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Using Artificial Intelligence in the Forensic Science for the Analysis of Microparticles: A Systematic Review

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Abstract: Technological advances in different industries have a tremendous impact on various aspects of human activities, including criminal activities. More complex and well-organized crimes often leave no room for the traditional analytical techniques, and require analysis of the tiniest pieces of the evidence – microobjects. Detection and study of these pieces of information obviously are time-consuming and demands more sophisticated equipment. This systematic review estimated the current status of the application of artificial intelligence systems in analysis of a specific type of the forensic evidence such as microparticles. Analysis of 27 articles extracted according to the PRISMA guidelines confirms the rationale behind using the AI for forensic investigation mainly to achieved automation of the most laborious aspects of the evidence investigation: image processing, matching a piece of the evidence to the created database and identification of the evidence. The AI technologies assist in identification of the victim or suspect personality thorough AI-assisted analysis of the DNA and RNA from the blood, saliva, urine; time of death and place of death via AI-assisted investigation of soil and fabric traces, and specific microbiome; tracking abusive substances; identification the cause of fires. The AI mainly serves as assistant to the convenient forensic methods, such as microscopy and spectroscopy, to process a big amount of data generated by the traditional techniques or to enhance the outcomes of the traditional techniques, such as image processing. The types of the AL the most widely used in the forensic science are machine learning algorithm.

Keywords: Forensic Science, Criminalistics, Evidence, Microparticles, Artificial Intelligence, Analytical Methods

Introduction

Artificial intelligence is a tool that has already forced the humanity to rethink the way we use and process information, perform routine and professional tasks, and form our perception of the world.

The term “artificial intelligence” first appeared in 1956. However 68 years later, despite the launch of Google Translate and ChatGPT, AI is still at the root of its wide practical implementation. Only recently, we as a society have started witnessing a rise in the adoption of AI in multiple fields, including criminology and forensic science, mainly because the very phenomenon of AI is complex and needs deep understanding.

According to Britannica, Artificial intelligence (AI) is a digital computer or computer-controlled robot able to perform tasks commonly associated with intelligent beings, namely learning, reasoning, problem solving, etc.

The Artificial Intelligence is broadly divided into narrow or weak AI and general or strong AI. General AI is considered to be machines that “think”, more precisely, mimic the cognitive processes attributed to human intelligence. On the contrast, narrow AI means systems purposely built for performing specific, precise, and well-defined tasks. In other words, narrow AI performs a highly specific, predefined task or set of tasks, is limited to these tasks only, cannot generalize knowledge, and lacks versatility.

Narrow AI is further divided into two types: rule-based AI and data-based AI. The rule-base AI operates on a set of predefined rules and logic, and follows these rules meticulously to perform the tasks, without the ability to learn or adapt beyond these rules. The data-based AI, on the contrast, learns from lots of examples and data to become skilled at the specific tasks, is able to recognize patterns and make decisions based on the pool of data that it has learned.

At present, narrow AI is revolutionizing various industries by providing precise and efficient solutions that are tailored to address specific challenges. To put it into the context, examples of the practical implementation of the narrow AI in daily routine include voice recognition systems such as Siri and Alexa (Latif et al., 2023; Tyagi et al., 2023); recommendation algorithms, e.g. those used by Netflix and Spotify (Necula & Păvăloaia, 2023); Chabot’s (Shahzad et al., 2024); and language translation services such as Google Translate (Yuxiu, 2024), etc.

Examples of the practical implementation in the specific, scientific, areas includes specialized image recognition software, e.g. those used in medical field for the purposes of the medical imaging analysis (Liu et al., 2020); AI-driven MRI, and X-ray systems, e.g. those used for early diagnosis of the cancer, fractures, or neurological disorders (Cè et al., 2023; Khalifa & Albadawy, 2024; Oren et al., 2020); fraud detection systems, e.g. those used by banks to detect unusual transaction patterns and anomalies; energy management systems, e.g. those used to optimize energy consumption in real-time and to save and reduce emissions (Lawal et al., 2021; Nazeer et al., 2023); tutoring systems adapted to individual learning styles and needs (Banawan et al., 2023); cybersecurity systems that learn from the attack patterns to prevent future attacks (Kaur et al., 2023), etc.

Brief scanning of the literature shows that AI is, steadily but gradually, paving its way into criminalistics and forensic science to assist in crime solving (Tynan, 2024). Possible ways for AI to impact the interpretation of evidence are fingerprint analysis by automating the process of matching fingerprints to known databases; DNA analysis by automating the processes of creating DNA profiles (Chen & Tseng, 2023; Sessa et al., 2024); digital evidence analysis to uncover evidence of cybercrime or aid in investigations involving electronic devices (Jada & Mayayise, 2024); facial recognition techniques to identify individuals in images and videos (Yu & Pei, 2021); voice analysis to identify the speaker; ballistics analysis by matching bullets and shell casings to specific firearms; autopsy techniques (Kumar & Vats, 2024) etc.

