as it is possible to capture fast and remote digital records of objects and features, taking into account an important aspect that when modeling the mechanical behavior of existing structures the accuracy in which the geometry of the actual structure is transferred into the numerical model to make its analysis relevant (Loverdos et al., 2021). However, there remains some uncertainty as to how to develop appropriate and cost-effective evaluation procedures that take into account the inherent advantages and disadvantages of various available tools and technologies (Lacroix et al., 2021).

The dangers of cracks in constructions, severely decrease the reliability and safety of structures, due to this receiving increasing attention to mitigate these failures (Yang & Xu, 2020), within the area of deep learning has been used in training to neural networks with Kohonen-type algorithms (Carreño et al., 2011), Canny algorithm, Decision Tree type algorithms, K-neighborhoods (Jitendra et al., 2020), deep convolutional neural network (DCNN) (Manjurul & Kim, 2019) to increase the accuracy and precision in the preliminary results of the digital images, evaluating finite aspects and methods (Zárate & Oñate, 2018) of reliability factor in a stipulated time (Ruiz et al., 2014).

The problem of accurately detecting and classifying cracks in structures is a critical one in the field of civil engineering. To address this problem, the use of neural networks for image recognition has been proposed as a potential solution. By training a neural network to identify and classify images of cracks, it is possible to improve the efficiency and accuracy of crack detection. The neural network is trained to classify cracks into two main categories: those of physical origin, such as those caused by humidity and temperature changes, and those of mechanical origin, such as those caused by movements on the surface, vibrations, or loads. Additionally, the network can also classify images without any cracks for reference.

The methodology for this project involves collecting a dataset of images of cracks, both of physical and mechanical origin, along with images without cracks. The dataset is then used to train the neural network. Once the network is trained, it can be applied to new images to detect and classify cracks. The results of this project will be evaluated through various metrics such as accuracy, precision, and recall. The performance of the neural network will be compared to traditional methods of crack detection and classification to determine its effectiveness.

Problem statement

As buildings age and undergo wear and tear, cracks may begin to appear in their structures. These cracks can be a serious issue, as they can compromise the integrity of the building and put the lives of those who use it at risk. To address this problem, it is desirable to develop a neural network-based system for the identification of cracks in buildings.

This system would use the classifications outlined in relevant documents to automatically detect cracks, saving time and reducing the potential for human error in manual inspections. By identifying cracks promptly, it would also be possible to take preventative measures to mitigate any further damage to the building, ensuring the safety of those who use it.

The neural network-based system would use image recognition and classification techniques to analyze images of buildings and identify cracks. These images could be captured using a variety of methods, such as drones or cameras mounted on building exteriors. The neural network would be trained on a dataset of images of buildings with known cracks, allowing it to learn to identify cracks based on specific patterns and features.

Once the neural network is trained, it could be used in real-time inspections of buildings to quickly and accurately identify cracks. The system could also be integrated with existing building management systems, allowing building managers to track the condition of their buildings over time and take proactive measures to address any issues that are identified.

Methods

The proposed methodology for detecting cracks in structures through a neural network involves several key steps. The first step is to gain an understanding of the available data. This includes analyzing the type of data that will be used to train and test the neural network, such as images of buildings with known cracks.

Once a clear understanding of the available data has been established, the next step is to test various segmentation models. Segmentation models are used to identify specific regions or objects within an image, such as cracks in a building. These models can be based on different techniques, such as convolutional neural networks (CNNs) or U-Net.

After testing and evaluating the performance of different segmentation models, the most appropriate one will be chosen and used to develop the computational model necessary for the automatic detection of cracks in structures. This computational model will be based on the chosen segmentation model and will be trained on the available data using techniques such as supervised learning.

Once the computational model has been developed, it will be applied to the available data (images) and the results will be checked. This will involve evaluating the model's performance in detecting and quantifying cracks in the images, and comparing the results to the known ground truth.

During this process, it is important to continually monitor and evaluate the performance of the computational model. As the model is being trained, it will become more accurate in identifying and quantifying cracks, but it may not reach optimal performance immediately. To achieve optimal results, the model will need to be constantly trained and fine-tuned, until an acceptable percentage in the identification and quantification of cracks is reached.

For this detection process it is of great importance to take into account the proposed categories, which are:

- Cracks of physical origin.
- Cracks of mechanical origin.
- Crack-free construction.

Once the Keras-based computational model for detecting cracks in structures has been developed and fine-tuned to an optimal or acceptable level using the proposed categories and the available databases, the next step is to generate conclusions and measure the failure rates of the model.

To generate conclusions, the model will be evaluated using various metrics such as accuracy, precision, recall, and F1 score. These metrics provide a quantitative measure of the model's performance in identifying and quantifying cracks in the images. Additionally, qualitative analysis can be performed by visualizing the model's predictions on the images and comparing them to the ground truth.

The failure rate is also an important metric to evaluate the model's performance. The failure rate is the percentage of images in which the model failed to detect or quantify cracks correctly. This metric indicates how often the model makes mistakes and how reliable it is. The failure rate of the model can be used to identify areas where the model is struggling and make adjustments to improve its performance. For example, if the model is failing to detect cracks in certain types of images or specific regions of the images, additional data or fine-tuning of the model may be needed in those areas.

In addition, it's important to evaluate the model's performance with a diverse set of data to test the robustness of the model. This includes testing the model on images taken under different lighting conditions, angles, and resolutions.

Results

The proposed methodology in this case involved the constant training of two different neural models using varying amounts of images. The goal of this approach was to observe the learning process of the models and how it is affected by the number of images used. However, the results of this methodology revealed that both models struggled to accurately identify more than one or two of the three proposed categories.

This outcome highlights the importance of having a sufficient amount of diverse images for training a neural model. Without a sufficient number of images, the model is unable to learn and generalize to new images effectively. Furthermore, it also indicates that having a diverse set of images is equally important, as it allows the model to learn from different examples of the same category and improve its ability to generalize to unseen examples.

Additionally, it also suggests that the quality of images used for training is an important factor that should be taken into consideration. A model trained on low-resolution images may struggle to identify features in the images and thus, fail to classify them correctly.

Furthermore, it also raises questions about the architecture of the neural models used. Different architectures have different strengths and weaknesses when it comes to image classification tasks. It may be beneficial to experiment with different architectures to find the best one for the specific application.

The attached images (Figs. 1 to 4) demonstrate the training of a ResNet neural network in comparison to a DenseNet model. The ResNet model was able to achieve a better performance in terms of image classification, compared to the DenseNet model which only recognized a single category. This outcome highlights the superiority of the ResNet architecture in this specific application, in comparison to the DenseNet architecture.

An analysis of the images loaded in the database revealed that a large percentage of the images belonged to category 2 (Mechanical). This indicates that the database was heavily skewed towards this category, which could have potentially contributed to the better performance of the ResNet model in recognizing images within this category. A well-balanced dataset with equal distribution of images across all categories would have been ideal to evaluate the performance of the models in a more accurate way.

Furthermore, it also suggests that the quality of images used for training is an important factor that should be taken into consideration. A model trained on a skewed dataset may struggle to identify features in the images belonging to the under-represented categories and thus, fail to classify them correctly.

Figure 1

Metrics obtained in 10 epochs

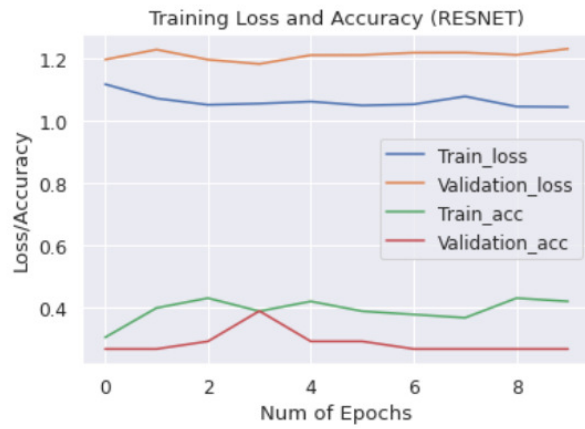
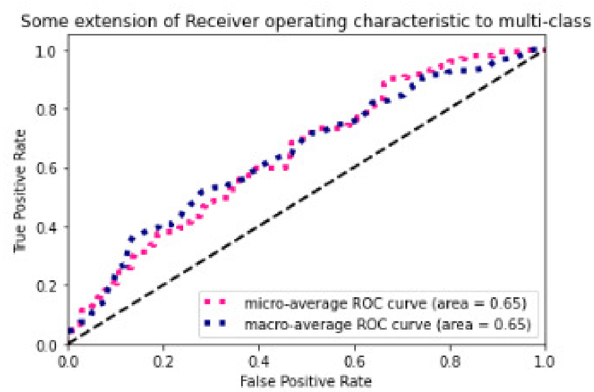


Figure 2

ROC curve



Conclusion

The training of a neural network is a crucial step in the development of any machine learning system. In this case, the DenseNet model was utilized as the initial implementation for training a neuron. Two training tests were conducted using a small database of captured images, which were classified into three different categories. The results of this training revealed that the number of images used was insufficient for the neural model, as it could only identify a single category out of the three proposed. This highlights the importance of having a larger and more diverse image database for training, to improve the efficiency and accuracy of the neuron's learning.

In addition to the DenseNet model, the ResNet neural model was also used for training. The image database was expanded in an attempt to improve the training process, but the neuron still struggled to recognize all the proposed categories. This suggests that the images used in the database may not have had the appropriate resolution for the model to effectively learn and classify the images.

Crack identification and classification is an important aspects in both industry and everyday life. Knowing the origin and type of a crack can greatly impact the safety and durability of a building. The application of a neural model in this field can greatly aid in the efficient identification

Figure 3

Confusion matrix

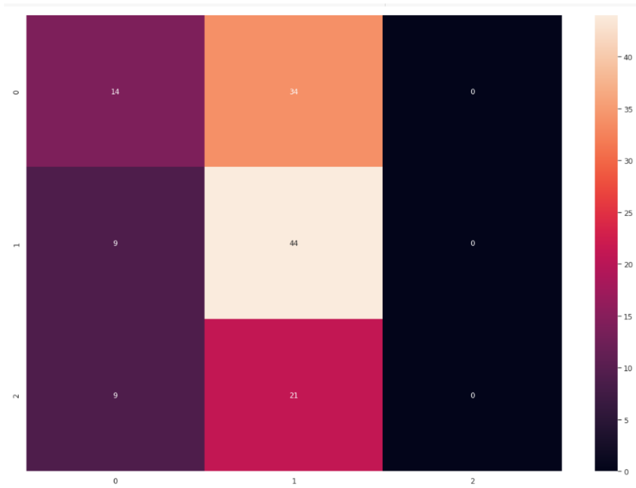


Figure 4

Metrics by category

	precision	recall	f1-score	support
0	0.44	0.29	0.35	48
1	0.44	0.83	0.58	53
2	0.00	0.00	0.00	30
accuracy			0.44	131
macro avg	0.29	0.37	0.31	131
weighted avg	0.34	0.44	0.36	131

and classification of cracks, providing valuable insights to building engineers and contractors.

To improve the performance of the neural model in identifying and classifying cracks, several steps can be taken. One of the most important is to increase the size and diversity of the image database used for training. This will allow the neuron to learn from a larger and more representative sample of images, which will improve its ability to generalize to new images. Additionally, it is important to ensure that the images used in the database have adequate resolution and quality, as this will allow the model to more accurately identify and classify the different types of cracks.

Another important factor to consider is the architecture of the neural model itself. Different architectures, such as DenseNet and ResNet, have different strengths and weaknesses when it comes to image classification tasks. It may be beneficial to experiment with different architectures to find the best one for the specific application of crack identification and classification.

Finally, it is important to fine-tune the parameters of the neural model through techniques such as hyperparameter tuning to optimize its performance. This can involve adjusting the number of layers, the number of neurons in each layer, the learning rate, and other parameters to find the optimal configuration for the specific task at hand.

