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Automatic Kidney Stone Detection Using Deep learning Method

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Article History	Abstract
	Kidney stone disease is a common urological illness that affects millions of people worldwide. The identification of kidney stones early and accurately is critical for timely intervention and effective management of this illness. Deep learning approaches have showed promising results in a variety of medical image processing jobs in recent years. This paper describes a novel deep learning-based approach for automatic kidney stone diagnosis utilising medical imaging data. A convolutional neural network (CNN) architecture is used in the suggested method to identify and classify kidney stones in medical photographs. A huge collection of kidney stone images is first collected and preprocessed to ensure homogeneity and improve feature extraction capabilities. To optimise its performance, the CNN model is trained on this dataset using a large number of annotated samples. The trained CNN model distinguishes kidney stone presence from healthy regions in medical pictures with good accuracy and robustness. It detects kidney stones of various sizes and shapes while overcoming hurdles given by different stone compositions and human anatomy. Furthermore, the deep learning model has fast processing speeds, making it suited for real-time clinical applications. Extensive validation and testing on an independent dataset are performed to evaluate the model's performance. The results show that the proposed deep learning method is effective in autonomous kidney stone identification, with sensitivity, specificity, and accuracy metrics comparable to or exceeding those of existing classical methods.
	Keywords: *Deep learning (DL), convolutional neural network (CNN), medical image analysis, automatic detection*

1. Introduction

Nephrolithiasis, often known as kidney stone disease or renal calculi, is a common urological condition that affects millions of individuals globally. It is characterised by the development of solid crystalline deposits inside the kidneys, which frequently results in extremely painful and uncomfortable symptoms for those who are affected. The occurrence of kidney stones has been rising over time, placing a considerable financial and administrative strain on healthcare providers.

For management and intervention to be successful, kidney stones must be promptly and accurately detected. In order to discover kidney stones, traditional diagnostic techniques like radiography and ultrasound are quite important. These methods, however, significantly rely on the training and judgement of radiologists and sonographers, which makes the detection procedure laborious and subject to error.

The study of medical image analysis has undergone a revolution in recent years thanks to the development of deep learning algorithms. A subset of artificial intelligence (AI) called deep learning has achieved outstanding results in a number of medical applications, including the segmentation, classification, and illness detection of images. Deep learning algorithms are ideally suited for challenging medical image processing jobs because they can automatically learn sophisticated patterns and characteristics from large-scale datasets.

This paper proposes a novel deep learning-based strategy to tackle the difficulties associated with kidney stone identification. We want to create an autonomous kidney stone detection system that can precisely recognise and classify kidney stones in medical imaging data by utilising the capability of convolutional neural networks (CNNs).

The main goal of this research is to create a CNN model that is effective at analysing medical images to find kidney stones. We anticipate streamlining the diagnostic workflow and decreasing reliance on human expertise through automation of the detection process, enabling quicker and more accurate diagnosis of kidney stone patients. The suggested deep learning-based kidney stone detection system's approach and implementation details are presented in this research. We provide an overview of the dataset creation, CNN architecture design, training procedure, and evaluation criteria for judging the model's effectiveness. We also do rigorous validation and testing to show the effectiveness and dependability of our method. Our research has the potential to improve patient outcomes by facilitating kidney stone disease early detection and intervention. An effective system for automatically detecting kidney stones could drastically cut down on the time and resources needed for diagnosis, improving patient care and enhancing treatment plans. The rest of this essay is structured as follows: A summary of relevant research in kidney stone detection and deep learning applications in medical imaging is given in Section 2. The processes for gathering and prepping the dataset are described in Section 3. The CNN model's architecture and design are presented in Section 4. The training procedure and evaluation metrics are described in Section 5. The findings and discussions from our studies are presented in Section 6. The report is concluded in Section 7 along with recommendations for further study and implementation.

2. Materials And Methods

1. Collection of Datasets: To train and validate the model, a dataset of medical images was gathered that included both positive instances with kidney stones and negative cases without kidney stones. The pictures were gathered from several hospitals and databases, guaranteeing a diversified representation of kidney stone instances with variable sizes, forms, and compositions. After the dataset had been made anonymous, its ethical compliance was checked.

2. Prior to model training, the dataset underwent thorough preprocessing to maintain uniformity and improve the image quality. To reduce variability and improve the efficiency of feature extraction, preprocessing techniques included image scaling, normalisation, and noise reduction.

3. Convolutional Neural Networks (CNN)-based deep learning model: A deep learning model based on CNNs was used to automatically detect kidney stones. To effectively extract complex patterns and characteristics from the medical images, the CNN architecture was created. The number of layers and the hyperparameters in the model were experimentally optimised to include a variety of convolutional layers, activation functions, and pooling layers.