Interestingly, the same decade the AI first appeared a new branch of criminalistics – microtrasology (microtrace evidence analysis) – also started developing out of the traditional trasology. The first relative term “microtraces” appeared even earlier, in 1951. Similar to AI, 73 years later, microtrasology is far away of its full-potential implementation. The main reason can lay in deep dependence of the AI technology and microtrace evidence analysis on the technological advancements. In terms of AI, its development heavily rely on novel computer technologies, and, in terms of microtrasology, its advancement strongly depends on microscopy and spectroscopy industries.

Extremely valuable and specific carriers of forensically significant information are provided by the main object of microtrasology – microobject (Kowalcze & Mirek, 2022). Wide spread of Internet and public access to vast amounts of information, whether useful or detrimental, provided means to commit more carefully planned and complex crimes, and methods and equipment to leave as less visible evidences as possible. Luckily, invisible, micro, evidences are always left at the crime scene.

The very term “microobject” gives birth to the heated debates in terms of its dimensions and what objects can be regarded as “micro” and what objects cannot. The aim of this study does not involve detailed covering this issue. Therefore, briefly, the microobjects are microtraces, microparticles and microquantities of a substance and are generally invisible or very slightly visible to the naked eye, and their study requires special equipment and trained personnel. The most common microobjects collected at the crime scene are particles of fibers and plastics, microquantities of the abusive or explosive substances, fragments of paint and protective coatings, metal particles separated from vehicles or instruments, shattered glass fragments, pieces of soil and dirt, individual hairs and fragments of the epidermis, etc.

The forensic work with microobjects involves the steps of detection, immobilization and collection of the microobjects for the subsequent investigation and examination.

Generally, before searching for microobjects, a forensic specialist determines the type of possible microobjects that separated from the criminal and his instruments during the commission of the crime, and expected location of the microobjects. The efficiency of the search is provided by the use of special tools such as forensic magnifying glasses, including illuminated magnifying glasses; portable microscopes; lighting devices (lanterns); portable sources of UV radiation; electron-optical converters; portable lasers; magnetic brushes and permanent magnets; dielectric rods; detectors of hidden traces. The smaller the object, the brighter the light it needs to be illuminated for being notices by the expert’s eye. UV illuminators are most effectively used when searching for microobjects of biological origin such as sperm, saliva, blood, as well as trace amounts of fuels and lubricants.

Immobilization of the microobjects is carried out in the same ways as for most macroobjects: description in the protocol of the investigative action; drawing up large-scale plans, diagrams, drawings, highlighting with arrows or dotted lines the places where microobjects were detected and applying the corresponding symbols; photographic recording, which serves, as a rule, to fix the location of microobjects. In addition, technical methods of immobilization include fixing microparticles to carrier objects.

Collection methods include removal the microobjects with a carrier object, and transferring the microobject to the appropriate immobilization material. The means for removing the microobjects are micro-vacuum cleaners (dust collectors); adhesive tapes (except for adhesive tape); permanent and electromagnets; electrostatic sticks; capillaries and pipettes; tweezers; scalpels (including special eye scalpels); dissecting needles; dental probes; instruments for eye surgeries; gauze, etc.

Overall, brief description of the steps of detection, immobilization and collection of the microobjects seems to leave no room for the AI application. In work with the microobjects, what truly gives a room for AI use is the step of the microobject analysis. The analysis of the microobjects provides

valuable information about a crime scene, victim and criminal, as well as particular links between them, through the properties of the microobjects:

- morphology, i.e. spatial external and internal structure of the microobject;
- composition, structure and other properties of the substance of the microobject;
- the state (usually changed from the original) of the substance of the microobject on the carrier object;
- location of the microobject on the carrier object;
- relative placement of dissimilar microobjects on the surface of the carrier object.

As we discuss above, microobjects are generally invisible or very slightly visible to the naked eye, and their study requires special equipment. The techniques to analyze the microparticles include many sensitive non-destructive analytical methods, that allow gathering information about a microobject without physical destruction of its structure. These techniques are broadly microscopy and spectroscopy. The most common methods are optical microscopy, scanning electron microscopy, microspectrophotometry, infrared spectroscopy, and Raman spectroscopy examinations, to name a few. Therefore, we assume that the AI could find its application in the forensic science in the microscopy and spectroscopy examinations of the microtraces, microparticles and microquantities of a substance.

Research Problem

The advancement in science and technologies is a double-edged sword that brings simplicity and security to everyday life, but may be also used by criminals to simplify and secure their unlawful activities. Therefore, we as a society need new technologies for crime scene investigations, particularly for analysis of the microevidences, to be able to solve the increasingly complex and well-organized crimes.

Currently, the main difficulty in forensic processing of the microobjects is their tiny sizes and amounts, which poses several obstacles to the experts, namely efficient detection of the microobjects, analysis of the microobjects in the field condition (not only in the lab with heavy equipment), and quick establishment of the links between a crime scene, victim and suspected individual. Moreover, there exist a mind-blowing number of the microobjects types that requires different approaches for their processing. For example, today, a number of abusive and explosive substances is huge, went beyond all possible boundaries and is still increasing, which poses a challenge for efficient detection and identification of the microquantities of such substances. These challenges could be effectively faced with the AI application.

Since both AI technology and microtratology are relatively new fields and their wide practical adoption has started only recently, it is worth studying the current achievements in their combinations in terms of the forensic investigation of the microobjects and their impact on the efficiency of the crime solving.

