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Early Detection of Diabetic Foot Using Thermal Imaging and Deep Learning Techniques

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الكشف المبكر عن قدم السكري باستخدام التصوير الحراري وتقنيات التعلم العميق

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Abstract
Diabetes mellitus is one of the most predominant diseases worldwide, affecting people of all ages. Foot ulcers are one of the most horrific complications of diabetes mellitus, which could result in amputation if not discovered quickly or if the ulcer is not taken care of properly. Infrared thermography has advanced significantly in recent years and has shown great promise in medical field, diagnosis of diabetic foot ulcers is one of the uses of this technology. It is a non-invasive method that involves acquiring thermal images of the patient's foot and preprocessing them before entering a deep learning trained model where the images would be classified and diagnosed.
This research is focusing on constructing a convolutional neural network to classify thermal images of feet into either "normal" or "diabetic" and increasing the model's accuracy by conducting several experiments on different parameters such as optimizers, activation functions, and transfer learning base models. The code is scripted using python language, TensorFlow, and Keras libraries, and the experiments are simulated and plotted in form of training and validation accuracy and loss graphs using matplotlib and Excel. in each experiment only one parameter is changed for comparison and the rest remain constant throughout the trials. For example, when experimenting to find a more efficient optimizer, other parameters remain unchanged for all trials so that the results are only affected by the change in optimizer, the same methodology is repeated for the rest of the experiments. The constructed convolutional neural network uses transfer learning to compensate for the small dataset and it also increases the efficiency and speed of the training. A comparison is made between some of the best transfer learning models, VGG16, ResNet-50, and EffecientNetB3. For optimizers, Adam and SGD were compared. And regarding activation functions, sigmoid was compared to ReLU.
It was assumed that by combining the best parameter from each experiment, the best result would be obtained. And indeed, it was an improvement from other results, it reached a validation accuracy of 90.5%. then, the model was tested on some thermal images that were left out from the training dataset and got an accuracy of 86.7%.

Keywords: Diabetic foot, Deep learning, Thermography, Image processing, Python, Convolutional neural network.

الملخص
مرض السكري هو أحد أكثر الأمراض انتشارًا في العالم، يصيب الناس من جميع الأعمار. قرحة القدم هي أحد المضاعفات المروعة لمرض السكري، التي قد تؤدي إلى البتر إن لم تُكتشف مبكراً أو لم يتم الاعتناء بها بشكل جيد.
التصوير الحراري بالأشعة تحت الحمراء قد تطور بشكل مذهل في السنوات الأخيرة وأظهر وعودا رائعة في المجال الطبي، تشخيص قرحة قدم السكري هي من أحد استخدامات هذه التكنولوجيا. انها تقنية غير باضعة أي لا تخترق الجسم وتتضمن التقاط صور حرارية لقدم المريض ومعالجتها لإدخالها في خوارزمية تعلم عميق سبق تدريبها حيث يتم تصنيف الصور والتشخيص.
في هذا البحث تم صب الاهتمام على إنشاء شبكة عصبونية التفافية لتصنيف صور الأقدام الحرارية إلى إما "طبيعي" أو "سكري" بالإضافة إلى تحسين دقة الخوارزمية عن طريق إجراء عدة تجارب على معاملات مختلفة في الخوارزمية مثل المحسنات ودوال التشغيل وخوارزميات التعليم المتنقل.
تمت كتابة الخوارزمية باستخدام لغة برمجة بايثون ومكتبة keras و TenserFlow، و تم محاكاة التجارب و رسمها على هيئة رسم بياني للتدريب و التحقق من الصحة باستخدام matplotlib و برنامج اكسل. في كل تجربة يتغيب معامل واحد للمقارنة وبقية المعاملات تضل ثابتة خلال التجارب. على سبيل المثال، عند إجراء تجارب لتحديد أفضل محسن تبقى باقي المعاملات ثابتة لكل التجارب بينما يتغير المحسن بحيث تعتمد النتائج فقط على تغير المحسن، نفس المنهجية يتم تطبيقها لكل التجارب. الشبكة العبودية الالتفاف التي تم انشاؤها تستخدم التعليم المتنقل للتعويض عن قاعدة البيانات المحدودة وكذلك لزيادة الفعالية وسرعة تدريب الشبكة. تم إجراء مقارنة بين بعض من أفضل خوارزميات التعليم المتنقل مثل EfficientNetB3 و VGG16 و ResNet-50 و بين المحسنات تمت المقارنة بين SGD و adam و بين دوال التشغيل تمت المقارنة بين ReLU وsigmoid .
كان الغرض من هذه التجارب هو إيجاد أفضل متغير تحت الدراسة في كل تجربة ومن ثم دمجها في خوارزمية على أمل أن تكون أكثر دقة وفاعلية وبالفعل هذا ما حصل حيث وصلت دقة التحقق أثناء تدريب الشبكة العصبونية إلى 90.5%. هنالك خوارزمية واحدة تجاوزتها وبلغت دقة 90.232%.
تم اختبار الشبكات العصبونية باستخدام صور حرارية تم إزالتها من قاعدة البيانات قبل تدريب الشبكات وقد بلغت من الدقة 86.7%.

