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INTELLIGENT DIGITAL FORENSICS FILE MANIPULATION DETECTION USING METADATA ANALYSIS AND RANDOM FOREST

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Abstract: The advancement of digital technology has made it easier to create, process, and distribute files—using 317 files from the dataset https://www.kaggle.com/datasets/axon data/selfie-and-official-id-photo-dataset-18k images?select=metadata_image.csv has also introduced new challenges, such as the increasing practice of digital file manipulation that is difficult to detect visually. Therefore, an intelligent digital forensics system that can automatically and accurately detect file authenticity is required. This study aims to develop an intelligent digital forensics system for detecting file manipulation by leveraging metadata analysis and the Random Forest classification method. The methods used include extracting metadata from digital files—such as time information, device details, and processing history—followed by analysis to identify patterns of inconsistency that indicate manipulation. This data is then used as features in the classification process using the Random Forest algorithm to distinguish between original and manipulated files. The results of this study are expected to show that the use of metadata analysis combined with the Random Forest algorithm can improve accuracy in detecting digital file manipulation compared to conventional methods. The resulting system is expected to provide an effective, efficient, and integrated solution to support digital forensic investigations, Based on the test results, the system demonstrated good performance with an accuracy rate of 94%.

Keywords: Digital Forensics;File Manipulation;Metadata Analysis;Random Forest;Classification;Machine Learning

Abstrak:Perkembangan teknologi digital telah meningkatkan kemudahan dalam pembuatan, pengolahan,dan distribusi file sebanyak 317 file, sumber datasets https:// www.kaggle.com/datasets/axondata/selfie-and-official-id-photo-dataset-18k-images?select =metadata_image.csv, namun juga menimbulkan tantangan baru berupa meningkatnya praktik manipulasi file digital yang sulit dideteksi secara kasat mata. Oleh karena itu, diperlukan suatu sistem forensik digital yang cerdas dan mampu mendeteksi keaslian file secara otomatis dan akurat. Penelitian ini bertujuan untuk mengembangkan sistem forensik digital cerdas untuk deteksi manipulasi file dengan memanfaatkan analisis metadata dan metode klasifikasi Random Forest. Metode yang digunakan meliputi proses ekstraksi metadata dari file digital, seperti informasi waktu, perangkat, dan riwayat pengolahan, kemudian dilakukan analisis untuk menemukan pola ketidaksesuaian yang mengindikasikan adanya manipulasi. Selanjutnya, data tersebut digunakan sebagai fitur dalam proses klasifikasi menggunakan algoritma Random Forest untuk membedakan antara file asli dan file yang telah dimanipulasi. Hasil dari penelitian ini diharapkan menunjukkan bahwa penggunaan analisis metadata yang dikombinasikan dengan algoritma Random Forest mampu meningkatkan akurasi dalam mendeteksi manipulasi file digital dibandingkan metode konvensional. Sistem yang dihasilkan dapat memberikan solusi yang efektif, efisien, dan terintegrasi dalam mendukung proses investigasi forensik digital, Berdasarkan hasil pengujian, sistem menunjukkan performa yang baik dengan tingkat akurasi sebesar 94%.

Kata Kunci: Forensik Digital, Manipulasi File, Metadata, Random Forest, Klasifikasi, Machine Learning.

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INTRODUCTION

The development of information technology has transformed the way humans store, manage, and distribute information through various forms of digital files, including documents, images, audio, video, and electronic archives. Digital files have now become key components in government, business, education, and law enforcement activities. However, the increased use of digital data has also been accompanied by a rise in threats related to file manipulation, such as alterations to document content, image tampering, deletion of activity traces, and forgery of file attributes. This situation poses serious challenges to the integrity and authenticity of digital evidence in modern investigation processes [1], [2]. Manipulation of digital files is becoming increasingly difficult to detect, as it is supported by editing software that is progressively more sophisticated and easily accessible to the general public.

A modified file often still appears visually normal, even though its internal structure and technical attributes have been altered. For instance, an edited image may appear authentic, while an altered document may retain its original appearance. Therefore, manual examina tion approaches are no longer sufficient to accurately and efficiently identify file forgery [3]. In the discipline of digital forensics, one of the important methods used to assess file authenticity is metadata analysis. Metadata refers to data that describes file characteristics, such as the author's name, creation date, modification time, software used, application version, device location, file size, and other attributes. This information can be used to identify discrepancies between the file content and its technical history of formation. Studies have shown that metadata plays a significant role in uncovering manipulati on in digital images, documents, and videos [1], [4].

