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**Medical Imaging for Dentistry Using Artificial Intelligence**

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**Abstract**

Medical imaging in general and dental imaging in particular are fields where Artificial Intelligence can be applied in order to provide quicker and more accurate results. Providing patients with better care and giving practitioners an opportunity to direct their focus where it is needed most are just two of the objectives such an approach strives towards.

This project uses deep learning techniques for segmenting images and providing dentists with baseline information which they can perfect with their expertise, which can also be used in automatic screenings. It aims to provide mandible segmentations, as well as automatic teeth measurements.

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**1. Introduction**

**1.1**

The problem being tackled here is reliable and fast segmentation of dental images. Progress in this area can lead to an increased quality of life for countless people by providing automated screenings, as well as assistance to practitioners.

The approach is based on deep learning, which has shown significant improvements compared to other methods in the past years. Particularly, this project aims to tweak some existing approaches for the given problem: (Kamnitsas, et al., 2017), (Qin, et al., 2020), (Weber, et al., 2021).

**1.2**

The research presented in this paper advances the theory, design, and implementation of several particular models. The main contribution of this report is to present an intelligent algorithm for solving the problem of dental imaging. The second contribution of this report consists of building an application where medical practictioners as well as patients can have seamless access to these imaging techniques. The application is also meant to encourage the usage of the developed models by integrating them in an intuitive and simple interface meant to digitalize the treatment process.

The present work is structured into five chapters as follows:

The first chapter is introductory, presenting general information and motivation.

The second chapter formulates the scientific problem.

The third chapter presents the current state of the art and work related to this topic.

The fourth chapter presents the particular approaches being investigated in this work.

The fifth chapter presents the application that integrates the developed intelligent algorithms.

**2. Scientific Problem**

**2.1**

**Problem definition**

The problem this project is aiming to solve is that of accurate and efficient segmentation of dental images. The aim is to provide doctors with aid in separating the mandible from the skull, as well as spotting dental assymetries through precise pixel-wise measurements.

The success of deep learning methods in the past years is the motivation for mainly focusing on such approaches in the present work.

As stated above, a reliable algorithm solving this problem can provide significant improvements to people’s lives’, by improving the reliability, as well as accessibility of diagnostics.

**3. State of the art / Related Work**

Previous work in this area can be broadly considered to be anything regarding image segmentation. DeepMedic (Kamnitsas, et al., 2017) uses Convolutional Neural Networks and Conditional Random Fields to segment brain images. U2Net (Qin, et al., 2020) employs Residual U-blocks (RSU) for general image segmentation. Deeplab (Weber, et al., 2021) is a well-known library comprising several projects employing different deep learning techniques. None of these target dental imaging in particular, but they can be adapted to this task. The Segment Anything model (Kirillov, et al., 2023) is a very popular baseline model. The YOLO models are also known for their efficiency.

Regarding work on the specific problem tackled here, U-net has been used for mandible segmentation (Abdi, Kasaei, & Mehdizadeh, 2015), as well as segmenting individual teeth (HELLİ & HAMAMCI), combined with non-deeplearning techniques to achieve pixel-wise measurements. The main dataset used in these endeavours is (Abdi A., 2017), with some modification for the tooth segmentation.

**4. Investigated approach**

First of all, it is important to make a distinction between the two problems tackled here. First, there is mandible segmentation, which is as straight-forward as it sounds: given an X-ray, we want to segment the pixels corresponding to the patient’s mandible. Second, there is pixelwise tooth measurement, which aims to measure the width and height of a all teeth given an X-ray.

**4.1**

**Initial models**

A x-ray of a person's chest

Description automatically generatedThis project aims to investigate different approaches in order to improve on previous developments in this area. The first experiment involved using the U2-NET architecture for both mandible segmentation and tooth measurements and comparing this to U-NET. Regarding mandible segmentation, an F1 score of 95% was achieved for U2-NET, which is a marginal improvement over the 94% of U-NET. This result has been deemed satisfactory and most future efforts have been focused on the tooth measurement problem.

Figure 1 - Mandible Segmentation

The first experiment was based on simple segmentation models such as those listed before. After segmenting individual teeth, some erosion was done to better delineate the teeth. Then, to get measurements, the connected components were separated.

A yellow and purple image of a mask

Description automatically generated

Figure 2 - Predicted Mask

X-ray of a person's chest

Description automatically generated

Figure 3 - Measurements based on mask prediction

A x-ray of teeth and gums

Description automatically generatedFor consistency’s sake the F1 score for this experiment is around 95% for both U-NET and U2-NET architectures. However, the F1 score, or other segmentation metrics would not be very telling for this particular approach, as any segmented connection between two teeth would lead to the algorithm measuring them together. A more appropriate metric would be measuring the ratio between the predicted number of teeth and the actual number of teeth. On the validation dataset, this method managed to detect 514 out of 796 teeth, divided between 28 images. The ratio is, therefore, 64%. This ratio might seem like an oversimplifcation of the evaluation process, but upon viewing the model results, it becomes clear that the measurements are nearly perfect everywhere and that a tooth rarely gets segmented where there is none. Therefore, the main challenge is getting the model to segment teeth that are very near to each other separately. The following image illustrates this point.

Figure 4 – Overlapping measurements.

It should be noted that the U-NET architecture does better than U2-NET on segmenting individual teeth, even though U2-NET has a slightly better F-score, by 1%. Once again, this is due to the fact that individual teeth measurements require precise boundaries between the teeth, which U2-NET doesn’t do as well as U-NET.