Overall, the application of neural models in the field of crack identification and classification has the potential to greatly improve the efficiency and accuracy of this task. However, to achieve this, it is important to consider factors such as image database size and quality, neural model architecture, and fine-tuning of parameters.

References

Barbat, A. B., Vargas, Y., Pujades, L., & Hurtado, J. E. (2016). Evaluación probabilista del riesgo sísmico de estructuras con base en la degradación de rigidez. *Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería*, *32*(1), 39–47. https://doi.org/https://doi.org/10.1016/j.rimni.2014.11.001

Bernat, A. M., Ibars, E. O., Bairán García, J. M., Gómez, N. D., & Bohigas, A. C. (2014). Comparación de resultados obtenidos en el proyecto de estructuras de hormigón aplicando la instrucción ehe-08 y el eurocódigo 2. *Hormigón y Acero*, *65*(271), 15–30. https://doi.org/https://doi.org/10.1016/S0439-5689(14)50004-6

Carrasco, M., Araya, G., Velázquez, R., & Visconti, P. (2021). Medición de ancho automatizada basada en imágenes de grietas superficiales. *Sensores*, *21*(22). https://doi.org/10.3390/s21227534

Carreño, M. L., Cardona, O. A., & T, B. A. (2011). Evaluación de la habitabilidad de edificios afectados por sismo utilizando la teoría de conjuntos difusos y las redes neuronales artificiales. *Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería*, *27*(4), 278–293. https://doi.org/https://doi.org/10.1016/j.rimni.2011.08.006

Donini, H. J. (2016). Hacia un conjunto de especificaciones argentinas para el control de la fisuración en estructuras con requerimientos de estanqueidad. *Hormigón y Acero*, *67*(280), 333–348. https://doi.org/https://doi.org/10.1016/j.hya.2015.12.002

Ercolani, G. D., Ortega, N. F., & Felix, D. H. (2018). Detección de daño en vigas de hormigón pretensado mediante el método de curvatura de la elástica. *Hormigón y Acero*, *69*(284), 39–48. https://doi.org/https://doi.org/10.1016/j.hya.2017.09.002

Jitendra, M. S., Naga, S. P., Shanmuk, Á., Srinivas A.and Nithya, & Kandulapati, S. K. (2020). Grieta detección en imágenes concretas mediante técnicas de clasificación en aprendizaje automático. *Revista de críticas críticas*, *7*(9), 1236–1241. https://doi.org/10.31838/jcr.07.09.224

La, H. M., Dinh, T. H., Pham, N. H., Ja, Q. P., & Pham, A. Q. (2019). Monitoreo robótico automatizado y inspección de estructuras de acero y puentes. *Robótica*, *37*(5), 947–967. https://doi.org/10.1017/S0263574717000601

Lacroix, F., Noël, M., Moradi, F., Laysi, H., & Tingson, T. (2021). Evaluación no destructiva de la condición de losas de hormigón con defectos artificiales mediante eco de impacto inalámbrico. *Diario de rendimiento de instalaciones construidas*, *35*(6). https://doi.org/10.1061/(ASCE)CF.1943-5509.0001651

Loverdos, D., Sarrosis, V., Adamopoulos, E., & Drugkas, A. (2021). Un marco innovador basado en el procesamiento de imágenes para el modelado numérico de estructuras de mampostería agrietada. *Automatización en la Construcción*, *125*. https://doi.org/10.1016/j.autcon.2021.103633

Manjurul, I. M., & Kim, J. M. (2019). Autónomo basado en la visión grieta detección de estructuras de hormigón utilizando una red de codificador-decodificador totalmente convolucional. *Sensores (Suiza)*, *19*. https://doi.org/10.3390/s19194251

Mullem, T. V., Gruyaert, E., Caspeele, R., & Belie, N. D. (2020). Primera aplicación a gran escala con hormigón autorreparable en bélgica: Análisis de las pruebas de control de laboratorio. *Materiales*, *13*(4). https://doi.org/10.3390/ma13040997

Naom, E. N., & Mohammad, J. I. (2022). Rehabilitación y reparación de la iglesia al- taheraenal- distrito de hamdaniya, ciudad de mosul, irak. *Casos de Estudio en Materiales de Construcción*, *16*. https://doi.org/10.1016/j.cscm.2021.e00787

Orozco R, B., & Mendoza P, M. (2017). Recimentación y hundimiento inducido de un edificio industrial mediante uso de pilotes de control y extracción de material. *Hormigón y Acero*, *68*(281), 57–68. https://doi.org/https://doi.org/10.1016/j.hya.2016.12.001

Ruiz, S. E., López, D., & Torres, N. M. (2014). Factor de confianza dependiente del tiempo para estructuras con deterioro causado por fatiga. *Ingeniería, Investigación y Tecnología*, *15*(3), 377–390. https://doi.org/https://doi.org/10.1016/S1405-7743(14)70348-8

Shamsudin, H., Hamid, N., Sidek, M., Aziz, T., Awang, H., & Chao, B. (2021). Grietas monitoreo y ensayo de resistividad para una casa de dos plantas por cavidad en la tierra. *Ingeniería Civil y Arquitectura*, *9*(9), 1376–1388. https://doi.org/10.13189/CEA.2021.090511

Woo, H. J., Seo, D. M., Kim, M. S., Parque, M. S., Hong, W. H., & Baek, S. C. (2022). Localización de grietas en estructuras de hormigón utilizando un vehículo aéreo no tripulado. *Sensors*, *22*(17). https://doi.org/10.3390/s22176711

Yang, H., & Xu, X. (2020). Inteligente grieta extracción basada en medición de escaneo láser terrestre. *Medición y Control (Reino Unido)*, *53*, 416–426. https://doi.org/10.1177/0020294019877490

Zárate, F., & Oñate, E. (2018). Predicción de fracturas en estructuras de hormigón combinando los métodos de elementos finitos y de elementos discretos. *Hormigón y Acero*, *69*, 53–69. https://doi.org/https://doi.org/10.1016/j.hya.2018.05.002

Tekhnê
July - December 2022, Vol. 19, No. 2, pp. 29 – 34

ISSN 1692-8407

Development and implementation of a low-cost security system

Desarrollo e implementación de un sistema de seguridad de bajo costo

Anderson A. Marin R.[1] and Juan S. Reyes R.[2]
[1]Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
aamarinr@correo.udistrital.edu.co
[2]Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
jusreyesr@correo.udistrital.edu.co

One of the main security problems in Colombia is home burglary since most of the time these are left alone during working hours or other types of occupations. This article presents an analysis of the problem of home security due to theft, looking for an effective solution at a lower cost than those available in the market. This arises from the analysis of the figures given by the DANE and a solution is proposed using the ESP32 development board, the HC-SR501 motion sensor, and the RC522 RFID (Radio Frequency Identification) reader, which allows us to generate an economical and reliable security system with the implementation of the IoT (Internet of Things) to make it more versatile.

Keywords: ESP32, HC-SR501, IoT, lector RFID, security system

Una de las principales problemáticas de la seguridad en Colombia es el hurto a viviendas, dado que en la mayoría del tiempo estas quedan solas durante los horarios laborales u otros tipos de ocupaciones. En este artículo se presenta un análisis a la problemática de seguridad en las viviendas por hurtos, buscando una solución efectiva y con un costo menor a los que hay en el mercado. Este surge del análisis realizado a las cifras dadas por el DANE y se propone una solución haciendo uso de la placa de desarrollo ESP32, el sensor de movimiento HC-SR501 y el lector RFID (Identificación por radiofrecuencias) RC522lo que nos permite generar un sistema de seguridad económico, fiable y con implementación de las IoT (Internet de las cosas) para que sea más versátil.

Palabras clave: ESP32, HC-SR501, IoT, lector RFID, sistemas de seguridad

Article typology: Research

Received: December 14, 2022
Accepted: December 23, 2022

Research funded by: Universidad Distrital Francisco José de Caldas (Colombia).

How to cite: Marin, A., Reyes, J. (2022). *Development and implementation of a low-cost security system.* Tekhnê, 19(2), 29 -34.

Introduction

Most individuals spend a significant portion of their day outside their homes, whether it be for work or other activities. As a result, homes are often left unoccupied for extended periods, making them a prime target for burglars. To address this issue, a prototype of an intelligent security system was proposed to protect homes from intruders.

The prototype security system was developed using a combination of different technology components (Escobar et al., 2008). An RFID (Radio Frequency Identification) reader RC522, an infrared motion sensor HC-SR501, and the ESP32 development board were used to fabricate an automatic home security device. The RFID reader was used to detect the presence of authorized individuals, while the infrared motion sensor was used to detect the presence of any intruders. The ESP32 development board was used as the main controller for the system, and it was connected to a wireless application that was implemented through the Arduino IDE software (Martínez et al., 2013).

The proposed security system works by alerting the homeowner when the presence of an intruder has been detected. The system is designed to be automatically activated when the home is left unoccupied, and it can only be deactivated or turned off by authorized individuals using the RFID reader. This provides an added layer of security, as it ensures that only authorized individuals can turn off the system and enter the home.

The proposed security system is not only limited to the detection of intruders, but it can also be extended to other security features such as monitoring the temperature, humidity, and other environmental factors, as well as providing notifications to the homeowner in case of any emergency.

Based on the annual Colombian report presented in 2021, there were approximately 33,306 reports of residential burglary and as of September of this year, 20,275 have been reported. 275, according to data recorded by DANE (Medina, 2020), it is evident that this type of crime does not decrease with the passing of the years, since in 2012 a total of 22,349 cases were reported, figures that have been widely surpassed reaching records of almost double these with almost 40,000 residential burglaries in the same year (Medina, 2020).

One way to address the issue of security is through the implementation of security systems. This is a common recommendation made by authorities to citizens as a means of preventing crime and keeping individuals and their property safe. However, while the implementation of security systems may seem like an obvious solution, it is important to consider the potential barriers to access for many individuals.

One such barrier is cost. Security systems can be quite expensive, with prices ranging from as low as $86 for the most basic options to over $200 for more advanced systems. Additionally, many of these systems require a monthly payment for ongoing monitoring and maintenance. For many individuals and families, these costs may be prohibitively high and make it difficult for them to access the benefits of a security system.

In light of this, it is important to explore alternative solutions that can provide the same level of security at a lower cost. One such solution is the use of the ESP32 development board in combination with a PIR sensor (HC-SR501) and a password system. This system can be further enhanced by incorporating RFID technology using the RC522 sensor to create a "key" system that allows individuals to access their homes or other secure spaces.

The use of the ESP32 development board allows for a more affordable and accessible solution as it is relatively low-cost. Additionally, the PIR sensor is a cost-effective way to detect movement and the password system can be used to prevent unauthorized access. The RFID technology allows the system to recognize authorized users and grant them access, providing an added layer of security.

It is important to note that while this system may not be as advanced or feature-rich as some of the more expensive options on the market, it can still provide a high level of security at a lower cost. Additionally, by using open-source technology, it is possible to customize and improve the system to better meet the needs of specific individuals or communities.

The security system we seek to develop will implement one or more PIR sensor sensors HC-SR501 connected simultaneously to the ESP 32 development board, similar to the one observed in the article by (Saleh et al., 2018) or in this other article by (Masykuroh et al., 2021), unlike the automatic lock will not be implemented, the most similar to what we seek is observed in the article by (Wahyuni et al., 2021). In addition, to facilitate the activation or deactivation of this system an RFID reader will be implemented as a "Key" which could be observed in the article of (Rusyn et al., 2022) in which a locking system with the RFID reader RC522 was observed, The goal is that the infrared sensor system to detect heat samples moving to send a signal to the board which in turn through the program designed in Arduino IDE request to disable the security system through the password or the "Key", in case of not being disabled send a signal either to an alarm or a notification to a mobile application via a WIFI or Bluetooth signal.

