

Lecture Notes in Networks and Systems 619

Miguel Botto-Tobar · Omar S. Gómez ·
Raul Rosero Miranda ·
Angela Díaz Cadena ·
Washington Luna-Encalada *Editors*

Trends in Artificial Intelligence and Computer Engineering

Proceedings of ICAETT 2022

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Miguel Botto-Tobar 
Eindhoven University of Technology
Eindhoven, The Netherlands

Omar S. Gómez 
Escuela Superior Politécnica de Chimborazo
Riobamba, Ecuador

Raul Rosero Miranda
Escuela Superior Politécnica de Chimborazo
Riobamba, Ecuador

Angela Díaz Cadena
Universitat de Valencia
Valencia, Valencia, Spain

Washington Luna-Encalada
Escuela Superior Politécnica del Chimborazo
Riobamba, Ecuador

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Preface

The 4th International Conference on Advances in Emerging Trends and Technologies (ICAETT) was held on the main campus of the Escuela Superior Politécnica de Chimborazo, in Riobamba–Ecuador, from October 26 to 28, 2022, and it was proudly organized by Facultad de Informática y Electrónica (FIE) at Escuela Superior Politécnica de Chimborazo and supported by GDEON. The ICAETT series aims to bring together top researchers and practitioners working in different domains in the field of computer science to exchange their expertise and to discuss the perspectives of development and collaboration [1, 2]. The content of this volume is related to the following subjects:

- Artificial Intelligence
- Communications
- e-Learning
- AT for Engineering Applications
- Security
- Technology Trends.

ICAETT 2022 received 234 submissions written in English by 940 authors coming from 15 different countries. All these papers were peer-reviewed by the ICAETT 2022 Program Committee consisting of 162 high-quality researchers. To assure a high-quality and thoughtful review process, we assigned each paper at least three reviewers. Based on the peer reviews, 54 full papers were accepted, resulting in a 23% acceptance rate, which was within our goal of less than 40%.

We would like to express our sincere gratitude to the invited speakers for their inspirational talks, to the authors for submitting their work to this conference and the reviewers for sharing their experience during the selection process.

October 2022

Miguel Botto-Tobar
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Contents

Artificial Intelligence

Recognition and Classification of Cardiac Arrhythmias Using Discrete Wavelet Transform (DWT) and Machine Learning Techniques	3
<i>Hermes Andrés Ayala-Cucas, Edison Alexander Mora-Piscal, Dagoberto Mayorca-Torres, Alejandro José León-Salas, and Diego Hernán Peluffo-Ordoñez</i>	
Artificial Firefly Meta-heuristic Used for the Optimization of a Fractional PID on an ARM Platform	16
<i>William Montalvo, Roger Catota Ñacata, and Sebastián Layedra Guayta</i>	
A Convolutional Neural Network-Based Web Prototype to Support COVID-19 Detection Using Chest X-rays	28
<i>Mauro Rosas-Lara, Julio C. Mendoza-Tello, Diana C. López-Olives, and Andrea P. Robles-Loján</i>	
Chatbots and Its Impact on the Information Support Service for Students of the Faculty of Computer Science of the Technical University of Manabí	43
<i>Marco Giler, Emilio Cedeño, Walter Zambrano, Michelle Zambrano, and David Zambrano</i>	
Neural Networks on Noninvasive Electrocardiographic Imaging Reconstructions: Preliminary Results	55
<i>Dagoberto Mayorca-Torres, Alejandro José León-Salas, and Diego Hernán Peluffo-Ordoñez</i>	
Socio-spatial Segregation Using Computational Algorithms: Case Study in Ambato, Ecuador	64
<i>Manuel Ayala-Chauvin, Paola Maigua, Andrea Medina-Enríquez, and Jorge Buele</i>	
Expert System with Facial Recognition Implemented in Human-Machine Conversation Services for the Automation of Multi-platform Remote Processes in the Identification of People Reported Missing	76
<i>Jefferson Panchi-Chacón, Cindy Ortiz-Araujo, and Milton Patricio Navas-Moya</i>	

Communications

Radar Probability of Detection in Multipath Environments 91
*Juan Minango, Andrea Flores, Marcelo Zambrano,
Wladimir Paredes Parada, and Cristian Tasiguano*

