Bachelor Project

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F3

Faculty of Electrical Engineering
Department of Cybernetics

Prediction of Atherosclerotic Plaque Parameters from In-Vivo Ultrasound Carotid Artery Images

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Field of study: Cybernetics and robotics
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Acknowledgements

Declaration

I declare that the presented work was developed independently and that I have listed all sources of information used within it in accordance with the methodical instructions for observing the ethical principles in the preparation of university theses. Prague, 20 May 2022

Abstract

The main goal of my bachelor thesis is to predict atherosclerotic plaque parameters such as echogenicity, homogeneity and degree of stenosis from in-vivo ultrasound carotid artery images using deep-learning methods. ResNet 34 and DenseNet 161 models were proposed as deep learning architectures. A novel context restoration strategy was successfully implemented in order to obtain good initialization parameters for target task models. Three architectures able to conduct fusion of ultrasound image and corresponding segmentation were designed. The best performance for echogenicity and homogeneity prediction has been achieved using ultrasound and segmentation images fusion and are equal to 75 % and 87 % correlation respectively.

Keywords: Deep learning, dataset, ultrasound image, atherosclerosis, atherosclerotic plaque, degree of stenosis, echogenicity, homogeneity

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Abstrakt

Hlavním cílem moje bakalá°ské práce je predikce parametr· aterosklerotického plátu jako jsou echogenita, homogenita a procento stenózy z in-vivo ultrazvukových obrázk· karotidy pomocí metod hlubokého u£ení. ResNet 34 a DenseNet 161 architektury byly navrºeny. Inova£ní strategie Context restoration byla implementována za ú£elem získání vhodných parametr· pro inicializaci model·. Byly implementovány t°i architektury schopné provád¥t fúzi ultrazvukového obrázku a odpovídající segmentace. Nejlep²í výsledky predikce echogenity a homogenity byly dosaºeny metodou fúze ultrazvukového obrázku a segmentace a jsou rovny 75% a 87% korelace.

Klí£ová slova: Hluboké u£ení, dataset, ultrazvukový obrázek, ateroskleróza, aterosklerotický plát, procento stenózy, echogenita, homogenita

P°eklad názvu: Predikce parametr· aterosklerotického plátu z in-vivo ultrazvukových obrázk· karotidy

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Chapter 1
Introduction

Atherosclerosis is a very common disease among people over the age of 60 or among people who do not lead a healthy lifestyle. [35] This illness occurs when cholesterol and other fatty products begin accumulating on inner walls of arteries consequently reducing the lumen area and hindering the blood ow. Severe narrowing of an artery lumen blocks the oxygen supply to organs and tissues, increases the probability of cerebrovascular and cardiovascular events and may even lead to lethal outcome. Signs of atherosclerosis develop slowly and gradually so patient may not observe any noticeable symptoms till the artery is heavily narrowed and blood ow is restricted. This fact insists on the importance of early detection, diagnosing and treatment of this disease.

Deep learning is a sub eld of Arti cial intelligence. Deep learning works on designing, developing and improving models inspired by the neural networks in human brain and are able to imitate human decision process. Such models have become widely used thanks to a large amount of data and rapid development of computational power. Application of deep learning techniques in medicine is a novel approach intending to automatize disease development prediction, grading of illness severeness and characterization of tissues composition.

This project aims to apply deep learning methods in order to predict atherosclerotic plaque parameters using in-vivo ultrasound carotid artery images and their semantic segmentations prepared by Martin Kostelanský in his Master degree thesis "Localization and segmentation of in-vivo ultrasound carotid artery images". Experts annotation including atherosclerotic plaque parameters grading is available for such parameters as echogenicity index, homogeneity of an atherosclerotic plaque, percentage of calci cation, atherosclerotic plaque width, type of plaque surface and degree of stenosis.