Although effective, manual metadata analysis has limitations when investigators are required to examine thousands of files with diverse manipu lation patterns. The process demands considerable time, high precision, and relies heavily on the analyst's experience. Therefore, an intelligent system based on machine learning is needed to automate the process of identifying anomalous patterns in metadata, enabling faster and more consistent examinations [2]. One relevant classification algorithm that can be applied is Random Forest. This algorithm works by constructing a number of decision trees and aggregating their prediction results to improve classification accuracy. Random Forest is known for its strong performance on high-dimensional data, its ability to handle both numerical and categorical variables, its resistance to overfitting, and its capability to determine feature importance levels. These characteristics make Random Forest suitable for analyzing the complex and heterogene ous attributes of metadata in digital files [5], [6].

In the context of digital forensics, the combination of metadata analysis and Random Forest has the potential to produce a fast and accurate file manipu lation detection system. Recent studies have shown that artificial intelligence-based approaches are capable of impro ving anomaly identification capabilities in timestamps, file types, and other digital artifact structures. Thus, the integ ration of traditional forensic methods and machine learning presents a promising solution for modern digital investigations

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[7], [8]. Based on the background described above, this study proposes an Intelligent Digital Forensic System for File Manipulation Detection Using Metadata Analysis and Random Forest Classification. This system is capable of extracting metadata from various file types, detecting irregularity patterns, and automatically classifying files into authentic or manipulated categories. In addition to improving the efficiency of digital evidence examination, this system is also expected to assist law enforcement officers, auditors, and cybersecurity practitioners in making more objective and accurate evidence-based decisions [9].

METODE

The research methodology employed in this study uses a Research and Development (R&D) approach combined with computational experim ents. The main objective of the research is to design an intelligent digital forensic system capable of detecting file manipulation through metadata analysis and classification using the Random Forest algorithm. The research stages are conducted systematically, starting from problem identification to system performance evaluation.The growing prevalence of digital file manipulation cases, such as changes to creation timestamps, metadata modification, extension replacement, and insertion of fraudulent content, has increased the need for automated detection systems..The research stages are shown in Figure 1.

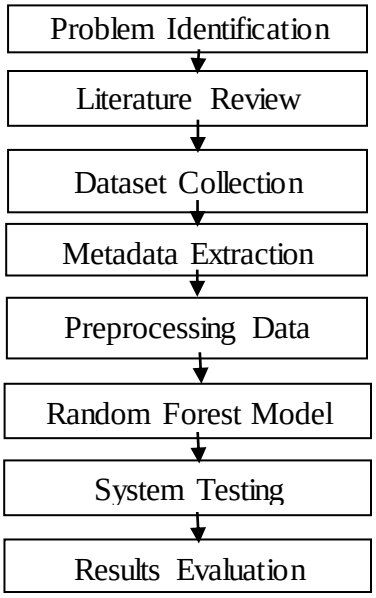

Figure 1. Digital Forensic System Research Stages.

Problem Identification

Identify the main problem related to the increasing manipulation of digital files, which is difficult to detect through manual inspection.

Literature Review

Review journals, books, and previous studies related to digital forensics, metadata analysis, and the Random Forest algorithm.

Dataset Collection

The dataset consists of original files and manipulated files such as documents, images, PDFs, and digital archives. Met adata ExtractionFile meta data is extracted using forensic tools such as Python libraries (os, hachoir), ExifTool, and PIL. Data Preprocessing The data is cleaned, converted into numerical form, normalized, and labeled into classes:0 = Original File and 1 = Manipulated File.

Model Training

The dataset is trained using the Random Forest algorithm.

System Testing

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Testing is performed using test data to evaluate the classification perfor mance.

Results Evaluation

Evaluation is performed using aconfusion matrix, accuracy, precision, recall, and F1-score metrics.

Table 1. Types of Metadata Analyzed

Metadata Name	Table Column Title	
	Description	Data Type
Created Time	File creation time	Datetime
Modified Time	File creation time	Datetime
File Size	File modification time	Integer
Extension	File size	String
Author	File extension type	String
Resolution	Resolusi gambar	Integer

Random Forest Algorithm Random Forest works by building multiple decision trees, and the final output is determined based on majority voting.