Low Detection Symbol Algorithm for MIMO Systems with Big Number
of Antennas 104
*Juan Minango, Marcelo Zambrano, Wladimir Paredes Parada,
and Cristian Tasiguano*

Deployable Networks. An Alternative for Communications in Critical
Environments 115
Marcelo Zambrano, Ana Zambrano, Juan Minango, and Edgar Maya

Application for the Study of Underwater Wireless Sensor Networks: Case
Study 124
*Fabián Cuzme-Rodríguez, Angel Velasco-Suárez,
Mauricio Domínguez-Limaico, Luis Suárez-Zambrano,
Henry Farinango-Endara, and Mario Mediavilla-Valverde*

e-Learning

Learning Performance Indicators a Statistical Analysis on the Subject
of Natural Sciences During the COVID-19 Pandemic at the Tulcán District 139
*Marcela Aza-Espinosa, Laura Guerra Torrealba,
Erick Herrera-Granda, María Aza-Espinosa, Marco Burbano-Pulles,
and Javier Pozo-Burgos*

Virtual Physics Learning for Basic Education 155
*Carmen Cecilia Ausay, Santiago Alejandro Acurio Maldonado,
Daniel Marcelo Acurio Maldonado, Pablo Israel Amancha Proaño,
and Francisco Javier Echeverría Tamayo*

Bibliometric Mapping of Scientific Literature Located in Scopus
on Teaching Digital Competence in Higher Education 167
*Andrés Cisneros-Barahona, Luis Marqués Molías,
Gonzalo Samaniego Erazo, María Isabel Uvidia-Fassler,
and Gabriela de la Cruz-Fernández*

Authentic Evaluation for the Improvement of the Argumentative Written
Essay in Virtual University Environments 181
*Soratna Verónica Navas, Eduardo Jesús Garcés,
María Cristina Pecho Rivera, Frank Luis Guanipa, and Felix Colina Ysea*

Computational Thinking as Instrument to Evaluate Student Difficulties in Higher Education: Before and During Pandemic Analysis	193
<i>Ana-Lucía Pérez-Suasnavas, Bayardo Salgado-Proaño, Karina Cela, and Jorge L. Santamaría</i>	
Systematization of Playful Teaching Using Games Aimed at Teachers and Students	208
<i>Albornoz Karina, Jurado Merlis, and Maldonado Michelle</i>	
Design of a Predictive Model to Evaluate Academic Risk Using Data Mining	221
<i>Shirley Alarcón-Loza, Diana Calderón-Onofre, Karen Mite-Baidal, and Mishel Macías-Plúas</i>	
Hope Project: Augmented Reality to Teach Dance to Children with ASD	236
<i>Mónica R. Romero, Estela M. Macas, Nancy Armijos, and Ivana Harari</i>	
An Approach to Scientific Research for the Continuous Improvement of Scientific Production in Ecuador	247
<i>Segundo Moisés Toapanta Toapanta, Marcelo Zambrano, Wladimir Paredes Parada, María José Rivera Gutierrez, Luis Enrique Mafla Gallegos, María Mercedes Baño Hifóng, Ma. Roció Maciel Arellano, and José Antonio Orizaga Trejo</i>	
Professional Skills for the Administration Career with a Higher Technological Level	262
<i>Rodríguez Edison, María Del Carmen Estevez, Luz Rodríguez-Cisneros, Galárraga Nuria, and Narvaez Hugo</i>	
Gamification as a Methodological Strategy and Its Impact on the Academic Performance of University Students	272
<i>Renato Coello-Contreras</i>	
Impact of Blended-Learning on Higher Education and English Language	287
<i>Mishell Angulo-Alvarez, Viviana Nagua-Andrango, Carmen Nato-Sierra, Enrique Rosero-Olalla, and Carlos Ruiz-Guangaje</i>	
Augmented Reality Application with Multimedia Content to Support Primary Education	299
<i>Jorge Buele, John Espinoza, Belén Ruales, Valeria Maricruz Camino-Morejón, and Manuel Ayala-Chauvin</i>	
Storytelling as a Motivational Resource in the Therapy of Childhood Cancer ...	311
<i>Mónica Liliana Castro Pacheco, Mateo Calle Loja, and Marco Segarra Chalco</i>	