1.1 Goals of the project

The intention of this thesis work is to propose a solution for atherosclerotic plaque parameters prediction from in-vivo ultrasound carotid artery images. In line with the proposed implementation the whole stated problem divides into following intermediate tasks:

- Firstly, we will get familiar with the available dataset and the corresponding experts annotation, describe atherosclerotic plaque parameters and nd mathematical interpretation for each of them;
- Secondly, we will propose some methods for images processing;
- Thirdly, we will implement various deep learning techniques including novel pre-training method and models for image fusion;
- Lastly, we will conduct experiments and make quantitative evaluation of the achieved performance.

1.2 Structure of the document

My bachelor thesis has in total 6 chapters and is structured in the next way: The rst chapter makes a concise overview of studied problematics, speci es the main goals of the project and outlines the documents structure. The second chapter provides the necessary understanding of carotid artery anatomy, closely related disease called atherosclerosis, its diagnosing and treatment. In chapter number three the target dataset and several atherosclerotic plaque parameters are presented. The chapter number four is going to describe methods applied for data processing and explains deep learning techniques implemented for problem resolving. In chapter number ve results of the experiments are presented and discussed. In the last chapter I am going to draw a conclusion about work done.

Chapter 2

Background

This chapter brie y explains and outlines the general medical background of my thesis project. The section 2.1 explains the structure and signi cance of the carotid artery. The section 2.2 o ers insight into the most widespread disease that is connected with carotid artery. The 2.3 sections main purpose is to make us familiar with the most common diagnostic procedures and investigations. The 2.4 section intends to describe the main treatment techniques and preventative recommendations.

2.1 The carotid artery structure

Figure 2.1: Carotid artery anatomy

The carotid arteries are the main blood vessels that carry blood and oxygen to the head. The are two Common Carotid Arteries (CCA) located in the neck - symmetrically one on either side. The right CCA arises from the brachiocephalic artery while the left CCA takes its origin directly o the aorta. Both carotid arteries splits into two parts:

- Internal Carotid Artery (ICA) is the terminal branch of the Common Carotid Artery (CCA) that carries blood and oxygen to the brain, eyes, scalp, scull and the mennings;
- External Carotid Artery (ECA) divides into seven branches that carry blood and oxygen to the face and neck.

Carotid artery walls, similarly to all other arteries in our body, are composed of three layered structures:

- Intima, a smooth inner layer that allows blood to ow easily;
- Media, a muscular middle layer that controls the diameter of the artery;
- Adventitia, the protective outer layer of the artery.

2.2 Atherosclerosis

Atherosclerosis is a slow-progressive disease which can be explained as narrowing, sti ening and hardening of the arteries that is caused by a buildup of plaques on the inner walls of the arteries. Plaques consist of deposits of cholesterol, calcium, brin, cellular waste products and fatty products. Atherosclerosis causes restrictions of the ow of oxygen-rich blood to di erent parts of the body [36].

Figure 2.2: Atherosclerotic plaque composition

The exact cause of atherosclerosis is not well explored but it is assumed that any damage or injury of intima layer of an artery may instigate this disease. In case when the inner wall of an artery is injured blood cells and other constituents may gather at the injury place over time fatty deposits build up and harden so this process results in lumen area restriction. The initial damage of the inner layer of an artery may become an outcome of high blood pressure, smoking, obesity or diabetes, high concentration of cholesterol or other lipid constituents in blood [34].

Signs of atherosclerosis usually progress gradually and patient would not feel any symptoms till blood ow isn't highly restricted because of narrowing or clogging of artery what consequently leads to situation when artery can not supply enough oxygen to tissues and organs. However, in case when blood ow through major artery is restricted symptoms may become severe. So the signs and symptoms depend on a ected artery. Atherosclerotic plaques in heart arteries may lead to chest pressure and pain. Restricted blood ow through carotid arteries may make patient feel weakness or numbness in limbs, di culties in speaking, temporary loss of vision or it can even progress to a stroke. Atherosclerosis in kidney arteries causes high blood pressure or even kidney failure. A ected arteries in limbs may develop decreased blood pressure or pain in a ected leg or arm. Also this disease leads to emerging of aneurysms anywhere in body.