الكلمات المفتاحية: قدم السكري، تصوير حراري، معالجة الصور، التعلم العميق، بايثون، شبكات عصبونية التفافية.

Introduction

Study background.

Diabetes mellitus is a metabolic disease marked by persistent high blood sugar levels due to abnormalities in the production of insulin, its effectiveness, or both. It can affect people of all age groups. Diabetes is classified into two main types are type 1 and type 2, Type 2 Diabetes Mellitus (T2DM) is the predominant form of diabetes [1]. Type 1 Diabetes occurs when the immune system malfunctions and attacks the beta cells in the pancreas, which are the cells responsible for producing insulin, it is considered an autoimmune disease which often occur at early age. It is managed by insulin injection. Type 2 diabetes is when the body is resistive to insulin or doesn't produce sufficient amount of it, this often occurs to people with obesity or low physical activity or genetic factors. It is managed by changing the unhealthy lifestyle and might require medication or insulin injection. [2]

Diabetic foot disease describes a group of problems affecting the feet because of circulatory disturbances and nerve damage caused by high blood sugar. Diabetic foot ulcers may develop as a result of neuropathy that affects sensation in the feet or decreased blood flow (ischemia) to the feet where poor blood supply can make wounds heal slower. If ulcers are not treated properly, they can progress into more serious problems. The ultimate endpoint of diabetic foot disease is amputation, which is associated with high morbidity and mortality rates, and can have significant social, psychological, and financial impacts on patients.
it is necessary to identify people at increased risk of diabetic foot disease and take appropriate preventive measures, Neuropathy and ischemia should be managed as well as structural deformities of the foot such as calluses, bunions, hammertoes, claw toes, flat feet, and underfoot. [3] Figure (1) shows diabetic foot in different stages. [4]