Problem statement

Theft from homes or commercial premises is a common crime that has remained at a constant level over the years, as evidenced by data from various studies and surveys (Table 1). Despite a recent decrease in these figures, it is still a significant problem that affects many individuals and businesses. One potential solution to help reduce this type of crime is the implementation of security systems. However, due to the high cost of many of these systems, this option is often only viable for those with significant financial resources.

Table 1

Annual residential burglary rates in Colombia (Policia Nacional, 2022)

Year	Number of residential burglaries
2018	47,373
2019	46,465
2020	32,324
2021	33,306
2022	23,484

Currently, many security systems include a wide range of complex components such as motion sensors, door and window opening detectors, and special functions such as notifications sent to mobile devices, automatic calls, and automatic locking. These features can be quite expensive and may not be accessible to individuals with limited financial resources. However, it is possible to replicate many of these features using cheaper components that are more affordable for those with fewer financial resources.

One example of this is the use of a simple motion sensor, such as the PIR sensor, which can detect movement and trigger an alarm or other response. This is a relatively low-cost component that can be easily integrated into a basic security system. Similarly, door and window opening detectors can be created using simple switch sensors, which can detect when a door or window is opened and trigger an alarm or other response.

Another potential solution is the use of open-source technology, which allows individuals to customize and improve their security systems to better meet their needs. For example, it is possible to use an ESP32 development board, which is a low-cost microcontroller that can be programmed to perform a wide range of functions, such as sending notifications to a mobile device or triggering an alarm.

Additionally, the use of a password system and RFID technology can enhance the security of the system, by allowing only authorized users to access the protected space. This can be a cost-effective way to ensure that only the right people have access to your home or business.

In conclusion, theft from homes or commercial premises is a common crime that remains a significant problem despite recent decreases in these figures. One potential solution to help reduce this type of crime is the implementation of security systems, however, the high cost of many of these systems makes them only accessible to people with large economic resources. By using cheaper components and open-source technology, it is possible to create a basic security system that is more affordable for those with less financial resources, therefore making it accessible for many people who can not afford the more advanced systems.

Methods

The development of a security dissuasive system requires the use of various components and technologies. The primary component of this system is the ESP32 30-pin development board, which serves as the central control unit for the system. This microcontroller board can be programmed to perform various functions and can be used to control and communicate with other components in the system.

Another key component of the system is the passive infrared (PIR) sensor HC-RC501, which is used to detect movement within the protected space. This sensor is designed to detect changes in infrared radiation and can be configured to trigger an alarm or other response when movement is detected.

In addition to the PIR sensor, the system also includes a 4x4 matrix keypad, which allows for the input of a password or other security code. This keypad can be used to arm and disarm the system, or to provide access to authorized users.

The system also includes an RFID reader and recorder module, the RC522 RFID reader, and the recorder. This module allows for the use of RFID technology to provide an added layer of security. RFID tags or cards can be assigned to authorized users, and the system can be configured to only grant access to individuals with the proper RFID tag or card.

ESP32

The ESP32 development board is a powerful and versatile tool for creating a wide range of projects, particularly those related to the Internet of Things (IoT). At its core, the ESP32 is a microprocessor that is capable of running a variety of programs and controlling various sensors and modules. One of the key advantages of the ESP32 is its ability to connect to both Wi-Fi and Bluetooth networks, which allows for a high level of flexibility and control in projects.

The built-in Wi-Fi connection allows for efficient and economical control of sensors and modules, as it allows for communication and data transfer without the need for additional hardware or cables. This can greatly simplify the design and implementation of projects and make them more cost-effective. The Bluetooth connection allows the ESP32 to communicate with other devices wirelessly, enabling the development of projects that require a low-power, short-range wireless connection.

The ESP32 development board is widely used in IoT projects, as it allows for the creation of smart devices and systems that can be controlled and monitored remotely. This opens up a wide range of possibilities for automating processes, collecting and analyzing data, and creating new applications and services.

HC-RC501

The HC-SR501 PIR sensor is a passive infrared motion sensor that is designed to detect movement within a specific range and field of view. The sensor is equipped with a Fresnel lens which helps to focus the infrared radiation, and has a detection range of 3 to 6 meters and a detection cone of 110°. This allows the sensor to detect movement within a specific area, making it a useful tool for security and automation applications.

The sensor has a continuous output of 3 seconds to 5 minutes, and the detection time can be adjusted by two potentiometers. This means that the sensor can be customized to meet the specific needs of a particular application, whether it's for a short-term or long-term detection.

The HC-SR501 operates on a voltage of 3.3 V to 5 V, which gives it a high output (3.3 V) when detecting moving heat samples, such as a person or an animal. This high output signal can then be used to trigger an alarm or other response, such as activating a camera or locking a door.

RC522

The RC522 module is a versatile and compact device that is designed for reading and recording RFID tags. It utilizes a modulation and demodulation system that operates at a frequency of 13.56 MHz, which is a commonly used frequency for RFID technology. The module is powered by a 3.3 V supply and utilizes the SPI protocol for communication. This allows for fast and reliable data transfer between the module and the host device. The module is small and lightweight, making it easy to integrate into a variety of projects and applications. Additionally, it is designed to be low-power, making it suitable for use in battery-powered devices. Overall, the RC522 module is an excellent choice for those looking to implement RFID technology into their projects.

Development procedure

The development of the security system requires a systematic and organized approach. One effective method for achieving this is by utilizing a flowchart, such as the one shown in Fig. 1, to guide the development process. To aid in the development process, the Wokwi simulator will be used. The Wokwi simulator is a powerful tool that allows developers to write, test and debug code in a virtual environment. The simulator is designed to be user-friendly and easy to use, making it an ideal choice for developers of all skill levels. By using the Wokwi simulator, developers can ensure that the code they are writing is compliant with what is established in the flowchart and that it will function correctly when implemented in the final system.

The operation of the code, starts with the detection of heat samples in motion (Presence), when a presence is detected a signal is sent to the ESP32 which initiates a process to identify if a key is entered, an RFID Tag is approaching or is deactivated by a command sent through a telegram message and verify if these are correct, in case an incorrect key is entered or a wrong Tag is entered, 1 failed attempt is counted, when 3 attempts are completed, it takes more than 30 seconds to enter the correct key, Tag or a command to activate using the telegram bot, a deterrent alarm is triggered for 1 minute, once the minute is over, the system returns to the initial stage (Presence detection); On the other hand, when the correct password or tag is entered, the system goes into a sleep state, waiting for the password to be re-entered to return to the initial state. In addition, thanks to the fact that the ESP32 has integrated Wifi, a Bot was implemented via Telegram with which the system can be managed.

The functional prototype can be seen in Fig. 2, which shows the ESP32 board, the HC-RC501 sensor, the RC522 module, the matrix keyboard, and the 16×2 LCD screen.

Results

During the sensor tests, it was observed that the device has a wide detection range, which is an important feature for a security system. It was also noted that when the device is first activated, it may be triggered 1 or 2 times during the first minute of operation. This is likely due to the device adjusting to its surroundings and fine-tuning its sensitivity.

When it came to mounting the prototype, the team encountered a small issue. The ESP32 board has 30 pins, but they were a little short, which made it necessary to mount and program the 4×4 matrix keyboard as a 4×3 matrix. This left the team with only 3 free pins that could be used as input. This limitation could potentially impact the system's flexibility, as it would limit the ability to add more motion sensors or other types of sensors, such as a magnetic sensor for doors or windows.

To overcome this limitation, the team decided to implement a system through IoT that allows the alarm to be activated or deactivated through the use of a Telegram bot. As shown in Fig. 3, the bot sends messages that can be used to control the alarm remotely. This allows the user to easily arm or disarm the system, even if they are not physically present. This can be especially useful for those who are away on vacation or at work, as it provides an added level of control and peace of mind.

Overall, the sensor tests showed that the device has a wide detection range and some minor issues were encountered during the prototype mounting, but the team was able to

Figure 1

Flowchart of the control scheme.

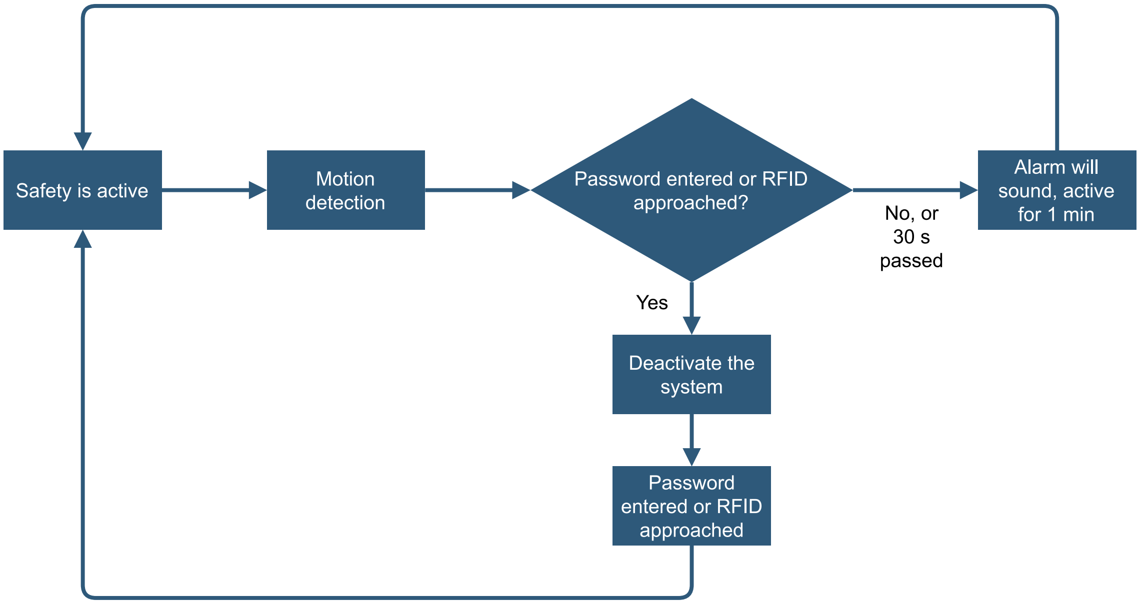
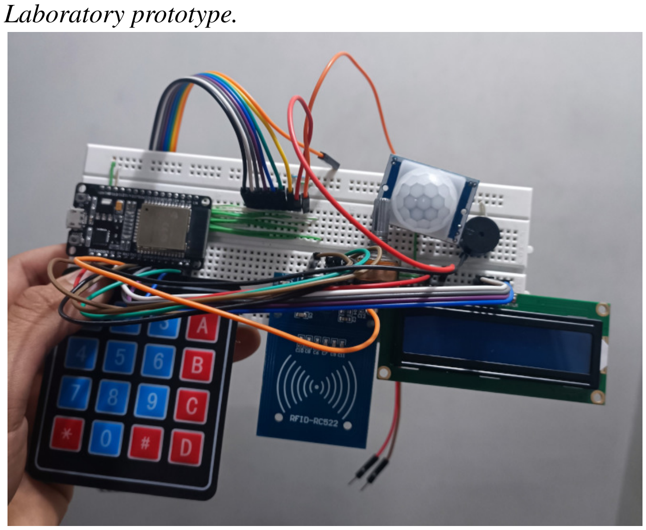


Figure 2

Laboratory prototype.



overcome them by implementing an IoT system through a Telegram bot, which provides a convenient and flexible way to control the alarm remotely. Despite the limitation of 3 usable input pins, the team will keep an eye on the possibility to add more motion sensors or other types of sensors in the future, to improve the overall security and performance of the system.

