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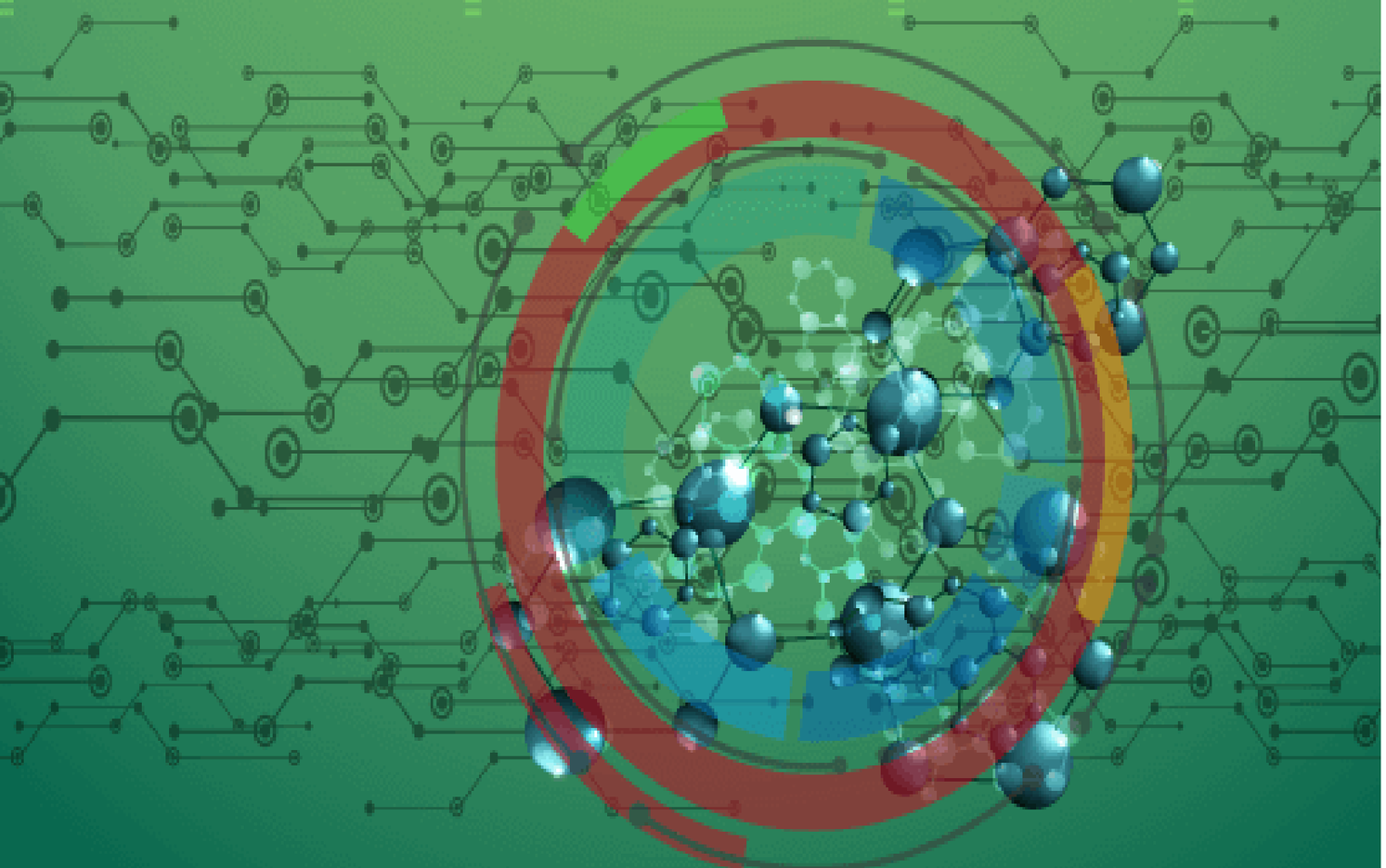

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Computers, Materials & Continua is a peer-reviewed Open Access journal that publishes all types of academic papers in the areas of computer networks, artificial intelligence, big data, software engineering, multimedia, cyber security, internet of things, materials genome, integrated materials science, and data analysis, modeling, designing and manufacturing of modern functional and multifunctional materials. This journal is published monthly by Tech Science Press.
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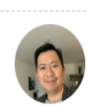

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Open Access ARTICLE

Distributed Trusted Computing for Blockchain-Based Crowdsourcing

Yihuai Liang, Yan Li, Byeong-Seok Shin*

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2825-2842, 2021, DOI:10.32604/cmc.2021.016682

(This article belongs to this Special Issue: Advances of AI and Blockchain technologies for Future Smart City)

Abstract A centralized trusted execution environment (TEE) has been extensively studied to provide secure and trusted computing. However, a TEE might become a throughput bottleneck if it is used to evaluate data quality when collecting large-scale data in a crowdsourcing system. It may also have security problems compromised by attackers. Here, we propose a scheme, named dTEE, for building a platform for providing distributed trusted computing by leveraging TEEs. The platform is used as an infrastructure of trusted computations for blockchain-based crowdsourcing systems, especially to securely evaluate data quality and manage remuneration: these operations are handled by a TEE group. First,... More >

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An Optimal Big Data Analytics with Concept Drift Detection on High-Dimensional Streaming Data

Romany F. Mansour[1,*], Shaha Al-Otaibi[2], Amal Al-Rasheed[2], Hanan Aljuaid[3], Irina V. Pustokhina[4], Denis A. Pustokhin[5]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2843-2858, 2021, DOI:10.32604/cmc.2021.016626

Abstract Big data streams started becoming ubiquitous in recent years, thanks to rapid generation of massive volumes of data by different applications. It is challenging to apply existing data mining tools and techniques directly in these big data streams. At the same time, streaming data from several applications results in two major problems such as class imbalance and concept drift. The current research paper presents a new Multi-Objective Metaheuristic Optimization-based Big Data Analytics with Concept Drift Detection (MOMBD-CDD) method on High-Dimensional Streaming Data. The presented MOMBD-CDD model has different operational stages such as pre-processing, CDD, and classification. MOMBD-CDD model overcomes class... More >

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Bayesian Analysis in Partially Accelerated Life Tests for Weighted Lomax Distribution

Rashad Bantan[1], Amal S. Hassan[2], Ehab Almetwally[3], M. Elgarhy[4], Farrukh Jamal[5], Christophe Chesneau[6], Mahmoud Elsehetry[7,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2859-2875, 2021, DOI:10.32604/cmc.2021.015422

Abstract Accelerated life testing has been widely used in product life testing experiments because it can quickly provide information on the lifetime distributions by testing products or materials at higher than basic conditional levels of stress, such as pressure, temperature, vibration, voltage, or load to induce early failures. In this paper, a step stress partially accelerated life test (SS-PALT) is regarded under the progressive type-II censored data with random removals. The removals from the test are considered to have the binomial distribution. The life times of the testing items are assumed to follow length-biased weighted Lomax distribution. The maximum likelihood method... More >

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A Novel Deep Neural Network for Intracranial Haemorrhage Detection and Classification

D. Venugopal[1], T. Jayasankar[2], Mohamed Yacin Sikkandar[3], Mohamed Ibrahim Waly[3], Irina V. Pustokhina[4], Denis A. Pustokhin[5], K. Shankar[6,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2877-2893, 2021, DOI:10.32604/cmc.2021.015480

Abstract Data fusion is one of the challenging issues, the healthcare sector is facing in the recent years. Proper diagnosis from digital imagery and treatment are deemed to be the right solution. Intracerebral Haemorrhage (ICH), a condition characterized by injury of blood vessels in brain tissues, is one of the important reasons for stroke. Images generated by X-rays and Computed Tomography (CT) are widely used for estimating the size and location of hemorrhages. Radiologists use manual planimetry, a time-consuming process for segmenting CT scan images. Deep Learning (DL) is the most preferred method to increase the efficiency of diagnosing ICH. In... More >

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Minimizing Warpage for Macro-Size Fused Deposition Modeling Parts

Thanh Thuong Huynh[1], Tien V. T. Nguyen[2,3], Quoc Manh Nguyen[4], Trieu Khoa Nguyen[2,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2913-2923, 2021, DOI:10.32604/cmc.2021.016064

(This article belongs to this Special Issue: Application of Artificial Intelligence, Internet of Things, and Learning Approach for Learning Process in COVID-19/Industrial Revolution 4.0)

Abstract In this study, we investigated warpage and corner lifting minimization for three-dimensional printed parts generated by macro-size fused deposition modeling (FDM). First, the reasons for warpage were theoretically elucidated. This approach revealed that the thermal deformation and differential volumetric shrinkage of the extruded molten plastic resulted in warpage of FDM parts. In addition, low adhesion between the deposited model and the heated or non-heated printing bed may intensify warpage further. As a next step, initial small-size and medium-size models were used to identify parameters to manage and minimize warpage in a way that would reduce material consumption and running time.... More >

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An Optimized SW/HW AVMF Design Based on High-Level Synthesis Flow for Color Images

Turki M. Alanazi[1], Ahmed Ben Atitallah[1,2,*], Imen Abid[2]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2925-2943, 2021, DOI:10.32604/cmc.2021.017575

Abstract In this paper, a software/hardware High-level Synthesis (HLS) design is proposed to compute the Adaptive Vector Median Filter (AVMF) in real-time. In fact, this filter is known by its excellent impulsive noise suppression and chromaticity conservation. The software (SW) study of this filter demonstrates that its implementation is too complex. The purpose of this work is to study the impact of using an HLS tool to design ideal floating-point and optimized fixed-point hardware (HW) architectures for the AVMF filter using square root function (ideal HW) and ROM memory (optimized HW), respectively, to select the best HLS architectures and to design... More >

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Machine Learning-Based Two-Stage Data Selection Scheme for Long-Term Influenza Forecasting

Jaeuk Moon, Seungwon Jung, Sungwoo Park, Eenjun Hwang[*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2945-2959, 2021, DOI:10.32604/cmc.2021.017435

(This article belongs to this Special Issue: Artificial Intelligence and IoT based intelligent systems using high performance computing for Medical applications.)