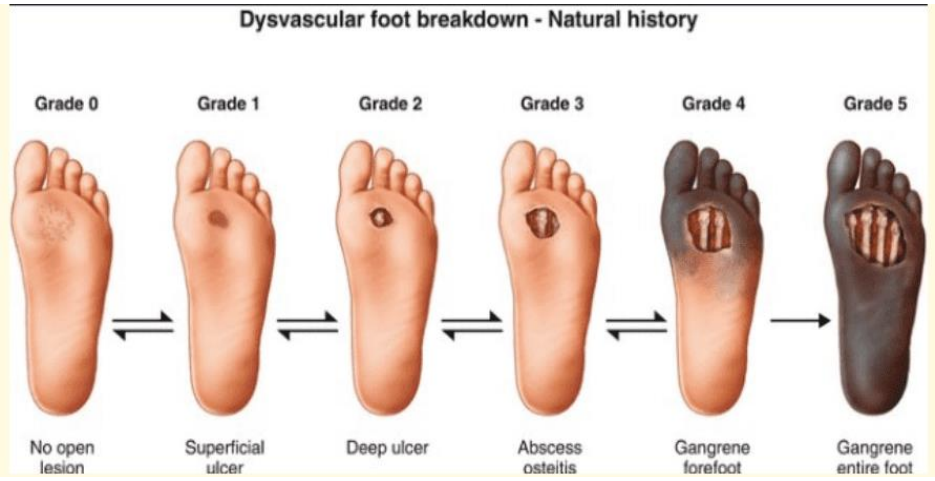

Figure 1. Stages of diabetic foot.

Thermal imaging is a non-destructive, non-contact and rapid system. It reports temperature by measuring infrared radiation emitted by an object/material surface. it is a technique that converts invisible infra-red (IR) radiation pattern into images which are processed later on.
With the recent development in cameras, thermal cameras have become of significance in many diagnostic fields. [5]
This chapter will focus on the uses of thermal imaging to help in early detection of diabetic foot using convolutional neural networks to build classification models.

Thermal images of diabetic feet are shown in Figure (2). [6]

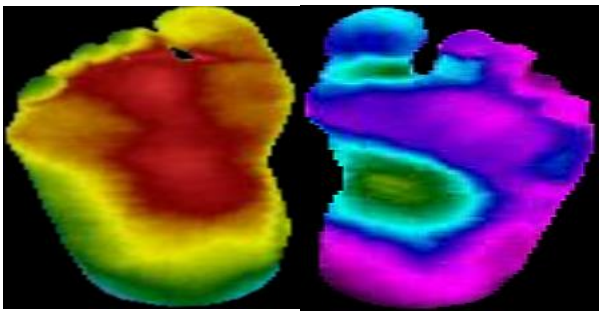

Figure 2. Thermal images of diabetic foot.

Problem statement.
Diabetic foot ulcers are not treatable but only manageable, hence, the faster discovered the better, there have been many ways of diagnosis but all of them require going to the hospital, many patients get tired or fed up with tedious routinely checks and end up diagnosed too late, and so comes the need for a diagnosis tool at home which would be accurate enough to not need a doctor.

Study objectives.
· To implement and optimize a CNN model using python with keras and TensorFlow libraries to classify thermal images of feet into "diabetic" and "normal."
· To conduct a Comparison of different activation functions to achieve best accuracy as well as other comparisons in the code.
· To construct an algorithm that uses the most efficient trained model to predict the health incoming images.
· To test the neural networks.

Conclusion.
This study focused on increasing the efficiency of the diagnosis of diabetic foot ulcers by testing and improving deep leaning model parameters and, and that was done by using artificial intelligent (AI) control and python language. Anaconda prompt and matplotlib/Excel were used in Simulating and comparing parameters.
The weights and biases were generated randomly to minimize the error in each epoch, the best accuracy which is obtained in any of the epochs will be saved in a file. The same model could have different outcomes every time it is trained, however, they don't vary a lot.
The purpose of the experiment was to obtain the highest accuracy possible, in other words, the best weights and biases that are saved later on to a h5 file. After performing the trials the following results were obtained, Adam optimizer proved to be more efficient than SGD, VGG16 pre-trained model had shown more accuracy than the other trained models. And then some random number of layers was added on top of the pre-trained model to see whether the accuracy improves, simulation showed that adding too many or too little layers wasn't good for accuracy and that the best accuracy was when there were five added layers and an output layer. Also, the model had shown best accuracy when the added layers are activated by sigmoid functions rather than ReLU.
It was intended to obtain a new dataset from patients in local hospitals, but it was not possible due to thermal cameras cost being expensive and unavailable locally to borrow. It was also intended to create a website or a phone app that runs the algorithm so that patients would be able to send pictures to the app and get a diagnosis while sitting at home. But unfortunately, due to lack of programming skills in this area it required more time than obtained.

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