An Overview of Application of Intelligent Systems in Forensic Investigations

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Abstract

Intelligent systems particularly artificial intelligence is the ability of machines or computers to perform tasks that normally require human intelligence. A few examples of such tasks are speech recognition, decision making, medical diagnosis, etc. Clinical use of intelligent programs in the medical field has gained popularity over few years; its application in various dental specialties is an active area of research. Intelligent programs could be used as an adjunctive tool by dentists to interpret complex radiographic images with more precision and accuracy. These programs have simplified the forensic investigations in terms of rapid collection and analysis of forensic evidence with reduced risk of errors that may occur due to cognitive bias. This review discusses the methods and applications of various intelligent software's in forensic investigations and also highlights future perspectives.

Keywords: Intelligent Systems, Clinical Applications, Digital Forensics, Digital Evidence Bag, Forensic Investigations

1. Introduction

India is technologically developing country, emergence of intelligent systems such as artificial intelligence (AI), deep learning (DL), and machine learning (ML) enables machines or computers to acquire human like intelligence, thereby assisting dentists in rapid analysis of complex data[1]. Although both terminologies are related to each other, are often used interchangeably but are not same. Clinical applications of AI, DL and ML in the medical field has been well documented in the literature, that ranges from medical diagnostics and imaging, risk assessment, patient monitoring, treatment response , drug monitoring and in hospital management[2]. Intelligent systems are also gaining interest in various dentistry specialties and are assisting forensic experts in rapid collection and correlation of evidences, and reduces the false interpretation of images[3].

This review focuses on the impact of intelligent systems on the forensic investigations at the crime or disaster site.

2. Intelligent Systems

Allan Turner, one of the founders of AI has defined it as the ability of machines to mimic the cognitive functions of humans i.e.to learn and solve problems based on computer algorithms[4].

ML is subset of AI, Arthur Samuel defined it as the ability of computers or machines to gain human like intelligence without explicit programming i.e. ML tasks depend upon the input signal or feedback given to the learning system[4]. ML algorithms are of three types i) supervised learning , is type of learning program in which both input and output data are available. It detects abnormalities within an image by means of hand labeled training data, ii)

unsupervised learning, in which machine has to learn by its own without any guidance, from the data that is unlabeled or not categorized. Unsupervised learning has two clustering subtypes:

i) Flat clustering in which machine by itself has to divide /cluster the available data into different categories
ii) Hierarchical clustering in which data is divided by the machine into different clusters

In both types machine has to solve the problem based on data which is not labeled, but inaccuracy of output is limitation of unsupervised learning, this differentiates it from supervised learning programs in which input is mapped to the corresponding available output and, lastly

iii) Reinforcement learning is based on dynamic programming i.e. machine learns from reward signal in which correct output is given reward or appreciation[4,5]

3. Learning Algorithms

Supervised learning algorithms are of following types that include linear and logistic regression, support vector machine, k-nearest neighbors and decision tree; a flow chart like structure that classifies the problems whereas unsupervised learning algorithms learn to figure out the structure from the information that is unlabeled, it uses a) k-means for categorization or clustering of the data, and b) Apriori algorithms to find out appropriate rule to categorize large volumes of the data[5].

4. Artificial Neural Networks

Artificial Neural Networks (ANN) is a computational model that is designed to simulate human brain. Just like neurons in human nervous system learns from the past data, similarly ANNs are able to learn from the training data sets, there is mapping of the resultant output to the input. Neural networks are composed of units/ nodes/neurons interconnected to each other by three types of layers that form the connection link: input, hidden and output layers. Input layers receive the input in form of texts, numbers, image pixels, etc and forwards it to other layers i.e. there is transfer of data from one layer to next layer by connection links. In a feed forward network, propagation occurs in single direction; from input to output layers whereas in recurrent network output is back propagated into its input [Figure 1]. These networks are trained and tested using validation data set; and during training each activation is weighed by numeric scale that corresponds to the strength of the connection. Multiple rounds of training is required to improve the diagnostic accuracy and efficiency[1,2].