Abstract One popular strategy to reduce the enormous number of illnesses and deaths from a seasonal influenza pandemic is to obtain the influenza vaccine on time. Usually, vaccine production preparation must be done at least six months in advance, and accurate long-term influenza forecasting is essential for this. Although diverse machine learning models have been proposed for influenza forecasting, they focus on short-term forecasting, and their performance is too dependent on input variables. For a country's long-term influenza forecasting, typical surveillance data are known to be more effective than diverse external data on the Internet. We propose a two-stage data selection... More >

Open Access ARTICLE

An Improved Jellyfish Algorithm for Multilevel Thresholding of Magnetic Resonance Brain Image Segmentations

Mohamed Abdel-Basset[1], Reda Mohamed[1], Mohamed Abouhawwash[2,3], Ripon K. Chakrabortty[4], Michael J. Ryan[4], Yunyoung Nam[5,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2961-2977, 2021, DOI:10.32604/cmc.2021.016956

Abstract Image segmentation is vital when analyzing medical images, especially magnetic resonance (MR) images of the brain. Recently, several image segmentation techniques based on multilevel thresholding have been proposed for medical image segmentation; however, the algorithms become trapped in local minima and have low convergence speeds, particularly as the number of threshold levels increases. Consequently, in this paper, we develop a new multilevel thresholding image segmentation technique based on the jellyfish search algorithm (JSA) (an optimizer). We modify the JSA to prevent descents into local minima, and we accelerate convergence toward optimal solutions. The improvement is achieved by applying two novel... More >

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A Secure Rotation Invariant LBP Feature Computation in Cloud Environment

Shiqi Wang[1], Mingfang Jiang[2,*], Jiaohua Qin[1], Hengfu Yang[2], Zhichen Gao[3]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2979-2993, 2021, DOI:10.32604/cmc.2021.017094

Abstract In the era of big data, outsourcing massive data to a remote cloud server is a promising approach. Outsourcing storage and computation services can reduce storage costs and computational burdens. However, public cloud storage brings about new privacy and security concerns since the cloud servers can be shared by multiple users. Privacy-preserving feature extraction techniques are an effective solution to this issue. Because the Rotation Invariant Local Binary Pattern (RILBP) has been widely used in various image processing fields, we propose a new privacy-preserving outsourcing computation of RILBP over encrypted images in this paper (called PPRILBP). To protect image content,... More >

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Hybrid Swarm Intelligence Based QoS Aware Clustering with Routing Protocol for WSN

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CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 2995-3013, 2021, DOI:10.32604/cmc.2021.016139

Abstract Wireless Sensor Networks (WSN) started gaining attention due to its wide application in the fields of data collection and information processing. The recent advancements in multimedia sensors demand the Quality of Service (QoS) be maintained up to certain standards. The restrictions and requirements in QoS management completely depend upon the nature of target application. Some of the major QoS parameters in WSN are energy efficiency, network lifetime, delay and throughput. In this scenario, clustering and routing are considered as the most effective techniques to meet the demands of QoS. Since they are treated as NP (Non-deterministic Polynomial-time) hard problem, Swarm... More >

Open Access ARTICLE

Frequency Reconfigurable Antenna for Portable Wireless Applications

Shakir Ullah[1], Sadiq Ullah[1], Inzamam Ahmad[1], Wasi Ur Rehman Khan[1], Toufeeq Ahmad[1], Usman Habib[2], Mahmoud A. Albreem[3], Mohammed H. Alsharif[4], Peerapong Uthansakul[5,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3015-3027, 2021, DOI:10.32604/cmc.2021.015549
(This article belongs to this Special Issue: Advances in 5G Antenna Designs and Systems)

Abstract In this paper, the design and experimental evaluation of a hexagonal-shaped coplanar waveguide (CPW)-feed frequency reconfigurable antenna is presented using flame retardant (FR)-4 substrate with size of 37 × 35 × 1.6 mm^3. The antenna is made tunable to three different modes through the status of two pin diodes to operate in four distinct frequency bands, i.e., 2.45 GHz wireless fidelity (Wi-Fi) in MODE 1, 3.3 GHz (5G sub-6 GHz band) in MODE 2, 2.1 GHz (3G Long Term Evolution (LTE)-advanced) and 3.50 GHz Worldwide Interoperability for Microwave Access (WiMAX) in MODE 3. The optimization through simulation modeling shows that... More >

Open Access ARTICLE

An Optimized Algorithm for D2D-MIMO 5G Wireless Networks

Shahid Bashir[1], Imran Khan[2], Fahd N. Al-Wesabi[3], Nadhem Nemri[3], Ammar Zahary[4], Quang Ngoc Nguyen[5,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3029-3044, 2021, DOI:10.32604/cmc.2021.017015

Abstract The device-to-device (D2D) networking technology is extended to the conventional cellular network to boost the communication efficiency of the entire network, forming a heterogeneous 5G and beyond (B5G) communication network. D2D communication in a cellular cell will boost the efficiency of the spectrum, increase the ability of the device, and reduce the communication burden of base stations through the sharing of approved cell resources, causing serious interference as well. The device-to-device (D2D) networking technology is extended to the conventional cellular network to boost the communication efficiency of the entire network, forming a heterogeneous 5G communication network. D2D communication in a... More >

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Gait Recognition via Cross Walking Condition Constraint

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CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3045-3060, 2021, DOI:10.32604/cmc.2021.017275
Abstract Gait recognition is a biometric technique that captures human walking pattern using gait silhouettes as input and can be used for long-term recognition. Recently proposed video-based methods achieve high performance. However, gait covariates or walking conditions, i.e., bag carrying and clothing, make the recognition of intra-class gait samples hard. Advanced methods simply use triplet loss for metric learning, which does not take the gait covariates into account. For alleviating the adverse influence of gait covariates, we propose cross walking condition constraint to explicitly consider the gait covariates. Specifically, this approach designs center-based and pair-wise loss functions to decrease discrepancy of... More >

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Modelling Intelligent Driving Behaviour Using Machine Learning

Qura-Tul-Ain Khan[1], Sagheer Abbas[1], Muhammad Adnan Khan[2,*], Areej Fatima[3], Saad Alanazi[4], Nouh Sabri Elmitwally[4,5]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3061-3077, 2021, DOI:10.32604/cmc.2021.015441
Abstract In vehicular systems, driving is considered to be the most complex task, involving many aspects of external sensory skills as well as cognitive intelligence. External skills include the estimation of distance and speed, time perception, visual and auditory perception, attention, the capability to drive safely and action-reaction time. Cognitive intelligence works as an internal mechanism that manages and holds the overall driver's intelligent system.These cognitive capacities constitute the frontiers for generating adaptive behaviour for dynamic environments. The parameters for understanding intelligent behaviour are knowledge, reasoning, decision making, habit and cognitive skill. Modelling intelligent behaviour reveals that many of these parameters... More >

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Development of Social Media Analytics System for Emergency Event Detection and Crisis Management

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CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3079-3100, 2021, DOI:10.32604/cmc.2021.017371
(This article belongs to this Special Issue: Machine Learning-based Intelligent Systems: Theories, Algorithms, and Applications)
Abstract Social media platforms have proven to be effective for information gathering during emergency events caused by natural or human-made disasters. Emergency response authorities, law enforcement agencies, and the public can use this information to gain situational awareness and improve disaster response. In case of emergencies, rapid responses are needed to address victims' requests for help. The research community has developed many social media platforms and used them effectively for emergency response and coordination in the past. However, most of the present deployments of platforms in crisis management are not automated, and their operational success largely depends on experts who analyze... More >

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Prediction of Parkinson's Disease Using Improved Radial Basis Function Neural Network

Rajalakshmi Shenbaga Moorthy[1,*], P. Pabitha[2]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3101-3119, 2021, DOI:10.32604/cmc.2021.016489
Abstract Parkinson's disease is a neurogenerative disorder and it is difficult to diagnose as no therapies may slow down its progression. This paper contributes a novel analytic system for Parkinson's Disease Prediction mechanism using Improved Radial Basis Function Neural Network (IRBFNN). Particle swarm optimization (PSO) with K-means is used to find the hidden neuron's centers to improve the accuracy of IRBFNN. The performance of RBFNN is seriously affected by the centers of hidden neurons. Conventionally K-means was used to find the centers of hidden neurons. The problem of sensitiveness to the random initial centroid in K-means degrades the performance of RBFNN.... More >

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Ergodic Capacity Evaluation of Multi-Hop Decode-and-Forward MIMO-OFDM Relaying Network

Latif Jan[1], Mohammad Haseeb Zafar[1], Abdul Waheed[2], Mahdi Zareei[3], Faisal Alanazi[4,*]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3133-3145, 2021, DOI:10.32604/cmc.2021.014857
Abstract Spatial diversity plays a significant role in wireless communication systems, including the Fourth Generation (4G) and Fifth Generation (5G) systems, and it is expected to be a fundamental part of the future wireless communication systems as well. The Multiple-Input Multiple-Output (MIMO) technology, which is included in the IEEE 802.16j standard, still holds the most crucial position in the 4G spectrum as it promises to improve the throughput, capacity, spectral, and energy efficiency of wireless communication systems in the 2020s. This makes MIMO a viable technology for delay constrained medical and health care facilities. This paper presents an approximate closed-form expression... More >

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Web Attack Detection Using the Input Validation Method: DPDA Theory

Osamah Ibrahim Khalaf[1], Munsif Sokiyna[2,*], Youseef Alotaibi[3], Abdulmajeed Alsufyani[4], Saleh Alghamdi[5]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3167-3184, 2021, DOI:10.32604/cmc.2021.016099
Abstract A major issue while building web applications is proper input validation and sanitization. Attackers can quickly exploit errors and vulnerabilities that lead to malicious behavior in web application validation operations. Attackers are rapidly improving their capabilities and technologies and now focus on exploiting vulnerabilities in web applications and compromising confidentiality. Cross-site scripting (XSS) and SQL injection attack (SQLIA) are attacks in which a hacker sends malicious inputs (cheat codes) to confuse a web application, to access or disable the application's back-end without user awareness. In this paper, we explore the problem of detecting and removing bugs from both client-side and... More >

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The Investigation of the Fractional-View Dynamics of Helmholtz Equations Within Caputo Operator

Rashid Jan[1], Hassan Khan[2,3], Poom Kumam[4,5,*], Fairouz Tchier[6], Rasool Shah[2], Haifa Bin Jebreen[6]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3185-3201, 2021, DOI:10.32604/cmc.2021.015252
(This article belongs to this Special Issue: Recent Advances in Fractional Calculus Applied to Complex Engineering Phenomena)
Abstract It is eminent that partial differential equations are extensively meaningful in physics, mathematics and engineering. Natural phenomena are formulated with partial differential equations and are solved analytically or numerically to interrogate the system's dynamical behavior. In the present research, mathematical modeling is extended and the modeling solutions Helmholtz equations are discussed in the fractional view of derivatives. First, the Helmholtz equations are presented in Caputo's fractional derivative. Then Natural transformation, along with the decomposition method, is used to attain the series form solutions of the suggested problems. For justification of the proposed technique, it is applied to several numerical examples.... More >

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Web Attack Detection Using the Input Validation Method: DPDA Theory

Osamah Ibrahim Khalaf[1], Munsif Sokiyna[2,*], Youseef Alotaibi[3], Abdulmajeed Alsufyani[4], Saleh Alghamdi[5]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3167-3184, 2021, DOI:10.32604/cmc.2021.016099
Abstract A major issue while building web applications is proper input validation and sanitization. Attackers can quickly exploit errors and vulnerabilities that lead to malicious behavior in web application validation operations. Attackers are rapidly improving their capabilities and technologies and now focus on exploiting vulnerabilities in web applications and compromising confidentiality. Cross-site scripting (XSS) and SQL injection attack (SQLIA) are attacks in which a hacker sends malicious inputs (cheat codes) to confuse a web application, to access or disable the application's back-end without user awareness. In this paper, we explore the problem of detecting and removing bugs from both client-side and... More >

