Final Year Project

Deep Learning Based Knee Osteoarthritis Predication

Detailed Project Plan

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1 Introduction

1.1 Overview of Knee Osteoarthritis

Knee osteoarthritis (OA) is the most common musculoskeletal disorder causing disability in elderly people in Hong Kong. It is the natural wear of lubricating plate, called Articular Cartilage, between the Femur and the Tibia bone in our knees. It has no cure, and treatments are limited to symptomatic relief only [1]. As a result, Timely identification and treatment are important in alleviating symptoms. However, due to the inadequate amount of orthopedists and clinical resources in Hong Kong, OA patients in Hong Kong need to queue for years for a single treatment, which is undesirable. Symptoms of patients may deteriorate due to late treatment. In this project, an OA prediction model utilizing Convolution Neural Network (CNN), and follow-up management plan prediction model building with eXtreme Gradient Boosting (XGBoost) will be constructed to shorten the waiting time of OA patients in Hong Kong.

1.2 Related work

There are many Deep Learning applications in various fields, but a few in OA. The first paper utilizing CNNs to predict OA from radiographs came from Tiulpin and his colleagues in 2019 [1].

![Figure 1: Model pipeline of Tiulpin’s model in 2019 [1]](image)

The above figure shows the schematic representation of the entire model pipeline of Tiulpin’s model in 2019[1]. The architecture of the prediction model is traditional Deep CNNs with Grad-CAM, which is a heat map visualizing the most important area in the input...
One of the outputs of his model is Kellgren-Lawrence (KL) grade prediction, which is the standard OA severity semi-quantitative scale [1]. Higher KL grade refers to severer OA.

In the bottom part of figure 1, he had included both X-ray images and clinical data as input data for comprehensiveness. This approach is coherent to the main objectives in this project which will be introduced in chapter 2. Therefore, he not only provided prior insight and investigation results on the OA prediction problem but also built a milestone for this project.

In 2020, there is another literature published by Tiuelpin on the same problem. In his paper, more advanced and complex CNNs architectures were used, including those top algorithms in ImageNet, a large visual object recognition research competition in 2016 [3]. Due to the algorithm improvement, the classification performance based on the OA X-ray image was boosted.

However, all the related work is done based on non-local datasets. As there are differences between body structure, demographics, assessment criteria, and clinical data distribution among Asians and non-Asians, the models trained on non-Asians are not applicable in Hong Kong.

2 Objective
There are two main objectives in this project. Both require building Deep Learning or Machine Learning models, but they are dependent and closed correlated.

Figure 2: Pipeline of the two models.

Figure 2 shows the pipeline of the two models needed to be built in this project. One can observe the inputs and the outputs of the two required models, which are indicated as arrays. There is an oblique arrow pointing from objective 1 to model 2. It shows that model 2 takes the KL grade predicted by model 1 as its input for management plan prediction. Details of the two models will be explained as follows.

To tackle the localization problem stated before, a customized model trained on local images and data is necessary to alleviate the long-queuing problem of orthopedic treatment in Hong Kong, which is stated as Model 1 in figure 1. It is the first and primary objective of
this project. It uses Knee X-ray images as input and predicts its KL grade. Deep neural networks, such as deep CNNs, will be used in developing the prediction model due to their high performance. Image attention map technique like Grad-CAM will also be conducted to not only evaluate the reliability of models but also generate a better representation of the model understanding on the domain.

Apart from KL grade predicted based only on knee X-ray images, there are various other criteria when providing suitable management plans by the orthopedists. Therefore, the second objective of this project is building a management plan prediction model, which is stated as Model 2 in figure 2. Since management plan assessment requires medical knowledge and experience of scarce orthopedists, an automatic prediction model on management plan would be beneficial in shortening the waiting time of patients. As management plan prediction is a more comprehensive and complex task compared to OA prediction, various clinical data is needed for prediction. In this project, predicted KL-grade, demographics, disease history and other clinical data will be included as input for model prediction.

If either or both models have satisfactory performance, they will be implemented to shorten the waiting time for booking at Orthopedics & Traumatology Specialist Out-patient Clinics in Hong Kong.

3 Methodology
3.1 Dataset
To achieve the above objectives, a large amount of data with high quality is needed for model training. About the non-local X-ray dataset, there are related datasets available online which are provided in Osteoarthritis Initiative (OAI) and Multicenter Osteoarthritis Study (MOST). OAI contains around 50,000 images, while MOST contains around 20,000 images. As most of them are non-Asians, they cannot be trained and implemented for usage in Hong Kong. However, the amount of datasets is greatly affecting the performance of prediction models. Therefore, they will be used to train an intermediate model for transfer learning, which will be introduced in the latter part of this chapter.