Research Focus

The research is focused on the interdisciplinary approach to the microobject detection, immobilization, collection, and examination using the specific forensic methods and current achievements in AI technology. Specifically, the research is focused on the AI impact on the microobject investigation without a deep dive into the technical details of the AI systems operation.

Research Aim and Research Questions

In this systematic review we are focusing on the application of the AI technologies in the forensic investigation of the microobjects. More precisely, we are interested in the overall current experience in the adoption of the AI technologies in the forensic investigation of the microobjects, at what steps of the microobjects processing the AI is applied, what types of AI are applied and what types of manual or

computational operation the AI can quicken and simplify, and what types of the microobjects are currently analyzed with the AI. Additionally, we are interested in the possibility of the AI application for the microobjects analysis directly in the field conditions.

Materials and Methods

This systematic review was conducted in compliance with the PRISMA guidelines, to evaluate the current status of the AI application in the forensic analysis of the microobjects.

For the literature search, the following free databases were used: Directory of Open Access Journals, Semantic Scholar, Science Open, and Google Scholar.

The following keywords regarding AI were used: Artificial Intelligence, Machine Learning, Deep Learning, and Neural Network. The following keywords regarding forensic science were used: Forensic, Criminalistics, Police Work, Microobject, Microtrace. Additional filters were: field – law, publication data 2019-2024, language – English. The following collocations gave the major results: Artificial Intelligence AND Forensic (258), AI AND Forensic (154), Machine Learning AND Forensic (319), Artificial Intelligence AND Criminalistics (6), Artificial Intelligence AND Police Work (31), Artificial Intelligence AND Microobject (1), Artificial Intelligence AND Microtrace (1), and Artificial Intelligence AND Microparticle (1).

The inclusion criteria were the following:

- Researches primarily focused on the use AI or ML technologies in the forensic investigation of the microobjects or sources of the microobjects;
- Researches that do not mention microobjects directly;
- Researches published in journals;
- Researches published in English;
- Researches that included quantitative studies and mixed studies;
- Researches the full texts of which are available
- Researches published since January, 1, 2019.

Since the research area is extremely specific the exclusion criteria applied were following:

- Researches published not in English;
- Reviews of different types, proceedings, books or their chapters, magazines, blogs, news;
- Researches the results of which do not mention application or potential application in the forensic science;
- Researches published before January, 1, 2019.

On the identification step, 771 articles were extracted based on the key words used. On the screening step, 254 articles were selected based on their titles, and 517 articles were excluded after reading their abstracts. Next, 201 articles were selected for studying the full texts, and 23 articles were excluded due to absence of their full texts in public domain. Next, full texts of 178 articles were evaluated for eligibility, and 41 were excluded due to their nature (reviews), and 110 articles were excluded due to no connection to the forensic or criminalistics. In total, only 27 articles were extracted for this review.

Results

Out of 771 articles, we extracted only 27 that somehow covered microobjects or the sources of the microobjects.

Brief summary of 27 extracted articles is provided in Table 1.

Table 1*The AI Applications Used in each Included Study and the Main Findings*

| First author and year | Article title | Type of Object | AI Type and Application |
|------------------------------|---|---|--|
| Aljannahi et al. (2022) | Forensic Analysis of Textile Synthetic Fibers Using a FT-IR Spectroscopy Approach | Fibers | The authors used Fourier transform infrared spectroscopy coupled with several machine learning techniques to enable classification of the fabric samples |
| Chen et al. (2021) | Identification of various food residuals on denim based on hyperspectral imaging system and combination optimal strategy | Traces of food and beverages | The authors combined hyperspectral reflectance imaging techniques with random forest algorithms and support vector machine algorithms to accurately describe the data, classify them into corresponding categories, and summarize them |
| Li et al. (2021) | Validation Studies of the Paradna® Intelligence System with Artificial Evidence Items | Traces of blood, saliva, and semen containing DNA | The authors studied a possibility of the practical implementation of ParaDNA® Intelligence Test System for rapid DNA profiling |
| Heaton et al. (2023) | Differentiation of Body Fluid Stains Using a Portable, Low-Cost Ion Mobility Spectrometry Device—A Pilot Study | Traces of body fluids | The authors evaluated portable ion mobility spectrometer integrated with machine learning algorithm for detection, identification, and discrimination of the body fluid traces |
| Thong et al. (2021) | Artificial neural network, predictor variables and sensitivity threshold for DNA methylation-based age prediction using blood samples | Blood | The authors evaluated Artificial Neural Network for identification of the age |
| Jin et al. (2022) | Systematic Selection of Age-Associated mRNA Markers and the Development of Predicted Models for Forensic Age Inference by Three Machine Learning Methods | Blood | The researchers investigated the contribution of the random forest algorithm in prediction of the age via RNA analysis |
| Wang et al. (2022b) | Forensic age estimation from human blood using age-related microRNAs and circular RNAs markers | Blood | The authors applied machine learning algorithm to predict the age |
| Hamadeh et al. (2022) | Machine Learning Analysis for Quantitative Discrimination of Dried Blood Droplets | Dry blood droplets | The authors studied samples of the dried blood droplets and their patterns with statistical ML algorithm |
| Pałka et al. (2021) | Hyperspectral Classification of Blood-Like Substances Using Machine Learning Methods Combined with Genetic Algorithms in Transductive and Inductive Scenarios | Blood | The researches investigated a new approach of using Genetic Algorithm based ML model for classification of the blood samples |