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Open Access ARTICLE

The Investigation of the Fractional-View Dynamics of Helmholtz Equations Within Caputo Operator

Rashid Jan[1], Hassan Khan[2,3], Poom Kumam[4,5,*], Fairouz Tchier[6], Rasool Shah[2], Haifa Bin Jebreen[6]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3185-3201, 2021, DOI:10.32604/cmc.2021.015252
(This article belongs to this Special Issue: Recent Advances in Fractional Calculus Applied to Complex Engineering Phenomena)
Abstract It is eminent that partial differential equations are extensively meaningful in physics, mathematics and engineering. Natural phenomena are formulated with partial differential equations and are solved analytically or numerically to interrogate the system's dynamical behavior. In the present research, mathematical modeling is extended and the modeling solutions Helmholtz equations are discussed in the fractional view of derivatives. First, the Helmholtz equations are presented in Caputo's fractional derivative. Then Natural transformation, along with the decomposition method, is used to attain the series form solutions of the suggested problems. For justification of the proposed technique, it is applied to several numerical examples.... More >

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Open Access ARTICLE

Secure Multifactor Remote Access User Authentication Framework for IoT Networks

Mohammed Mujib Alshahrani*

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3235-3254, 2021, DOI:10.32604/cmc.2021.015310
(This article belongs to this Special Issue: Security Issues in Industrial Internet of Things)

Abstract The term IoT refers to the interconnection and exchange of data among devices/sensors. IoT devices are often small, low cost, and have limited resources. The IoT issues and challenges are growing increasingly. Security and privacy issues are among the most important concerns in IoT applications, such as smart buildings. Remote cybersecurity attacks are the attacks which do not require physical access to the IoT networks, where the attacker can remotely access and communicate with the IoT devices through a wireless communication channel. Thus, remote cybersecurity attacks are a significant threat. Emerging applications in smart environments such as smart buildings require… More >

Open Access ARTICLE

Hybrid Nanofluid Flow with Homogeneous-Heterogeneous Reactions

Iskandar Waini[1,2], Anuar Ishak[2,*], Ioan Pop[3]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3255-3269, 2021, DOI:10.32604/cmc.2021.017643

Abstract This study examines the stagnation point flow over a stretching/shrinking sheet in a hybrid nanofluid with homogeneous-heterogeneous reactions. The hybrid nanofluid consists of copper (Cu) and alumina (Al_2O_3) nanoparticles which are added into water to form Cu-Al_2O_3/water hybrid nanofluid. The similarity equations are obtained using a similarity transformation. Then, the function bvp4c in MATLAB is utilised to obtain the numerical results. The dual solutions are found for limited values of the stretching/shrinking parameter. Also, the turning point arises in the shrinking region ($\lambda < 0$). Besides, the presence of hybrid nanoparticles enhances the heat transfer rate, skin friction coefficient, and… More >

Open Access ARTICLE

Enhanced Deep Autoencoder Based Feature Representation Learning for Intelligent Intrusion Detection System

Thavavel Vaiyapuri*, Adel Binbusayyis

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3271-3288, 2021, DOI:10.32604/cmc.2021.017665
(This article belongs to this Special Issue: Machine Learning-based Intelligent Systems: Theories, Algorithms, and Applications)

Abstract In the era of Big data, learning discriminant feature representation from network traffic is identified has as an invariably essential task for improving the detection ability of an intrusion detection system (IDS). Owing to the lack of accurately labeled network traffic data, many unsupervised feature representation learning models have been proposed with state-of-the-art performance. Yet, these models fail to consider the classification error while learning the feature representation. Intuitively, the learnt feature representation may degrade the performance of the classification task. For the first time in the field of intrusion detection, this paper proposes an unsupervised IDS model leveraging the… More >

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Unknown Attack Detection: Combining Relabeling and Hybrid Intrusion Detection

Gun-Yoon Shin[1], Dong-Wook Kim[1], Sang-Soo Kim[2], Myung-Mook Han[3,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3289-3303, 2021, DOI:10.32604/cmc.2021.017502

Abstract Detection of unknown attacks like a zero-day attack is a research field that has long been studied. Recently, advances in Machine Learning (ML) and Artificial Intelligence (AI) have led to the emergence of many kinds of attack-generation tools developed using these technologies to evade detection skillfully. Anomaly detection and misuse detection are the most commonly used techniques for detecting intrusion by unknown attacks. Although anomaly detection is adequate for detecting unknown attacks, its disadvantage is the possibility of high false alarms. Misuse detection has low false alarms; its limitation is that it can detect only known attacks. To overcome such… More >

Open Access ARTICLE

CARM: Context Based Association Rule Mining for Conventional Data

Muhammad Shaheen[1,*], Umair Abdullah[2]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3305-3322, 2021, DOI:10.32604/cmc.2021.016766

Abstract This paper is aimed to develop an algorithm for extracting association rules, called Context-Based Association Rule Mining algorithm (CARM), which can be regarded as an extension of the Context-Based Positive and Negative Association Rule Mining algorithm (CBPNARM). CBPNARM was developed to extract positive and negative association rules from Spatio-temporal (space-time) data only, while the proposed algorithm can be applied to both spatial and non-spatial data. The proposed algorithm is applied to the energy dataset to classify a country's energy development by uncovering the enthralling interdependencies between the set of variables to get positive and negative associations. Many association rules related… More >

Open Access ARTICLE

Suggestion Mining from Opinionated Text of Big Social Media Data

Youseef Alotaibi[1,*], Muhammad Noman Malik[2], Huma Hayat Khan[3], Anab Batool[2], Saif ul Islam[4], Abdulmajeed Alsufyani[5], Saleh Alghamdi[6]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3323-3338, 2021, DOI:10.32604/cmc.2021.016727

Abstract Social media data are rapidly increasing and constitute a source of user opinions and tips on a wide range of products and services. The increasing availability of such big data on biased reviews and blogs creates challenges for customers and businesses in reviewing all content in their decision-making process. To overcome this challenge, extracting suggestions from opinionated text is a possible solution. In this study, the characteristics of suggestions are analyzed and a suggestion mining extraction process is presented for classifying suggestive sentences from online customers' reviews. A classification using a word-embedding approach is used via the XGBoost classifier. The… More >

Open Access ARTICLE

Numerical Solution of a Problem of Thermal Stresses of a Magnetothermoelastic Cylinder with Rotation by Finite-Difference Method

F. S. Bayones[1], A. M. Abd-Alla[2], A. M. Farhan[3,4,*]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3339-3352, 2021, DOI:10.32604/cmc.2021.016021
Abstract The present article deals with the investigation thermal stress of a magnetothermoelastic cylinder subjected to rotation, open or closed circuit, thermal and mechanical boundary conditions. The outer and inner surfaces of the cylinder are subjected to both mechanical and thermal boundary conditions. A The transient coupled thermoelasticity in an infinite cylinder with its base abruptly exposed to a heat flux of a decaying exponential function of time is devised solve by the finite-difference method. The fundamental equations' system is solved by utilizing an implicit finite-difference method. This current method is a second-order accurate in time and space; it is also… More >

Open Access ARTICLE

Hybrid Trainable System for Writer Identification of Arabic Handwriting

Saleem Ibraheem Saleem[*], Adnan Mohsin Abdulazeez
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3353-3372, 2021, DOI:10.32604/cmc.2021.016342
(This article belongs to this Special Issue: AI, IoT, Blockchain Assisted Intelligent Solutions to Medical and Healthcare Systems)
Abstract Writer identification (WI) based on handwritten text structures is typically focused on digital characteristics, with letters/strokes representing the information acquired from the current research in the integration of individual writing habits/styles. Previous studies have indicated that a word's attributes contribute to greater recognition than the attributes of a character or stroke. As a result of the complexity of Arabic handwriting, segmenting and separating letters and strokes from a script poses a challenge in addition to WI schemes. In this work, we propose new texture features for WI based on text. The histogram of oriented gradient (HOG) features are modified to… More >

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Unsupervised Domain Adaptation Based on Discriminative Subspace Learning for Cross-Project Defect Prediction

Ying Sun[1], Yanfei Sun[1,2,*], Jin Qi[1], Fei Wu[1], Xiao-Yuan Jing[1,3], Yu Xue[4], Zixin Shen[5]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3373-3389, 2021, DOI:10.32604/cmc.2021.016539
Abstract Cross-project defect prediction (CPDP) aims to predict the defects on target project by using a prediction model built on source projects. The main problem in CPDP is the huge distribution gap between the source project and the target project, which prevents the prediction model from performing well. Most existing methods overlook the class discrimination of the learned features. Seeking an effective transferable model from the source project to the target project for CPDP is challenging. In this paper, we propose an unsupervised domain adaptation based on the discriminative subspace learning (DSL) approach for CPDP. DSL treats the data from two… More >

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Kernel Search-Framework for Dynamic Controller Placement in Software-Defined Network

Ali Abdi Seyedkolaei[1], Seyed Amin Hosseini Seno[1,*], Rahmat Budiarto[2]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3391-3410, 2021, DOI:10.32604/cmc.2021.017313
(This article belongs to this Special Issue: Intelligent Software-defined Networking (SDN) Technologies for Future Generation Networks)
Abstract In software-defined networking (SDN) networks, unlike traditional networks, the control plane is located separately in a device or program. One of the most critical problems in these networks is a controller placement problem, which has a significant impact on the network's overall performance. This paper attempts to provide a solution to this problem aiming to reduce the operational cost of the network and improve their survivability and load balancing. The researchers have proposed a suitable framework called kernel search introducing integer programming formulations to address the controller placement problem. It demonstrates through careful computational studies that the formulations can design… More >

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L-Moments Based Calibrated Variance Estimators Using Double Stratified Sampling

Usman Shahzad[1,2,*], Ishfaq Ahmad[1], Ibrahim Mufrah Almanjahie[3,4], Nadia H.Al –Noor[5]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3411-3430, 2021, DOI:10.32604/cmc.2021.017046
Abstract Variance is one of the most vital measures of dispersion widely employed in practical aspects. A commonly used approach for variance estimation is the traditional method of moments that is strongly influenced by the presence of extreme values, and thus its results cannot be relied on. Finding momentum from Koyuncu's recent work, the present paper focuses first on proposing two classes of variance estimators based on linear moments (L-moments), and then employing them with auxiliary data under double stratified sampling to introduce a new class of calibration variance estimators using important properties of L-moments (L-location, L-cv, L-variance). Three populations are… More >

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Research on Forecasting Flowering Phase of Pear Tree Based on Neural Network

Zhenzhou Wang[1], Yinuo Ma[1], Pingping Yu[1,*], Ning Cao[2], Heiner Dintera[3]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3431-3446, 2021, DOI:10.32604/cmc.2021.017729
Abstract Predicting the blooming season of ornamental plants is significant for guiding adjustments in production decisions and providing viewing periods and routes. The current strategies for observation of ornamental plant booming periods are mainly based on manpower and experience, which have problems such as inaccurate recognition time, time-consuming and energy sapping. Therefore, this paper proposes a neural network-based method for predicting the flowering phase of pear tree. Firstly, based on the meteorological observation data of Shijiazhuang Meteorological Station from 2000 to 2019, three principal components (the temperature factor, weather factor, and humidity factor) with high correlation coefficient with the flowering phase… More >