Presyllabic Method to Correct Dysorthography in Elementary School Students	325
<i>Kate Lizbeth Pazmiño, Editha Jael Guerrero, Franklin Daniel Aguilar E., Paulina Renata Arellano G., and Fernando Garcés Cobos</i>	
State of ICTs as Support for the Educational Process in the Andean Region	337
<i>Wladimir Paredes-Parada, Christian Del Pozo, Silvia Elizabeth García González, and Franz Del Pozo</i>	
AT for Engineering Applications	
Computerized Planning of Surface Ratios in a Milk Extraction Plant	349
<i>Alexis Suárez del Villar, Ana Álvarez Sánchez, and Alexander Ricardo Galarza Tipantuña</i>	
Methodological Proposal for Micro-enterprises Through a Mathematical - Statistical Model Based on Integral Logistics	361
<i>Marcelo Javier Mancheno-Saá, Jenny Margoth Gamboa-Salinas, and Jacqueline del Pilar Hurtado-Yugcha</i>	
Material Selection for a Biomass Heat Exchange Multicriteria Decision Methods: Study Case on Ecuador	374
<i>Juan Francisco Nicolalde, Javier Martínez-Gómez, Ricardo A. Narvaez C., Daniel Rivadeneira, Boris German, Michelle Romero, Cristhian M. Velalcázar Rhea, P. Cuji, Danny F. Sinche Arias, Carlos A. Méndez Durazno, and E. Catalina Vallejo-Coral</i>	
Design and Simulation of an Aircraft Autopilot Control System: Longitudinal Dynamics	388
<i>Luis A. Coello, Fausto A. Jácome, Jonathan R. Zurita, Carlos W. Casa, and Jonathan S. Vélez</i>	
Management Innovation and Competitive Success in Peruvian Companies of the Manufacturing Sector	403
<i>Rina A. Valencia-Durand, Aleixandre Brian Duche-Pérez, Cintya Yadira Vera-Revilla, Olger Albino Gutiérrez-Aguilar, Milena Ketty Jaime-Zavala, and Anthony Medina Rivas Plata</i>	
Comparative Study of Accounting and Management Perceptions of the Usefulness of Financial Information in Small and Medium-Sized Timber Companies in Colombia	417
<i>María del Pilar Corredor García, Natalia Murillo Gallego, and Jasleidy Astrid Prada Segura</i>	

Influence of Aqueous Phase of Hydrothermal Carbonization Feeding on Carbon Fixation by Microalgae 429
Mayra S. Andrade Guerrero, Daysi N. Bayas Moposita, Crithian M. Velalcázar Rhea, P. Cuji, Danny F. Sinche Arias, Carlos A. Méndez Durazno, and Javier Martínez-Gómez

Assessment of the Thermal Behavior in Social Housing in Hot Humid Climate in Ecuador 442
E. Catalina Vallejo-Coral, Francis Vásquez-Aza, Luis Godoy-Vaca, Marco Orozco Salcedo, and Javier Martínez-Gómez

Implications of Spraying Powder Paint 455
Paúl Caza, Díaz Rodrigo, Víctor López, Cruz Patricio, and Villarreal Pamela

Heat Transfer Adhesion Factor on Metal Surfaces 468
Paúl Caza, Díaz Rodrigo, Víctor López, and Villarreal Pamela

Virtual Laboratory of Electronic Instrumentation Based on a Programming Proposal Focused on Systems 483
Yngrid J. Melo Q., Andrés E. Castillo R., Enrique I. Valencia V., Edgar A. Bravo D., and Wilson G. Simbaña L.

Thermal-Mechanical Properties of Recycled PVC Used in Schrader Valve Caps 497
Jose Vicente Manopanta-Aigaje and Diana Peralta-Zurita

Consequence of a Geriatric Psychomotricity Program on the Quality of Life of Older Adults 510
Veronica Molina, Nuria Galárraga, Gabriela Enríquez, Rocío Duque, and Ismenia Araujo

Laboratory-Scale Determination of the Influence of Temperature, Time, and Mordant on the Tensile Strength and Elongation of Abaca Yarn Dyed with Marco Extract (Ambrosia Peruviana) Subjected to Seawater 524
Elsa Sulay Mora Muñoz, Elvis Ramírez, and Omar Lara Castro

