Develeopment of Analysis Techniques for dynamic magnetic resonance imaging

– Master Thesis –

to be awarded

Master of Science in Medical Photonics

submitted by

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Abstract

Short summary of your thesis (max. 250 words) ...

Acknowledgements

If you want to thank anyone (optional) ...

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FSU Jena	Friedrich-Schiller-Universität Jena

1 Introduction

1.1 The Knee

The knee, a pivotal structure in the human body, plays an essential role in locomotion, supporting not just the physical weight of the individual but also facilitating a wide range of movements crucial for daily activities. Beyond its mechanical functions, the knee's health and integrity are vital for overall quality of life, influencing everything from basic mobility to participation in complex sports. In a comprehensive survey across 15 European countries and Israel, it was found that knee pain was the third most commonly reported location of chronic pain, highlighting the significant concern it poses to public health (Breivik et al. 2006). Furthermore, arthritis/osteoarthritis (OA) was identified as the most common cause of this pain.

And this situation has not improved with time. In Germany, a recent retrospective study has found that the number of patients with OA is steadily rising (Obermüller et al. 2024). Part of the reason knee-related issues are so prevalent and impactful is the inherent complexity of the knee joint itself. As a hub of various anatomical structures working in unison, the knee supports a range of movements and bears significant loads, making it susceptible to a variety of injuries and conditions. Understanding the anatomy of the knee is the first step in tackling this problem.

Anatomy and Function: Provide a detailed look at knee anatomy and its biomechanical functions, focusing on elements that are particularly relevant to imaging and dynamic activity.

Importance of Imaging for Knee Analysis:

Directly link the discussion on anatomy and function to the utility of imaging, specifically MRI, highlighting how detailed knee structure and motion understanding is crucial for accurate imaging. Introduce the concept of dynamic MRI here as a method that offers enhanced capabilities to observe and analyze the knee's dynamic nature, bridging directly to the next section without a separate transition.

1.2 Dynamic MRI

Begin this section by highlighting the limitations of traditional MRI in capturing the full range of knee joint motion, setting the stage for the introduction of dynamic MRI. Outline the importance of dynamic MRI in knee analysis, emphasizing how it provides a more nuanced and complete picture of knee mechanics, especially in motion. Discuss the applications of dynamic MRI in biomechanics and review existing methods for analyzing dynamic knee MRI data, setting the context for your research.

1.3 Foundational Work

Describe the two key papers that form the foundation of your thesis: the construction of the MRI knee loading device (Brisson et al. 2022) and the development of the imaging sequence used for capturing data. (Aleksiev et al. 2022)

1.4 Research Necessity

Discuss the necessity for further analysis of the acquired images, emphasizing the gap between data collection and data interpretation within the current literature.

Clearly state the objectives of your research, focusing on the development of new analytical techniques to interpret the existing dynamic MRI data.

Explain the expected contributions of your research to the field, including the potential implications for biomechanical understanding and clinical applications.

1.5 Thesis Structure

Structure of the thesis is as follows:

2 Methodology

some text

2.1 Data Collection Methods

2.1.1 The Device

A novel MRI-compatible device was integrated into the MRI scanner setup to facilitate guided knee motion in patients (Brisson et al. 2022). This device allowed for a range of motion of approximately 30 degrees, enabling subjects to perform knee flexion and extension cycles under both loaded and unloaded conditions. For loading, the device was equipped with compartments for weight plates (maybe picture here?) and sandbags, providing a physiological load of 10 to 12 kilograms.

Central to this device's functionality is an optical fiber position sensor actual citation needed?(MR3 Y10C10, Micronor, 155 Camarillo, CA, USA), which precisely which measures the ab solute angle from 0° to 360° with a resolution of 0.025°. This measurement capability is critical for synchronizing the knee's movement with MRI data reconstruction. To enhance signal acquisition and the clarity of imaging, two flexible coils (cite the coils here, perhaps also show a picture) were positioned at key anatomical locations: one at the distal femur and another at the proximal tibia, as specified in the MRI protocol. perhaps show a picture outside the scanner of the patient wearing it?

2.1.2 Procedure Details

MRI measurements were performed on four healthy volunteers (aged between 28 and 37 years, body mass between 55 and 90 kg) using a clinical 3 T Siemens Prisma fit scanner. Volunteers had no known musculoskeletal conditions and gave written informed consent in accordance with the guidelines set out by the institutional ethics committee. from device paper For all of these subjects, the left leg was used.

The thigh is secured on a wedge positioner, and the lower leg is attached to an ankle rest, just above the malleoli, using Velcro straps to minimize lateral movement. Once positioned at the scanner's isocenter, the volunteer then engages in a controlled exercise, following a metronome set at 60 beats per minute. This pace dictates a four-beat flexion to extension cycle, where the leg is flexed at the first beat and fully extended by the fourth. This exercise is performed for approximately 2 minutes throughout the duration of the scan, totaling between 100 to 120 repetitions. Initially conducted under a loaded condition with weights, the process is repeated without the added resistance to compare both states.

2.1.3 Sequence Parameters and Reconstruction

2.2 Data Analysis

All the analysis and data visualization were done using the python programming language (v3.11.5). To begin, the data in nifti (Neuroimaging Informatics Technology Initiative) format is loaded using nibabel (v5.1.0) library. It is then visualized using napari(v0.4.18), a multi-dimensional interactive image viewer in Python.

2.2.1 Segmentation

Step 1: Edge Detection Using the Canny Algorithm

The Canny filter (Canny 1986), as implemented in the scikit-image's feature library (v0.21.0), was employed to apply an edge filter to the images. Various parameters of the Canny algorithm were adjusted, including edge thresholds and Gaussian blur, to optimize edge detection. Subsequently, the scikit-image's morphology library was utilized to remove small elements from the binary image. The image was then skeletonized to a one-pixel width, retaining only long and consistent edges. The final selection of the desired edge was accomplished using scipy's label algorithm (v1.11.3).

2.3 Validity and Reliability

Validation Methods: Detail the steps taken to validate the segmentation techniques and the biomechanical parameters you derived. Reliability Measures: Describe any repeat analyses or cross-verifications done to ensure the consistency and reliability of your results.

3 Results

3.1 Segmentation

some text

3.2 Parameter Extraction

some text

4 Discussion

4.1 Technique Evaluation

Assess the effectiveness and accuracy of your segmentation techniques.

4.2 Biomechanical Insights

Discuss the biomechanical parameters obtained and their implications for understanding knee movement.

4.3 Comparison with Existing Methods

Compare your results with current analysis techniques.

5 Conclusion

5.1 Summary of Contributions

Recap the novel analysis techniques developed and their significance.

5.2 Limitations and Challenges

Discuss any limitations encountered and the challenges in the analysis process

5.3 Future Work

Suggest potential improvements and future directions for research

References

Aleksiev, Martin et al. (Oct. 2022). "High-resolution CINE imaging of active guided knee motion using continuously acquired golden-angle radial MRI and rotary sensor information". In: *Magnetic Resonance Imaging* 92, pp. 161–168. ISSN: 0730725X. DOI: 10.1016/j.mri.2022.06.015. URL: https://linkinghub.elsevier.com/retrieve/pii/S0730725X22001096 (visited on 02/12/2024).

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A Appendix

If needed for supplementary material, such as detailed description of data collection, tables, or figures.

Statutory Declaration:

I declare that I have developed and written the enclosed Master Thesis completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. The Master Thesis was not used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

Place, Date

Signature