| | | | |
|-----------------------------|--|---|--|
| Govender et al. (2022) | The application of machine learning to predict genetic relatedness using human mtDNA hypervariable region I sequences | Blood | In their study, the authors used the AI-assisted approach to identify the genetic relatedness |
| Wang et al. (2022a) | Circular RNA as a Potential Biomarker for Forensic Age Prediction | Blood | The researchers used machine learning algorithm to identify age-related circRNAs out of 40,000 and develop age-prediction model |
| Pérez-Sánchez et al. (2021) | An Indexing Algorithm Based on Clustering of Minutia Cylinder Codes for Fast Latent Fingerprint Identification | Fingerprints | In their study, the authors proposed an algorithm for identification of the latent fingerprints based on minutia cylinder descriptor |
| Deshpande et al. (2020) | End-to-End Automated Latent Fingerprint Identification With Improved DCNN-FFT Enhancement | Fingerprints | The authors proposed a method for AI-assisted improvement of the latent fingerprint images |
| Spanier et al. (2024) | Enhancing Fingerprint Forensics: A Comprehensive Study of Gender Classification Based on Advanced Data-Centric AI Approaches and Multi-Database Analysis | Fingerprints | In the paper, the AI application for the extraction of the specific information about nationality, gender, and age of the person from their fingerprints |
| Maione et al. (2021) | A Cluster Analysis Methodology for the Categorization of Soil Samples for Forensic Sciences Based on Elemental Fingerprint | Traces of soil and dirt | The authors employed a Correlation-Based Feature Selection algorithm and classification model to study the elemental composition of the soil and identification of the soil traces |
| Akmeemana et al. (2022) | Convolutional Neural Network Applications in Fire Debris Classification | Traces of ignitable liquids | The authors applied convolutional neural networks for the classification of the ignitable liquids into ignitable and non-ignitable |
| Huang et al. (2022) | The application of wavelet transform of Raman spectra to facilitate transfer learning for gasoline detection and classification | Traces of gasoline | The authors described the hybrid of Raman spectroscopy and convolutional neural network for gasoline identification in the field conditions |
| Yankova et al. (2024) | Identification and Discrimination of Petrol Sources by Nuclear Magnetic Resonance Spectroscopy and Machine Learning in Fire Debris Analysis | Traces of petrol | The authors developed a combined NMR-ML approach to identify and classify petrol brands |
| Burlacu et al. (2023) | Harnessing Deep Convolutional Neural Networks Detecting Synthetic Cannabinoids: A Hybrid Learning Strategy for Handling Class Imbalances in Limited Datasets | Traces of designer drugs, particularly synthetic cannabinoids | The authors developed a deep convolutional neural network framework based on two platforms for detection and discrimination of the drugs |

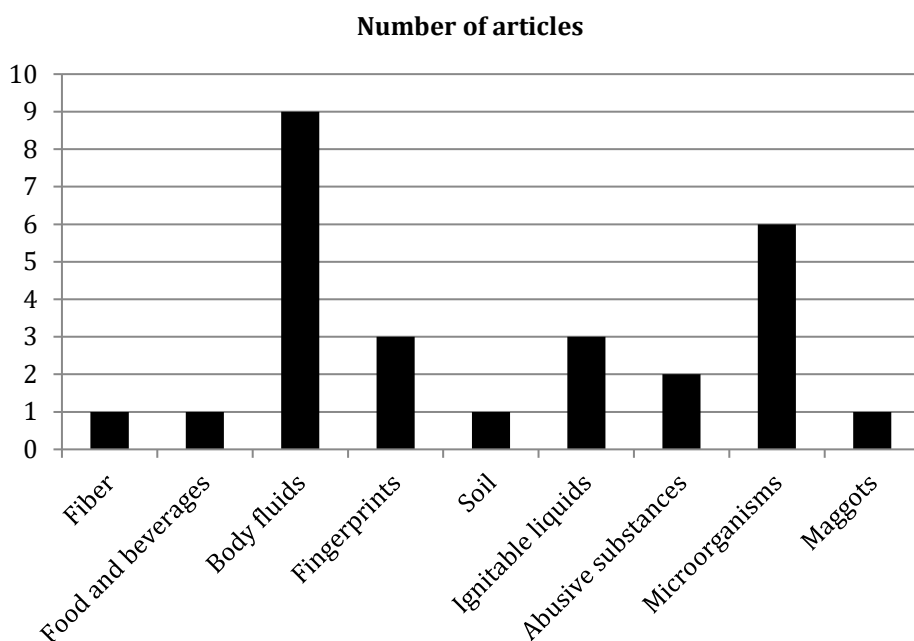
| | | | |
|----------------------------|--|----------------------------|---|
| Grijalva et al. (2024) | Analysis of major cannabinoids using Raman microscopy, density functional theory, chemometrics and a novel artificial intelligence approach | Traces of cannabinoids | The authors combined Raman microscopy method with convolutional neural network for identification and classification of the cannabinoids |
| Yu et al. (2022) | An improved automated diatom detection method based on YOLOv5 framework and its preliminary study for taxonomy recognition in the forensic diatom test | Diatoms | The authors proposed an application of YOLOv5-based AI technology for the automatic detection and recognition of the genera of the specific microorganisms called diatoms |
| Bhattacharya et al. (2022) | Supervised Machine Learning Enables Geospatial Microbial Provenance | Microbial fingerprints | The authors used supervised machine learning for examination of 4305 microbial fingerprints in order to determine the regional specificity |
| Cui et al. (2022) | Predicting the Postmortem Interval Based on Gravesoil Microbiome Data and a Random Forest Model | Bacterial fingerprints | The researchers used random forest algorithm to identify biomarkers using gravesoil bacterial communities for postmortem interval evaluation |
| Walker et al. (2019) | Identification of city specific important bacterial signature for the MetaSUB CAMDA challenge microbiome data | Microbial fingerprints | The authors used machine learning techniques to evaluate the specificity of the urban microbiome |
| Dmitrijs et al. (2022) | Bacterial Succession in Microbial Biofilm as a Potential Indicator for Postmortem Submersion Interval Estimation | Bacteria | The authors used random forest models for estimation of the postmortem submersion interval on the swine models |
| Apasrawirote et al. (2022) | Assessment of deep convolutional neural network models for species identification of forensically-important fly maggots based on images of posterior spiracles | Fly maggots | The researchers used convolutional neural networks for identification and classification of the fly maggots for the forensic entomology purposes |
| Lee & Lee (2023) | A Study of Mycobacterium tuberculosis Detection Using Different Neural Networks in Autopsy Specimens | Mycobacterium tuberculosis | The paper describes the use of the AI to enhance the tuberculosis diagnoses |