Cryptocurrencies Towards Financial Innovation in the Microenterprise Sector 535
Jessica Quispe, Cesar Segovia, Rubén Jaramillo, and Darwin Arias

3D Modelling of Freedom Summit for Virtual Environments 548
Aguas Luis, Suárez Lizbeth, Coral Rosario, and Machay Byron

**Model of Technological Competencies as Determinants of Innovation:
A Comparative Intersectoral Study in Ecuador** 561
Claudio Arcos and Adrian Padilla

**Micro-enterprise Management Towards Scenario Building for Decision
Making** 575
*Paula Flores, Estefani Segura, Rubén Jaramillo, Luis Ulcuango,
and Lizbeth Suárez*

**Analysis of Business Efficiency Considering the Influence of the Particular
Events on Sales Increase Period 2016–2020** 585
*Ximena Elizabeth Cayambe Badillo, Willman Leonel Bravo Espinoza,
Luis Alberto Carrera Toro, and Hilberth Alexis Villalba Bejarano*

**Income from Ordinary Activities and Its Tax Impact on Companies
in the Automotive Sector in Ecuador** 600
*Aníbal Altamirano Salazar, Carla Valdiviezo Morales,
Ramiro Pastás Gutiérrez, and Lenin Altamirano Gallegos*

Security

**Proof of Concepts of Corda Blockchain Technology Applied on the Supply
Chain Area** 619
*Juan Minango, Marcelo Zambrano, Wladimir Paredes Parada,
Cristian Tasiguano, and Maria Jose Rivera*

**Spread Virus: Usability Evaluation on a Mobile Augmented Reality
Videogame** 632
Alvaro Poma, Piero Aldaves, and Luis Canaval

Security Mechanisms and Log Correlation Systems 644
*Andy Mora-Cruzatty, Jose Villacreses-Chancay,
Cesar Moreira-Zambrano, Josselyn Pita-Valencia,
and Leonardo Chancay-García*

Technology Trends

**Identification of Corn Leaves Diseases Images Using MobileNet
Architecture in SmartPhones** 661
*Juan Minango, Marcelo Zambrano, Wladimir Paredes Parada,
Cristian Tasiguano, and Karla Ayala*

Experimental Assessment of Photovoltaic Systems Using One-Axis Tracking and Positioning Strategies in Equatorial Regions 674
Cristian Alarcón, Carlos López, Cristian Tasiguano Pozo, and Freddy Ordóñez

Evaluation of the Reliability of a LiDAR Sensor Through a Geometric Model in Applications to Autonomous Driving 688
Danny J. Zea, Alex P. Toapanta, César A. Minaya, Carlos A. Paspuel, and Irlanda E. Moreno

Design of Optimal Controllers Applying Reinforcement Learning on an Inverted Pendulum Using Co-simulation NX/Simulink 706
Henry Díaz-Iza, Karla Negrete, and Jenyffer Yépez

Author Index 719

Artificial Intelligence



Recognition and Classification of Cardiac Arrhythmias Using Discrete Wavelet Transform (DWT) and Machine Learning Techniques

Hermes Andrés Ayala-Cucas¹, Edison Alexander Mora-Piscal¹,
Dagoberto Mayorca-Torres^{1,2}(✉), Alejandro José León-Salas²,
and Diego Hernán Peluffo-Ordoñez³

¹ Grupo de investigación de Ingeniería Mecatrónica, Universidad Mariana,
Pasto, Colombia

{hayala,dmayorca}@umariana.edu.co

² Departamento de Lenguajes y Sistemas Informáticos, Universidad de Granada,
C/Periodista Daniel Saucedo Aranda s/n, 18071 Granada, Spain

³ Modeling, Simulation and Data Analysis (MSDA) Research Program,
Mohammed VI Polytechnic University, Ben Guerir, Morocco