Open Access ARTICLE

UFC-Net with Fully-Connected Layers and Hadamard Identity Skip Connection for Image Inpainting

Chung-Il Kim[1], Jehyeok Rew[2], Yongjang Cho[2], Eenjun Hwang[2,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3447-3463, 2021, DOI:10.32604/cmc.2021.017633
(This article belongs to this Special Issue: Machine Learning-based Intelligent Systems: Theories, Algorithms, and Applications)

Abstract Image inpainting is an interesting technique in computer vision and artificial intelligence for plausibly filling in blank areas of an image by referring to their surrounding areas. Although its performance has been improved significantly using diverse convolutional neural network (CNN)-based models, these models have difficulty filling in some erased areas due to the kernel size of the CNN. If the kernel size is too narrow for the blank area, the models cannot consider the entire surrounding area, only partial areas or none at all. This issue leads to typical problems of inpainting, such as pixel reconstruction failure and unintended filling.... More >

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Visibility Enhancement of Scene Images Degraded by Foggy Weather Condition: An Application to Video Surveillance

Ghulfam Zahra[1], Muhammad Imran[1], Abdulrahman M. Qahtani[2,*], Abdulmajeed Alsufyani[2], Omar Almutiry[3], Awais Mahmood[3], Fayez Eid Alazemi[4]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3465-3481, 2021, DOI:10.32604/cmc.2021.017454
(This article belongs to this Special Issue: Recent Advances in Deep Learning, Information Fusion, and Features Selection for Video Surveillance Application)

Abstract In recent years, video surveillance application played a significant role in our daily lives. Images taken during foggy and haze weather conditions for video surveillance application lose their authenticity and hence reduces the visibility. The reason behind visibility enhancement of foggy and haze images is to help numerous computer and machine vision applications such as satellite imagery, object detection, target killing, and surveillance. To remove fog and enhance visibility, a number of visibility enhancement algorithms and methods have been proposed in the past. However, these techniques suffer from several limitations that place strong obstacles to the real world outdoor computer... More >

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Race Classification Using Deep Learning

Khalil Khan[1], Rehan Ullah Khan[2], Jehad Ali[3], Irfan Uddin[4], Sahib Khan[5], Byeong-hee Roh[3,*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3483-3498, 2021, DOI:10.32604/cmc.2021.016535

Abstract Race classification is a long-standing challenge in the field of face image analysis. The investigation of salient facial features is an important task to avoid processing all face parts. Face segmentation strongly benefits several face analysis tasks, including ethnicity and race classification. We propose a race-classification algorithm using a prior face segmentation framework. A deep convolutional neural network (DCNN) was used to construct a face segmentation model. For training the DCNN, we label face images according to seven different classes, that is, nose, skin, hair, eyes, brows, back, and mouth. The DCNN model developed in the first phase was used... More >

Open Access ARTICLE

Novel Unilateral Dental Expander Appliance (UDEX): A Compound Innovative Materials

Hasan Sabah Hasan[1,*], Abdallah A. Abdallah[2], Imran Khan[3], Hala Sadek Alosman[4], Ayshan Kolemen[5], Bilal Alhayani[6]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3499-3511, 2021, DOI:10.32604/cmc.2021.015968
(This article belongs to this Special Issue: Wireless Sensors Networks Application in Healthcare and Medical Internet of Things (Miot) in Bio-Medical Sensors Networks)

Abstract True unilateral posterior crossbite in adults is a challenging malocclusion to treat, especially when we need to correct cross-arch segments with unwanted effects on non-cross segments. Conventional expansion methods are expected to have some shortcomings; the Unilateral dental expander appliance used to restore unilateral cross bite dental arch is an uncommon appliance; for this, a designed new device is needed. This paper aimed to invite a new unilateral dental expander appliance (UDEX) to treat unilateral dental posterior crossbite in adults using available dental material, easy to use and handle, well tolerated by the patient, and biocompatible with oral structure. It... More >

Open Access ARTICLE

A Hybrid Approach for Performance and Energy-Based Cost Prediction in Clouds

Mohammad Aldossary[*]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3531-3562, 2021, DOI:10.32604/cmc.2021.017477

Abstract With the striking rise in penetration of Cloud Computing, energy consumption is considered as one of the key cost factors that need to be managed within cloud providers' infrastructures. Subsequently, recent approaches and strategies based on *reactive* and *proactive* methods have been developed for managing cloud computing resources, where the energy consumption and the operational costs are minimized. However, to make better cost decisions in these strategies, the performance and energy awareness should be supported at both Physical Machine (PM) and Virtual Machine (VM) levels. Therefore, in this paper, a novel hybrid approach is proposed, which jointly considered the prediction... More >

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DTLM-DBP: Deep Transfer Learning Models for DNA Binding Proteins Identification

Sara Saber[1], Uswah Khairuddin[2,*], Rubiyah Yusof[2], Ahmed Madani[1]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3563-3576, 2021, DOI:10.32604/cmc.2021.017769

Abstract The identification of DNA binding proteins (DNABPs) is considered a major challenge in genome annotation because they are linked to several important applied and research applications of cellular functions e.g., in the study of the biological, biophysical, and biochemical effects of antibiotics, drugs, and steroids on DNA. This paper presents an efficient approach for DNABPs identification based on deep transfer learning, named "DTLM-DBP." Two transfer learning methods are used in the identification process. The first is based on the pre-trained deep learning model as a feature's extractor and classifier. Two different pre-trained Convolutional Neural Networks (CNN), AlexNet 8 and VGG... More >

Open Access ARTICLE

Stock Price Prediction Using Predictive Error Compensation Wavelet Neural Networks

Ajla Kulaglic[1,*], Burak Berk Ustundag[2]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3577-3593, 2021, DOI:10.32604/cmc.2021.014768

Abstract Machine Learning (ML) algorithms have been widely used for financial time series prediction and trading through bots. In this work, we propose a Predictive Error Compensated Wavelet Neural Network (PEC-WNN) ML model that improves the prediction of next day closing prices. In the proposed model we use multiple neural networks where the first one uses the closing stock prices from multiple-scale time-domain inputs. An additional network is used for error estimation to compensate and reduce the prediction error of the main network instead of using recurrence. The performance of the proposed model is evaluated using six different stock data samples... More >

Open Access ARTICLE

Energy Efficient Clustering Protocol to Enhance Network Lifetime in Wireless Sensor Networks

S. Nanthini[1,*], S. Nithya Kalyani[2], Sudhakar Sengan[3]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3595-3614, 2021, DOI:10.32604/cmc.2021.015038

Abstract In this paper, the energy conservation in the ununiform clustered network field is proposed. The fundamental reason behind the methodology is that in the process of CH election, nodes Competition Radius (CR) task is based on not just the space between nodes and their Residual Energy (RE), which is utilized in Energy-Aware Distributed Unequal Clustering (EADUC) protocol but also a third-degree factor, i.e., the nearby multi-hop node count. In contrast, a third-factor nearby nodes count is also used. This surrounding data is taken into account in the clustering feature to increase the network's life span. The proposed method, known as... More >

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Describe the Mathematical Model for Exchanging Waves Between Bacterial and Cellular DNA

Mohamed S. Mohamed[1,*], Sayed K. Elagan[1], Saad J. Almalki[1], Muteb R. Alharthi[1], Mohamed F. El-Badawy[2], Amr M. S. Mahdy[1]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3615-3628, 2021, DOI:10.32604/cmc.2021.017208
(This article belongs to this Special Issue: Artificial Intelligence and Healthcare Analytics for COVID-19)

Abstract In this article, we have shown that bacterial DNA could act like some coils which interact with coil-like DNA of host cells. By decreasing the separating distance between two bacterial cellular DNA, the interaction potential, entropy, and the number of microstates of the system grow. Moreover, the system gives its energy to the medium and the temperature of the host body grows. This could be seen as fever in diseases. By emitting some special waves and changing the temperature of the medium, the effects of bacterial waves could be reduced and bacterial diseases could be controlled. Many investigators have shown... More >

Open Access ARTICLE

Enhancements of SDR-Based FPGA System for V2X-VLC Communications

Lukas Danys[1], Radek Martinek[1], Rene Jaros[1,*], Jan Baros[1], Petr Simonik[2], Vaclav Snasel[3]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3629-3652, 2021, DOI:10.32604/cmc.2021.017333

Abstract This pilot study focuses on a real measurements and enhancements of a software defined radio-based system for vehicle-to everything visible light communication (SDR-V2X-VLC). The presented system is based on a novel adaptive optimization of the feed-forward software defined equalization (FFSDE) methods of the least mean squares (LMS), normalized LMS (NLMS) and QR decomposition-based recursive least squares (QR-RLS) algorithms. Individual parameters of adaptive equalizations are adjusted in real-time to reach the best possible results. Experiments were carried out on a conventional LED Octavia III taillight drafted directly from production line and universal software radio peripherals (USRP) from National Instruments. The transmitting/receiving... More >

Open Access ARTICLE

Energy-Efficient Deployment of Water Quality Sensor Networks

Qian Sun[1,2], Zhiping Shen[1,2], Jinglin Liang[1,2], Xiaoyi Wang[1,2,*], Jiping Xu[1,2], Li Wang[1,2], Huiyan Zhang[1,2], Jiabin Yu[1,2], Ning Cao[3], Ruichao Wang[4]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3967-3977, 2021, DOI:10.32604/cmc.2021.017252

Abstract Water quality sensor networks are promising tools for the exploration of oceans. Some key areas need to be monitored effectively. Water quality sensors are deployed randomly or uniformly, however, and understanding how to deploy sensor nodes reasonably and realize effective monitoring of key areas on the basis of monitoring the whole area is an urgent problem to be solved. Additionally, energy is limited in water quality sensor networks. When moving sensor nodes, we should extend the life cycle of the sensor networks as much as possible. In this study, sensor nodes in non-key monitored areas are moved to key areas.... More >

Open Access ARTICLE

Digital Forensics for Skulls Classification in Physical Anthropology Collection Management

Imam Yuadi[1,*], Myrtati D. Artaria[2], Sakina[3], A. Taufiq Asyhari[4]

CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3979-3995, 2021, DOI:10.32604/cmc.2021.015417

Abstract The size, shape, and physical characteristics of the human skull are distinct when considering individual humans. In physical anthropology, the accurate management of skull collections is crucial for storing and maintaining collections in a cost-effective manner. For example, labeling skulls inaccurately or attaching printed labels to skulls can affect the authenticity of collections. Given the multiple issues associated with the manual identification of skulls, we propose an automatic human skull classification approach that uses a support vector machine and different feature extraction methods such as gray-level co-occurrence matrix features, Gabor features, fractal features, discrete wavelet transforms, and combinations of features.... More >