Conclusion

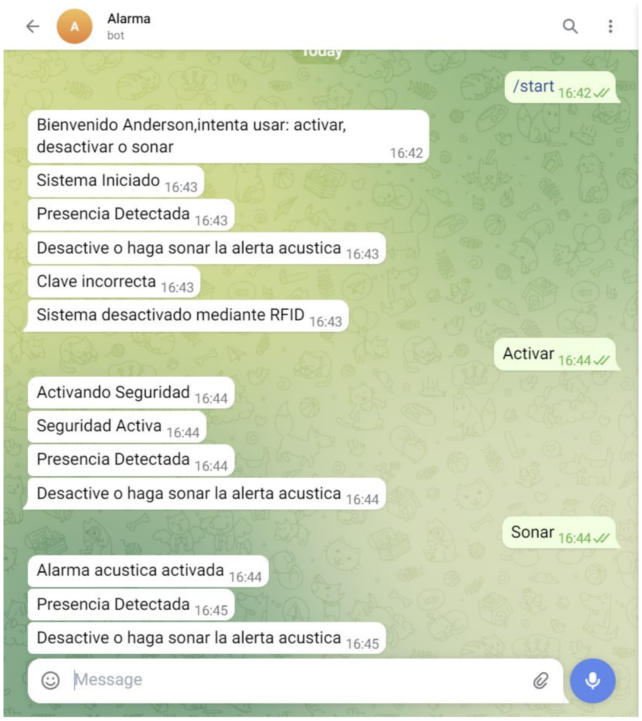
We have successfully developed a low-cost security system that is more affordable compared to traditional systems, with an approximate cost of $20 USD. While this is a significant achievement, there are some limitations to the system as it is currently designed. One limitation is the use of a development board that is short on pins, which reduces the flexibility to add additional features. In the case that more features are needed, we would opt to use the ESP32 version of the board, which has 38 pins, which would provide more options for expansion.

Another advantage of the system is the use of low-consumption components, which allows for the option of adding an external battery to the system. This would allow the security system to continue operating even in the event of a power outage, providing added protection for the protected space. Additionally, the system includes an IoT component, which allows for the activation or deactivation of the alarm via Telegram. This allows for the ability to keep a record of who deactivated the alarm in the case that it has been physically disabled, providing an extra level of security and access control.

The system can be configured to send notifications to the user's mobile device or even call the owner in case of an intrusion, this would allow the owner to take action immediately in case of an emergency. Additionally, if the alarm is triggered, it can trigger an automatic lock system that would prevent intruders to access the protected space.

Figure 3

Bot messages on Telegam.



In conclusion, we have developed a low-cost security system that is more affordable compared to traditional systems. Despite the limitations of the development board used, the system is still functional and provides a good level of security. The low consumption of components allows for the addition of an external battery, providing protection even in case of power outages, and the IoT component allows for remote activation and deactivation of the alarm, as well as providing access control and record keeping, making it a versatile and cost-effective solution for security.

The video in the following link shows how the security system works.

https://youtu.be/pLQFtftzxXE

References

Escobar, A., Hernández, C., & Martínez, F. Adaptive fuzzy control applied to a speed control (J. S. for Fuzzy Theory & I. Informatics, Eds.). In: *4th soft computing and intelligent systems (scis) and the 9th international symposium on advances intelligent systems (isis) (scis & isis 2008)* (J. S. for Fuzzy Theory & I. Informatics, Eds.). Ed. by for Fuzzy Theory, J. S., & Informatics, I. 2008, SA-D3–2.

Martínez, F., Jacinto, E., & Ramírez, D. (2013). Desarrollo e implementación de fotocontrol temporizado con tecnología de bajo consumo. *Redes de Ingeniería*, *4*(2013), 114–121. https://doi.org/10.14483/2248762X.6373

Masykuroh, K., Syifa, F. T., Setiyanto, G. R., Ramadhani, A. D., Kurnianto, D., & Iryani, N. (2021). Prototype smart door lock by using wireless network based on arduino uno. *2021 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT)*, 342. https://doi.org/10.1109/comnetsat53002.2021.9530806

Medina, C. C. (2020). Metodología general encuesta de convivencia y seguridad ciudadana (ecsc).

Policia Nacional. (2022). *Estadística delictiva*. https://www.policia.gov.co/grupo-informacion-criminalidad/estadistica-delictiva

Rusyn, V., Sambas, A., & Skiadas, C. H. (2022). Security access using simple RFID reader and arduino UNO: A study case. In *Lecture notes in networks and systems* (pp. 193–202). Springer International Publishing. https://doi.org/10.1007/978-3-031-03877-8_17

Saleh, S. B., Mazlan, S. B., Hamzah, N. I. B., Karim, A. Z. Z. B. A., Zainal, M. S. B., Hamzah, S. A. B., Nor, D. B. M., & Poad, H. B. M. (2018). Smart home security access system using field programmable gate arrays. *Indonesian Journal of Electrical Engineering and Computer Science*, *11*(1), 152. https://doi.org/10.11591/ijeecs.v11.i1.pp152-160

Wahyuni, R., Rickyta, A., Rahmalisa, U., & Irawan, Y. (2021). Home security alarm using wemos d1 and HC-SR501 sensor based telegram notification. *Journal of Robotics and Control (JRC)*, *2*(3), 200. https://doi.org/10.18196/jrc.2378

Tekhnê
July - December 2022, Vol. 19, No. 2, pp. 35 – 44

ISSN 1692-8407

Three neural architectures implemented in photovoltaic panel anomaly detection and categorization

Tres arquitecturas neuronales implementadas en la detección y categorización de anomalías en paneles fotovoltaicos

Kevin S. Sánchez C.[1] and Carlos A. Reyes G.[2]
[1]Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
kessanchezc@correo.udistrital.edu.co
[2]Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
carareyesg@correo.udistrital.edu.co

Solar panels are useful and efficient tools. They need to be kept in excellent working condition, but as time goes by, they suffer from external failures manifested in the environment. Therefore, the need for effective monitoring of such systems is highlighted. Neural models are perfect candidates to perform physical damage recognition. In this case, we compare the performance of three artificial neural networks, the multilayer perceptron, the densely connected neural network, and the ResNet-50 network in this identification problem. What is intended to be obtained from this method is the practical demonstration of the use of neural networks to solve real problems.

Keywords: Anomalies, diagnosis, learning, neural network, solar panels, training, visual inspection

Los paneles solares son herramientas útiles y eficientes. Necesitan mantenerse en excelente estado de funcionamiento, pero a medida que pasa el tiempo, sufren fallos por externos manifestados en el ambiente. Por lo tanto, se resalta la necesidad de hacer un seguimiento efectivo de dichos sistemas. Los modelos neuronales son candidatos perfectos para realizar el reconocimiento de los daños físicos. En este caso, se compara el desempeño de tres redes neuronales artificiales, el perceptrón multicapa, la red neuronal densamente conectada y la red ResNet-50 en este problema de identificación. Lo que se pretende obtener de este método es la demostración práctica del uso de las redes neuronales para solucionar problemas reales.

Palabras clave: Anomalías, aprendizaje, diagnóstico, entrenamiento, inspección visual, paneles solares, red neuronal

Article typology: Research

Received: December 14, 2022
Accepted: December 23, 2022

Research funded by: Universidad Distrital Francisco José de Caldas (Colombia).

How to cite: Sánchez, K., Reyes, C. (2022). *Three neural architectures implemented in photovoltaic panel anomaly detection and categorization*. Tekhnê, 19(2), 35 -44.

Introduction

The following paper presents one of the applications that can be made based on the anomaly recognition model which aims to categorize the possible aspects that can present a solar panel or a photovoltaic plant using a convolutional artificial neural network, a model specialized in image characterization. In general, we propose a model that can identify the physical states of solar modules, but the internal operating system is irrelevant to this article. The reason why this study is completely necessary is that a visual detection model allows to speed up the inspection that is normally done manually by a technical agent that supervises the state of the panel, therefore it is possible to reduce the inspection time in addition to the cost that this may mean for the owner of the photovoltaic panel.

The characteristics that make solar panels one of the most effective and outstanding energy-generating tools in the world of sustainable development, however, are certain factors that affect the proper functioning of these energy sources over time, not only the complexity of its physical form but also for the efficiency during energy collection. For this reason, it is necessary to recognize each of the situations in which a photovoltaic system is affected due to different factors. It is intended to design a visual recognition system that allows the identification of many of the possible physical, and superficial aspects that a photovoltaic panel may have to predict possible unknown anomalies. This is to minimize the human effort on technical revisions and maintenance that these systems need.

According to (Nomura et al., 2022), solar panels have been implemented with greater intensity since the advent of the environmental initiative with the Paris Agreement of 2016 which proposed the decrease of greenhouse gases, which has caused a high demand in the field of renewable energy collection systems, which positions solar panels as pioneers in the field of environmental care and responsible use of nature for the satisfaction of needs. As these systems are implemented by public entities and independent companies, the common interest in understanding how solar panels work is also awakening. Based on the above it is imminent that to keep a panel working optimally it is necessary to perform proper maintenance and above all be aware of possible failures that this may have in reaction to the environment where it operates, for example in urban areas where a study of degradation during the life cycle of the panel should be performed (Radovanovic & Popovic, 2021). One of the most common failures in photovoltaic panels Power-Voltage (PV) is the production of hot spots according to (Lamb et al., 2022).

Challenges related to the technical performance and reliability of crystalline silicon solar cells in hot desert climates, where the heat and high ultraviolet radiation experienced in the region pose a challenge to optimal performance. A comprehensive analysis of the performance degradation and failure modes of c-Si modules in the Algerian desert climate was previously conducted. Several modules were tested using a visual inspection Intensity-Voltage (IV) tracer. The solar modules have been in the field for a considerable time about 6 to 11 years. The results revealed some defects, such as; physical defects of the material, a decrease in cell shunt resistance, and an increase in the series resistance of the cell they have, this mainly contributed to the drop in power output. In addition, Hot desert climates affect the performance and lifetime of silicon (Kahoul et al., 2021).

On the other hand, an efficient method for PV plant quality monitoring was proposed that combines technologies such as an Unmanned Aerial Vehicle (UAV), using thermal imaging and machine learning so that the systematic inspection of a PV farm can be performed with simultaneous frequency. More emphasis is added to the use of deep neural networks to analyze thermographic images according to (Jumaboev et al., 2022; Masita et al., 2022; Segovia et al., 2022), who confirm that this can be implemented to reduce personnel costs and above all the inspection time normally used by an expert technician. The methods required for the inspection of solar plants are based on current technology such as drones, which are an efficient method to perform preventive and corrective maintenance on solar panels installed in large-scale connected photovoltaic plants. Also, quite a few studies have been conducted to detect anomalies in photovoltaic modules from these thermal images captured by such drones according to (Lin et al., 2014), who also mentions One of the general edge detection techniques, which uses the contrast between the target object and the background of the image to convert the target object into a real meaningful brightness value.

Meanwhile, using the linear relationship, the detailed parts of the image are used to present the location of the object and determine the precise positioning of the target object by linear regression. Among others, there are various image edge inspection methods, which differ in application perspectives. Also, other types of inspection studies can be found and tracked the status of a test object by monitoring through telemetry of a solar panel and corresponding optoelectronic devices, (Lin et al., 2014) mentions the Charge-Coupled Device (CCD) camera, which is triggered by the system proposal and captures the image of the test target in real-time, which is transferred to the system for image filtering, spatial masking, boundary tracing and other means of image processing. Another recognition method, according to (M. Wang et al., 2022; Zhang et al., 2022), suggests a non-clustered convolutional neural network (NPCNN), as a prediction module with the combination of the pattern symmetrized points based on deep learning, which is trained, developed and trained using the processed data to identify nonlinear features; there are other similar methods such as a multi-scale convolutional neural network using transfer learning (Korkmaz & Acikgoz, 2022).

Historical forecast errors are constructed and trained to be corrected by using an error correction module based on a hybrid Wavelet transform (WT) parallel to the K-Nearest Neighbors (KNN) model. In simulations, the proposed method is extensively evaluated on real PV data in Limburg, Belgium, where experimental results show that the proposed hybrid model is beneficial in improving the PV power forecasting performance compared to the benchmark methods (Zhang et al., 2022). At present, several studies have been conducted based on Artificial Intelligence (AI) implemented in the fault detection in PV systems (Eskandari et al., 2023). In addition, pse has implemented neural network models such as U-net neural network accompanied with image detection using true color infrared sensors, this model was applied by (Ahmed et al., 2022; Catalano et al., 2021; Kim et al., 2021; X. Wang et al., 2022), another model using neural networks in three steps by (Tchoketchkebir et al., 2021), which are data feeding step, fault modeling step and decision step.