Abstract. Cardiac arrhythmias are heart rhythm problems that usually occur when the electrical impulses coordinated with the heartbeat do not work correctly. For this reason, detecting abnormalities in an electrocardiogram (ECG) plays a vital role in patient follow-up. Due to the presence of noise, the irregularity of the heartbeat, and the non-stationary nature of ECG signals, their interpretation can be difficult, requiring the use of advanced computer systems to support the diagnosis of cardiac disorders. Therefore, the development of assisted ECG analysis systems is a current topic of study, and the main challenge is to achieve adequate accuracy for application in the clinical setting. Therefore, this article describes a software tool for classifying ECG samples into the main classes of cardiac arrhythmias by removing noise from the ECG signal at the preprocessing stage using conventional digital filters; the location of the QRS complex is essential for the identification of the ECG signal. Therefore, the position and amplitude of the R peaks are determined in the segmentation stage. Then the selection of the most relevant features of the ECG signal is performed using the discrete wavelet transform (DWT). The ability of the extracted features to differentiate between different classes of data is tested using machine learning techniques such as k-Nearest Neighbors, Neural Networks, and Decision Trees with 10-fold cross-validation. These methods are evaluated and tested with the MIT-BIH arrhythmia database, achieving the best accuracy of 98.54% using the k-Nearest Neighbors classifier.

Keywords: Electrocardiogram (ECG) · Cardiac arrhythmia · Feature extraction · Machine learning · Performance measures

1 Introduction

Cardiovascular diseases are the leading cause of death in the world; around 17.5 million people die from these heart disorders, which represents 31% of deaths worldwide [2]. In general, the increase in the mortality rate from cardiovascular disease is related to unhealthy lifestyles, such as lack of physical activity, poor diet, and smoking. The main factors in these cardiovascular conditions are cardiac arrhythmias, which are disturbances or disorders that alter the normal functioning of the heart's electrical activity [10]. Electrical activity monitoring is performed through the electrocardiogram (ECG), a non-invasive method in which the propagation of the electromagnetic wave propagating in the heart can be recorded through a series of electrodes placed on the body's surface. From these recordings, it is possible to study, analyze and identify irregular patterns in the ECG signal. Because the recorded data is so extensive, it is necessary to classify or categorize the different types of signal beats using advanced computer diagnostic tools. Hence, in recent years, the development of computational systems and the adoption of artificial intelligence techniques to support the detection and diagnosis of cardiovascular diseases have increased. Not to mention that, at times, cardiologists must perform analyses on extensive records of different patients, which can lead to erroneous diagnoses.

Some researchers have proposed different studies with efficient methods for classifying cardiac arrhythmias in the scientific literature. Briefly, Malik *et al.* [12] proposes an optimized classification model for automated cardiac arrhythmia recognition. First, it uses the discrete wavelet transform (DWT) to extract the most significant features from the ECG signal. It then evaluates the multidomain features using machine learning techniques such as support vector machine (SVM) and the Grasshopper optimization algorithm to identify five classes of cardiac arrhythmias. Similarly, Madan *et al.* [11] uses a hybrid approach based on deep learning for cardiovascular disease detection and classification, using various configurations; in a first step, they use 2D Scalogram images to reduce signal noise and extract features. The second step uses a combination of deep learning models, such as convolutional neural networks (CNN) and short-term memory networks (LSTM), to identify abnormal heartbeats. On the other hand, statistical analysis techniques and hybrid feature-based techniques are used for feature selection and extraction. These features can be classified using machine learning techniques, such as Decision Trees [19], k-Nearest Neighbor (KNN) classification techniques [7], Support Vector Machines (SVM) [20], and Neural Networks (NN) [4], among others.

In arrhythmia classification techniques using machine learning approaches, achieving acceptable accuracy with efficient features is desirable. In this regard, this paper presents a novel technique that uses discrete wavelet transform (DWT) based ECG beat features and efficiently classifies five classes of abnormal ECG beats using machine learning techniques such as K-Nearest Neighbors, neural networks, and decision trees. These techniques are fundamental in this field as they are becoming an essential method for reliable decision-making by analyzing large data sets and events. Likewise, it is used to study and analyze the cardiac

rhythm problems that the heart presents, identify the type of arrhythmia that the person may manifest, as well as to implement prevention strategies adopted by different types of processing and characterization of ECG signals.

This paper is structured as follows: Sect. 2 specifies the methodological design and the stages of database selection, data processing, segmentation, feature extraction, and classification. Section 3 describes the results and discussions and Sect. 4 concludes future work. One of the significant contributions of this study is the development of a methodology based on conventional methods.

