

A Systematic Review of Bone Fracture Detection Models using Convolutional Neural Network Approach

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DOI: 10.47750/pnr.2022.13.S09.019

Abstract

Purpose: Automated processing of digital x-rays, specific to bone fractures, may reduce the involved diagnosis cost as well as provide support to a non-orthopaedic or a small clinician at a remote place to identify a bone fracture and take corrective action.

Method: Machine Learning (ML) approach is establishing itself as a viable technique to automate its diagnosis using digital x-rays. ML approach involving Convolution Neural Network (CNN) is also extensively used in the domain of computer vision. This study follows PRISMA guidelines prescribed to conduct a systematic review. It reviews existing CNN approaches used in the bone fracture detection domain and summarises the findings with respect to specific bone fractures.

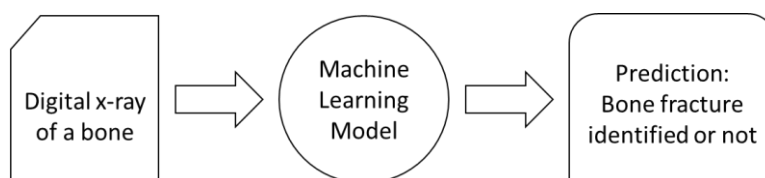
Result: This review revealed the existence of different approaches to apply CNN and transfer learning to detect fractures in different types of bones as currently there is no universal approach applicable to detect fractures in different types of bones.

Discussion: The present status of ML domain does not provide a universal method to support all bone fracture scenarios. This limitation may be addressed through synchronization of different CNN approaches into a synthesized hybrid pipeline.

Keywords: Bone Fracture, Digital X-Ray, Machine Learning (ML), Deep Learning, Convolution Neural Network (CNN).

INTRODUCTION

Bone fracture is a partial or complete break in continuity of a bone. It is the major bone injury these days due to increasing number of vehicles, traffic, improper road conditions and unhealthy lifestyles. An automated processing of digital x-rays may reduce the involved diagnosis cost as well as provide support to a non-orthopaedic or a small clinician at a remote place to identify a bone fracture and take corrective action. Machine Learning (ML) approach is establishing itself as a viable technique to automate its diagnosis using digital x-rays. ML approach involving Convolution Neural Network (CNN) is extensively used in the domain of computer vision. The interest in CNN started with eight layer AlexNet in 2012 and progressed up to 152 layer ResNet. Main advantage of CNN is that it automatically detects important features without human supervision. Deep learning follows the ML approach with extra hidden layers, and CNN is one such approach with a combination of feature extraction and classification. Its performance keeps increasing with increasing data as it automatically extracts the features from raw data. The extraction of complex features at different levels is carried out without any human interaction. Literature review from this domain revealed a research gap with respect to a need to explore its applicability with respect to bone fracture domain (Figure 1).



(Figure 1: Bone Fracture Detection using ML)