About the local dataset, there are at least 100 Knee X-ray images and corresponding clinical data collected by the Li Ka Shing Faculty of Medicine of the University of Hong Kong. The X-ray images are well captured with fixed coordination and will be used for final model weight fine-tuning in transfer learning. The clinical data will be used for the training management plan prediction model.

About the dataset partition, 70% will be used as the training set, which will contribute to the model training process, 20% of the dataset will be used as the validation set, which evaluating the model architecture performance. The remaining 10% will be used as the test set, which will be evaluated as the independent final performance.
3.2 Convolutional Neural Network
Invented by Alex Krizhevsky and his colleagues in 2012, CNN brings lots of breakthroughs in the field of Computer Vision [4]. It is a special kind of Neural Network utilizing sharing sliding filters to extract spatial features effectively. In this project, CNNs will be used as the main building block of KL grade prediction based on knee X-ray images. As there are many different combinations of models utilizing CNNs and optimal model architecture and weights can only be investigated empirically, top models in ImageNet competition will be first investigated and experimented with, such as Xception, VGG, and ResNet.

The Deep Learning framework selected in this project is TensorFlow in Python because it provides an interactive visualization platform and good modularity of model building blocks.

3.3 Transfer learning
The layer characteristics of the Neural Network can be utilized to conduct transfer learning. Since CNN is a variant of a Neural Network, it is formed in layers.

Figure 3 shows the Convolution filters in the first few layers of AlexNet, which is the first CNN model in the world. As the complexity of filters increases when CNN models get deeper. Simple feature extraction such as lines with different slopes and regions with various values in Figure 3 are located in the first layers. Under this mechanism, transfer learning can be done by using a model pre-trained on similar problems and fine-tuned with local data such as the Hong Kong Knee X-ray images in this project. Therefore, a mature common feature extractor can be reused, which is beneficial for problems with small datasets.
In this project, transfer learning will be conducted twice. The non-local MOST and OAI datasets will first retrain with the pre-trained models to reduce the scope of model prediction domain from a thousand object classification problem in ImageNet to KL grade prediction problem only. After that, the last few layers will be retrained with Hong Kong OA X-ray image dataset to perform localization.

3.4 eXtreme Gradient Boosting
Apart from the OA KL grade prediction objective, a management plan prediction model will also be built in this project with Gradient Boosting. It is a model constructed by sequential small trees, which are simply sets of yes-no questions. It is powerful in classification problems with structural data. One of the variants is eXtreme Gradient Boosting (XGBoost), it is built in C++ language and makes use of multiple CPUs in parallel, therefore it boosts the speed of training. In addition, many winning models in Kaggle, a Deep Learning or Machine Learning competition platform, are constituted by XGBoost.

Therefore, in this project, XGBoost will be first experimented on management plan prediction problem using the official package XGB in Python.

4 Schedule
The following table summarizes the tentative schedule and tasks. It is subject to changes in later progress.

<table>
<thead>
<tr>
<th>Time</th>
<th>Task</th>
<th>Deliverable</th>
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<tbody>
<tr>
<td>Sep-Oct 2021</td>
<td>Literature review</td>
<td>Phase 1: Detailed Project Plan</td>
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<td></td>
<td>Non-Asian X-ray image collection and cleansing</td>
<td>Project website</td>
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<td>Oct-Nov 2021</td>
<td>Setting up pre-trained models in ImageNet</td>
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<td>Retraining the pre-trained model with non-Asian X-ray images</td>
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<td>Evaluating and comparing the performance of different model architectures</td>
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<tr>
<td>Dec-Jan 2021</td>
<td>Pre-processing local X-ray images</td>
<td>Phase 2: Finalized OA prediction model</td>
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<td>Retraining model on local X-ray images</td>
<td>Interim Report</td>
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<td>Finalizing model architecture and weight</td>
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5 Conclusion
Due to the severity of knee OA and shortage of clinical resources situation in Hong Kong, this project targets to develop an OA KL grade prediction model and a follow-up management plan prediction model to shorten the waiting time of OA patients and minimize deterioration of patients' symptoms due to late treatment. If the models have satisfactory performance, they will be implemented to shorten the waiting time for booking at Orthopedics & Traumatology Specialist Out-patient Clinics in Hong Kong.

After the completion of the project plan and literature review, protocols of OA KL grade prediction using CNNs are started building. It will be done in the next one or two weeks.

6 References