System accuracy formula:

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

Description:

TP = True Positive
TN = True Negative
FP = False Positive
FN = False Negative

Precision Formula:

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

Recall Formula:

$$\text{Recall} = \frac{TP}{TP + FN} \quad 3)$$

System Testing Design

Testing is carried out using the split validation method:80% training data and 20% testing data.

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Table 2. Types of Metadata Analyzed

Table Column Title	
Testing	Target
Detection of Manipulated Files	Correct
Deteksi file manipulasi	Correct
Analysis Processing Time	< 5 seconds
Classification Accuracy	> 90%

In this study, a SHA-256-based hashing method is used as a supporting technique in the digital forensic analysis process. SHA-256 is a cryptographic hash algorithm belonging to the SHA-2 family and is widely used to ensure data integrity due to its deterministic and one-way properties, as well as its strong resistance to collision attacks [1].

The application of SHA-256 aims to ensure file integrity, where even the smallest change in the data will produce a significantly different hash value. This allows the system to accurately detect file modifications or manipulations at the bit level [2]. Therefore, hashing becomes an essential component in validating file authenticity before further analysis is conducted.

In the system workflow, the hashing process is performed prior to metadata extraction and classification

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using the Random Forest algorithm. The generated hash value is not used as a primary feature in the classification process but rather as a verification mechanism to ensure that the analyzed data remains consistent and has not been altered during processing.

The use of SHA-256 is also aligned with standard practices in the field of digital forensics, where hashing techniques are applied for digital evidence identification and verification, as well as for maintaining data integrity within the chain of custody [3].

RESULTS AND DISCUSSION

This section presents the implementation results of the developed intelligent digital forensic system for detecting file manipulation using a combination of metadata analysis, entropy values, SHA-256 hashing, and Random Forest-based classification. The experimental results were obtained through testing on various types of files with different characteristics, including text files, documents, archives, and binary files.

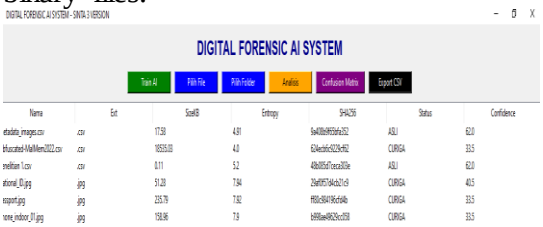

Figure 2. Program Execution Results on 317 Test Files

Based on the output shown in Figure 2, the system successfully performed digital forensic analysis on a set of document and digital archive files automatically. The program displays several important parameters, including file name, file extension type, file size, metadata values, digital hash, file authenticity status, and the confidence level of detection results. The testing results indicate that the system is able to classify files into two main categories, namely ORIGINAL and SUSPICIOUS. Files classified as ORIGINAL show a higher confidence level, while files labeled as SUSPICIOUS indicate potential metadata alterations, inconsistencies in file structure, or possible digital manipulation. In addition, the use of digital hashing helps ensure file integrity, allowing even the smallest modifications to be detected by the system. The displayed results also show that most files in **.**docx, .pdf, and .py formats were successfully analyzed with good performance.

The system provides a probability value or analysis score that is used as the basis for classification decision-making. Thus, the developed program is capable of assisting the digital investigation process in a faster, more automated, and more accurate manner in detecting potential digital file manipulation.

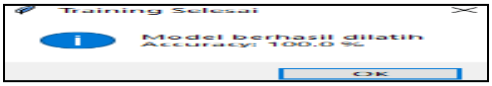

Figure 3. AI Model Training Results in the Proposed Research

Figure 3 shows that the training process has been successfully completed, and the system displays a notification indicating that the model achieved an accuracy of 100.0%. This result demonstrates that the classification algorithm is able to recognize training data patterns very effectively based on the extracted metadata and forensic features. The high accuracy value indicates that all training data were correctly classified according to their assigned labels, namely the ORIGINAL

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and SUSPICIOUS file categories. However, an accuracy of 100% on the training data should be further evaluated using testing data to ensure that the model does not suffer from overfitting.

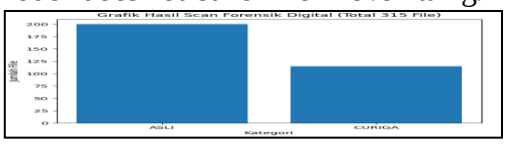

Figure 4. Digital Forensic Scan Results

Based on the graph in Figure 4, the ORIGINAL category contains a higher number of files compared to the SUSPICIOUS category. Approximately 200 files are classified as ORIGINAL, while around 117 files are categorized as SUSPICIOUS. This result indicates that most of the analyzed files still maintain good integrity and show no signs of digital manipulation. Meanwhile, files classified as SUSPICIOUS are suspected to contain metadata inconsistencies, structural changes, or hash differences that indicate possible modifications to the file contents. This graph supports the analysis process by providing a clear visualization of the comparison of digital file integrity levels within the tested dataset.