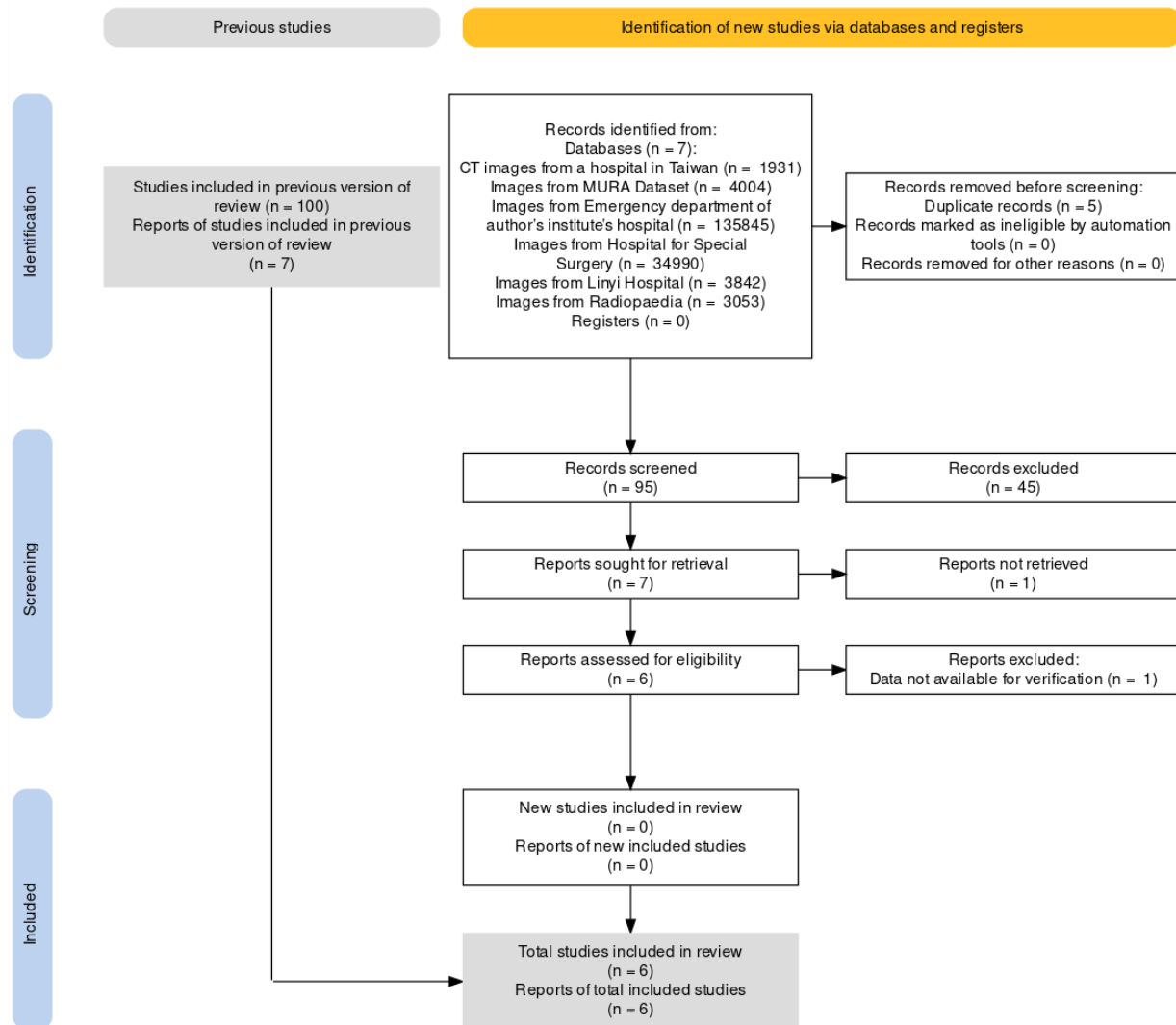
Research Problem: CNN approach is inherently suitable for analogue data (such as image, text, audio etc.) but also involves different algorithms and their innumerable customizations. There exist different algorithms for different problems and a researcher needs to identify a suitable one for any given scenario. This study explores previous studies with respect to the bone fracture detection domain with an objective to synthesize their results.

Research Hypothesis: Scenario specific CNN algorithms can be synchronized together as individual units to establish a ML pipeline specific for bone fracture detection domain.

Research Methodology:

This study follows PRISMA guidelines prescribed to conduct a systematic review. ML approach involving Convolution Neural Network (CNN) is extensively used in the domain of computer vision. This study reviews existing CNN approaches with respect to the bone fracture detection domain, and synthesizes its applications to various parts of bones along with respective results.

Data Collection: Literature review revealed existence of different methods to automate the detection of bone fractures with respect to different bones. Different researchers applied different deep and transfer learning techniques on various types of bone fractures. This study explores these approaches with an objective to find various applied methods which can be used to create a pipeline for feature detection and classification to provide better performance. In the first stage researchers conducted a web search using keywords “bone fracture”, “automated fracture detection”, “fracture detection using deep learning”, and “fracture detection using transfer learning”, “fracture detection using CNN” etc. to identify relevant research articles. These were then further filtered with a defined scope of automated detection using deep and transfer learning techniques. The filtered articles then studied with respect to various factors such as datasets used, pre-processing applied, algorithms or functions applied and prediction accuracy for specific bones in selected dataset. The result of this analysis is then synthesized and summarized according to specific details like study, author, type of bone, dataset used, method applied, pre-processing used, prediction accuracy etc. The study selection process is pictorially represented in Figure 2.