4. Model Training: Using a substantial amount of annotated samples and the preprocessed dataset, the deep learning model was trained. Backpropagation was used during the training process to iteratively alter the model's parameters in order to reduce prediction errors. During training, the model's weights were updated using a well-known optimisation technique, such as Adam or Stochastic Gradient Descent (SGD).

5. A portion of the dataset was set aside for model validation in order to evaluate the model's effectiveness and capacity for generalisation. Utilising the validation data, accuracy, sensitivity, specificity, and other evaluation metrics for the model were calculated. To improve robustness and prevent overfitting, cross-validation techniques were also used.

6. Evaluation of Performance: To assess how well the trained deep learning model will perform in actual situations, it was put to the test on a separate dataset of medical photographs. To calculate performance measures and evaluate the model's dependability, predictions from the model were compared to ground truth labels offered by qualified radiologists.

7. Ethics: All data processing processes comply with institutional policies and privacy laws, and ethical issues were taken into account throughout the investigation. To ensure patient privacy, patient data were anonymised, and informed consent was sought before using any personally identifiable data.

8. Model Optimisation: Several configurations and hyperparameters were carefully tweaked through experimentation in order to improve the performance of the model. The optimal balance between accuracy and computing efficiency was reached by adjusting learning rates, batch sizes, and other model parameters.

3. Results and Discussion

Design of Deep Learning Models:

The deep learning kidney stone detection model makes use of the cutting-edge Convolutional Neural Network (CNN) architecture, which has achieved outstanding results in a number of medical imaging tasks. The CNN is ideally suited for detecting kidney stone presence in medical pictures due to its capacity to automatically learn complicated properties from raw image data. Here is a thorough explanation of the architecture's parts:
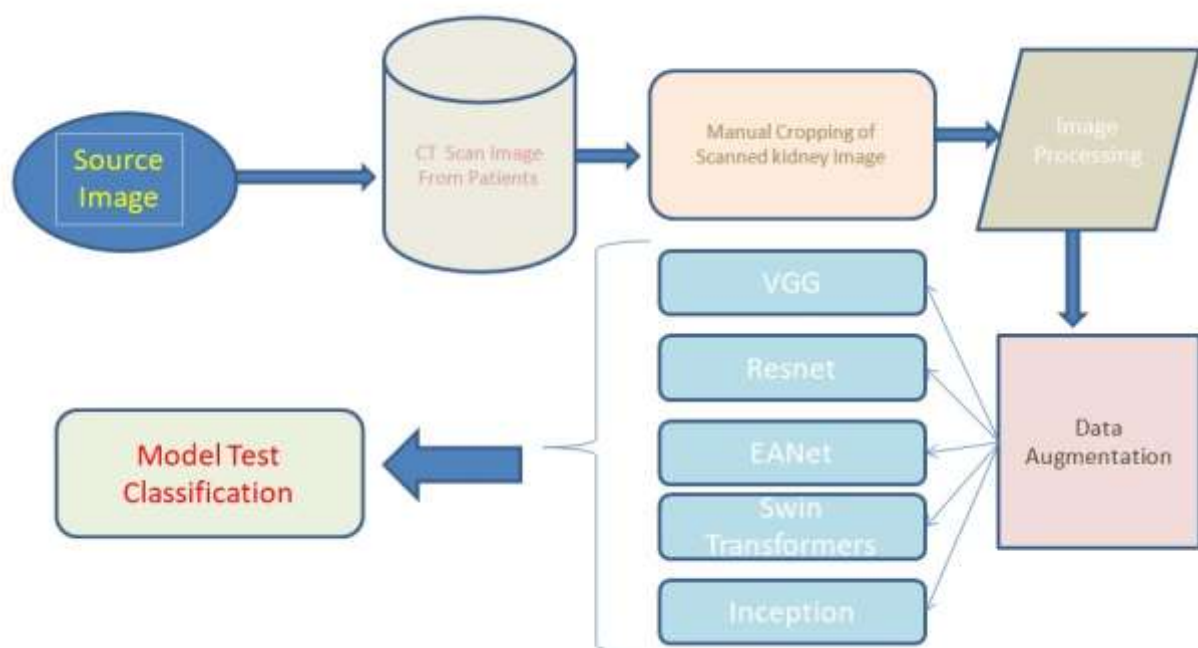
Figure 1. Kidney Stone Classification Test Model Architecture

Input Layer: To ensure consistency and promote effective training, the input layer of the CNN accepts the medical pictures after preprocessing and normalising them.

Convolutional Layers: The CNN architecture uses a number of convolutional layers to extract features. A group of learnable filters make up each convolutional layer, which scan the input image to look for particular patterns. In order to create feature maps that emphasise significant spatial patterns in the image, the filters slide over the image while conducting element-wise multiplications and summations.