Source: Author's own development.

Grouping of the articles based on the specific microobject is presented in Figure 1.

Figure 1

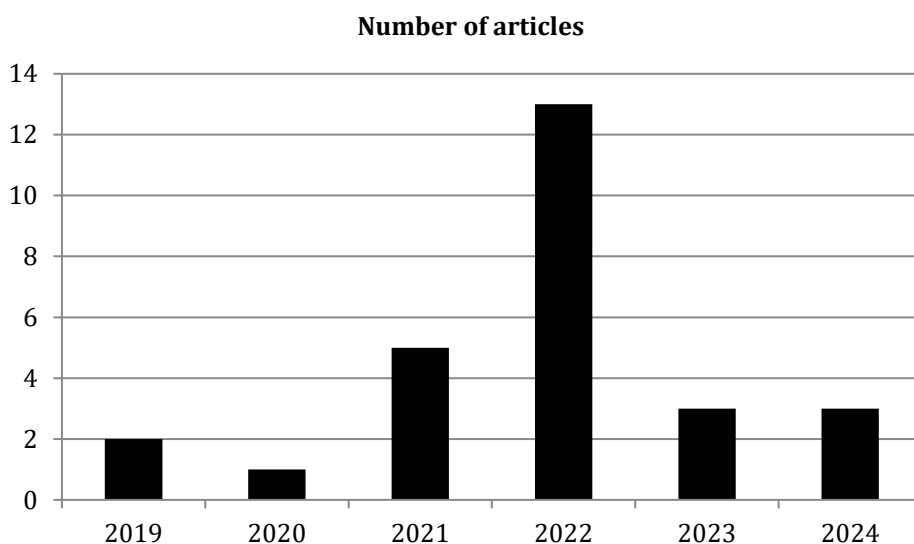
Groups of the Articles According to the Microobject Type



Interestingly, 2022 seems to be the most fruitful year when the strongest interest in investigation of the microobjects with the AI was observed (as can be seen in Figure 2).

Figure 2

Groups of the articles according to the year of publication:



Brief summary of the extracted articles shows that machine learning approach is the main type of the AI used in forensic science to investigate the traces that provides algorithms to enable computers to learn from previously uploaded data. Described machine learning methods included k-nearest neighbor algorithms, random forest algorithms, support vector machine algorithms, and artificial neural network.

Machine learning approach does not require writing a code to perform its tasks. Instead it is trained with a number of data and algorithms, usually a huge number of data, and eventually learns how to accomplish its task. One of the examples is a machine learning algorithm trained on the set of spectra in order to identify the substance from the provided spectra.

Discussion

This systematic review has detected several forensic areas that can potentially use the AI technologies to advance the crime solving procedure.

Food and Beverages

The earliest step of the forensic investigation that can utilize the AI technologies is the evidence detection step. Beverages, blood, semen, saliva, urine and sweat that could be a source of the microtraces and microquantities of the substance often are main form of the material evidence at the crime scene. Their analysis presents a major challenge, because the microtraces and microquantities of the substance are invisible or slightly visible to the naked eye and their amount is minor or trace.