2 Methodology

The methodological scheme of the proposed method for detecting and classifying cardiac arrhythmias is presented in Fig. 1. The following subsections specify the database to be used, the stages of preprocessing, segmentation, feature extraction, and classification.

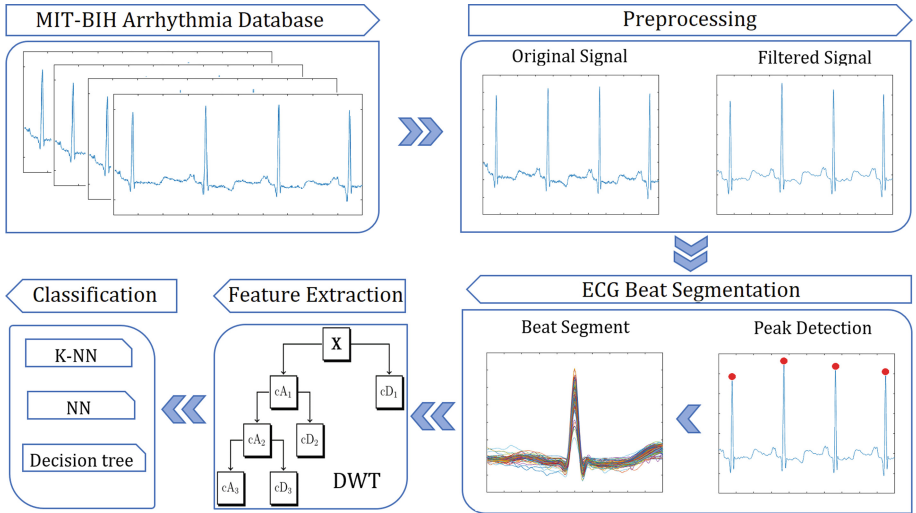


Fig. 1. Methodological scheme for the detection of cardiac arrhythmias.

2.1 MIT-BIH Arrhythmia Database

The dataset selected for this study corresponds to the MIT-BIH cardiac arrhythmia database [6]. The database contains two-channel ambulatory ECG records from 47 individuals analyzed by the BIH Arrhythmia Laboratory between 1975 and 1979. Forty-eight half-hour recordings were collected using analog Holter equipment with a sampling rate of 360 Hz and 11-bit resolution over a range of 10 mV. The database includes about 110.000 records, with five classes of arrhythmias: Nonectopic beats (N), Fusion beats (F), Supraventricular ectopic beats (S),

Ventricular ectopic beats (V), and Unknown beats (U). Cardiologists performed the classification and annotation of the recordings of each heartbeat. Table 1 shows the specifications of the different beats from the MIT-BIH database and summarizes the five types of ECG beat samples used in this study.

Table 1. MIT-BIH arrhythmia beat classification according to the ANSI/AAMI EC57:1998 standard database.

AAMI classes	MIT-BIH annotation	Type	No. of beats
Non-ectopic beat (N)	N	Normal beat	90.604
	L	Left bundle branch block	
	R	Right bundle branch block	
	j	Nodal (junctional) escape	
	e	Atrial escape beat	
Supra-ventricular ectopic beat (S)	A	Aberrated atrial premature	2.781
	a	Atrial premature	
	S	Supraventricular premature	
	J	Nodal (junctional) premature	
Ventricular ectopic beat (V)	V	Ventricular escape	7.235
	E	Premature ventricular contraction	
Fusion beat (F)	F	Fusion of ventricular and normal	802
Unknown beat (U)	U	Unclassifiable	8.041
	p	Paced	
	f	Fusion of paced and normal	
Total number of beats			109.463

2.2 Preprocessing

ECG signals obtained from the MIT-BIH arrhythmia database are affected by different types of noise classified as network disturbances (60 Hz), deviation from baseline, muscle artifacts, and disturbances generated by various electrical equipment. In a stage of identification and selection of the most relevant parameters found in the signal, the elimination of these types of noise is fundamental. If the ECG signal being analyzed contains a high noise level, the identification task becomes even more difficult.