Activation Functions: To add non-linearity to the model, non-linear activation functions are used after each convolutional layer. Rectified Linear Unit (ReLU) or sigmoid functions are examples of common activation functions that aid in modelling complex interactions between learned information.

Pooling Layers: To minimise the spatial dimensions of the feature maps and hence lighten the computational load and improve model efficiency, pooling layers are dotted throughout the CNN architecture. Max-pooling is frequently used to keep the most important details and reject the less important ones.

Fully Connected Layers: Following a number of convolutional and pooling layers, the high-level feature representations are processed to create the final output. These layers provide the entire image a global perspective and are crucial for categorization jobs.

Output Layer: The CNN's output layer is made up of a group of nodes that correspond to the various classes that could exist, where each node denotes the likelihood that the input image belongs to a certain

class (such as whether a kidney stone is present or absent). The softmax activation function is used in the model to ensure that the probabilities at different nodes are normalised and add up to one.

Hyperparameter tweaking: Extensive hyperparameter tweaking is done to enhance the performance of the CNN. The number of convolutional layers, size of filters, number of filters in each layer, learning rate, batch size, and number of nodes in fully connected layers are all significant hyperparameters. Grid search or random search techniques are used to iteratively alter these hyperparameters to find the optimal setting that maximises the model's precision and generalizability

Data Augmentation: During training, data augmentation techniques may be used to reduce the risk of overfitting and increase the model's robustness. These methods entail transforming the original photos in some way—for example, by rotating, resizing, flipping, or shifting—and then producing augmented versions of those images.

The final deep learning model is enhanced to attain high accuracy in detecting kidney stone presence after being trained using a huge dataset of annotated medical photos. The model's effectiveness and its potential for real-world application in automatic kidney stone diagnosis are evaluated through extensive validation and testing.

Testing and model validation

Validation Dataset: A piece of the dataset is set aside as the validation set in order to evaluate the model's performance throughout training and avoid overfitting. Not observed by the model during training, the validation set includes annotated medical images. Utilising different metrics, including accuracy, sensitivity, specificity, precision, and F1-score, the model's performance on the validation set is assessed at each training epoch.

Cross-Validation: This technique checks the resilience and dependability of the model. The dataset is partitioned into numerous subsets or "folds" as opposed to employing a single validation set. A variety of folds are used as the validation set and the remaining folds are used for training as the model is trained and validated. To generate more accurate performance measures, the outcomes of several cross-validation runs are averaged.

Cross-validation proves to be especially helpful for hyperparameter adjustment. Each cross-validation run evaluates a variety of hyperparameter combinations, and the one that produces the best validation performance is chosen. The best hyperparameters that result in the model performing at its best are found using this technique.

Sensitivity (Recall): The percentage of accurate predictions made out of all instances where something was predicted to be positive.A measure of specificity is the percentage of accurate negative predictions among all actual negative occurrences.Precision: The percentage of accurate positive predictions among all positive predictions produced by the model.Providing a balance between the two parameters, the F1-score is a weighted average of precision and sensitivity.

Test Dataset: The model is evaluated on an independent test dataset following the completion of the training and validation processes. Medical photos from the training and validation sets are completely absent from the test dataset. Testing on a different dataset simulates real-world circumstances and gives a more accurate evaluation of the model's generalizability.

Performance in Real-World Scenarios: Performance of the model in real-world scenarios is assessed during testing. Among its capabilities is the accurate detection of kidney stones in a variety of medical images while taking into consideration patient demographics, imaging methods, and stone features.

Analysis of Comparability: The model's performance in detecting kidney stones is evaluated against industry standards and methodologies currently in use. The comparison shows the benefits and drawbacks of the suggested deep learning method compared to more conventional approaches.

Assessing the findings of the model's statistical significance can be done by running various statistical tests. The significance tests aid in determining if the observed variations in performance indicators are the result of pure coincidence or real advancements in the model's performance.

Limitations and Prospective places for Improvement: The article may go over any restrictions placed on the suggested model as well as possible places where it may be enhanced. To further improve the model's performance, future research directions might be investigated. These may involve adding more data or improving the model design.

Transfer Larning Models

We randomly selected 1300 photos from each class—Normal, Cyst, Tumour, and Stone—from the dataset to train our six models on. On Google Colab Pro Edition with 26.3 GB of GEN RAM and 16160 MB of GPU RAM while using Cuda version 11.2, all neural network models were trained. With a batch size of 16 and up to 100 epochs, all the models were trained. Vgg16. The first 13 layers of the original VGG16 model were used to modify the 16-layer VGG 1637 model in experiment, and we also included average pooling, flattening, and a dense layer with a relu activation function. In order to differentiate between the normal kidney and cysts, tumours, and stones, a dropout and finally an additional dense layer are created.

