Motion Artifact Reduction in Dynamic 3D Ultrasound Imaging of Human Tibialis Anterior Muscle

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Summary

While 3D ultrasound imaging offers a more portable and affordable alternative to MRI for in vivo muscle assessment in static conditions, capturing dynamic muscle contraction with this system remains challenging due to motion artifacts. This paper presents an enhanced 3D reconstruction pipeline that corrects misalignment between 2D ultrasound frames. The performance of the proposed pipeline is demonstrated through the reconstruction of 3D image sequences of the tibialis anterior (TA), using data recorded on a healthy subject performing periodic foot movements.

Introduction

Recent research [1] has demonstrated the potential of an automated 3D ultrasound imaging system for skeletal muscle investigation. By stacking 2D ultrasound images in 3D space, this system reconstructs high-quality 3D volumetric data of muscles in static states. However, applying this system for 3D muscle imaging in dynamic conditions [2] faces challenges such as misalignments between frames due to the inevitable shift of the subject's position during dynamic muscle contraction. This work aims to reduce such artifacts by incorporating image registration and interpolation algorithms in the 3D reconstruction pipeline.

Methods

The data acquisition setup integrates a customized ultrasound device with an IsoMed dynamometer for TA scanning. To minimize leg position shift, the subject's lower leg is fixated on the dynamometer during periodic plantarflexion and dorsiflexion, which are guided by the dynamometer. The acquired dataset consists of 2D ultrasound frames and their respective probe position, joint angle, and force output as labels.

The 3D reconstruction pipeline categorizes the 2D slices into discrete bins defined by joint angle intervals. The Enhanced Correlation Coefficient (ECC) algorithm [3] is used within each bin to sequentially correct misalignment between consecutive slices by computing alignment scores and transformation vectors (Figure 1). Subsequently, missing slices in the reconstructed 3D volume are interpolated by computing dense 2D optical flow between the adjacent slices.

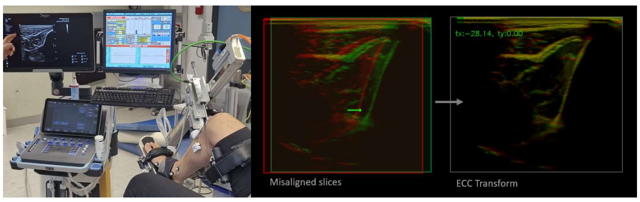

Figure 1: Data acquisition setup (left) and demonstration of ECC algorithm for misalignment correction between consecutive slices in the reconstruction pipeline (right).

Results and Discussion

A series of 3D images was generated for ankle joint angles ranging from -4° (plantarflexion) to 4° (dorsiflexion) using both 1° and 2° increments. TA volume at each joint angle interval is segmented semi-automatically. The results show a significant reduction in motion artifacts compared to reconstructions without misalignment correction (Figure 2). Minor artifacts persist due to slight contraction variations between cycles, which needs further improvement in the pipeline to compensate for this inherent variability.

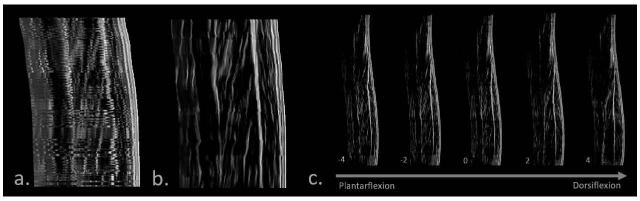

Figure 2: (a) Motion artifacts in reconstructed volume. (b) Reconstructed volume after artifact correction. (c) Sagittal view of reconstructed 3D volume sequence.

From the 3D image sequence, dense deformation fields can be computed to determine muscle mechanical properties. When combined with EMG data, the proposed method facilitates future muscle research in internal activation patterns.

Conclusions

Leveraging computer vision technologies, this work presents an approach for dynamic 3D ultrasound muscle imaging with reduced motion artifacts, enabling further investigation of muscle behavior in its functional condition.

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References

[1] Sahrmann, A.S. et al. (2024). A system for reproducible 3D ultrasound measurements of skeletal muscles, *IEEE Transactions on Biomedical Engineering*, **71(7)**: 2022–2032.

[2] Sahrmann, A.S. et al. (2024). Determination of muscle shape deformations of the tibialis anterior during dynamic contractions using 3D ultrasound, *Frontiers in Bioengineering and Biotechnology*, **12**.

[3] Evangelidis, G.D. and Psarakis, E.Z. (2008). Parametric image alignment using enhanced correlation coefficient maximization. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, **30(10)**:1858–1865.