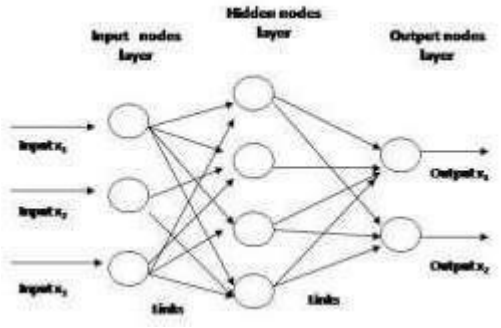

Figure 1: Schematic representation of Artificial Neural Networks(ANN)

5. Deep Learning and Convolutional Neural Networks

Deep learning (DL) is type of AI subset based on convolutional neural networks (CNN) in which multiple processing layers are interconnected with each other, they can have up to 150 hidden layers in comparison to ANN that has usually single, or maximum 2 to3 hidden layers (Figure 2) [6] . These are trained using set of unlabeled data, have the capacity to extract the features directly from the images. It has profound application in medical imaging but its application in dentistry is scarce, confined to analyze large and complex 2D and 3D radiographic images, detection of oral cancer risk , periodontal bone loss, and automatic segmentation of mandibular third molar roots and inferior alveolar nerve thus helping the maxillofacial surgeons in prevention of inferior alveolar nerve injuries prior to surgery[7,8]. Recently MATLAB software for DL is gaining popularity in both medical and dentistry

fields, software tools enables researchers to label the region of interest or relevant information within the images for training of DL models and provides the user with more accurate results in less time[9]. Use of MATLAB software tools are gaining interest in forensic investigations , it is in use by forensic anthropologists to estimate age /sex estimation of an unknown from the skeletal remains or the teeth in mass disaster cases[9].

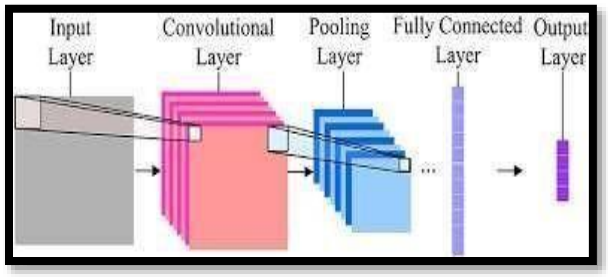

Figure 2: Shows Convolutional Neural networks(CNN)

6. Computer Aided Diagnosis

Computer aided diagnosis (CAD) or computer aided detection, introduced in 1990s , is a software technology that assists professionals in interpretation of medical images, manual feature extraction from images, lesion localization, diagnosis of tumors. Diagnostic performance of CAD systems could be increased by feeding large volumes of training data sets but even after multiple rounds of training their performance is lower or comparable to clinicians and has been reported to produce false interpretations. With technology advancement, AI will replace the CAD diagnosis in near future by its ability to detect lesions in a more accurate and precise way that may go unnoticed and eliminates the need to perform segmentation manually[1,10].

7. Applications of Intelligent Systems in Forensic Dentistry

Forensic Dentistry has become an integral part of forensic science that plays a major role in identification of deceased individuals who cannot be identified visually or by other means after mass disasters or crimes. Identification of individuals often becomes difficult where an individual is unable to give accurate answers or answers are often misleading. Digital Forensics has simplified the forensic investigations in terms of collection and analysis of data by application of computerized software's. It plays an important role in person identification in cases of mass disasters, terrorism, aviation, earthquakes, child exploitation, forgery of documents, etc and has opened up new directions to solve civil and criminal cases[11].

Currently, AI is an ideal approach to provide easy rapid solutions of many complex problems that exist in digital forensics. AI algorithms are the pathway to increase communication between forensic experts, lawyers and crime investigators and are assisting criminal lawyers and judges in the rapid interpretation thus preventing wrong decisions, judicial errors or delayed judgments. In addition, it is also helping different judges in evaluation of information of the particular judgment[10]. The main problem faced by forensic experts is interpretation of large amount of stored data and prevention of misuse of stored data in destructive way. AI is a promising approach to evaluate and simplify the stored data in a short time, reduces the need of repeated data analysis and prevents harmful use of the stored data by the third party [12,13].