(Figure 2: Study Selection Process as per PRISMA Guidelines)

Review Analysis: The identified articles filtered as per PRISMA guidelines generally found to be focused on a specific bone such as calcaneus, arm, wrist, thigh, tibia and skull, upper trunk, lower trunk, lower limb and upper limb. Two articles found to be exhaustive enough to cover details about all involved parameters including method applied, dataset used and prediction accuracy.

Study-1 Specific to Calcaneus Fracture Detection: Yoga Dwi Pranata etc.³ applied fracture detection on Computed tomography images. Main purpose of the study was classification of fractured and non fractured bone and detection of location of calcaneus fracture in CT images. They have concluded that CNN can achieve 98% accuracy in automated classification of calcaneus bone fracture. Authors used transfer learning and used the pre-trained model like ResNet and concluded that ResNet with SURF can give 98% accuracy in automated diagnosis of calcaneus bone. Transfer learning reduces time to train the model. Dataset containing 1931 (638 fractured and 1248 normal) CT images was obtained from a hospital in Taiwan. A 80-20 split of dataset is used for training and testing the model. Main thing in this study is the use of speed-up robust feature SURF for feature extraction. Canny edge selection and OpenCV was used in the study for contour detection.

Study-2 Specific to Arm Fracture Detection: Bin Guan, Guoshan Zhang etc.² applied a novel deep learning method to arm bone X-rays. Main purpose is classifying fractured and non fractured bone X-rays and detection of arm fracture location. Authors used the MURA dataset for this study and claimed an average precision of 62.04% better than other state of art methods

(According to the author previous AP was 60%). Novel deep learning method proposed by them is a two stage R-CNN method. After applying opening and pixel transformation as a pre-processing they have used feature pyramid architecture for feature extraction. Manually annotated images were used. Model is trained for 3392 images and tested by 612 images. This method cannot detect some fractures like too tiny fractures, a hidden line in the fracture and the overlapping fracture.

Study-3 Specific to Wrist Fracture Detection: Thian YL, Li Y5 applied automated bone fracture detection on wrist radiographs and demonstrated ability of object detection CNN to detect and localize radius and ulna fracture on wrist radiographs. They achieved per image AUC of 91% on frontal view and 93% on lateral view. They have used a dataset consisting of wrist radiographs obtained from the emergency department of their institute's hospital. Dataset contains a total of 7356 images which is split as 90% training and 10% testing images. The images were annotated by experts. Special thing about this study is that they performed training and testing on adult and paediatric images separately. For pre-processing horizontal flipping was used. STATA statistical software was used for analysis. Only emergency department's images were considered for the study.

Study-4 Specific to Wrist Fracture Detection: Lindsey et.4 Applied CNN on wrist radiographs and tried to classify fractured and non fractured radiographs. They also tried to find the region of fractured bone in the image. They have used DCNN which is a non linear regression model. Dataset was obtained between September 2000 and March 2016 from the Hospital for Special Surgery (HSS). 135,845 radiographs of various parts of the body were collected out of which 34,990 were wrist radiographs. For testing the model 3500 wrist and 1400 posterior-anterior- and lateral-view de-identified images were used. Pre-processing in this study is done by rotating, cropping and applying an aspect ratio preserving rescaling operation to yield a fixed resolution of 1,024 512. This study showed that a deep learning model can be trained to detect wrist fractures in radiographs with diagnostic accuracy similar to that of senior sub-specialized orthopaedic surgeons. Model is evaluated by multiple orthopaedic hand surgeons. This model achieved an AUC of 96%.