According to these criteria, the ECG signal preprocessing stage has the initial phase, eliminating the baseline noise and filtering the ECG signal. For these purposes, a digital Butterworth filter configured as a third-order high-pass filter with a cutoff frequency of 1 Hz has been implemented to remove low-frequency noise from baseline deviation. In the next phase, the ECG signal is filtered using the Savitzky-Golay (SG) polynomial order digital filter with a window dimension between 5 and 21 according to [9] to reduce the low and high-frequency interferences present in the whole signal. Figure 2 shows the original ECG signal in the presence of noise and the result of the filtered signal.

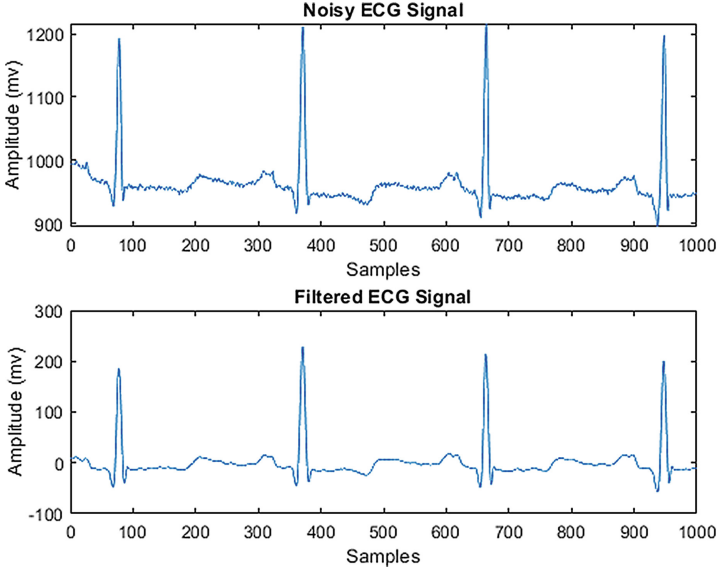


Fig. 2. Removal of noise from ECG signal (Non-ectopic beat).

2.3 ECG Beat Segmentation

In this stage, the location of the QRS complex and landmarks are essential to perform beat segmentation of the ECG signal. Specifically, the QRS complex describes the depolarization originating from the ventricles' contraction [10]. One aspect to consider is that the QRS complex is a fundamental part of the ECG signal that must be analyzed and evaluated.

In this regard, the annotations provided by the MIT-BIH dataset are used for QRS complex localization. The developed algorithm detects the positions of each R peak of the ECG signal (called the midpoint of the QRS complex), whereby a fixed-width window of 200 data is generated with 99 data from the left side and 100 from the right side. The aim is to divide the ECG signal into beat-like fragments with a regular width. The segmentation step results are shown in Fig. 3.

2.4 Feature Extraction

At this stage, the most crucial step is appropriately selecting the most relevant features of the beat segments created in the previous stage to obtain an acceptable classification performance [15, 18]. Based on the above, the discrete wavelet transform (DWT) is used for feature extraction. This technique usually decomposes a signal using approximate versions of several families of wavelets,

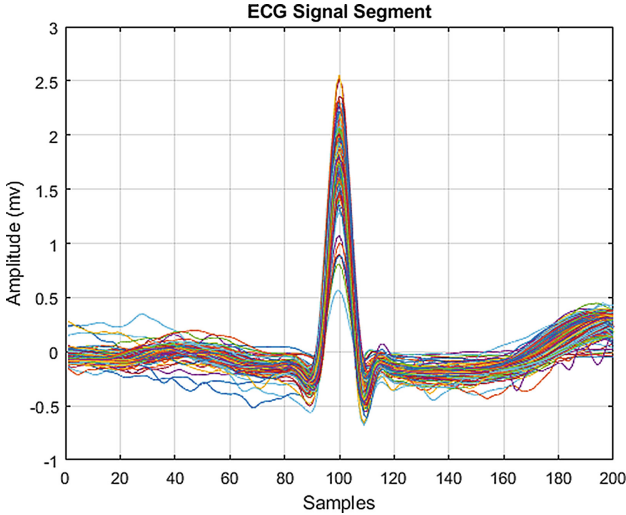


Fig. 3. 200-sample segment of the ECG signal (Non-ectopic beat).

such as Haar, Daubechies, and Symlet [3]. One aspect to consider is that the selection of a wavelet type is made according to the kind of signal to be studied and the information to be obtained from it. For this purpose, signal features are extracted using the Daubechies wavelet family of order 6 (db6) because it has a morphological structure similar to the signal of an electrocardiogram [17]. The signal decomposition is performed up to eight levels obtaining a series of coefficients from which a feature space of the different types of families is generated. The decomposed signal is made up of a series of detail coefficients (D1 to D8) and an approximation coefficient (A8). From each subband of the detail coefficients, three statistical characteristics are calculated: Maximum, Minimum, and variance, collecting a total of 24 features extracted from each beat and will be fed into the supervised machine learning classifiers.