Other sources of information such as (Prabhakaran et al., 2023) suggest the implementation of models based on multivariate deep learning in real-time, which focuses on physical aspects of the solar panel such as cracks, fissures, among others to detect the location of the defects. A specific algorithm used for detecting faults in solar panels is (Et-taleby et al., 2022). Other previously used methods such as (García et al., 2022) lie in the monitoring of abnormal predictive electrical parameters to alert and stop by automatic disconnection to avoid irreparable failures. Some failures can incur permanent damage and the impact on personnel safety becomes significant, increasing the risk of fire or fatal consequences.

Now, if we go into detail, to ensure the proper functioning of a solar panel, it is necessary to keep away any threat that interferes with its functional process. This is why it is necessary to recognize the possible circumstances in which a photovoltaic system is involved in efficiency mishaps due to its physical state. There are certain factors that directly and indirectly influence solar panels, such as cracking of the panel cells, obstruction of the cells by stains or liquids on the surface of the module, cracks in the metal edges, or unevenness of the panel due to geographical location or destruction of the support base.

The following section presents a broader view of the problem, taking into account the different modules in which it is planned to structure the segmentation of the erroneous physical aspects and consequently the mention of the recognition method without going into further detail. This is followed by the methodological specification proposed to be adopted in the project, to focus it and to obtain a series of conclusions attributed to the adopted solution.

Problem statement

Recognizing the various factors that can impact the performance of solar panel installations is crucial for ensuring their efficient operation. One key aspect to consider is the potential for obstructions on the surface of the panels, which can prevent sunlight from reaching the cells and impede the conversion of solar energy to electricity. Additionally, damage to the panels themselves, such as cracks or breaks in the cells or edges of the modules, can also negatively affect performance.

To address these concerns, a methodology has been developed that utilizes a deep learning model to more effectively and efficiently diagnose issues with solar panels. This model has been chosen for its ability to quickly and accurately identify potential problems, with the ultimate goal of reducing the cost and effort required for ongoing maintenance and supervision.

In detail, the methodology involves the categorization of potential anomalies that may occur in the solar panel environment. This includes issues such as surface obstructions that impede light penetration, as well as damage to the panels themselves, such as cracks or breaks in the cells or edges of the modules.

Once these potential issues have been identified, a deep learning model is used to analyze data and identify any signs of these anomalies. This approach has been chosen for its ability to effectively process large amounts of data and identify patterns that may not be immediately apparent to human observers. Additionally, the deep learning model is expected to be more efficient than other models in terms of diagnostic speed and accuracy.

The ultimate objective of this methodology is to optimize the cost of supervision that the exercise entails. By using the deep learning model to more quickly and accurately identify issues with solar panels, it is hoped that maintenance and repair efforts can be more effectively targeted and managed, resulting in cost savings over time.

Overall, the methodology adopted for this project is designed to recognize the influencing factors in the solar panel installation environment and to effectively diagnose and address any issues that may arise. By utilizing a deep learning model, it is expected that the diagnosis of solar panels will be done in a faster and more effective way, ultimately allowing for more efficient and cost-effective management of solar panel installations.

Methods

The experimental method adopted in this application project is a system based on deep learning. The convolutional neural network mentioned in the introduction is one of the most effective image recognition models, besides being modern, it can generate excellent results, speeding up detection and categorization. Therefore, it is the most attractive model to perform the diagnosis of the solar panel using images taken from it, to categorize the anomalies that appear in the image. To begin with the methodological description, the number of possible categories to be recognized by the system is taken into account; in particular, it is trained with individual output data for each category, i.e. the characteristic parameter cannot belong to two different categories. Furthermore, it must be an abnormal appearance evident to the camera lens with which the panel state is captured for example shown in Fig. 1, Fig. 2 and Fig. 3.

Figure 1

Category of solar panels with crystallization in the cells

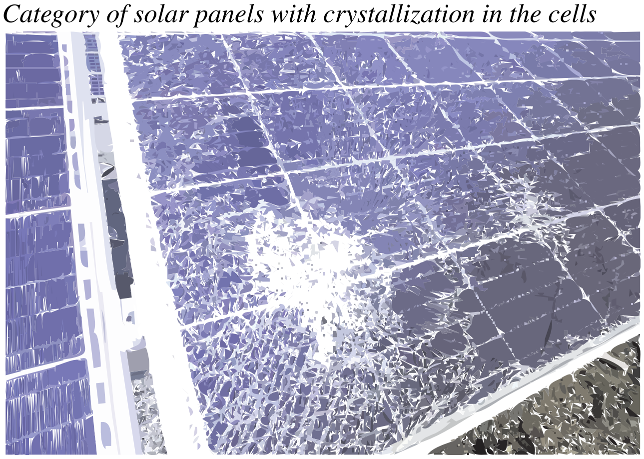


Figure 2

Category of intact solar panels

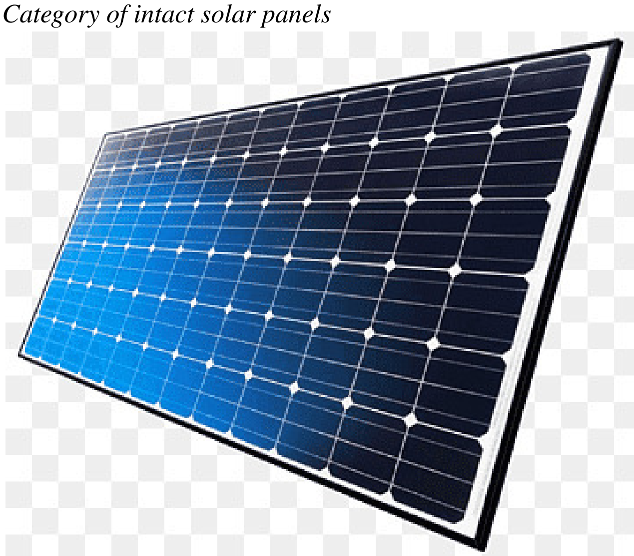


Figure 3

Category of superficially obstructed solar panels

These images have different characteristics and therefore each one belongs to a single category of the model. The neural network must be able to categorize the images correctly, guaranteeing the segmentation of the images according to their anomalies.

To achieve the general objective of this research, four specific objectives have been designated. Each specific objective is related to different activities that, when completed, fulfill each objective. For simplicity, the time at which the activities of each specific objective are carried out will be called phases. The activities to be carried out are detailed below.

Phase 1: Definition and treatment of variables

At the beginning of the procedure, an exhaustive bibliographic review was carried out to validate the importance and to find the technological gaps that are planned to be covered by the project. Likewise, as a result of the bibliographic review, the variables that have been used in similar models are found and the ones that will be used in the neural model can be chosen.

The next step was to choose the neural models to compare their behavior in particular, to conclude the project by selecting the model that most closely resembles the process of characterization of the images of solar panels. For this specific problem, a basic neural model was implemented, i.e. the multilayer perceptron, a model which needs certain adjustments in the parameters of the hidden layers for its correct operation; finally, the densely connected neural network or Dense-Net, which is a recursive network, was implemented. In particular, it emerges as an improvement of the networks with a scheme with greater depth, thanks to the fact that it has a higher convergence speed during training. The idea is that in this network all the neurons of the input layer are connected with all the neurons of the next layer so that each layer uses the parameters of the previous ones, which can be deduced as a better result in terms of efficiency for both training and validation. As for the previous networks, the main task for which they were designed was image recognition, although it should be noted that there are densely connected models designed to perform other types of tasks. Both of the above models are convolutional neural networks adapted for image categorization.

Phase 2: Implementation and training

The next step consisted of the implementation of the respectively selected neural models, adjusting the same database for each network, which contains a sufficient amount of images to perform the training and evaluation of the error behavior and accuracy of the models, based on which the respective comparison and selection are made.

Phase 3: Comparison and selection

In each of the cases of implementation of the selected neural models, it is quite important to highlight the functionality of the model in any percentage, because it is expected to obtain relevant results in each one. As mentioned above, the selection of the model is based on the best performance of the results obtained where the main objective of the project is fulfilled.

Phase 4: Performance analysis of the selected model

Finally, an account of the implemented prediction algorithms was made and after selecting the best-performing model, the results of the neural model and its classification errors were analyzed in detail.

During the implementation of the neural models, certain determining factors were found regarding the proper functioning of the model, such as the number of images in the database, which may be insufficient and incompatible with the structure of the neural network, the differences may also lie in the poor integration of the database along with the structure of the neural network.

Results

In the results section are the plots corresponding to the data yielded by the neural models. Fig. 4 and Fig. 5 show the error and accuracy plots corresponding to the traditional neural model of the multilayer perceptron, used in this case for image categorization. In addition, the respective confusion matrix is added to the model in Fig. 6 and the ROC curve in Fig. 7.

Figure 4

Training accuracy vs. validation accuracy plot

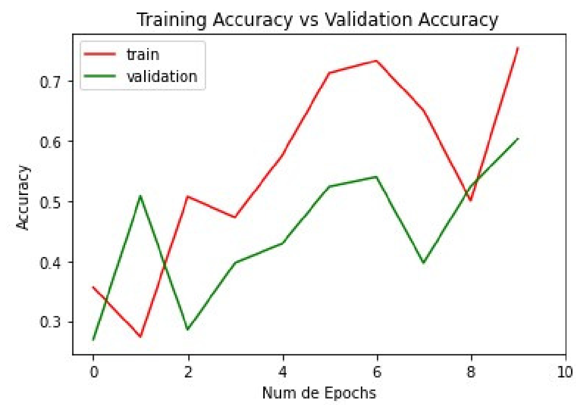
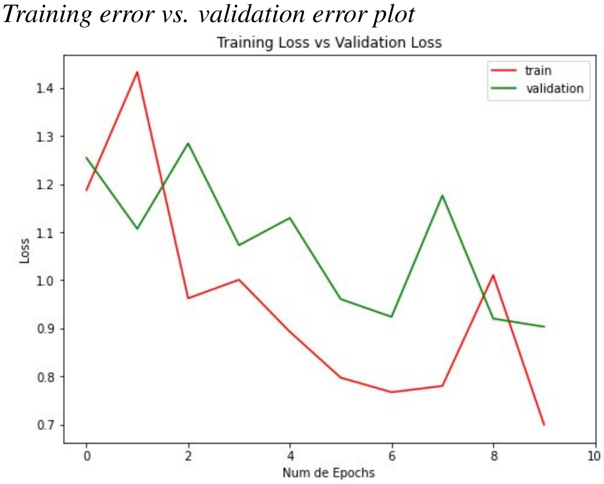


Figure 5

Training error vs. validation error plot



In the accuracy graph the behavior is erroneous but not so far from the result expected by the model, it may be due to the number of images it is recognizing. From the error graph, it can be deduced that it is decreasing with difficulty, over more

Figure 6

Confusion matrix of the multilayer perceptron model

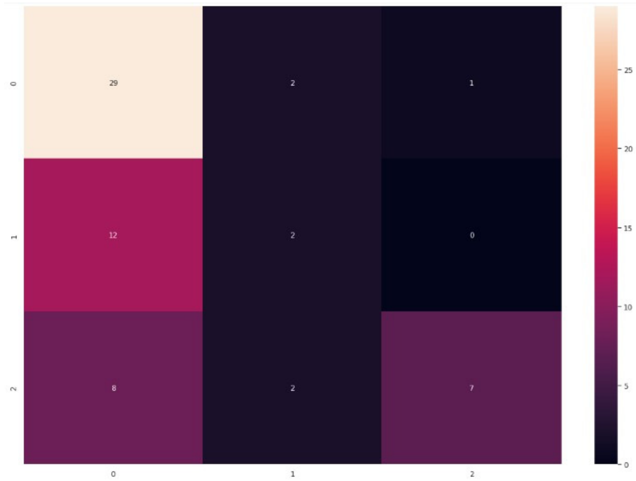
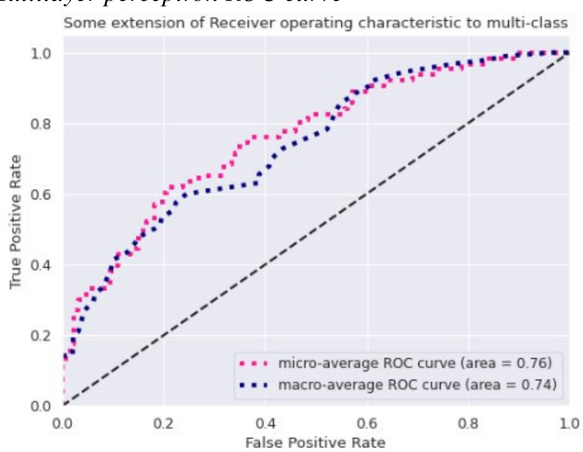


Figure 7

Multilayer perceptron ROC curve



epochs it would be easier to say that the behavior is likely to be correct. The model recognizes twenty-nine images correctly classified in the first category of intact panels, two images in the category of broken panels, and seven in the category of superficially obstructed panels, there is another twenty-five that was added to the wrong categories. The model has more trouble recognizing anomalies in the panels such as crystallization and surface obstruction, contrary to the intact panels which the model has less probability of error in recognizing.

