APPLICATION OF PHOTOGRAMMETRY TO BRAIN ANATOMY


Contents:
- Recap about human brain
- Project aims
- Photogrammetry for brain anatomy
- Results
- Conclusions

INTRODUCTION

The Central Nervous System (CNS) is composed of the brain, with all its nerves and spinal cord.

The human CNS is our control center, it keeps track of our body’s functions (i.e. breathing, heartbeat, digestion, etc.) and control actions like movement and speech.
INTRODUCTION

The human brain is divided into 3 parts: the cerebrum (largest), the cerebellum and the brain stem.

Human Brain

Cerebrum: touch, vision, hearing, speech, reasoning, emotions, learning & fine control movements.

Cerebellum: coordinate muscle movements, maintain posture, and balance.

Brain Stem: connecting the cerebrum and cerebellum to the spinal cord. Breathing, heart rate, body temperature, wake and sleep cycles, digestion, sneezing, coughing, vomiting, and swallowing.

Frontal Lobe
- Problem solving
- Emotional traits
- Reasoning (judgment)
- Speaking
- Voluntary motor activity

Parietal Lobe
- Knowing right from left
- Sensation
- Reading
- Body orientation

Occipital Lobe
- Vision
- Color perception

Temporal Lobe
- Understanding language
- Behavior
- Memory
- Hearing

Cerebrum

Brain Stem
- Breathing
- Body temperature
- Digestion
- Alertness/sleep
- Swallowing

Cerebrum is the largest part of our brain and it is split in the right and left hemispheres, having each four lobes.
INTRODUCTION

- The surface of the cerebrum is known as cortex.
- The cortex has a folded appearance: a fold is called gyrus, a groove is called sulcus.
- The cortex contains a complex network of neurons (gray or grey matter), connected by the white matter.

Gray matter (GM) vs White matter (WM)

- GM is composed of groups of neurons’ bodies and dendrites.
- GM receives and processes the signals.
- WM is composed of axons (carriers of cell signals).
- WM is the messenger and takes the signals of a single neuron to other neurons all across the brain.

https://www.anandatech.com/brain/structure.html
White matter (WM) is subject to a large spectrum of diseases (e.g. multiple sclerosis, etc.)

Two important research topics RE to the brain’s WM:

1) study WM anatomy for an exhaustive understanding of the brain diseases and functioning, but also to optimize the quality of neurosurgical approaches

2) study brain connectivity and identify axons (or bundle of axons, i.e. fascicles) in the WM to understand how information travels across the brain.

INTRODUCTION

METHODS FOR WM ANALYSIS

- Post-mortem invasive/destructive dissection of the brain

- In-vivo non-invasive analysis using diffusion magnetic resonance imaging (dMRI) and tractography
IN-VIVO NON-INVASIVE WM ANALYSIS

- In-vivo diffusion magnetic resonance imaging (dMRI): is sensitive to the diffusion of water molecules within the different biological compartments of the brain
- **Tractography**: identification of bundle of axons in the brain WM

  Model reconstruction of water diffusion in bundle of axons (tracts)

Data Acquisition (dMRI)  Fiber Tracking \(\rightarrow\) tractography

TRACTOGRAPHY VALIDATION

TRACTOGRAPHY from dMRI  TRACTS measured on real brain

TRACTOGRAPHY from dMRI has **not** yet been **validated** at anatomical level, thus it is still very common to measure the tracts on the brain (post-mortem) to verify what has been extracted from dMRI
PROJECT AIMS

- Provide an alternative digital solution to tractography in order to identify / track / measure tracts and bundle of axons in the brain WM
- Use photogrammetry and high-resolution 3D reconstructions (ca 50 micron) to analyse white matter during human brain dissection

INTERDISCIPLINARY PROJECT

Neuroinformatics

Surveyors & Photogrammetrists

Neuroanatomist & Neurosurgeons
The right hemisphere (95×175×70 mm³) is prepared (Klingler’s technique) with a process of formalin fixation, freezing and gradual defrosting of the brain.

Insertion of coded targets for scaling and co-registration of the multi-temporal models
Vessels and the meningeal layer are slowly and progressively removed using wooden spatulas by gently peeling the matter underlying the cortical layer.

WM fibres are so progressively manually exposed removing the matter underlying the cortical layer.
PHOTOGRAMMETRIC APPROACH

Six dissection stages of the right hemisphere (95x175x70) mm³

<table>
<thead>
<tr>
<th>0 - Cortical surface</th>
<th>1 - Cortical surface after removal of grey matter along the sulci</th>
<th>2 - Posterior part of the indirect path of the superior longitudinal fascicle (SLF)</th>
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<tbody>
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<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
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3 - Anterior and posterior part of the indirect path of the SLF
4 - Partial exposition of direct fibres (arcuate fascicle)
5 - Direct fibers (arcuate fascicle)

PHOTOGRAMMETRIC SURVEY

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Sample image @ full size</th>
<th>Sample image detail @ 100% zoom</th>
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<table>
<thead>
<tr>
<th>Equipment</th>
<th>Image scale</th>
<th>GSD</th>
<th>Focus distance</th>
<th>DOF @ CoC=3×pixel</th>
<th>Number of images</th>
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<tbody>
<tr>
<td>Nikon D3X + AF Nikkor 50mm f/1.8 D</td>
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<td>0.12 mm</td>
<td>1 m</td>
<td>180 mm</td>
<td>≈24</td>
</tr>
<tr>
<td>Nikon D750 + AF-S Micro Nikkor 60mm f/2.8G ED</td>
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<td>0.05 mm</td>
<td>0.5 m</td>
<td>35 mm</td>
<td>≈140</td>
</tr>
</tbody>
</table>
Two sets of images (24 + 140) at different resolution (0.12 and 0.05 mm) and with different cameras.

Two sets of images (24 + 140) at different resolution (0.12 and 0.05 mm) and with different cameras.
DENSE IMAGE MATCHING

Final average resolution of the dense point cloud: ≈ 0.05 mm (i.e. one GSD)

Multi-temporal (6 epochs) photogrammetric point clouds co-registered in a unique coordinate reference system

DENSE CLOUDS COMPARISON

Signed distances between point clouds corresponding to consecutive dissection stages: the differences highlight the removed parts, as well as the deformation occurred.

Colour-coded map of differences in mm between stage 2 and stage 3.
The blue colour represents removed parts in the dissection process.
The red might indicate deformation occurred
PRELIMINARY MEDICAL ANALYSES

Analyses white matter tracts on multi-temporal dense point clouds

REGISTRATION WITH MRI DATA

co-registration of MRI and dense point clouds (epoch 0) in order to transfer the annotations from the photogrammetric data to the MRI data and validate tractography
CONCLUSIONS & FUTURE WORKS

- An innovative method based on photogrammetry to support the visualisation and the acquisition of metric information on the structural connectivity and white matter of the human brain.

- 3D models are useful to doctors as non-invasive tools to analyze connectivity, axons and, in general, brain’s white matter.

- Annotations on the 3D dense point clouds useful to validate tractography performed on MRI data.

CONCLUSIONS & FUTURE WORKS

- Non-rigid transformation approaches will be investigated to improve (i) the registration between the multi-temporal photogrammetric point clouds and (ii) the dense point clouds with the MRI volumetric rendering.

- The tracts annotated on the multi-temporal photogrammetric dense point clouds will be mapped back on the MRI to validate the brain tractography.