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A New Hybrid Feature Selection Method Using T-test and Fitness Function

Husam Ali Abdulmohsin[1,*], Hala Bahjat Abdul Wahab[2], Abdul Mohssen Jaber Abdul Hossen[3]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 3997-4016, 2021, DOI:10.32604/cmc.2021.014840
(This article belongs to this Special Issue: AI, IoT, Blockchain Assisted Intelligent Solutions to Medical and Healthcare Systems)
Abstract
Feature selection (FS) (or feature dimensional reduction, or feature optimization) is an essential process in pattern recognition and machine learning because of its enhanced classification speed and accuracy and reduced system complexity. FS reduces the number of features extracted in the feature extraction phase by reducing highly correlated features, retaining features with high information gain, and removing features with no weights in classification. In this work, an FS filter-type statistical method is designed and implemented, utilizing a t-test to decrease the convergence between feature subsets by calculating the quality of performance value (QoPV). The approach utilizes the well-designed fitness function... More >

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Data Matching of Solar Images Super-Resolution Based on Deep Learning

Liu Xiangchun[1], Chen Zhan[1], Song Wei[1,2,3,*], Li Fenglei[1], Yang Yanxing[4]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 4017-4029, 2021, DOI:10.32604/cmc.2021.017086
Abstract The images captured by different observation station have different resolutions. The Helioseismic and Magnetic Imager (HMI: a part of the NASA Solar Dynamics Observatory (SDO) has low-precision but wide coverage. And the Goode Solar Telescope (GST, formerly known as the New Solar Telescope) at Big Bear Solar Observatory (BBSO) solar images has high precision but small coverage. The super-resolution can make the captured images become clearer, so it is wildly used in solar image processing. The traditional super-resolution methods, such as interpolation, often use single image's feature to improve the image's quality. The methods based on deep learning-based super-resolution image... More >

Open Access ARTICLE

Mobile Memory Management System Based on User's Application Usage Patterns

Jaehwan Lee, Sangoh Park[*]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 4031-4050, 2021, DOI:10.32604/cmc.2021.017872
Abstract Currently, the number of functions to improve user convenience in smartphone applications is increasing. In addition, more mobile applications are being loaded into mobile operating system memory for faster launches, thus increasing the memory requirements for smartphones. The memory used by applications in mobile operating systems is managed using software; allocated memory is freed up by either considering the usage state of the application or terminating the least recently used (LRU) application. As LRU-based memory management schemes do not consider the application launch frequency in a low memory situation, currently used mobile operating systems can lead to the termination of... More >

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Image-to-Image Style Transfer Based on the Ghost Module

Yan Jiang[1], Xinrui Jia[1], Liguo Zhang[1,2,*], Ye Yuan[1], Lei Chen[3], Guisheng Yin[1]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 4051-4067, 2021, DOI:10.32604/cmc.2021.016481
Abstract The technology for image-to-image style transfer (a prevalent image processing task) has developed rapidly. The purpose of style transfer is to extract a texture from the source image domain and transfer it to the target image domain using a deep neural network. However, the existing methods typically have a large computational cost. To achieve efficient style transfer, we introduce a novel Ghost module into the GANILLA architecture to produce more feature maps from cheap operations. Then we utilize an attention mechanism to transform images with various styles. We optimize the original generative adversarial network (GAN) by using more efficient calculation... More >

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Multi-Modal Data Analysis Based Game Player Experience Modeling Using LSTM-DNN

Sehar Shahzad Farooq[1], Mustansar Fiaz[1], Irfan Mehmood[2], Ali Kashif Bashir[3], Raheel Nawaz[4], KyungJoong Kim[5], Soon Ki Jung[1,*]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 4087-4108, 2021, DOI:10.32604/cmc.2021.015612
(This article belongs to this Special Issue: Machine Learning for Data Analytics)
Abstract Game player modeling is a paradigm of computational models to exploit players' behavior and experience using game and player analytics. Player modeling refers to descriptions of players based on frameworks of data derived from the interaction of a player's behavior within the game as well as the player's experience with the game. Player behavior focuses on dynamic and static information gathered at the time of gameplay. Player experience concerns the association of the human player during gameplay, which is based on cognitive and affective physiological measurements collected from sensors mounted on the player's body or in the player's surroundings. In… More >

Open Access ARTICLE

Performance Comparison of Deep CNN Models for Detecting Driver's Distraction

Kathiravan Srinivasan[1], Lalit Garg[2,*], Debajit Datta[3], Abdulellah A. Alaboudi[4], N. Z. Jhanjhi[5], Rishav Agarwal[3], Anmol George Thomas[1]
CMC-Computers, Materials & Continua, Vol.68, No.3, pp. 4109-4124, 2021, DOI:10.32604/cmc.2021.016736
(This article belongs to this Special Issue: Emerging Applications of Artificial Intelligence, Machine learning and Data Science)
Abstract According to various worldwide statistics, most car accidents occur solely due to human error. The person driving a car needs to be alert, especially when travelling through high traffic volumes that permit high-speed transit since a slight distraction can cause a fatal accident. Even though semi-automated checks, such as speed detecting cameras and speed barriers, are deployed, controlling human errors is an arduous task. The key causes of driver's distraction include drunken driving, conversing with co-passengers, fatigue, and operating gadgets while driving. If these distractions are accurately predicted, the drivers can be alerted through an alarm system. Further, this research… More >

Open Access ARTICLE

Segmentation of Brain Tumor Magnetic Resonance Images Using a Teaching-Learning Optimization Algorithm

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Abstract Image recognition is considered to be the pre-eminent paradigm for the automatic detection of tumor diseases in this era. Among various cancers identified so far, glioma, a type of brain tumor, is one of the deadliest cancers, and it remains challenging to the medicinal world. The only consoling factor is that the survival rate of the patient is increased by remarkable percentage with the early diagnosis of the disease. Early diagnosis is attempted to be accomplished with the changes observed in the images of suspected parts of the brain captured in specific interval of time. From the captured image, the… More >

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Virtual Reality-Based Random Dot Kinematogram

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(This article belongs to this Special Issue: Integrity and Multimedia Data Management in Healthcare Applications using IoT)
Abstract This research implements a random dot kinematogram (RDK) using virtual reality (VR) and analyzes the results based on normal subjects. Visual motion perception is one of visual functions localized to a specific cortical area, the human motion perception area (human analogue for the middle temporal/middle superior temporal area) located in the parieto–occipito–temporal junction of the human brain. The RDK measures visual motion perception capabilities. The stimuli in conventional RDK methods are presented using a monitor screen, so these devices require a spacious dark room for installation and use. Recently, VR technology has been implemented in different medical domains. The test… More >

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Digital Forensics for Skulls Classification in Physical Anthropology Collection Management

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Abstract: The size, shape, and physical characteristics of the human skull are distinct when considering individual humans. In physical anthropology, the accurate management of skull collections is crucial for storing and maintaining collections in a cost-effective manner. For example, labeling skulls inaccurately or attaching printed labels to skulls can affect the authenticity of collections. Given the multiple issues associated with the manual identification of skulls, we propose an automatic human skull classification approach that uses a support vector machine and different feature extraction methods such as gray-level co-occurrence matrix features, Gabor features, fractal features, discrete wavelet transforms, and combinations of features. Each underlying facial bone exhibits unique characteristics essential to the face's physical structure that could be exploited for identification. Therefore, we developed an automatic recognition method to classify human skulls for consistent identification compared with traditional classification approaches. Using our proposed approach, we were able to achieve an accuracy of 92.3–99.5% in the classification of human skulls with mandibles and an accuracy of 91.4–99.9% in the classification of human skills without mandibles. Our study represents a step forward in the construction of an effective automatic human skull identification system with a classification process that achieves satisfactory performance for a limited dataset of skull images.

Keywords: Discrete wavelet transform; Gabor; gray-level co-occurrence matrix; human skulls; physical anthropology; support vector machine

1 Introduction

1.1 Background and Motivation

Researchers in digital forensics commonly deal with a series of activities, including collecting, examining, identifying, and analyzing the digital artefacts required for obtaining evidence regarding physical object authenticity [1]. Several research challenges are associated with the digital

forensic attributes found during physical anthropology investigation. One prevalent example is the management of skull collections in museums, which will benefit future research and education. A skull cataloging and retrieval system is a major component of skull collection management. Within this system, skulls with lost labels can be identified via an investigation process. This process includes labeling the collection in the form of a call number attached to each skull. This ensures that the skulls belong to a specific collection and facilitates their identification. This is equally important for proper documentation, development, maintenance, and enhancement of existing collections and making them available to curators who want to use them according to classification standards [2].

However, the utilization of ink streaks on skulls to apply an alphanumeric code can damage the authenticity of the skull as a study material. Hence, skull collection management necessitates a certain approach to maintain the authenticity of the collection and avoid damage through the use of chemicals. Attaching stickers with the call number is an alternative. However, this method also has drawbacks because stickers can become loose, fall off, and become fixed to other skulls.

Therefore, it is challenging to increase the number of new skull collections because of difficulties associated with their storage and collection. Skulls can include those separated from the mandible. Labelling errors are a major problem when human skulls and other skeletal collections in an anthropology forensics laboratory are ink out. Apart from the loss of labels attached to new bone collections, the mixing of old bone collections with new bones and high usage factors are challenges that must be overcome in skull collection management.

The use of digital cameras by anthropologists and other researchers to classify human bones is currently limited to manual investigation and comparison. Although some previous studies have applied automatic methodologies, such as machine learning, to identify human skulls, the majority of the samples were obtained via computerized tomography (CT) scans of living participants. These samples have limited relevance with respect to the analysis of skulls of dead subjects, as required in physical anthropology forensics.

1.2 Contributions of This Work

In this study, we investigate a digital forensics approach for the physical anthropological investigation of skulls of dead humans based on their specific characteristics. Our main contributions are as follows. First, the significance of this work lies in the application of machine learning and data analytics knowledge to the new domain of physical anthropology collection management and addressing its unique challenges. Second, given the aforementioned problems introduced by manual labeling techniques, this study aims to evaluate the relevant contrasting features of human skulls and build skull-based identities from various positions via automatic classification. Third, our work proposes automatic classification of the skull beneath the human face that would allow curators to identify features based on skeletal characteristics. This technique would potentially assist in the management of museum collections or the laboratory storage of skulls; skulls could be identified without being manually marked or labeled, thereby maintaining their authenticity.

This study is inspired by face recognition technology. The structure of the mandible, mouth, nose, forehead, and the overall features associated with the human skull can be recognized using various means and properties. Based on the availability of these properties, face recognition can be conducted by comparing different facial images and classifying the faces using a support vector machine (SVM). The study [3] has applied SVMs to identify human faces, achieving face prediction accuracy rates of >95%. These studies applied different feature processing methods to acquire relevant statistical values before classification. Specifically, Benitez-Garcia et al. [4]

and Hu [5] applied the discrete wavelet transform (DWT) for feature extraction to identify a human face. Eleyan [6] used the wavelet transform, whereas Dabbaghchian implemented the discrete cosine transform (DCT) for human face analysis [7]. Krisshna et al. [8] used transform domain feature extraction combined with feature selection to improve the accuracy of prediction. In contrast, Gautam et al. [9] proposed image decomposition using Haar wavelet transforms through a classification approach in which the quantization transform and the split-up window of facial images were combined. Faces were classified with backpropagation neural networks and distinguished from other faces using feature extraction when considering a grayscale morphology. In addition, a combined feature extraction of Gaussian and Gabor features has been applied to enhance the verification rate of face recognition [10].