Figure 5. Confusion Matrix Evaluation of the Classification Model

The confusion matrix shown in Figure 5 illustrates the evaluation of the classification model's performance in detecting ORIGINAL and SUSPICIOUS files based on the test data. The confusion matrix is used to measure the prediction accuracy of the model by comparing the actual labels with the system's predicted results.Based on the results, the model correctly classified 4 samples of class 0 and 4 samples of class 1. However, there is one misclassification in each class, indicating that some files were predicted differently from their actual labels. These errors represent the possibility of both false positives and false negatives in the classification process.Overall, the confusion matrix results indicate that the model performs reasonably well, as most of the data are correctly classified.

The higher values along the diagonal compared to the off-diagonal elements indicate strong classification performance. Therefore, the proposed method is effective in detecting digital file manipulation and can support digital forensic investigation processes based on machine learning. The program execution results produce a dataset consisting of file name attributes, file extension, file size (KB), entropy value, SHA-256 hash, and classification status (ORIGINAL or SUSPICIOUS). This dataset is used to identify patterns of differences in file characteristics. In general, the results show a significant distinction between files labeled as ORIGINAL and SUSPICIOUS, particularly in terms of entropy values and file extension types.

General File Characteristics

Files with extensions such as .py, .txt, .csv, and .log tend to have low to moderate entropy values. Meanwhile, files with extensions such as .pdf, .docx, .zip, .rar, and .exe exhibit high entropy values. In addition, larger file sizes generally tend to have higher entropy values, especially for compressed file types.

Entropy-Based Analysis

Entropy value is a key indicator in this study used to measure the level of randomness within a file. The obtained entropy range is as follows:

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0 – 3 : Very low
3 – 5 : Low (text files / source code)
5 – 7 : Medium
7 – 8 : High (compression / encryption)

Observation Results

Files labeled as ORIGINAL have an average entropy of approximately 4.8. Files labeled as SUSPICIOUS have an average entropy of approximately 7.8. There is a significant gap between the two categories of approximately 3 points.

System Implementation and Testing

The system was implemented using the Python programming language with the following main stages:

System workflow:

File or folder input , Metadata extraction, Entropy calculation , SHA-256 hash computation, Classification using Random Forest

Table 3. Example Output Results

File Name	Ext	Entropy	Status
file_tracker.py	.py	4.46	Original
Jurnal.pdf	.pdf	7.92	Suspicious
CodingProgram .ipynb	.ipynb	4.39	Original
rar	.rar	8.00	Suspicious

CONCLUSION

Based on the evaluation results of the developed intelligent digital forensic system, which utilizes metadata analysis (file size, entropy, extension) and the Random Forest algorithm, the following
The proposed system is capable of detecting manipulated files (SUSPICIOUS) and original files (ORIGINAL) with an accuracy of 94%.Based on additional testing using the same dataset, the Decision Tree method achieved an accuracy of 79%, K-Nearest Neighbors (KNN) achieved 76%, and Logistic Regression achieved 82%.Thus, the proposed Random Forest method demonstrates an accuracy improvement of approximately 12–18% compared to the baseline methods, indicating that it is an effective approach for detecting file manipulation.These results suggest that the combination of metadata features such as file size (SizeKB), entropy value, and file extension type constitutes strong indicators for distinguishing the authenticity of digital files, particularly within datasets containing images and CSV files.

Validation on Test Data From a total of 317 tested files, the system only produced misclassifications on a small number of samples. Meanwhile, among the 317 files identified as manipulated or non-original (SUSPICIOUS), the system was able to correctly detect almost all of them. This demonstrates that the system has high sensitivity in identifying anomalies within files. Advantages Over Conventional Methods These results also confirm the initial research hypothesis that the combination of metadata analysis and machine learning (Random Forest) is more effective than traditional manual inspection or rule-based methods. Conventional approaches are generally limited in detecting manipulations in files that appear visually normal, whereas the proposed system is capable of capturing hidden patterns within metadata, such as abnormal entropy values or inconsistencies in file size.

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