There are several major and most widespread risk factors that can cause atherosclerosis disease or support its progress with very high probability: high blood pressure, smoking, stress, physical inactivity, obesity, unhealthy and fat saturated diet, diabetes, high cholesterol and triglyceride level.

2.3 Diagnosis

The diagnosis of atherosclerosis disease usually starts with a physical test and continue with one or several next investigations:

- Blood test is a simple test which can reveal the risk of having atherosclerosis, like increased level of lipids like cholesterol or blood sugar;
- Ultrasound (including Doppler sonography) is the procedure when doctor uses a special probe to direct sound waves into a blood vessel to evaluate blood ow. Faintness of sound may mean there is narrowing or blockage;
- Computerized tomography angiography (CTA) is a type of X-ray investigation that can reveal calci cations;
- Magnetic resonance angiography (MRA) is the test that is quite similar to CTA which does not use ionizing radiation;
- Blood pressure comparison (Ankle-brachial index) is the test when specialist compares blood pressure in ankles and in arms. Signi cant di erence may acknowledge existence of narrowings because of atherosclerosis;
- Cerebral angiography is the procedure in which doctor puts dye into arteries and they become visible on an X-ray. It helps to spot and localize arterial narrowings;
- Stress test is the survey when patient is subjected to exercising while doctors monitor patients heart rate, blood pressure, breathing and other health parameters.

2.4 Prevention and treatment

Atherosclerosis disease is prevented or delayed by reducing in uence of the most common risk factors. Lifestyle changes like health diet, quit smoking, physical activity lead to reducing the risk. Patients that are at risk because of high cholesterol or high blood pressure should take medicines which help to slow down or even halt atherosclerosis progress. [34]

More serious cases of this disease require invasive techniques to get rid of blockages:

- Stenting and angioplasty is the surgery when catheter with a balloon tip is injected into an artery and balloon tip is in ated to clear the artery, insert a stent and hold it open
- Bypass surgery is the procedure when doctor uses a healthy blood vessel from another part of patients body to go around blocked segment;
- Endarterectomy is the surgery when doctor removes plaque with any injured part of artery to ease blood ow;
- Fibrinolytic therapy - some medicines are used to dissolve blockages in arteries [33].

Chapter 3

Dataset and atherosclerotic plaque parameters

Chapter number 3 intends to present the target datasets and the atherosclerotic plaque parameters which are going to be predicted in further experiments. In section 3.1 we are going to get familiar with the available datasets that consist of in-vivo ultrasound images of the carotid artery and prepared automatic segmentation of ultrasound images based on manual segmentation. Section number 3.2 presents experts annotation for target dataset. Further in section 3.3 we will specify and make a brief description of several atherosclerotic plaque parameters in accordance with its medical de nitions.

Machine learning is a fast emerging eld of Arti cial intelligence. The main reason of machine learnings rapid development is a large amount of available annotated datasets, which become an essential resource to build smart systems, required for an improvement of machine learning models performance and are suitable for variety of tasks. However the situation is contrary when we take into consideration the application of machine learning techniques on medical problems and tasks. Collecting a qualitative large medical dataset is challenging because of 2 main reasons: rstly, patient health data are mostly not publicly available and are well protected by patient data laws, secondly, annotation and labelling of such datasets require expert knowledge compare to annotating natural images, when just basic human experience is enough.

The concept "labelled dataset" can be explained as a collection of pairs of observations X_i and tag Y_i. Each such pair observation-label is considered as a single unit by machine learning model.

3.1 Dataset description

The ANTIQUE dataset was collected during the research project called "Atherosclerotic Plaque Characterisation Associated With a Progression Rate of the Plaque in Carotids and a Risk of Stroke" [22]. The main goal of this study was to examine dependence between risk factors such as greater plaque thickness, coronary heart disease, smoking etc. and progression of carotid