As observed in the present study, the effective combination of different feature filters is a step forward in using machine learning to conduct investigations in physical anthropology and its sub-areas. Researchers in the physical anthropology field often focus on analyzing the data characteristic obtained from the skulls of dead humans; this characteristic has rarely been found in previous studies on automatic face recognition. Therefore, this work offers a new perspective on the application of machine learning to physical anthropology and tackling its challenges, i.e., the limited physical collection of skulls of dead humans, variation in the completeness of skull construction, and deterioration of the skull condition over time. All these challenges are obstacles to the training of appropriate machine learning techniques and obtaining appropriate feature extraction is the key to achieve the learning objective, successful facial classification.

The remaining sections of this manuscript are as follows. Section 2 presents related works. Section 3 discusses the skull structure that provides the initial information for skull classification. Section 4 presents our main research approach and contribution to developing a machine learning-based automatic classification platform for classifying human skulls in physical anthropology. Section 5 reports our experimental results and validates our research approach. Finally, we summarize the main results of this research and directions of our future work in Section 6.

2 Related Works

There is increasing demand for an image classification system that can perform automatic facial recognition tasks [11–13]. Several studies have investigated facial recognition and facial perception. Automatic facial processing [11] is a reliable method and realistic approach for facial recognition. It benefits from the use of deep neural networks [12], dictionary learning [13], and automatic partial learning. These tools can be utilized to create a practical face dataset using inexpensive digital cameras or video recorders. Several studies have also addressed human recognition based on various body images captured using cameras.

Elmahmudi et al. [14] studied face recognition through facial rotation of different face components, i.e., the cheeks, mouth, eyes, and nose, and by exploiting a convolutional neural network (CNN) and feature extraction prior to SVM classification. Duan et al. [15] investigated partial face recognition using a combination of robust points to match the Gabor ternary patterns with the local key points. Several studies [16–18] have used CNNs to extract complementary facial features and derive face representations from the layers in the deep neural network, thereby achieving highly accurate results.

Furthermore, Chen et al. [16] applied similarity learning using a polynomial feature map to represent the matching of each sub-region including the face, body, and feet to investigate the similarity learning for person re-identification based on different regions. All the feature maps

were then injected into a unified framework. This technique was also used by Wu et al. [17], who combined deep CNNs and gait-based human identification. They examined various scenarios, namely cross-walking and cross-view conditions with differences in pre-processing and network architecture. Koo et al. [18] studied human recognition through a multimodal method by analyzing the face and body, using a deep CNN.

A previous anthropology study [19] provided complete information for facial identification by investigating skull objects in different positions. In forensic anthropology, experts use bones and skulls to identify missing people via facial reconstruction and to determine their sex [20]. The identification of craniofacial superimposition can provide forensic evidence about the sex and specific identity of a living human. Furthermore, tooth structure provides information about food consumed. Craniofacial superimposition is based on a skeletal residue, which can provide forensic artefacts prior to identification. Therefore, the skull overlay process is applied by experts to examine the ante-mortem digital figures popular in skull morphology analysis [21].

The so-called computational forensics method is a specific to the forensic anthropology approach [22]. In this area of research, Bewes et al. [23] adapted neural networks for determining sex on the basis of human skulls using data obtained from hospital CT scans. Furthermore, an automatic classification method for determining gender was developed by Walker [24], who investigated and visually assessed modern American skulls based on five skull traits. He used discriminant function analysis to determine sex based on pelvic morphology. He evaluated sexual dimorphic traits to determine sex. By using a logistic model, it can be seen that the classification accuracy rate is 88% for modern skulls with a note that a negligible sex bias of 0.1% exists. Another study on the skulls of white European Americans was conducted by Williams and Rogers [25], who accurately identified more than 80% of skulls. Angelis [26] developed another method to predict soft face thickness for face classification.

As observed in most of the above studies, automatic face recognition is mainly focused on the analysis of data obtained from living humans, be it in the form of digital camera or CT images. Even though the physical characteristics for facial identification and computational forensics for gender classification have been investigated in the anthropology literature, automated digital tools that are robust in terms of facial identification appear to be lacking. Thus, this work is a step forward in developing an automated tool by incorporating machine learning and knowledge about robust features.

3 Skull Structures

In principle, the facial skeleton or viscerocranium comprises the anterior, lower, and skull bones, namely, facial tissue, and other structures that form the human face. It comprises various types of bones, which are derived from the branchial arches interconnected among the bones of the eyes, sinuses, nose, and oral cavity and are in unity with the calvarias bones [27]. Naturally, the viscerocranium encompasses several bones, which are illustrated in Fig. 1 and are organized as follows.

1) Frontal—This bone comprises the squamous, which tends to be vertical, and the orbital bones, which are oriented horizontally. The squamous forms part of the human forehead, and the orbital part is the part of the bone that supports the eyes and nose.
2) Nasal—The paired nasal bones have different sizes and shapes but tend to be small ovals. These bones unite the cartilage located in the nasofrontal and upper parts of the

lateral cartilages to form the human nose and consists of two neurocraniums and two viscerocraniums.

3) Vomer—The vomer bone is a single facial bone with an unpaired midline attached to an inferior part of the sphenoid bone. It articulates with the ethmoid, namely, the two maxillary bones and two palatine bones, forming the nasal septum.
4) Zygomatic—The zygomatic bone is the cheekbone positioned on the lateral side and forms the cheeks of a human. This bone has three surfaces, i.e., the orbital, temporal, and lateral surfaces. It articulates directly with the remaining four bones, i.e., the temporal, sphenoid, frontal, and maxilla bones.
5) Maxilla—This is often referred to as the upper jaw bone and is a paired bone that has four processes, i.e., the zygomatic, alveolar, frontal, and palatine processes. This bone supports the teeth in the upper jaw but does not move like the lower jaw or mandible.
6) Mandible—The mandible is the lower jaw bone or movable cranial bone, which is the largest and strongest facial bone. It can open and close a human's mouth. The mandible has two basic bones, i.e., the alveolar part and the mandible base, located in the anterior part of the lower jaw bone. Furthermore, it has two surfaces and two borders [28].

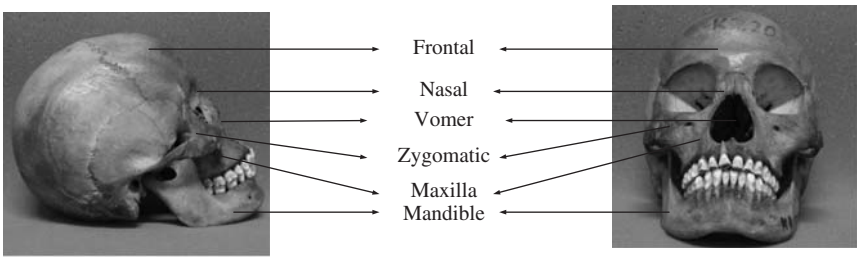

Figure 1: Structure of a human skull

4 Research Approach

In the following subsections, we describe the systematic design steps adopted for developing an automatic intelligent human skull recognition system using data collection and processing, feature extraction filters, and skull classification to obtain maximum prediction accuracy.

4.1 Tools and Software Platform

We used hardware and software platforms that would allow us to meet the objectives of this study and conduct forensic tests on human skulls. First, we used a DSC-HX300 digital camera (Sony Corp., Japan) equipped with high-resolution Carl Zeiss lenses for obtaining the skull images. Then, we applied Matlab software version R2013a to convert the image data into a numeric form. Finally, we implemented an SVM classifier with Eclips SDK in Java for skull classification. To run the aforementioned software, we used a personal computer with the following specifications: Intel Core i5 Processor equipped with 8 GB of RAM, using the Windows XP operating system.

4.2 Framework

Fig. 2 presents the framework used for digital forensics when investigating the characteristics of human skulls in this work. It indicates the step-by-step investigation procedures, beginning with

the digitalization of skull data and ending with skull identification. This process is explained in detail below:

1) Digitizing human skulls: In the first step, skulls were digitized by taking their photos from various angles using a digital camera. Thus, images of the face or front, left, right, bottom, and top areas could be obtained. The obtained results were then documented and saved as digital image files. Fig. 4 presents the region of interest (ROI) of an image sample. This figure shows the skull area corresponding to a set of pixels, where (i,j) denotes a spatial location index within the picture.
2) Feature extraction: This step was conducted to obtain certain values from skull images via feature filtering or extraction based on pixel characteristics and other criteria. Various feature filters were applied to compare the accuracy rates of the implemented filters. This was the major image processing activity prior to the segmentation and classification steps. We considered four different feature-filtering techniques to determine the relevant features and extract their corresponding values from the images. We conducted a texture analysis approach using this feature filter before classifying the human skulls. Four feature filters were separately applied to obtain a different accuracy rate for classification. For this study, we used 22 feature-level, co-occurrence matrices (GLCM), 12 features of the discrete wavelet transform (DWT), 48 Gabor features, and 24 fractal features or segmentation-based fractal texture analyses (SFTA). In total, we used 106 features. The filters were applied to analyze 24 images of skulls at various rotation angles (from 1° to 360°); each image was extracted with these filters to obtain a different statistical decomposition. Therefore, each skull image produced a minimum of 360 images to be extracted through the deployment of various filters before classification.
3) Classification: The support vector machine (SVM) is a widely applied method developed by Awad and Khanna [29] for data classification and regression. This method can maximize the distance between several data classes even when applied to a high-dimensional input space. It also has the ability to process and group images based on patterns, which is an advantage of the SVM, especially against the drawback of dimensionality. Furthermore, the SVM can solve the problem of limited training and can minimize the parameter associated with its structure based on its ability to work on nonlinear problems by adding a high-dimensional kernel [30]. The SVM works by finding the best hyperplanes to classify the different space classes in the input space. Classification can be conducted by finding a hyperplane that separates groups or classes through margins and maximum points. Therefore, it can run on nonlinear kernel data with nonlinear kernel functions by mapping the product point from lower to higher dimensions. In this study, radial basis function (RBF)-based kernels were selected to build a nonlinear classifier for identifying 24 different types of skull. More specifically, we applied the RBF-based kernel function used in a previous study to build this SVM-based classifier [31], i.e., $K_{RBF}(x_i, x_j) = \exp(-\gamma \|x_i - x\|_j^2)$. Here, $\gamma > 0$ and $\|.\|$ denotes the kernel-spreading coefficient and the Euclidean norm applied to the difference between two data points, x_i and x_j. The value of γ was optimized via a coarse grid search by transforming the original data to the feature space.