2.5 Classification

The features extracted in the previous step are evaluated by supervised machine learning algorithms to check which classifier is the most suitable for the task at hand. For comparative purposes, three different classification algorithms were tested:

K-Nearest Neighbor Classifier (KNN). It is considered one of the nonparametric instance-based classification algorithms due to its simplicity and versatility. Classification is performed based on the information provided at the training time to determine that an element x belongs to a class C [22]. The algorithm selects the closest data in the learning dataset to perform classification: its “near-

est neighbors”. The nearest neighbors are those that show several similarities to the new case. The value of the nearest neighbors to be analyzed is specified by k .

Neural Network Classifier (NN). Neural networks are widely used in various applications, such as parameter identification and classification tasks. In the structure of a neural network model, each neuron performs the balanced sum of its inputs and superimposes the result of the sum on a nonlinear activation function [5]. Similarly, the performance of this type of classifier depends on the parameters set on the number of input neurons, the number of hidden layers, the number of output neurons, and the activation function.

Decision Tree Classifier. Decision trees are the most widely used methods for techniques such as classification and regression. In general, they consist of tracing all possible paths taking into account the importance of each attribute using recursive partitioning to classify the data [14]. When constructing a decision tree, it is crucial to determine which attribute is the best or most predictive for splitting the data based on the feature. Decision trees are constructed by dividing the training set into different nodes, where a node contains most of a data category.

In this study, a search for the best parameters for each of the classifiers was performed using the hyperparameter optimization method. Table 2 shows the parameters that gave the best results for the evaluation metrics used, which are presented later in the experimental design.

Table 2. Parameters used in each classifier.

Classifier	Parameters
K-nearest neighbor	Number of neighbors = 4 Distance metric = Mahalanobis Distance weight = ‘Squared inverse’ Standardize data = No
Neural network	Number of fully connected layers = 1 First layer size = 80 Activation = ‘Relu’ Iteration limit = 1000 Regularization strength = 0 Standardize data = Yes
Decision tree	SplitCriterion = ‘deviance’ MaxNumSplits = 794 Surrogate = off

2.6 Experimental Design

This section describes the design of experiments and metrics to evaluate the performance of the developed algorithms. The MIT-BIH database contains a total of 110.000 records with 5 types of arrhythmias (N, S, V, F, U). A total of 3 experiments, including a filtering technique (SG), a feature extraction technique (DWT), and three machine learning algorithms (KNN, NN, TREE), were applied for irregular beat recognition.

The evaluation of the classification models is performed using 10-fold random cross-validation and performance metrics such as Accuracy, Precision, Sensitivity, and F1 Score of four parameters as shown in Eqs. (1), (2), (3) and (4).

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

$$Sensitivity = \frac{TP}{TP + FN} \quad (3)$$

$$F1 - Score = \frac{TP}{TP + 0.5(FP + FN)} \quad (4)$$

where TP corresponds to correctly classified beats, FN to unclassified beats, TN to correctly unclassified beats, and FP to incorrectly classified beats.

3 Results

Table 3 shows the results of the 3 experiments, considering the stages of filtering, feature extraction, and classification techniques.

Table 3. Classification results with three different classifiers.

Diagnostic system			Performance metrics			
Filtering	Features	Classifier	Accuracy	Precision	Sensitivity	F1-Score
SG	DWT	KNN	98.54%	98.64%	99.59%	99.12%
		NN	98.34%	98.72%	99.30%	99.01%
		TREE	97.09%	97.52%	98.96%	98.23%

To contrast the classification results obtained in Table 3, Fig. 4 shows the box plots of the accuracies of the three classifiers used in this study with 10-fold cross-validation.

As seen in Fig. 4, the KNN classifier is the best performer in terms of the accuracy metric represented with an average of 98.54%, a precision of 98.64%, a