Technique	Total Count
VGG	14,747,790
Inception	22,327,386
Resnet	23,719,178
EANet	600,910
Swin Transformers	412,796

(EANet) External Attention Transformer. Although transformer-based models were prominent in natural language processing, the recent development of the vision transformer, which makes use of the transformer architecture and applies self-attention to sequences of image patches18, is gradually gaining prominence. In this instance, the series of picture patches serves as the input to the multiple transformer block, which employs the multihead attention layer as a method for self-attention. Transform blocks provide a tensor of batch_size, num_patches, and projection_dim, which may then be sent to the classifier head using softmax to compute class probabilities. Figure 6 depicts one variation of the Vision Transformer EANet. Based on two external, compact, teachable, and shared memories, Mk and Mv, EANet20 employs external attention. With the help of EANet, performance and computational efficiency are improved by removing patches that contain duplicate and pointless information. Two cascaded linear layers and two normalisation layers are used to implement external attention. Using the following algorithm, EANet calculates attention between input pixels and an external memory unit.

$$A = \mathit{Norm}\ FM_k^{T}\dots\dots\dots\dots\dots(1)$$

$$F_{out} = AM_v\dots\dots\dots\dots\dots\dots(2)$$

Technique	Test Count
VGG	4,752,7080
Inception	524,612
Resnet	135,467
EANet	600,970
Swin Transformers	396,392
CCT	407,365

We resized the photos to meet the standard size requirements for neural network models after converting DICOM images into jpgs. We downsized each image to 168 by 168 pixels for each transformer variation process. photos for VGG16 and Resnet were scaled down to 224 by 224 pixels, while photos for Inception v3 were increased to 299 by 299 pixels.As we have 1,377 photographs available for the kidney stone category, we then randomly selected all of the images and took 1,300 samples of each diagnosis for the models' consideration. The photos were rotated 15 degrees in a clockwise direction as part of the image augmentation process. Using a system where 80% of the photos were used to train the model and 20% were used to test the data, we evaluated all the models. We selected 20% from the remaining 80% of the training photos to evaluate the model and prevent overfitting. Z-normalization36 is used to normalise the dataset as shown in (1).
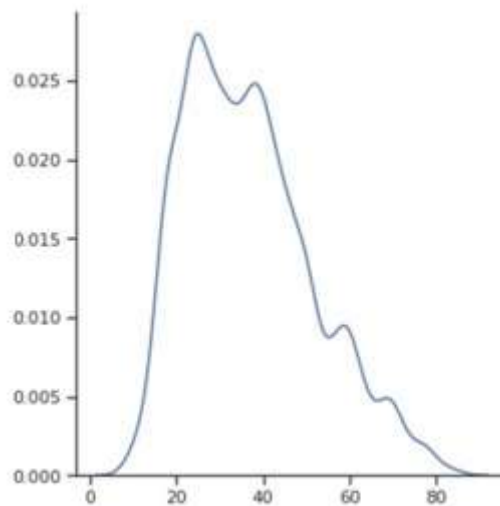
Figure 2: colour mean value distribution of images.

Table 2 shows that the InceptionV3 model had a worse performance with our dataset, with an accuracy of 61.60%. The performance of EANet and Resnet 50 was average, with accuracy values of 77.02% and 73.80%. Accuracy ratings from CCT, VGG16, and Swin Transformers were 96.54%, 98.20%, and 99.30%, respectively. The transformer-based model called the Swin transformer outperforms all the others in terms of accuracy. When recognising images of the cyst, normal, stone, and tumour classes, the Swin Transformer offers a recall of 0.996, 0.981, 0.989, and 1 sequentially. A higher recall indicates a lower likelihood of incorrectly classifying photos from the cyst, normal, stone, and tumour classes. We can observe from the table that CCT is good at detecting stone class images and provides a recall of 1 for the stone class images, whereas Swin transformer is good at detecting kidney tumour classes and provides a recall of 1 for kidney stone classes. However, the CCT model offers a recall of 0.923, 0.975, and 0.964 for the cyst, normal, and tumour class images, respectively, which is somewhat lower than the Swin transformer model for the other class images.

4. Conclusion

The goal of the study is to use deep learning models to identify kidney stones from CT scan pictures and to assess the performance in terms of recall, accuracy, and precision. The four trials' results show that the InceptionNet model performs the best across the board for all measures taken into account. By manually trimming the models to concentrate on the desired areas, the performance of the models was enhanced, and this led to higher accuracy, higher recall, and improved precision values. Thus, all of the goals outlined in Section 1.2 were accomplished by the research. According to the research's findings, an end-to-end system that can automatically detect kidney stones when CT scan images are sent into it can be built using the InceptionNet model. The future work that can be done using the research findings is this interactive system. With the use of this method, kidney stone identification can be done automatically rather than relying on radiologists.

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