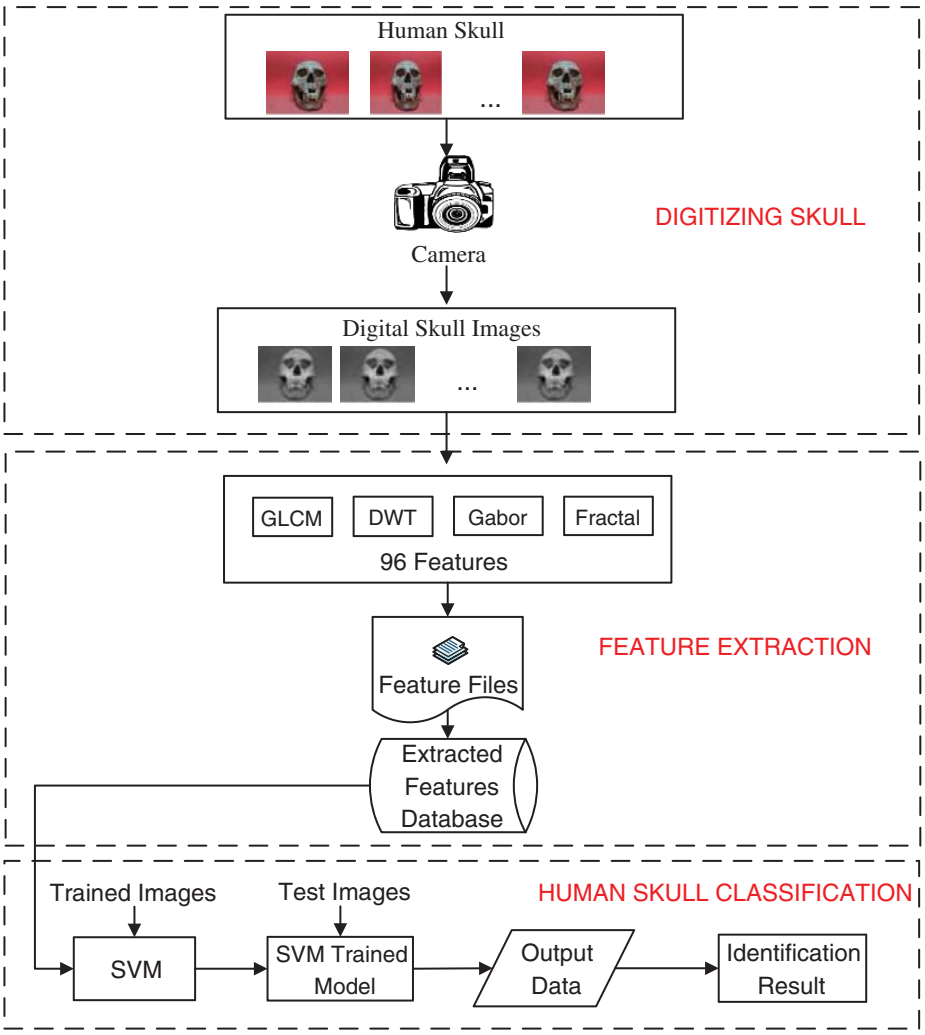

Figure 2: Framework used for digital forensics when investigating the characteristics of human skulls

4.3 Feature Extraction

Feature extraction involves the transformation of data. The derivative values from original data are transformed into variable data with statistical values that can be further processed. Here, we used the following techniques for feature extraction.

1) GLCM is a popular filter for texture analysis. It captures information regarding the gray-value spatial distribution in an image and the image texture's corresponding frequency at given specified angles and distances. Feature extraction using GLCM is conducted based on the estimated probability density function of a pixel using a co-occurrence matrix along with its pixel pairs, where features can be statistically and numerically quantified [32]. Four angular directions are considered during matrix generation for feature extraction. Specifically, the statistical characteristics are calculated in the 0°, 45°, 90°, and 135° directions. Fig. 3 presents direction (horizontal and vertical orientations) as a spatial representation based on different reference pixels. Let us assume that reference pixel i is defined with

a 45° orientation based on which an adjacent pixel can be located. The direction of the pixel is calculated when considering pixel j next to pixel i, as demonstrated by Tsai et al. [33]. Following this work, Fig. 4 illustrates the ROI of human skulls showing the pixels generated by GLCM in gray color, as captured by Eq. (1).

$$\boldsymbol{R} = \sum_{(\boldsymbol{i},\boldsymbol{j})\in \boldsymbol{ROI}} 1. \tag{1}$$

Thus, pixels are labeled as "1" if they belong to the ROI and "0" otherwise. From Eq. (1), we can obtain the predictable values from the normalized GLCM.

$$GLCM\ (i,j) = \frac{1}{\sum_{(i,j)} Img(i,j)} Img(i,j). \tag{2}$$

Here, (i,j) denotes the index of the pixel in the image, and Img (i,j) denotes the probability of the pixel index (i,j). GLCM can generate 22 texture features, as explained in detail by Tsai et al.

2) Wavelet features. A digital image comprises many pixels that can be represented in a two-dimensional (2D) matrix. Outside the spatial domain, an image can be represented in the frequency domain using a spectrum method called the DWT. In several studies (e.g., [34,35]), the feature sets are focused on 2D-scale wavelets because of their underlying functions. The feature filter direction follows subsampling with two factors, and each sub-band is equivalent to the output filters, which contain several samples compared with the main 2D matrix. The filtered processing outputs are considered to be the DWT coefficients. This filter set of DWT coefficients, as shown in Fig. 4, contains 12 statistical features that include kurtosis (HH, LH, HL, and LL sub-bands), standard deviation, and skewness.
3) Gabor features. Gabor filters are shaped through dilation and rotation in a single kernel with several parameters. The corresponding filter function is used as a kernel to obtain a dictionary filter for analyzing the texture images. The 2D Gabor filter has several benefits in a spatial domain, such as a number of different scales and orientations allows for feature extraction and also, invariance for rotation, illumination, and translation involving the Gaussian kernel function [36] modulated by complex sinusoidal waves [37,38]. Inspired by these works, we used the function in Eq. (3) to extract human skull images.

$$GG(x,y,\theta,f) = \exp\left(\left[-\frac{1}{2}\left\{\left(\frac{x'}{Sx}\right)^2 + \left(\frac{y'}{Sy}\right)^2\right\}\right]\right)\cos(2\pi f x'). \tag{3}$$

Here, parameter x' is expressed as $x\cos(\theta) + y\sin(\theta)$, and y' is expressed as $y\cos(\theta) - x\sin(\theta)$. S_x and S_y denote the variances along the x and y axes, respectively. Finally, parameter f denotes the frequency of the sinusoidal function, and θ represents the orientation of the Gabor filter. Subsequently, the following numerical values were considered as part of Gabor feature extraction: Sy = 4; Sx = 2; f = 2, 4, 8, and 16; and $\theta = 0$, $\pi/2$, $\pi/4$, and $3\pi/4$. Then, we extracted and acquired all 48 Gabor features from each image.
4) Fractal features are considered when evaluating images with similar textures. Features are obtained from the fractal dimensions of the transformed images obtained from the boundary of segmented image structures and grayscale images. Fractal features can be used to compute the fractal dimension for any surface roughness. Furthermore, they can be used to evaluate the gray image and compare various textures. Fractal dimensions can

be realized as a measure of irregularity or heterogeneity. If an object has self-similarity properties, then the entire set of minimized subsets will have the same properties. In this study, the boundaries of the feature vector were used to measure fractals. The measurement is represented as Δ (x, y), and can be expressed as follows:

$$\Delta(x,y) = \begin{cases} 1 & \text{if } (x',\, y')\, N_4[(x,y)]: \\ & I_b(x',\, y') = 0 \wedge I_b(x',\, y') = 1, \\ 0 & otherwise. \end{cases} \tag{4}$$

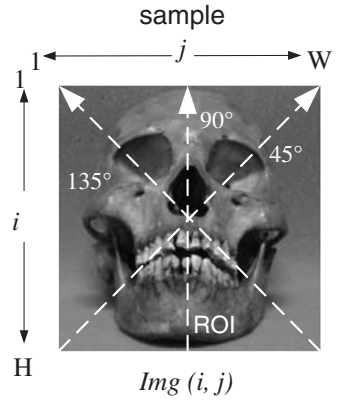

Figure 3: Estimation of texture orientation from a skull image. The pixel of GLCM (n, m) from four different regions of interest (ROIs), where the spatial location of the skull image is indicated by i and j. At a point, pixel separation (W and H) is applied as W = 0 and H = 1 to obtain the number of gray-level pixels n and m

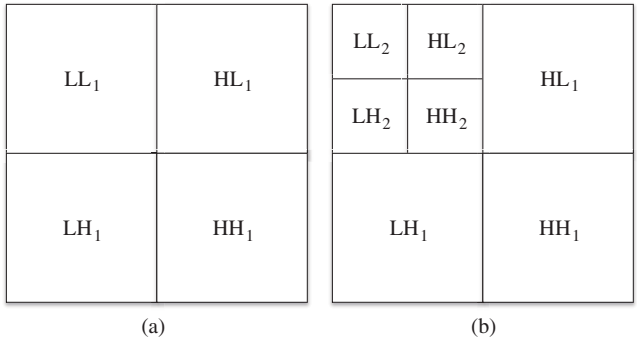

Figure 4: Discrete wavelet transform image decomposition for (a) one and (b) two levels of resolution

This measurement function is similar to the one in Costa et al. [39], except, instead of N_8 (x, y), N_4 [(x, y)] is used to denote a grayscale skull image that has a vector size threshold of 4 in related to (x, y) in a group of pixels. For binary decomposition, they applied a thresholding

mechanism to the input image. In this study, we applied a four-connected pixel in the case of threshold segmentation to (x, y). Thus, 24 features could be extracted.

4.4 Data Samples

In this study, human skulls were categorized based on their mandibles. We validated and compared the samples' unique characteristics (not only skulls with mandibles but also those without mandibles), as shown in Fig. 5. To obtain fair research results, we considered 24 skulls with mandibles and 24 skulls without mandibles to define our target classes for classification. We then took pictures of the samples using the aforementioned digital camera. The skulls were obtained from the Physical Anthropology Laboratory at Airlangga University. The original skull images can be accessed from http://fisip.unair.ac.id/researchdata/Skulls/.

Figure 5: Skulls with a mandible (top) and without a mandible (bottom)

We experimented with seven different angles for the images of skulls with and without mandibles: front, top, and back angles, as well as 45° right-angle, 45° left-angle, 90° right-angle, and 90° left-angle rotations. Then, we rotated the image step-by-step by 360°; each degree of rotation produced one sample image that was stored as the input sample for machine learning. For example, the front angle was rotated by 360°, and thus we analyzed 360 data samples. Subsequently, we converted all the images to grayscale in jpeg (jpg) format, set a pixel size of 53 × 40 for each image, and set the file size to 4 kb. Tab. 1 details the 360 processed sample images for each skull image that were obtained via rotation. The total number of images used in this experiment was 8,640. We classified 24 skull images as the target class of classification. The result of a given experiment was the average of ten rounds of the given experiment. For each round of an experiment, a set of 300 images was uniformly sampled.