Earlier the only tools to analyze the microobjects directly in the field conditions were destructive and detrimental chemical tests that still required laboratory equipment for further analysis. Nowadays, forensic experts are able to use non-contact, express field methods such as portable spectrometers, field light equipment, and computer vision for the evidence detection at the crime scene. However, further analysis still requires the laboratory conditions and use of more powerful microscopy and spectroscopy.

Chen et al. (2021), studied the traces of juice, fizzy drink, coffee, tea and milk on cotton fabrics of different colors with an overall goal to develop optimal classification method to recognize and classify various liquid stains. In terms of AI, the authors combined hyperspectral reflectance imaging techniques with random forest algorithms that accurately describe the data, classify them into corresponding categories, and summarize them, and support vector machine algorithms that classify the data. This combined method enabled detection of the liquid traces on the cloth, categorization of liquid, identification of the typed of the fabric and cloth item, and even the residue time, but only in the laboratory conditions and with sufficient amount of time. Moreover, the traces were simulated by soaking pieces of the fabric with the size of 4 cm×4 cm in the beverages. Therefore, the liquid traces cannot be strictly considered as the microobjects. However, the developers are optimistic and suppose that, eventually, the hybrid hyperspectral reflectance imaging and AI algorithms will be able to find the exact location of the liquid traces via scanning the entire fabric and classify the traces directly at the crime scene.

Thus, to study the traces of food and beverages, it is rational to combine analytical methods with those types of the AI that enables identification and classification of the traces for future use in creation of the dedicated databases.

Fibers

Concerning spatial material forensically valuable microobjects, Aljannah et al. (2022), investigated fiber traces and their classification. Generally, for the fiber analysis three main techniques are applied: ultraviolet-visible microspectrophotometry, polarized light microscopy, and Fourier-transform infrared spectroscopy, and the very fabric traces are sources of abundant information, e.g., color, composition, specific substituents, fracture patterns, etc., ultimately, leading to crime solution. In their article, authors went even further to couple Fourier-transform infrared spectroscopy with machine learning algorithm to classify 138 fabric samples with estimated accuracy of 97.1%.

Thus, similarly to the previous conclusion, to study the traces of fiber, it is rational to combine analytical methods with those types of the AI that enables identification and classification of the traces for future use in creation of the dedicated databases.

Body Fluids

Another potential field of the AI application is manipulation with DNA and information that it can provide about suspect individual or victim.

As we mentioned above, evidences such as biological and body fluids (blood, semen, saliva, urine and sweat) are the promising and extremely important in forensic investigation to narrow down the number of suspects and to identify the human personality or some traits. The information they bear helps experts to identify the individual using extracting DNA from the evidence item and matching it to the existent DNA database.

Li et al. (2019) tested ParaDNA® Intelligence Test System developed in UK for both laboratory and field DNA analysis directly from an evidence item (e.g., glass, plastic bottles, fabrics, cigarettes etc.) or from a swab. In terms of AI, the ParaDNA® Intelligence System has been built based on a search-and-compare approach that allow identification of the objects potentially containing DNA from a human subject or from a piece of the evidence in approximately 75 min. To test this system authors simulated two crime scenarios and confirmed the efficiency of the ParaDNA® in terms of generating useful DNA profiles for evidence samples. Similarly, Heaton et al. (2023) studied the potential of a portable device based on ion spectrometry and machine learning algorithm for investigation, importantly, identification and discrimination, of the body fluid traces.

Although these articles do not clearly stated that the study dealt with microobjects, blood, semen, saliva, urine and sweat often can be presented at the crime scene as microquantities of the substances, and the ParaDNA® detects DNA in neat 1 µL sample. Moreover, ParaDNA® has been already launched for the practical use in the forensic investigations.

Another study conducted by Thong et al. (2021), evaluated the efficacy of the artificial neural network in estimating the age of the individual from the traces of the body fluid recovered from a crime scene. The article provide detailed description of the artificial neural network work and DNA analysis, however it does not mention any microobjects as crime evidences. In addition, the minimal sample sizes sufficient for the analysis are not clear, the article is strongly focused on the technical details of the AI operation and functions, and only briefly describes the possible ways the development contributes to the forensic investigations. Similar approach was described by Wang et al. (2022a), and Jin et al. (2022), who used RNAs as a markers and a number of machine learning algorithms for prediction of the age of the human samples at the crime scene. Random forest model was found to be particularly useful.

Pałka et al. (2021) and Govender et al. (2022) studied the possibilities of the classification and identification of the blood samples based on the genetic markers using and comparing different AI algorithm. One of the potential extremely useful application of the genetic approach in forensic science is identification of the victim's relatives.

Another method to obtain valuable information out of the blood is investigation of the patterns of the dried blood droplets, as Hamadeh et al. (2020) accomplished, for the purpose of body exhaustion level estimation. The developed method using logarithmic power spectrum, principal component analysis, and linear discriminant analysis was able to achieve 95% accuracy in the exhaustion level prediction.

Thus, the blood as whole is a valuable source of the forensic information, but DNA and RNA are of the particular interest. Summarizing the describes article, the AI can be effectively used for the identification of different genetic markers to identify the human personality, relatedness, age, nationality, sex, and body condition, in combination with DNA and RNA processing methods.