Study-5 Specific to Thigh Fracture Detection: Bin Guan etc.1 applied CNN to thigh bone images and achieved an average precision (AP) of 82%. Authors proposed dilated convolutional feature pyramid network (DCFPN) and proved that DCFPN has strong applicability in the clinical environment. Model is trained and tested for the thigh bone. Dataset is obtained from Linyi hospital. A total of 3842 thigh fracture images were obtained using DR technology. 3484 images were randomly selected as training data and 358 as testing data. For pre-processing horizontal flipping is used to do data augmentation. Authors have used R-CNN, backbone network (ResNet as back bone) to extract features of thigh fracture. Dilated CNN means normal CNN with 'hole'. Stochastic Gradient Descent (SGD) is adopted to update the weights of the network. This method is implemented using PyTorch v0.4.04 GPU Nvidia GeForce GTX 1080Ti is used in the training, and the total training time costs 6h. Some false positives are possible in this method. Like others this method also has limitations, some fractures cannot be accurately detected by this algorithm.

Study 6 Specific to Skull, Upper Trunk, Lower Trunk, Lower Limb and Upper Limb Fracture Detection: Yangling Ma. etc.7 proposed a new classification network for binary classification as fractured and non-fractured bone, named cracknet which is a combination of Schmid Convolution layer and traditional convolutional layer. First they have applied Faster R-CNN for finding 20 different regions in X-ray images and then applied cracknet to find fracture in these 20 regions. They have achieved an accuracy of 90.11% and an AP of 82. Study is performed on bones like skull, upper trunk, lower trunk, lower limb and upper limb. Data set of 3053 X-ray images is obtained from the website Radiopaedia and from a hospital. 2001 images were used for training. ResNet101 architecture was used to extract features in Faster-RCNN. Authors claimed that deep learning provides fast and accurate solutions in medical diagnostics. The method proposed by them works in two stages which can be converted to a single stage by further research.

Result:

This study initially started with 100 research articles out of which 5 found to be duplicate. 50 articles from the remaining 95 found to be relevant as they focused on deep learning. Out of these 50 articles five full text articles were selected for further analysis as per research criteria. This exploration revealed studies specific to various types of bones like tibia, fibula, calcaneus, arm, wrist, hand, thigh, skull, upper trunk, lower trunk, lower and upper limbs etc. The analysis results of this study are summarised in Table 1.

Table 1: Summary of Review Analysis

Study	Bone Type	Dataset	Size	Pre - Processing	Algorithm	Accuracy (%)	Conclusion
1	Calcaneus	CT images from a hospital in Taiwan	1931	Resizing, Vector Conversion and Normalisation	ResNet with SURF	98	Transfer learning using VGG or ResNet with CNN and SURF for the calcaneus bone will be a feasible method for these bones. ³
2	Arm	Images from MURA Dataset	4004	Pixel Transformation	R-CNN, Feature pyramid architecture	62.04 AP	Even for low quality datasets like MURA 62.01% AP is achieved. Therefore it has strong potential application in real clinical environments. ²
3	Wrist	Images from Emergency department of author's institute's hospital	135845	Horizontal Flipping and Data Augmentation	Object detection CNN	95% Accuracy	The ability to find the location of a fracture with deep Neural networks is an important tool in developing useful AI tools for radiologists. ⁵
4	Wrist	Images from Hospital for Special Surgery	34990	Rotating and Cropping	D-CNN (a nonlinear regression model)	96% AUC	A deep learning model can be trained to detect wrist fractures in radiographs with diagnostic accuracy similar to that of senior sub-specialized orthopaedic surgeons. ⁴
5	Thigh	Images from Linyi Hospital	3842	Horizontal Flipping	New R-CNN backbone (DCFPN)	82.1% AP	AP of 82.1% achieved in the study indicates deep learning will play an increasingly accurate role in fracture detection. ¹
6	Skull, Upper Trunk, Lower Trunk, Lower Limb and Upper Limb	Images from Radiopaedia	3053	Rotation	Faster RCNN	82% AP	Deep learning techniques can be harnessed to provide fast and accurate solutions to automate medical image analysis. ⁷

Discussion:

A better dataset consisting of high quality homogeneous data, like images of single bones, provides better results as compared to low quality heterogeneous data. This review revealed the existence of different approaches to apply CNN and transfer learning to detect fractures in different types of bones as currently there is no universal approach applicable to detect fractures in different types of bones. This scenario may be improved upon by a synchronization of different CNN approaches into a synthesized hybrid pipeline.

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