i) Intelligent Approaches

Digital Evidence Bag (DEB) captures and stores the forensic evidence i.e. all the relevant information and evidences pertaining to crime. Application of intelligent systems with DEB enables the expert to select and examine only relevant evidences pertaining to the investigation on a hard drive. Another approach for examination of large volume data is cross drive analysis (CDA) that is application of statistical tools to correlate data within a single disk and across multiple disks. Computational methods have also improved the performance of Distributed Digital Forensics, that utilizes distributed approach to perform the forensic examinations at multiple work stations in less time and also applies case based reasoning (CBR) to guide several forensic investigations[14].

ii) Intelligent Software Agent

Recently introduced Intelligent Software Agent (ISA) uses AI to perform various tasks; it

Interacts with an environment in an autonomous manner to achieve specific goals. Another multiagent system interacts with an environment in a cooperative or competitive way to accomplish group targets. It has been found that Multi Agent Digital Investigation Tool Kit (MADIK) composed of set of ISA performs analysis on digital evidence related to the case and is assisting forensic experts in various criminal investigations[15]. It also employs CBR to determine the agents suitable for particular investigation. ISA first uses hash sets related to case for example child abuse, to give an expert rapid feedback on presence of files within evidence. Then files are compared to a knowledge base, which contains set of system files, that can be irrelevant or important files i.e. information about the child abuse. ISA agents have revolutionized the forensic examinations in analysis and correlation of digital evidence beyond the simple tools in acquisition and extraction of data[15]. Besides this specialists can insert their remarks or conclusions in the blackboard. There are three different levels of recommendation for a file i) ignore- strongest recommendation to ignore a file, ii) alert- strongly recommends selection of file , iii) inform – this is of intermediate value that contains information for the reviewer to select or ignore a file. This has tremendously reduced the time spent to select a file in comparison to human examiner[14].

iii) Clinical Applications

Neural networks could improve forensic investigative process by rapid collection of evidence and presentation of collected data in form of graphical structures. Clinical applications of neural networks in the forensic investigations are as follows:

a) Sex and Age Determination

Sex and age determination from skeletal remains form an important basis of forensic investigations in identification of victim at crime site. Forensic literature has proved teeth to be a significant tool in person determination as they are highly resistant to decay and remain unaffected even after decomposition of soft tissue and skeletal structures. Intelligent systems could improve the Accuracy of age estimation methods. So far very limited studies have been done on the application of neural networks in age determination of an individual. Gross GW et al[16] trained neural networks to calculate skeletal age from 521 hand wrist radiographs and found accuracy of age calculated by neural networks close to the chronological age in 243 i.e. 47 % cases whereas Avuclu E et al[17] found high success rates of 99.9% with multilayered perceptron neural networks. All these studies suggested neural networks as a reliable method for age and gender determination but research should be done to establish the accuracy of these systems in this field.

b) Biometric Technology

Fingerprints are widely used in criminal investigations as they are unique to an individual. [18] Development of biometric technology is a recent automated way to establish identity of an individual based on their physical (fingerprint, hand scan, DNA) and behavioral (persons gait, voice, etc) characteristics. Fingerprint biometric systems trace specific features of a fingerprint, such as ridge line patterns, valleys between the ridges, etc., these features are later transformed to a code that is well recognized by the intelligent systems[19]. In biometric system, too many perfect attempts may lead to false positive and negative authentication process. Intelligent systems enable monitoring of biometric systems to reduce errors in authentication process. In near future, use of biometric algorithms will definitely benefit the medico- legal cases in identification of the suspect at the crime site[20].

c) 3D Printing and Bio printing

3D printing also known as rapid prototyping or additive manufacturing is a process of generation of physical models from digital layouts[21]. Applications of 3D printing in forensic odontology include: facial recognition, bite mark analysis, lip printing, etc. . It is performed in following steps i) conversion of object into digital model, ii) continuous volume layer by layer is created and, finally iii) printing is done. Terrestrial 3D laser scanners have been seen to be used by law enforcement agencies whereas close range scanners that record evidences from skull,

Bone are not commonly used by the investigators, and this is the reason of less applicability of 3D printing in forensic practice. Intelligent systems are enhancing 3D printing process by improving manufacturing in prefabrication stage; they have software tools to improve resolution of scanned images before printing, thus enhancing the quality of printed images. In near future 3D printing with intelligent systems aim to overcome the problems related to cyber security[22].