The results for this particular case were not very accurate but neither can we affirm the inefficiency of the model for the moment, on the contrary in the following comparisons we find the evident fact that the other networks do not exceed the performance of the model mentioned above. For the case of the multilayer perceptron the metrics to be evaluated are located in Table 1, which indicate that accuracy in the categorization of the images was obtained between 33% and 88%, in addition, the completeness of the model is appreciated when characterizing the images, which indicates the proportion of the number of images that the model categorized correctly which was 14% in the second category, 41% in the third and 91% in the first category. The third metric is the ratio of accuracy to the completeness, the combined performance of the model can be said to be between 20 and 72%.

Table 1

Table of metrics evaluated for the multilayer perceptron model

	precision	recall	f1-score	support
0	0.59	0.91	0.72	32
1	0.33	0.14	0.20	14
2	0.88	0.41	0.56	17
accuracy			0.60	63
macro avg	0.60	0.49	0.49	63
weighted avg	0.61	0.60	0.56	63

As for the second architecture used to solve this problem, which has been implemented before, it has been a hit or miss in many cases. This convolutional neural network is densely connected which makes it work more efficiently, propagating the error signals to previous layers in a more direct way. In other studies comparing neural classifiers, the densely connected model is found to be at a disadvantage concerning other recognized neural models.

In Fig. 8, Fig. 9, Fig. 10 and Fig. 11 the error and accuracy plots corresponding to the densely connected neural model can be evidenced and the respective ROC curve and confusion matrix are also included. This model particularly presents a disadvantage with the prediction of the images in the respective categories, it can be affirmed with certainty that it is due to the size of the database which is insufficient for the correct execution of the model, even though the results are duly reflected in the article.

From the figures it is evident that the network is not performing optimally and is probably memorizing the images, but is not classifying them as expected, possibly due to overfitting in the composition of the neural network or as mentioned above by the database used in this particular case. The neural network does not fit the data and the categorization error persists, therefore the validation accuracy remains constant and does not climb as it should. The model is classifying all the validation images in the crystallized panel category when thirty-two should belong to

Figure 8

Training error vs. validation error plot

Figure 9

Training accuracy vs. validation accuracy plot

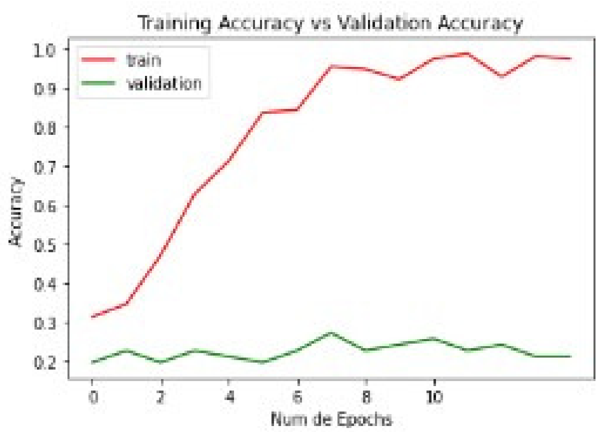


Figure 10

ROC curve of the densely connected model

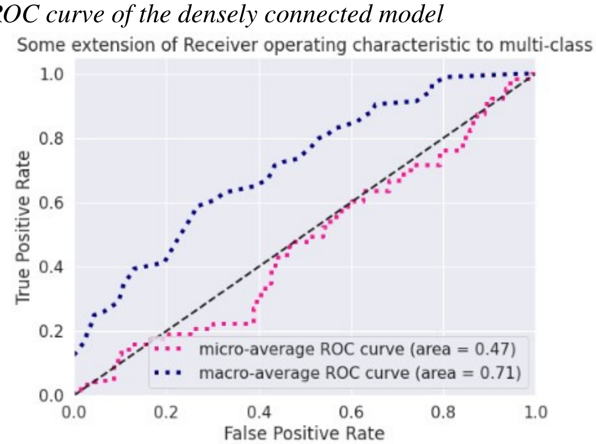
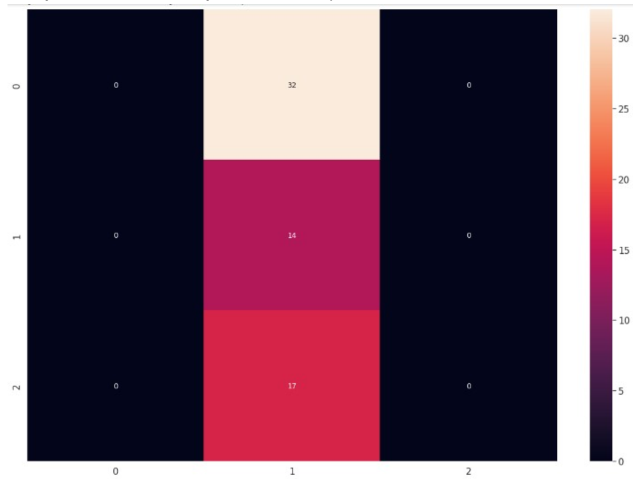


Figure 11

Confusion matrix of the densely connected model



the intact panel category and seventeen to the superficially obstructed category. The ROC curve, although it presents positive points, meaning the correct classifications when recognizing the images, also presents negative indexes, meaning the unification of all the images in a single category.

Table 2 shows the performance of the network during its training and the result as expected, was a failure in terms of classifying the images, which are not being properly categorized by the neural network.

Table 2

Table of metrics evaluated for the densely connected model

	precision	recall	f1-score	support
0	0.00	0.00	0.00	32
1	0.22	1.00	0.36	14
2	0.00	0.00	0.00	17
accuracy			0.22	63
macro avg	0.07	0.33	0.12	63
weighted avg	0.05	0.22	0.08	63

The only metrics obtained with the densely connected model are relapses in the second category of crystallized or broken panels, with accuracy and completeness below the favorable rate, not to mention erroneous data due to the inefficiency of the network for this problem. As a consequence of the above result analysis, the possible selection of the neural network as the solution to the problem of solar panel anomaly classification by imaging is completely ruled out.

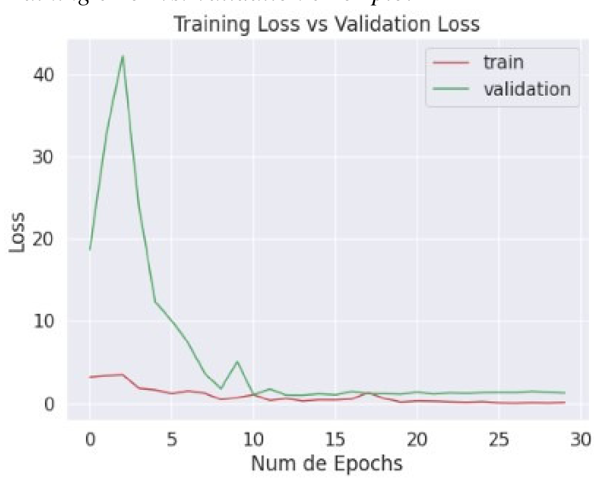
To have a clearer expectation of the problem it was decided to add a different neural architecture, which will be tested with the updated database, followed by scoring the same metrics previously evaluated for all the neural networks under evaluation. The interpretation of the metrics will respond to the objective of this article with the certainty of selecting the most efficient model in the categorization of images based on the problem of the physical state of the solar panels.

The third neural architecture is better known as ResNet-50 network, it is a convolutional neural network with 50 layers deep which not only interacts in the same way as a multilayer perceptron but also sends the original information to all neurons from the first layer to the last layer of the network, to preserve important information across epochs. This network is shown below in the form of results under the constraints of a finite database.

In Fig. 12, Fig. 13, Fig. 14 and Fig. 15 show the actual behavior of the ResNet-50 neural network along with its respective evaluation metrics.

Figure 12

Training error vs. validation error plot



In the figure of the error in the evaluation, the behavior tries to stabilize, reaching a value very close to what it should be, throughout thirty epochs it presents a positive behavior in terms of error decrease. The opposite happens with accuracy, which performs an unstable behavior with no desire to improve increasing through the epochs. The confusion matrix reveals the problem that exists in the case of the superficial obstruction category, the images do not seem to be sufficient and it categorizes them incorrectly, however, the misclassified images may be due to the lack of attention paid by the network to the third category. The ROC curve shows a behavior of mostly positive points, indicating a higher accuracy in classifying the images. Finally, the respective metrics for the ResNet-50 model are shown in

Figure 13

Training accuracy vs. validation accuracy plot

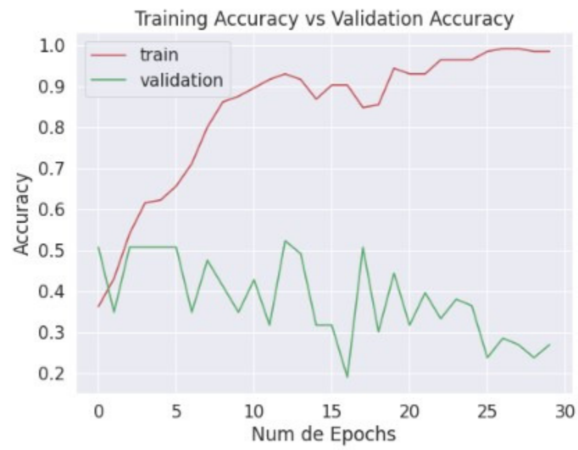


Figure 14

Confusion matrix of the ResNet-50 model

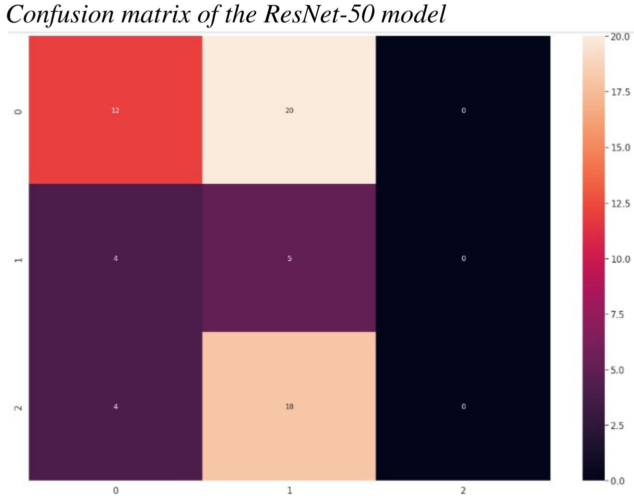


Figure 15

ROC curve of the ResNet-50 model

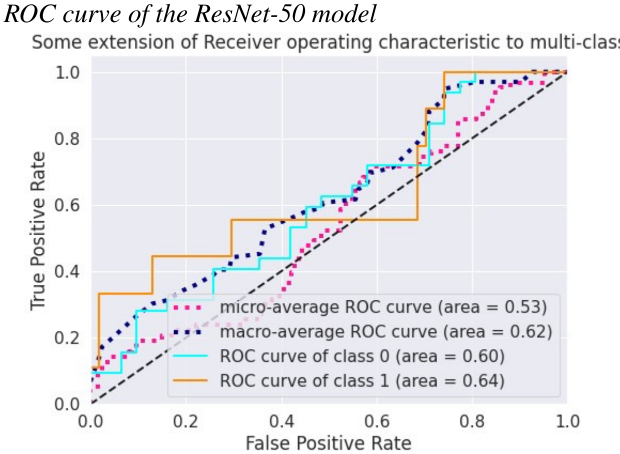


Table 3. According to the table, the accuracy abounds mostly in recognizing the category of intact panels with 60%, and a lower percentage in the category of crystallizations. Completeness is not very good but ranges from 38% to 56% correct categorization. The combined performance does not exceed 50%. The category recognition mishap makes the model very suboptimal for the image classification required to solve the problem.