In this experiment, it was conducted by dividing into training and testing data with a ratio of 2:1. There were ten sets and each set comprised 300 images selected for training data and another 150 images for test data.

Table 1: Data sample of human skulls

Class	Sample	Pixels	Size	Total Data
Skull with mandible		53 × 40	4.00 kb	8,640
Skull without mandible		53 × 40	4.00 kb	8,640

4.5 Research Limitation

The limitations of this study were difficulty in obtaining experimental data and using camera settings to ensure the same resolution when capturing skull images. Another limitation was that seven different angles were considered to perform comparisons between skulls with and without mandibles. Because of the difficulty associated with finding research objects, this study focused on the classification of 24 skulls, which were all in an incomplete condition, especially those that had teeth attached.

5 Experimental Results

As described previously, we considered two different digital skull images: skulls with mandibles and skulls without mandibles. We first applied each feature extraction filter separately to clearly understand the factors influencing the experimental results. This process was followed by combining all the feature extraction filters. The following subsections discuss the application of filters and obtained classification accuracy.

5.1 Experiment i: Identification of Skulls with Mandibles

In Experiment I, we considered the images of human skulls with mandibles and examined them from different angles as shown in Fig. 6. Prior to classification, the feature extraction techniques (see Section 4) were applied to the images, and Matlab was used to obtain the numerical values of the generated features. Then, we exported the numerical values on the basis of a filter set into a MySQL database for future referencing. Subsequently, we performed image-driven skull classification using the SVM implemented in a Java programming environment to compute the accuracy of the classification task on the basis of a given set of features. We considered all the individual treatments of each feature extraction filter and the combined effect. The accuracy rates of predicting the skulls from different angles are presented in Tab. 2.

The detailed steps of this experiment were as follows.

(1) Step 1: We used 24 sets of images extracted using various extraction filters. Each resulting set of images contained 360 transformed images obtained by rotating the original image via one-degree rotation per step. From all the available images, we selected 200 skull images as training data and 100 skull images as testing data. Our four extraction filtering techniques were then applied for feature extraction.
(2) Step 2: We ran the SVM to predict human skulls with mandibles using the four filtering techniques individually and then a combination of all four filters.

(3) Step 3: We conducted a series of image testing steps on the basis of the appropriate model constructed in Step (2) for human skulls with mandibles.
(4) Finally, we repeated Steps (1)–(3) nine more times (for a total of ten replicates) and obtained the average performance.

The classification of skulls differed in accuracy across the seven angles of interest. Evidently, each filter had a different accuracy even though the within-filter results were numerically stable. Gabor feature extraction was stable, i.e., higher than 90%, making it the superior feature filter among the four considered techniques. In contrast, the DWT filter resulted in an accuracy rate as low as 89.73%. Conversely, the GLCM, Gabor, and fractal filters consistently achieved a classification accuracy >98%. With prediction accuracies that were mostly >90%, all four filters are promising tools for assisting the SVM in automatically classifying human skulls for physical anthropology applications.

(a) (b) (c) (d) (e) (f) (g)

Figure 6: Various angles used for depicting images: (a) front angle, (b) 45° right-angle rotation, (c) −45° left-angle rotation, (d) 90° right-angle rotation, (e) −90° left-angle rotation, (f) top angle, and (g) back angle

Table 2: Accuracy of prediction (%) for human skulls with mandibles

Filter	Front	−45° left	45° right	−90° left	90° right	Back	Top
GLCM	98.07	99.90	99.75	99.76	99.81	99.74	99.99
DWT	92.37	94.05	89.73	94.01	93.77	94.97	97.05
Gabor	99.24	99.55	99.21	99.43	99.45	99.44	99.69
SFTA	99.33	99.21	99.00	98.98	98.57	98.68	99.51
All	99.52	99.57	99.53	99.57	99.39	99.46	99.80

5.2 Experiment II: identification of Skulls Without Mandibles

We also conducted identifications of skulls without mandibles to evaluate the robustness of our classification system.

Tab. 3 presents the performance accuracy of the five filters for human skulls without mandibles (we selected 24 out of 99 available samples in this table). The classification results obtained using the SVM varied according to the different feature extraction filters. Overall, the GLCM filter offered superior prediction capabilities, achieving higher than 99% accuracy for all the angular positions of the skulls. The discrete wavelet transform had the lowest accuracy. Almost all filters had prediction accuracies >90%, except for DWT at −45° left (88.36%). The prediction accuracy was 99.61% when we combined the features from all the filters.

Table 3: Accuracy prediction (%) for human skulls without mandibles

Filter	Front	−45° Left	45° Right	−90° Left	90° Right	Back	Top
GLCM	99.95	99.92	99.88	99.87	99.86	99.87	99.95
DWT	91.45	88.36	92.18	90.58	93.43	95.18	96.24
Gabor	99.29	99.19	99.39	99.27	99.34	99.65	99.63
SFTA	98.97	99.00	98.46	98.82	98.69	99.42	99.48
All	99.61	99.56	99.56	99.32	99.46	99.50	99.72

In automatic human skull classification, the implementation of feature extraction and the combination of different feature filters play a significant role in the accumulation of relevant features. Each filter can produce several features. A classification system with diverse results can be produced by using four different filters and combining all generated features. For example, in this study, the use of GLCM comprising 22 features resulted in a classification accuracy rate of 99.86–99.95% depending on the angular position of the skull. Conversely, DWT feature extraction had a much lower accuracy rate of 88.36–96.24%.

5.3 Experiment III: Different Resolutions for Skull Classification

We also used different electronic imaging devices to compare and validate the results of the previous experiments in which we used a high-resolution camera; however, in Experiment III, we used a mobile camera (NOKIA 3.1 plus) with a lower resolution. We used the same experimental approach but captured the skull front angle images with different lens sizes for camera resolutions of 2, 4, and 9 MP.

Tab. 4 presents the accuracies obtained when identifying human skulls using three different camera resolutions. The accuracy of predictions increased with increasing resolution. For example, a 2-MP camera resolution resulted in a prediction accuracy of 91.41% for GLCM, lower than those for a 4-MP resolution (93.17%) and a 9-MP resolution (97.83%).

Table 4: Accuracy prediction (%) for different resolutions

Filter	2 MP	4 MP	9 MP
GLCM	91.41	93.17	97.83
DWT	67.38	67.89	70.07
Gabor	88.48	91.50	93.55
SFTA	79.32	80.20	90.67
All	83.75	86.98	94.62

5.4 Discussion

Our experimental results indicate that the classification of skulls with mandibles was as accurate as that of skulls without mandibles. However, the required calculation time for processing the images of skulls with mandibles was shorter than that for skulls without mandibles.

This study extends the analysis and framework for the identification of human faces reported in previous studies [4,5,9], and [40,41] but uses a different approach to the classification of human

skulls. The results from previous studies are summarized in Tab. 5 for further comparison of identification accuracy. The majority of these approaches achieved an average accuracy higher than 90%. The lowest accuracy was observed with the method used by Hu et.al (94.67%) [5]. Other studies exhibited much better accuracies, with averages >95%. The most accurate approach was obtained via research with CNNs [41], resulting in an accuracy of 98.43%. Other approaches, such as principal component analysis, Euclidean, and Gaussian mixture model [40], also exhibited a high accuracy. Nevertheless, our method of analyzing human skulls rather than the faces of living persons resulted in even higher accuracies. Using the framework presented in Fig. 2, we obtained a high classification accuracy when identifying skulls. Thus, our novel approach could be a promising application in digital forensics with respect to human skull identification.

Table 5: Results of different face recognition approaches

Research	Research object	Approach	Accuracy rate (%)
[4]	Live human face	PCA, sub-block processing	97.60
[5]	Live human face	PCA, dual-tree complex wavelet transform (DT-CWT), and single-tree complex wavelet transform (ST-CWT)	94.67
[9]	Live human face	Principal component analysis (PCA), particle swarm optimization (PSO)–SVM (PSO–SVM)	98.00
[40]	Live human face	PCA, Euclidean, Gaussian mixture model (GMM)	97.04
[41]	Live human face	CNNs	98.43
Our work	**Dead human skull**	SVM	99.50

Unlike human face recognition research, one of the major challenges associated with the present study was the acquisition of human skull data. This is because the skull is an inanimate object that must be moved to obtain data from various angles. This movement was achieved by manually turning the skull to appropriate angles to obtain images from various positions. This is highly challenging, especially when the skull is in an incomplete condition.

Moreover, variation in the amount of training data can impact the accuracy of the classification task. It is thus of interest to investigate how various training dataset sizes can affect the performance of SVM classification. The prediction accuracy rates for skulls with and without mandibles show that the amount of training and testing data affects the prediction accuracy. For example, with the GLCM filter, when we used only one training data item to predict skulls with

mandibles, we obtained an accuracy rate of 18.33%. However, when we used 100 training data items, the accuracy rate was 97.03%. Thus, a greater amount of applied training data will result in a higher accuracy.

Skulls generally have one dominant texture and color but may have different shapes and sizes even if the skulls share ancestry. However, if the bones are buried in different soils (for example, clay or calcareous soils), they will have different colors.

In this forensic study, we applied a digital camera to digitize the skulls. The implementation of different digitizing tools will affect the level of accuracy, especially regarding image resolution. Therefore, in further research, we recommend the use of advanced digital technology capabilities such as, postmortem computed tomography (PMCT) and angiography, as well as X-rays.

This study focused on only 24 human skulls with mandibles and 24 skulls without mandibles because of the limitations and difficulties in obtaining sample data in physical anthropology. However, we also conducted experiments on other skulls without mandibles (99 skulls) even though with some bone structures were incomplete when they were discovered. Therefore, we only focused on the classification of skull faces. Our results were similar to those obtained from Experiments III, although the level of accuracy was slightly higher than those in previous experiments.

6 Conclusion

We developed an automatic computerized digital forensics approach for human skull identification using feature extraction in tandem with an SVM. We applied a digital forensics framework to classify human skulls with and without mandibles. We tested four different feature extraction filters for feature extraction that resulted in different classification accuracies. GCLM achieved the maximum accuracy with features generated from Gabor and fractal features (>99%). In contrast, DWT features resulted in identification prediction accuracies <95%. The combination of the four feature extraction techniques produced an accuracy rate >99% for skulls both with and without mandibles. Thus, every human skull has unique features that can be used to distinguish its identity in forensics applications, especially in physical anthropology collection management.

We can identify several future directions for research related to skull identification. For future work, it will be necessary to optimize the combined feature extraction and classification method and to explore other feature extraction techniques and classification methods for performance comparisons. Utilizing additional skull data when using the CNN method could be the main focus for such future research. Furthermore, the determination of the age and gender associated with the skulls will greatly assist researchers in identifying humans who disappeared due to natural disasters or who were victims of criminal activities.

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