3D bio printing is another domain in which biomaterials such as cells and growth factors are combined to create tissue like structures in layer by layer manner that mimic natural tissues and reconstructs oral hard and soft tissues lost due to an accident. Attempts have been made to construct tooth and its supporting periodontium; trials are being conducted that aim to restore microvasculature of pulp by use of AI[23].

d) Cybersecurity

Computers are benefitting law enforcement agencies to fight crimes but recently it has been reported that there is increase in rate of cybercrimes worldwide such as child pornography, cyber stalking, virus dissemination, software piracy, credit card frauds, etc[24,25]. Human intervention alone is not sufficient to prevent cyber-attacks; this led to the development of separate branch, cyber forensics that uses DL algorithms to enhance cyber security[26]. Karie NM[27] proposed a Deep Learning cyber –forensics (DLCF) model organized into five layers (Figure 3). In coming decades, these DL computational techniques will become a promising tool to detect and prevent cyber based threats.

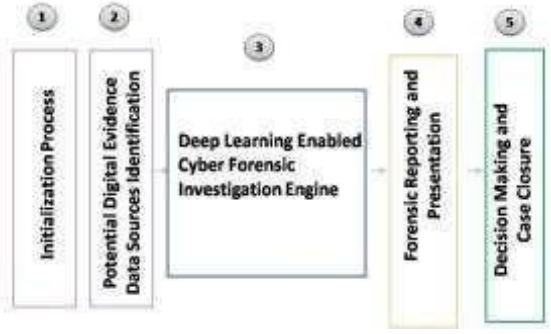

Figure 3: Proposed Deep Learning Cyber-Forensics (DLCF) Framework.

e) Mass Disasters (Terrorism)

Terrorism/ Mass Disasters is another threat that affects large scale of population worldwide; and sharing of data by the third party or organization is one of the major concern. Intelligent systems have overcome the problem of data misuse; as it is difficult to share intelligent information due to incompatible format. These systems could help in tracing the crime locations so that equipment and personnel could be timely directed to these areas to prevent occurrence of terror attacks. Financial support or funding sources are required for proper implementation of the intelligent based operation[28].

Counties like Britain, China, India, North Korea, France, Russia United States and Pakistan possess 14500 nuclear arms, of which India and Pakistan together have around 280. In 1998, Pokhran in India as the first nuclear power station became a matter of national pride for every citizen of the country. Although these nuclear weapons are a matter of national pride and power but if circumstances demand nuclear war in future involving any of these countries its impact is going to be global. The destruction of the Japanese cities of Hiroshima and Nagasaki in 1945 by American nuclear bombs named "Little Boy" and "Fat Man" is the constant reminder of the destruction.

In the current scenario, constant conflict between India and Pakistan encourages the use of verbal nuclear exchange but India remains firmly committed to the doctrine of "no first use." Recently developed AI software's has challenged the conventional approaches of threat assessment and now it's time to make threat posed by AI as a permanent part of national security and military strategy. But major concern is misuse of this software which is being used indiscriminately to guide the warfare and smarter weapons have been developed that rely on AI. They are beyond the human control and could make war happen as easy as flipping a switch. Besides this destructive use new types of radar, laser and infrared sensors have been developed to guide the position and orientation of missiles and drones. To conclude these better smarter weapons are only good if they are used wisely to reduce indiscriminate killing[29].

8. Limitations

Intelligent software's have simplified the forensic investigations, has well established ability to explain the reasoning process that varies from one algorithm to another and has reduced the errors that may occur due to cognitive bias. As it is well said that every technology has some limitations, similarly intelligent systems require huge database of knowledge, may result in false positive or negative interpretations if images are outside the trained data sets. Forensic radiologists and experts should have adequate knowledge regarding computational models, biometrics, etc for better implementation of this technology.

9. Conclusion

Intelligent systems are breakthrough in the field of technology and have captivated the minds of researchers all over the globe. Neural networks assist the forensic experts in rapid collection and interpretation of stored images. Distribution platform enables experts to perform new complicated analysis such as face recognition in mass disasters that couldn't be carried out by single workstation in a reasonable time. These software technologies have a bright future but they are still in their nascent stage and more clinical trials should be done to validate the accuracy of the intelligent systems in forensic examinations.

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