Table 3

Table of metrics evaluated for the ResNet-50 model

	precision	recall	f1-score	support
0	0.60	0.38	0.46	32
1	0.12	0.56	0.19	9
2	0.00	0.00	0.00	22
accuracy			0.27	63
macro avg	0.24	0.31	0.22	63
weighted avg	0.32	0.27	0.26	63

Conclusion

In summary, of the three architectures evaluated, the traditional neural network or multilayer perceptron model demonstrated the highest performance when considering the number of images used within the selected model. Through an exhaustive analysis, the specific network architecture was chosen, which included 1230 neurons in the first layer and 894 neurons in the hidden layer. Both layers utilized the Rectified Linear Unit (ReLU) as the activation function, and the model was trained over ten epochs.

The results of the neural network showed that a total of 4,883,884 parameters were used, making it the model that used the least input parameters yet still obtained the best result. Even though the behavior of the selected network was not perfect, it did demonstrate a clear learning pattern, where the error was consistently reduced and accuracy increased as the number of evaluated epochs increased.

It is worth noting that the process of selecting the architecture and training the model was not perfect and that there are always trade-offs. However, the model with the highest performance was the one that used the least input parameters and obtained the best result. It is also important to mention that in any machine learning task, the performance of a model is not only dependent on the architecture but also the quality of data and the hyperparameters tuning.

In general it can be concluded that:

- We can appreciate higher performance of the traditional neural network or multilayer perceptron than the densely connected network and the RedNes-50 for this specific recognition problem.
- It can be deduced that the size of the database is essential in terms of the correct operation, which makes the network have such a performance, in addition it is necessary to take into account the correct design of the database, making sure that an image does not correspond to two categories.
- The selection of the neural network suitable for solar panel image classification does not indicate that the other two networks in comparison are inefficient in general. Only in this case, the densely connected networks and ResNet-50 did not perform well, in other studies and in other projects they are pioneering networks in the field of convolutional artificial neural networks.

In conclusion, the traditional neural network or multilayer perceptron model was found to be the most effective architecture when considering the number of images used within the selected model. The specific network architecture chosen had 1230 neurons in the first layer, and 894 neurons in the hidden layer, and utilized the Rectified Linear Unit (ReLU) as the activation function. Although the behavior of the selected network was not perfect, it did demonstrate a clear learning pattern, where the error was consistently reduced and accuracy increased as the number of evaluated epochs increased.

References

Ahmed, W., Ali, M., Hussain, S., Zafar, A., & Hasani, S. (2022). Visual vocabulary based photovoltaic health monitoring system using infrared thermography. *IEEE Access*, *10*, 14409–14417.

Catalano, A., Scognamillo, C., Guerriero, P., Daliento, S., & d'Alessandro, V. (2021). Using emphasis for the thermography-based fault detection in photovoltaic plants. *Energies*, *14*.

Eskandari, A., Aghaei, M., Milimonfared, J., & Nedaei, A. (2023). A weighted ensemble learning-based autonomous fault diagnosis method for photovoltaic systems using genetic algorithm. *International Journal of Electrical Power and Energy Systems*, *144*.

Et-taleby, A., Chaibi, Y., Boussetta, M., Allouhi, A., & Benslimane, M. (2022). A novel fault detection technique for pv systems based on the k-means algorithm, coded wireless orthogonal frequency division multiple. *Solar Energy*, *237*, 365–376.

García, E., Ponluisa, N., Quiles, E., Zotovic-Stanisic, R., & Gutiérrez, S. (2022). Solar panels string predictive and parametric fault diagnosis using low-cost sensors. *Sensors*, *22*.

Jumaboev, S., Jurakuzie, D., & Lee, M. (2022). Photovoltaics plant fault detection using deep learning techniques. *Remote Sensing*, *14*.

Kahoul, N., Chehhib, H., Sidrach de Cordona, M., Affari, B., Younes, M., & Kherici, Z. (2021). Performance degradation analysis of crystalline silicon solar cells in desert climates. *Energy for Sustainable Development*, *65*, 189–193.

Kim, B., Serfa, R., Lee, D., & Chen, Z. (2021). Importance of image enhancement and cdf for fault assessment of photovoltaic module using ir thermal image. *Applied Sciences (Switzerland)*, *11*.

Korkmaz, D., & Acikgoz, H. (2022). An efficient fault classification method in solar photovoltaic modules using transfer learning and multi-scale convolutional neural network. *Engineering Applications of Artificial Intelligence*, *113*.

Lamb, W., Asnes, D., Kupfer, J., Lickey, E., Bakken, J., Haskell, R., Saeta, P., & Yang, Q. (2022). Real-time anticipation and prevention of hot spots by monitoring the dynamic conductance of photovoltaic panels. *IEEE Journal of Photovoltaics*, *12*, 1051–1057.

Lin, C., Tzeng, G., Cheng, C., Lay, Y., & Tien, C. (2014). An automatic optical inspection system for the detection of three parallel lines in solar panel end face. *Optik*, *125*, 688–693.

Masita, K., Hasan, A., & Shongwe, T. (2022). 75mw ac pv module field anomaly detection using drone-based ir orthogonal images with res-cnn3 detector. *IEEE Access*, *10*, 83711–83722.

Nomura, Y., Inoue, M., & Kuroki, H. (2022). Anomaly detection for solar panel joint clamps using deep learning based detection and recognition techniques. *Zairyo/Journal of the Society of Materials Science, Japan*, *71*, 289–295.

Prabhakaran, S., Uthra, R., & Preetharoselyn, J. (2023). Deep learning-based model for defect detection and localization on photovoltaic panels. *Computer Systems Science and Engineering*, *44*, 2683–2700.

Radovanovic, I., & Popovic, I. (2021). Identification of degrading effects in the operation of neighboring photovoltaic systems in urban environments. *Electronics (Switzerland)*, *10*.

Segovia, R., J., P., & García, F. (2022). Unmanned aerial vehicle integrated real time kinematic in infrared inspection of photovoltaic panels. *Measurement: Journal of the International Measurement Confederation*, *18*.

Tchoketchkebir, S., Cheggaga, N., Ilinca, A., & Boulouma, S. (2021). An efficient neural network-based method for diagnosing faults of pv. *Sustainability (Switzerland)*, *13*.

Wang, M., Lin, Z., & Lu, S. (2022). A fault detection method based on cnn and symmetrized dot pattern for pv modules. *Energies*, *15*.

Wang, X., Yang, W., Qin, B., Wei, K., Mamá, Y., & Zhang, D. (2022). Intelligent monitoring of photovoltaic panels based on infrared detection. *Energy Reports*, *8*.

Zhang, R., Li, G., Bu, S., Kuang, G., He, W., Zhu, Y., & Aziz, S. (2022). A hybrid deep learning model with error correction for photovoltaic power forecasting. *Frontiers in Energy Research*, *10*.

Instrucciones para los autores

Tekhnê
Tecnología al servicio de la sociedad
Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

Revista Tekhnê
Universidad Distrital Francisco José de Caldas
Facultad Tecnológica

Alcance y política editorial de la revista

La revista **Tekhnê** es una revista institucional de la Facultad Tecnológica de la Universidad Distrital Francisco José de Caldas (Colombia). Es arbitrada, y acepta trabajos originales en el campo de la ingeniería, la tecnología y las ciencias aplicadas, con la condición de que sean producto de trabajos de investigación. Desde su primer número en el año 2003, la revista ha mantenido su regularidad.

Posee un carácter científico-académico, y atiende a la comunidad nacional e internacional especialista en áreas de ingenierías eléctrica, electrónica, mecánica, de sistemas, industrial y civil. Publica resultados de investigación en inglés (artículos originales e inéditos), y está completamente abierta a especialistas de todo el mundo en calidad de autores y/o lectores. Es arbitrada mediante un proceso doble ciego, con rotación continua de árbitros.

La revista **Tekhnê** posee una periodicidad semestral, coincidente con los semestres académicos de la Universidad Distrital. La publicación se realiza los meses de junio y diciembre de cada año. El proceso de evaluación de los trabajos sometidos para la publicación contempla una etapa de aceptación inicial por parte del Comité Editorial, quien verifica el cumplimiento de los parámetros editoriales, y una evaluación por pares académicos mediante un proceso doble ciego. El tiempo que toma decidir sobre la aceptación de un trabajo nunca supera los seis (6) meses a partir de la fecha de recepción.

La revista **Tekhnê** está comprometida con altos estándares de ética y toma las medidas posibles para evitar las malas prácticas como el fraude y el plagio. Todos los autores deben declarar que sus manuscritos son originales, inéditos y de su autoría, condición necesaria para ser considerados por el Comité Editorial. La revista **Tekhnê** también se compromete a garantizar una justa, objetiva y rápida revisión de los manuscritos tanto por árbitros como por parte del Editor. Los autores reconocen que han dado a conocer cualquier conflicto real o potencial de intereses con su trabajo o de beneficios parciales asociados a través de la cesión de derechos.

La revista **Tekhnê** es financiada por la Universidad Distrital Francisco José de Caldas, razón por la cual NO cobra por procesamiento y/o publicación de artículos (APCs).

Tipos de artículos aceptados

La revista publica exclusivamente artículos de Investigación Científica y Tecnológica (según clasificación del Índice Nacional de Publicaciones Científicas y Tecnológicas Publindex de Colciencias), los cuales se caracterizan por presentar resultados originales de proyectos terminados de investigación, con secciones claramente diferenciadas de introducción, metodología, resultados y conclusiones. Otro tipo de artículos como los denominados de reflexión, revisión, artículos cortos o reportes de casos no son aceptados, y serán rechazados por el Comité Editorial sin surtir proceso alguno de evaluación.

Formato del manuscrito

En cuanto a estructura, deben ser evidentes las secciones de introducción, metodología, resultados, conclusiones y referencias. El resto del documento se debe conformar en concordancia con su contenido. La longitud no debe superar las 25 páginas en su totalidad. En la parte inicial de la primera página se debe incluir: (1) Un título del manuscrito (en español e inglés), corto, descriptivo del contenido y atractivo para el lector. (2) Nombre completo de los autores y detalles de afiliación institucional, incluido correo electrónico. (3) Resumen (en español e inglés) del manuscrito con un tamaño máximo de 250 palabras, que establezca el objetivo, la metodología, los resultados y principales conclusiones. (4) Palabras claves, máximo cinco, en minúsculas y separadas por comas.