**4.2**

**SAM**

Since the main problem was the segmentation of the boundaries between the teeth, the next investigated approach was to try giving the model a prompt for how many teeth should be measured. The SAM model was ideal for this, since it can accept bounding boxes as prompts. In order for this to work, a model for providing it with bounding boxes had to be trained. Also, a new data set had to be created based on the already existing masks. Therefore, using the same erosion and connected component separation method as before, bounding boxes were extracted from the ground truth masks. A YOLOv8 model was trained on this new dataset. It achieved a mean average precision of 93%.

A graph of a graph

Description automatically generated

Figure 5 – YOLO PR-curve

A x-ray of a person's teeth

Description automatically generated

Figure 6 – Bounding Boxes provided to SAM prompt encoder

It should be noted that, since some of the teeth were at an angle, the boxes could not be used as accurate measurements.

The way the SAM model works is it encodes the image and the given prompt and then processes these with a lightweight decoder (can run in browser) to get the final segmentation. This opened up many possibilities for the overall project, starting from having a single stored encoding per image, making all algorithms running on it more efficient, to providing prompts in real-time for segmenting individual parts of an image.

However, training the model turned out to be more of a challenge than expected. The output of the model is a mask for each given prompt. Therefore, for an image of, say, 20 teeth, there would be 20 masks. Since the ground truth was not separated this way, the 20 masks had to be combined somehow. The only differentiable operation for doing this would be adding them together. A further problem was the fact that some boudning boxes contained parts of more than one tooth.

A variety of loss functions and adjustments were tried. Binary crossentropy combined with sigmoid soft thresholding led the model to learn to segment the entire image. A hypothesis for this behavior is that overlapping pixels would get values closer to 1, whereas the ones with no overlap would get 0.7, which means overlapping is better than correctly segmented.

Mean squared error led to the model learning to segment too little, possibly due to oversensitivity to the overlapping pixels. This can be seen in the following image, where the prediction is to the left and the ground truth is to the right.

Yellow and purple background with white lines

Description automatically generated

Figure 7 – SAM segmentation results after 20 epochs

Training in batches was not possible, because different images had different output shapes based on the number of segmented teeth. However, gradient accumulation was still possible, and it was used to more closely approximate the gradient of the entire dataset. This was tried with both loss functions mentioned above but did not improve the outcome.

All that was stated above are hypotheses, and it is possible that the model did not achieve the desired outcome for entirely different reasons. Perhaps the dataset encoder simply doesn’t generalize well to such images. Fine-tuning the encoder would have been the next step, but first a new idea was investigated.

**4.3**

**Oriented bounding boxes**

Having realised that the main problem of the SAM training was the overlap between the segmentation masks, which was liekly due to overlap between the bounding box prompts, it was decided to investigate a model that could provide better box predictions. That is to say, the bounding boxes also needed to have orientation. Initially, modifying the prompt encoder to accept orienting bounding boxes was considered, but experiments showed that the bounding boxes themselves were very accurate measurements.

The model used for this was the oriented bounding box YOLO model. A new dataset had to be created for this, once again based on the ground truth masks.

Comparing this model to the initial U-NET approach, the results were a significant improvement. The oriented bounding box model detected 773 out of 796 teeth: a 97% ratio compared to the previous 63%. The following images are a comparison of some of the predictions. The oriented bounding box model is to the left.

A close-up of a radiograph

Description automatically generated

Figure 8 – OBB YOLO(left) and segmentation model comparison

A close-up of a person's chest

Description automatically generated

Figure 9 – OBB YOLO (left) and Segmentation model comparison

Whereas the measurements are much better in the oriented bounding box model, one can tell by comparing the images that certain teeth get better measurements with the segmentation model. Future work might involve a combination between the two models, as well as heuristics for pruning measurements that are obviously wrong.

**5. Application**

The application is supposed to complement the trained models, providing a platform where parts of the diagnosis process can be digitalised and automatised.

**5.1**

**Functionality**

Patients and doctors can both create accounts. Both types of users log in using their email and password.

A screenshot of a login box

Description automatically generated

Figure 10 - Login

Doctors can add a new patient to their patient list by email and create appointments for a given patient. The appointments specify a date and place, as well as any medical investigations that might be required, for example panoramic X-rays.

A screenshot of a computer

Description automatically generated

Figure 11 – Appointment Creation

A close-up of x-ray images

Description automatically generatedAfter a patient has uploaded images, doctors can view them in the image processing part of the app. Here, they can use the intelligent algorithms described in part 4, as well as place a diagnosis for any given image.

Figure 12 – Image Processing

A screenshot of a computer

Description automatically generated

Figure 13 - Diagnostic

Patients can view their appointments and upload the required images. They can also view diagnostics that are already finished, as well as delete their images if they no longer want them to be stored by the app.

A screenshot of a computer

Description automatically generated

Figure 14 – Appointment Details

**5.2**

**Architecture**

The app has a very simple client-server architecture. The frontend is implemented using Angular, the backend uses Flask, and the database is Postgresql. The backend technology choice was made considering the fact that the project uses AI, and that the Python programming languages has very good deep learning libraries.

**5.3**

**Security**

Regarding security when making API requests, the app uses JWT tokens. They cater well because different endpoints require different authorizations. For example, only a doctor can access the image processing endpoints, but both doctors and patients should have access to the details of an appointment. This can be easily achieved by adding a role to the JWT token dictionary, and is very easy to abstract away implementing a single doubly-decorated function.

Although this is not necessarily a technical point, creating a doctor account requires the approval of an administrator. Administrators can access the app’s dashboard and manage accounts. Here, they can activate or deactivate a given account.

A screenshot of a computer

Description automatically generated

Figure 15 - Admin Dashboard

**6. Conclusion and future work**

The main contribution of this work is an investigation of approaches regarding mainly tooth measurement, as well as mandible segmentation. Future work may include combining the oriented bounding box and segmentation models, as well as continuing work on the finetuning of a baseline model such as SAM.

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