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Master Programme in Life Science Informatics
Master Thesis

Brain Tractography Registration with Nonrigid ICP

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ABSTRACT

The registration problem (also known as alignment, absolute orientation) is one of the outstanding and very basic problems in computer vision. In this problem, two or more datsets of points are given and the task is to optimally align them by estimating a best transformation (combination of translation, rotation and scaling). Due to its fundamental importance, it arises as a subtask in many different applications (e.g., object recognition, tracking, range data fusion, graphics, medical image alignment, robotics and structural bioinformatics etc [1].

In This thesis we show how to extend the ICP framework to nonrigid registration, while retaining the convergence properties of the original algorithm. The resulting optimal step nonrigid ICP framework allows the use of different regularisations, as long as they have an adjustable stiffness parameter. The registration loops over a series of decreasing stiffness weights, and incrementally deforms the template towards the target, recovering the whole range of global and local deformations. To find the optimal deformation for a given stiffness, optimal iterative closest point steps are used. Preliminary correspondences are estimated by a nearestpoint search. Then the optimal deformation of the template for these fixed correspondences and the active stiffness is calculated. Afterwards the process continues with new correspondences found by searching from the displaced template vertices. We present an algorithm using a locally affine regularisation which assigns an affine transformation to each vertex and minimises the difference in the transformation of neighbouring vertices. It is shown that for this regularisation the optimal deformation for fixed correspondences and fixed stiffness can be determined exactly and efficiently. The method succeeds for a wide range of initial conditions, and handles missing data robustly. It is compared qualitatively and quantitatively to other algorithms using synthetic examples and real world data[2].

1

INTRODUCTION

1 BRAIN STRUCTURE (FIBER PATHWAYS)

HUMAN BRAIN , which is our focus in this thesis, is the central organ of the human nervous system, it is made up of two main components, gray matter and white matter. Scientists have learned a lot about gray and white matter and the two halves of the brain through autopsies and imaging techniques and by studying diseases or conditions associated with brain damage.
The thesis focused on **White Matter** which is refers to areas of the central nervous system that are mainly made up of myelinated axons, also called tracts or fiber pathways [3]. It is composed of bundles, which connect various gray matter areas of the brain to each other, and carry nerve impulses between neurons. Myelin acts as an insulator, which allows electrical signals to jump, rather than coursing through the axon, increasing the speed of transmission of all nerve signals [4].
Long thought to be passive tissue, white matter affects learning and brain functions, modulating the distribution of action potentials, acting as a relay and coordinating communication between different brain regions [5].

The Human Brain consits of these tracts in left and right side:

- Anterior Thalamic Radiation (ATR)
- Corpus Callosum (CC)
- Genu of the Corpus Callosum (genu)
- Splenium of the Corpus Callosum (splenium)
- Body of Corpus Callosum (truncus)
- Body of Corpus Callosum (truncus)
- Cingulum (Cing)
- Corticospinal Tract (CST)
- Inferior Fronto-occipital Fasciculus (IFO)
- Inferior Longitudinal Fasciculus (ILF)
- Superior Longitudinal Fasciculus (SLF)

- Ventral Tegmental Area (VTA)

2 REGISTRATION

The registration problem (also known as alignment, absolute orientation) is one of the outstanding and very basic problems in computer vision. In this problem, two or more datsets of points are given and the task is to optimally align them by estimating a best transformation (combination of translation, rotation and scaling). Due to its fundamental importance, it arises as a subtask in many different applications (e.g., object recognition, tracking, range data fusion, graphics, medical image alignment, robotics and structural bioinformatics ... etc) [1].

2.1 *Iterative closest point (ICP)*

ICP, which is an algorithm employed to minimize the distance between two or more points clouds, is one of the widely used algorithms in aligning three dimensional models given an initial guess of the rigid body transformation required [6]. In ICP (in our case) one points cloud (vertex cloud), the reference, or target, is kept fixed, while the other one, the source, is transformed to best match the reference. The algorithm iteratively revises the transformation (combination of translation, rotation and scaling) needed to minimize a distance from the source to the reference points cloud.

3 PCA TRANSFORMATION

PCA is mathematically defined as an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance by some projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on[7]. PCA is used in the code as a preliminary step, so that the template and target are aligned as much as possible before the registration can begin.

4 LEAST SQUARES (LSQR)

LSQR uses an iterative method to approximate the solution. The number of iterations required to reach a certain accuracy depends strongly on the scaling of the problem ($||Ax - b||^2$). Poor scaling of the rows or columns of A should therefore be avoided where possible [8].

2

METHOD

The main subject of the thesis is demonstrating how the ICP framework can be extended to nonrigid registration, whilst retaining the convergence properties of the original algorithm. The main idea is application of the presented in [2]. The resulting optimal step nonrigid ICP framework allows for the use of different regularisations, as long as they have an adjustable stiffness parameter. The registration loops over a series of decreasing stiffness weights and incrementally deforms the template towards the target, recovering the whole range of global and local deformations. To find the optimal deformation for a given stiffness, optimal iterative closest point steps are used. Preliminary correspondences are estimated by a nearest point search. Subsequently, the optimal deformation of the template for these fixed correspondences and the active stiffness is calculated. Afterwards, the process continues with new correspondences found by searching from the displaced template vertices. We present an algorithm using a locally affine regularisation which assigns an affine transformation to each vertex and minimises the difference in the transformation of neighbouring vertices. It is shown that for this regularisation, the optimal deformation for fixed correspondences and fixed stiffness can be determined exactly and efficiently. The method is successful for a wide range of initial conditions, and handles missing data robustly. Furthermore, it is compared qualitatively and quantitatively to other algorithms using synthetic examples and real world data.

As it is defined in the introduction that vertex registration is a problem when two or more datsets of points are given and the task is to optimally align them by estimating a best transformation. In our case we use dense registration method to find a mapping from each point in the template onto the target while sparse methods find correspondence only for selected feature points. This is done by deforming the template, localy moving it closer in each iteration to the target in order to wrap them together with respect to stiffnes.

In the implementation we use homogeneous coordinates $[x, y, z, 1]$ in the 3D Euclidean space, the parameters X_i are 3×4 affine matrices for each vertex in the template. The X_i affine matrices are organized in $4n \times 3$ matrix X.

$$X = [X_1, X_2, ..., X_n]^T \tag{1}$$

3

RESULT

4

CONCLUSION

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