En cuanto al formato de documento solicitado a los autores, se pide utilizar LaTex de acuerdo con la plantilla disponible en el portal web de la revista. No se debe modificar el formato de la plantilla. Las tablas y figuras deben ser claras y nítidas, insertadas como archivos EPS con la mayor calidad posible. Se pide que estas figuras sean remitidas en un archivo comprimido por separado. Si se usan líneas o figuras en colores, no se debe usar colores claros (amarillos, celestes y similares). El Editor se reserva el derecho de eliminar toda figura o tabla que no cumpla las normas. Toda figura, tabla, ecuación o referencia incluida en el manuscrito debe estar referenciada/ citada en el cuerpo del documento. Las referencias deben manejar correcto estilo APA sexta edición. No se deben utilizar notas al pie de página, y usar máximo tres niveles para los títulos. Se puede incluir una sección de Agradecimientos (altamente recomendada), redactada en forma sobria, de no más de cuatro líneas justo después de las Conclusiones.

Se deben remitir todos los archivos fuente. Para todos los casos, los autores deben remitir, junto con las imágenes, un archivo BibTeX (un único archivo *.bib) con todas las referencias utilizadas en el artículo, cada referencia con una key única. Este archivo puede ser generado desde manejadores de referencias como Mendeley y Zotero, o generado con herramientas como JabRef.

En cuanto al lenguaje y estilo de redacción, se deben utilizar oraciones simples y evitar regionalismos. Se debe poner especial cuidado en el correcto uso de la ortografía y redacción, de acuerdo a las reglas del lenguaje.

Formato de publicación

Los manuscritos son publicados siguiendo el estilo APA sexta edición. Esto es realizado en la diagramación, y es transparente para los autores.

Cambios en la edición

El Editor se reserva el derecho, y así lo acepta el(la)(los) autor(a)(es) con el sólo envío del manuscrito, de realizar modificaciones con el objeto de lograr una mejor presentación e impacto del trabajo. Estas modificaciones pueden incluir cambios en el título, resumen, palabras clave, figuras, tablas y texto, entre otros, cambios que no afectan, según el Editor, la esencia del trabajo enviado por los autores. En particular, figuras que no pueden ser bien reproducidas pueden ser eliminadas por el Editor. Las referencias incompletas serán también eliminadas por exigencias de las bases de datos.

Envío de manuscritos

Los autores deben enviar sus artículos a través de la aplicación para tal fin del Open Journal System (http://revistas.udistrital.edu.co/ojs/index.php/tekhne/index) en formato digital, adjuntando:

- La carta de presentación.
- La carta de cesión de derechos (según formato).

La carta de presentación debe estar dirigida al director y editor de la revista, Ing. Fredy H. Martínez S., y debe incluir:

- Solicitud expresa de considerar el artículo para publicarlo en la revista **Tekhnê**.
- Título completo del trabajo.
- Nombres completos de todos los autores, con detalle de entidad a la que se encuentran vinculados, dirección e-mail institucional, títulos académicos, ciudad y país.
- Certificación de la originalidad y el carácter inédito del artículo.
- Exclusividad de su remisión a la revista **Tekhnê**.
- Confirmación de la autoría con la firma de todos los autores.
- Institución que financió o avaló el proyecto.

El proceso de envío consta de tres etapas:

1. Envío del artículo en formato PDF. Se carga al OJS un único archivo sin comprimir.
2. Registro de los datos. Se regista en el OJS los datos básicos de los autores y del artículo.
3. Envío de Archivos Complementarios. Todos los archivos complementarios se envían en un único archivo comprimido. Estos archivos complementarios incluyen: los archivos fuente del documento, tanto texto como imagenes en alta calidad, archivo BibTeX con todas las referencias utilizadas, la carta de presentación, y la carta de cesión de derechos.

Proceso de publicación

El proceso que sigue la revista para la evaluación y publicación de trabajos es el siguiente:

- Recepción del manuscrito (primera versión, convocatoria permanente)
- Verificación de normas por parte de auxiliar de la revista
- Notificación a autores de recepción, solicitud de ajustes de forma y de diligenciamiento de formato de datos de autores
- Recepción de manuscrito (segunda versión) y formato de datos de autores
- Revisión por parte del Comité Editorial
- Notificación a autores de si el manuscrito entra o no a evaluación por parte de pares
- Envío de manuscrito a pares seleccionados
- Recepción de evaluación de pares
- Notificación de evaluación a autores, y solicitud de correcciones si son pertinentes
- Recepción de manuscrito (tercera versión)
- Estudio de manuscrito corregido por parte del Comité Editorial
- Notificación a autores de decisión final de publicación y solicitud de carta de cesión de derechos
- Recepción de carta de cesión de derechos
- Corrección de estilo y diagramación del manuscrito
- Envío de versión final a autores para verificación de errores y aprobación final
- Publicación del artículo
- Notificación a autores de publicación
- Entrega de ejemplares a autores

Contacto

Para cualquier solicitud de información adicional puede comunicarse con:

Prof. Fredy H. Martínez S.
Editor y director revista Tekhnê
Sala de Revistas, Bloque 5, Oficina 301
Facultad Tecnológica
Universidad Distrital Francisco José de Caldas
Transversal 70B No. 73A-35 sur
Teléfono: (571) 3238400 Ext. 5003
Celular: (57) 3005585481
Bogotá D.C., Colombia
E-Mail: fhmartinezs@udistrital.edu.co
Url: http://revistas.udistrital.edu.co/ojs/index.php/tekhne/indexl

Instructions for authors

Tekhnê
Tecnología al servicio de la sociedad
Universidad Distrital Francisco José de Caldas - Facultad Tecnológica

Tekhnê Journal
Universidad Distrital Francisco José de Caldas
Facultad Tecnológica

Scope and editorial policy of the journal

The **Tekhnê** journal is an institutional journal of the Technological Faculty of District University Francisco José de Caldas (Colombia). It is arbitrated, and accepts original articles in the field of engineering, technology and applied sciences on the condition that they are the product of research work. Since its first issue in 2003 the journal has maintained its regularity.

It has a scientific-academic nature and attends the specialist national and international community in the areas of electrical, electronics, mechanical, systems, industrial and civil engineering. Publishes research results in English (original and unpublished articles), and is fully open to experts from around the world as authors and/or readers. It is arbitrated by a double-blind process, with continuous rotation of evaluators.

The **Tekhnê** journal has twice a year periodicity, coinciding with the academic semesters of the District University. The publication is made in June and December each year. The evaluation process of the papers submitted for publication includes a stage of initial acceptance by the Editorial Committee, which verifies compliance with the editorial parameters and an evaluation by academic peers through a double blind process. The time taken to decide on the acceptance of a paper never exceeds six (6) months from the date of receipt.

The **Tekhnê** journal is committed to high ethical standards and take possible measures to avoid bad practices such as fraud and plagiarism. All authors must declare that their manuscripts are original, unpublished and of his own, needed condition to be considered by the Editorial Committee. The **Tekhnê** journal also is committed to ensuring a fair, objective and quick review of manuscripts both referees as by the Editor. The authors recognize that they have disclosed any actual or potential conflict of interest with their work or partial benefits associated through the transfer of rights.

The **Tekhnê** journal is funded by the District University Francisco José de Caldas, which is why it does NOT charge for processing and/or publishing articles (APCs).

Types of articles accepted

The journal publishes only Scientific and Technological Research articles (as classified by Publindex, the National Abstracting and Indexing System for Serial Publications in Science, Technology and Innovation of Colciencias), which are characterized by original results of completed research projects with clearly distinct sections of introduction, methodology, results and conclusions. Other articles as called reflection, review, short articles or case reports are not accepted and will be rejected by the Editorial Committee without dispensing any evaluation process.

Manuscript format

Regarding the structure, should be evident the sections of introduction, methodology, results, conclusions and references. The rest of the document must conform in accordance with its contents. The length should not exceed 25 pages in full. In the initial part of the first page should include: (1) A manuscript title (in Spanish and English), short, descriptive of the content and attractive to the reader. (2) Full name of the authors and institutional affiliation details, including email. (3) Abstract (in Spanish and English) of the manuscript with a maximum size of 250 words, which set the objective, methodology, results and major conclusions. (4) Keywords, up to five, lowercase and separated by commas.

Regarding the document format requested by authors, it is requested to use LaTex according to the template available in the journal's web portal. The format of the template should not be modified. Tables and figures should be clear and sharp, inserted as EPS files with the highest possible quality. It is requested that these figures be submitted in a separate compressed file. If colored lines or figures are used, light colors (yellow, light blue, and similar) should not be used. The Editor reserves the right to delete any figure or table that does not comply with the rules. Any figure, table, equation, or reference included in the manuscript must be referenced/cited in the body of the paper. References must use the correct APA sixth edition style. Footnotes should not be used, and a maximum of three levels should be used for headings. An Acknowledgements section may be included (highly recommended), written soberly, of no more than four lines just after the Conclusions.

All source files must be submitted. In all cases, authors should submit, together with the images, a BibTeX file (a single *.bib file) with all the references used in the article, each reference with a unique key. This file can be generated from reference managers such as Mendeley and Zotero, or generated with tools such as JabRef.

Regarding the language and style of writing, the author must use simple sentences and avoid regionalisms. He must take special care to use the correct spelling and writing, according to the rules of language.

Publication format

The manuscripts are published following the APA style 6th edition. This is done in the layout, and is transparent to the authors.

Editing changes

The Editor reserves the right, and is accepted by the author(s) with the only article shipping, to make changes in order to achieve a better presentation and impact of the work. These modifications may include changes in the title, abstract, keywords, figures, tables and text, among others, changes that do not affect, according to the Editor, the essence of the work submitted by the authors. In particular, figures that can not be well reproduced can be eliminated by the Editor. Incomplete references will also be eliminated by demands of databases.

Sending manuscripts

Authors must submit their articles through the application for the purpose of the Open Journal System (http://revistas.udistrital.edu.co/ojs/index.php/tekhne/index) in digital format, attaching:
• The presentation letter.
• The transfer of rights letter (according to format).

The presentation letter should be addressed to the director and editor of the journal Prof. Fredy H. Martínez S., and it should include:
• Express request to consider the article for publication in **Tekhnê** journal.
• Full title of the article.
• Full names of all authors, detailing entity linked, institutional e-mail address, academic degrees, city and country.
• Certification of the originality and novelty of the article.
• Exclusivity of submission to **Tekhnê** journal.
• Confirmation of authorship with the signature of all authors.
• Institution financing the project.

The submission process consists of three stages:

1. Sending the article in PDF format. OJS is charged with a single uncompressed file.
2. Data recording. the basic data of the authors and article are registered in the OJS.
3. Complementary files. All additional files are sent in a single compressed file. These complementary files include: the source of the document, both text and images in high quality, BibTeX file with all references used, the presentation letter, and the transfer of rights letter.

Publishing process

The process followed by the journal for evaluation and publication of articles is as follows:
• Receipt of the manuscript (first version, continuously open call)
• Verification of standards by the assistant of the journal
• Notification to authors of receipt, request for the form adjustments and filling of authors data format
• Receipt of the manuscript (second version) and authors data format
• Review by the Editorial Committee
• Notification to authors if the manuscript is sent or not to evaluation by peers
• Sending the manuscript to selected peers
• Reception peer evaluation
• Notification of evaluation to authors, and request corrections if they are relevant
• Receipt of the manuscript (third version)
• Study of manuscript corrected by the Editorial Committee
• Notification to authors of publication and final decision, and request the rights transfer letter
• Reception of the rights transfer letter
• Style correction and layout of the manuscript
• Send final version to authors for error checking and final approval
• Publication of the article
• Notification to authors of the publication
• Delivery of copies to authors

Contact

For any request for additional information please contact:

Prof. Fredy H. Martínez S.
Editor and director Tekhnê Journal
Sala de Revistas, Bloque 5, Oficina 301
Facultad Tecnológica
Universidad Distrital Francisco José de Caldas
Transversal 70B No. 73A-35 sur
Phone: (571) 3238400 Ext. 5003
Cell phone: (57) 3005585481
Bogotá D.C., Colombia
E-Mail: fhmartinezs@udistrital.edu.co
Url: http://revistas.udistrital.edu.co/ojs/index.php/tekhne/index