Fingerprints

Another example of the microobjects can be fingerprints. However arguable it may be, in some cases fingerprints and its fragments can be invisible or slightly visible to the naked eye, therefore, can be considered as microtraces.

The work of Pérez-Sánchez et al. (2021), covered the application of AI in the identification of the latent fingerprints. The main obstacle in the fingerprint identification is necessity to match a fingerprint

to the items of the large database that is expensive, time-consuming and requires good computational resources. The issue with the latent fingerprints is that they often provide a bad quality image and only partial information about the fingerprint. Therefore, identification of such samples is challenging and prone to numerous errors. Thus, Pérez-Sánchez et al. (2021) presented a clustering-based indexing algorithm built upon minutiae-based descriptor specifically designed to simplify the identification of the fingerprints that are latent. The same issue was studied by Deshpande et al. (2020), who investigated the possibilities of the automated deep convolutional neural network in enhancement of the fingerprint images of poor quality. The authors claimed to validate their algorithm on 1.1 M of the samples and achieve adequate results that can have huge contribution in more accurate and precise identification of the victim or suspected individual, even in cases of bad-quality evidences. However, it is not clear whether the algorithm has been practically implemented, or anywhere near to the practical implementation.

Completely different approach in fingerprint analysis was demonstrated by Spanier et al. (2024), who used the convolutional neural network, specifically VGG type, for extraction the information from the fingerprints such as nationality, age, and sex, which can significantly contribute in the human being identification. Depending of the fingerprint image quality, the researchers achieved the identification accuracy of 70-95%.

Thus, concerning the fingerprint analysis, the AI is of particular importance for the quality enhancement of the fingerprint images, especially latent or partially damaged fingerprints, as well as for extracting specific personal information, such as nationality, age, and sex. If developed, this method could conquer with the DNA and RNA processing techniques.

Soil

Similarly to the fingerprints, microparticles of the soil and dirt are sources of valuable forensic information; their analysis can assist in linking victims, suspects, and crime scenes with each other, mainly due to their property to being transferred from the ground to a large number of objects such as clothe, shoes, hair, skin, nails, vehicle interior, tires, crime instruments, etc. Another reason is the complexity of elemental composition of the soils, wherein types and quantities of the elements strongly depend on climate of the particular region, types and composition of the local pollutions, human activities etc., thereby being a soilprint.

Maione et al. (2021) employed correlation-based feature selection algorithm together with inductively coupled plasma-mass spectrometry to analyze the soil samples. Based on this analysis the authors further developed classification system based on support vector algorithm for the future establishing the profiles of the soil samples collected at the crime site, matching them to the already analyzed groups of the samples, and linking these profiles to the subjects that might be involved in the crime. Basically, the model of Maione et al. (2021) works on combination of the data mining techniques, feature selection and classification techniques.

Again this article does not mention any microobjects, but the soil particles of tiny sized being present at the crime scene or being transferred from the crime scene can be considered as microparticles. Additionally, since mass spectrometry method is used the proposed model is highly likely appropriate for the microobject analysis.

Thus, again the most important attributes of the AI in soil traces investigation is its ability to classify the huge amount of data to enable future precise identification.

Ignitable Liquids

Next group of the objects that can be a source of various microtraces is fuels, e.g. gasoline that is one of the most commonly found ignitable liquids at the crime scene in cases of intentionally set fires; petrol, and ignitable liquids in general.

Huang et al. (2022) proposed and tested combination of the portable Raman spectrometer and convolutional neural network (deep learning algorithm GoogLeNet) on 17 types of liquids. The main advantage the authors stressed on is room for accelerated, accurate, and manual-free detection whether the sample contains gasoline or not in the field conditions contrast to the current forensic techniques that require sample preparation and time-consuming and laboratory implemented gas chromatography-mass spectrometry analysis. Yankova et al. (2024), in their work, offered a combination of the nuclear magnetic resonance spectroscopy with specifically developed machine learning model.

The similar, wider, approach was described by Akmeemana et al. (2022), who attempted to classify the samples of the ignitable liquids into two categories: ignitable and non-ignitable, and achieved sufficient results when identifying neat ignitable liquids, and controversial results when the liquids were analyzed on substrates.

Thus, concerning ignitable liquids, the AI can assist in detection of the traces and classification them into related categories directly at the crime scene. At least, the AI can be very useful in fast and field classification of the liquid traces in Yes/No mode.

Abusive Substances

Yet next group of the objects that can be a source of various microtraces is abusive substances, e.g. cannabis. The main issue with the designer drugs is their structural variability and the constant creation of new types. The impact the AI can have in this field stems from the extremely wide variety of the synthetic drugs and ceaseless evolution of the diversity of their structures that make traditional analytical methods inadequate and insufficient. In this context, deep convolutional neural networks possess a number of advantages due to their specific tailoring for image processing tasks. Thus, Burlacu et al. (2023), proposed a combination of multinomial classification model based on Fourier-transform infrared spectroscopy and convolutional neural network for detection and classification of various categories of the designer drugs, in their case synthetic cannabinoids. Another study with the similar objects and similar approach was conducted by Grijalva et al. (2024) and cannabinoid classification rate of 99 %.

Thus, similar to the ignitable liquids, the AI can assist in detection of the traces and classification of the abusive substances into related categories directly at the crime scene, at least in Yes/No mode.

Microorganisms

The last detected source of the microobjects is microbes. Microorganism is a general term for commonly known bacteria, viruses, and fungi. The prefix “micro” indicates their invisibility to the naked eye or inability to being observed without special equipment. Therefore, they are clearly considered as the microobjects in the forensic terminology. The major role of the microorganism can be assistance in estimation of the postmortem interval (the time between the discovery of the body and time of death), postmortem submersion interval (Dmitrijs et al., 2022), place of death, cause of drowning, etc. (He et al., 2022; Wang et al., 2022c). And, rapidly development of the microorganism analysis techniques is mainly due to the progress of microbial sampling and genome sequencing methods.

Yu et al. (2022) showed the potential of coupling microscopy techniques with artificial intelligence technologies to make observation and counting of diatoms, supportive evidence in the diagnosis of drowning, less laborious, time-consuming, and automatic. In his study, the AI aims at automatic detection and recognition of the diatom genera.

Bhattacharya et al. (2022), conducted extensive study to identify city-specific microbial fingerprints, classify them, and, eventually, develop their own random-forest-based classifier called Cassandra capable to identify bioindicator species for the potential use in the microbial forensics. The same approach was used by Walker et al. (2019), who analyzed microbe samples from 12 cities in 7

countries, and concluded that microbiome may be extremely specific depending on the geographical region and serve as a valuable forensic piece of evidence.

Jumping from the microorganisms to the insects, Apasrawirote et al. (2022) researched the possibility of the convolutional neural network application in the identification and classification of the fly maggots. Generally, fly maggots have very small sizes, approximately half of the adult fly, thus, may be classified into the microobjects. In addition, they are widely populated and are used as post-mortem interval indicators worldwide. What the researches did was taking images of the maggots via camera connected to the microscope and using four convolutional neural networks to identify four fly maggot species. The claimed identification accuracy was 100% during the validation step with some misclassification during the test step.

Thus, of all the described microobjects, what are truly precious are microorganisms that can provide abundant information about time and place of death even in complex cases when place of death and place of body detection are completely different. For their investigation, the AI can assist in detection and classification of the specific species, as well as study of their regional specificity.

At last, peculiar article in terms of the forensic science was written by Lee et al. (2023), who used a number of the neural networks to detect the *Mycobacterium tuberculosis* in the images of the histopathological slides. The authors achieved the accuracy of 90% per slide with one of the neural networks, and predict the usefulness of this kind of the AI networks in reduction of the Tuberculosis diagnostic time and identification the cause of death. This approach can definitely find its way in the medical and diagnostic procedures, however, whether it can be of any real use in the forensic autopsy procedures is debatable.

Conclusions and Implications

In conclusion, out of 27 extracted articles that somehow covered microobjects or the sources of the microobjects only those concerning the microorganisms were clearly dedicated to the analysis of the microobjects using combination of the traditional forensic methods and the AI technologies. The rest, were not clearly dedicated to the study of the microobjects, however, considering the substances indicated, we can assume that the developed methods can be applied to the forensic investigation of the microobjects. The reason for such results could be partially the fact that this systematic review was limited by the information from the free databases.

Therefore, considering the numbers, today, there is a minor amount of the works that univocally describe analysis of the microobjects using the AI technology. From the studied scientific information, we can conclude that there are attempt to develop technologies for the detection and analysis of the forensic evidences directly on the field during detection step using portable spectroscopy equipment coupled with the machine learning algorithm. At least, there are some advancement in the field detection of the traces and field classification of them in Yes/No mode. However, major efforts are still focused on the analysis step in the laboratory conditions.

In majority of the cases, the main type of the AI was machine learning algorithm that analyze big amount of the data, e.g. photo, images, and spectra, classify them into the corresponding categories creating databases, identify and classify a new piece of the evidence based on the learnt information. We saw this approach with the blood samples, fingerprints, gasoline samples, soil samples, abusive substances, and microorganisms using a coupling of the phototechniques, microscopy and spectroscopy with different models of the AI. It worth mentioning that the researchers attempt to use and compare different models to achieve the greatest precision and accuracy.

Finally, regarding the types of the possible microobjects, combinations of the forensic methods and the AI methods were adopted for analysis of the fluid traces, e.g. beverages, body fluids, and fuels, as well as solid traces, e.g., soils. However, we would like to stress again that only few articles dealt with

the microobjects, the rest covered traces can be a source of the microobjects in particular cases. In the end, we would like to stress again that in 100% of the cases it was a combination of the convenient forensic methods with AI algorithms, meaning the AI is used to take upon itself all the time-consuming and laborious steps in microobject investigation making it as fast and easy for personnel as possible for today.

Suggestions for Future Research

Our first attempt to broadly analyze the current state of the AI application for the forensic investigation of the microobjects showed that there are relative works, but the number is few. However, we identify the main ways the AI is applied in the forensic science. Therefore, it is worth focusing the future researches on the more narrow approach to conducting systematic reviews, and exploring the AI application in the field of microscopy and spectroscopy.

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Conflict of Interest

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