Improved Tracking of Muscle Tendon Junctions in Ultrasound Images Using Speckle Reduction

Bernhard ENGLMAIR[a,1], Christoph LEITNER[a,b,1] and Christian BAUMGARTNER[a]
[a] *Institute of Health Care Engineering with European Testing Center of Medical Devices, Graz University of Technology, Graz, Austria*
[b] *Institute of Sport Science, University of Graz, Graz, Austria*

Abstract. Ultrasound imaging enables in-vivo investigations of muscle and tendon behaviour during human movement. Individual contributions of muscles and tendons to the behaviour of the whole muscle-tendon unit during locomotion are versatile. Therefore, movements of distinct landmarks, such as muscle tendon junctions are recorded and tracked in order to investigate internal dynamics of the muscle-tendon complex. In this study, we use a semi-automatic tracking method based on image segmentation and investigate how tracking accuracy can be improved using a sticks filter. We demonstrate that a speckle reduction decreases the root-mean-square error of the tracking result by up to 78.1%, depending on the chosen window size of the sticks filter.

Keywords. image processing, ultrasound, speckle noise, sticks filter

1. Introduction

As with all vertebrates, human movement is based on the contraction and relaxation of skeletal muscles. Thus, the activated muscles shorten and the muscle-tendon unit changes in length. Human movement initiates when generated forces are transferred via tendons to the bones and joints. In order to study neuromuscular functions and diseases, direct views on muscles and tendons during movement are necessary. Currently, researchers investigate material properties and behaviour of muscles and tendons using ex-vivo experiments. Others apply inverse approaches, in which again cadaver based skeletal muscle models are scaled to the body anthropometry of test subjects [1].

Recently, musculoskeletal ultrasound (US) has been used to directly investigate the in-vivo behaviour of muscles and tendons during human movement and posture [2]. Contributions of muscles and tendons to the behaviour of the whole muscle-tendon unit are versatile [3]. To identify their properties, locomotion researchers use US to record the dynamic behaviour of the muscle tendon junction (MTJ) [4]. Since manual tracking of the MTJ in large cohorts is time consuming, numerous fully and semi-automated tracking algorithms have been proposed [5] [6].

[1] Corresponding Authors: Bernhard Englmair & Christoph Leitner, Institute of Health Care Engineering with European Testing Center of Medical Devices, Graz University of Technology, Stremayrgasse 16/II, 8010 Graz, Austria, E-Mail: b.englmair@student.tugraz.at, christoph.leitner@tugraz.at

However, US imaging is prone to errors such as refraction, reverberation, comet tail or ring-down artifacts. Our study focuses on image enhancement by reducing speckle artifacts. Speckling is identified as the coarseness of gray areas in US images. It occurs due to constructive and destructive interference of diffuse reflected echos [7]. From the medical standpoint, speckling is not an undesirable occurrence, as it is used as diagnosis criteria, e.g. in myocardial strain analysis with speckle-tracking echocardiography [8]. This cannot be generalized for all applications in computer vision, because speckling can also be an unwanted artifact for certain tasks. In literature the term "speckle noise" is widespread, although technically speckling is a deterministic artifact rather than a random noise.

This study investigates the effects of speckle reduction on a semi-automatic tracking strategy for the MTJ. In section 2 we describe the acquisition of US images and the properties of the proposed speckle filter. Further, we demonstrate how the speckle filter is integrated into the tracking algorithm using MATLAB (Mathworks, Natick, Massachusetts, USA). We present tracking results dependent on filter size in Section 3 and discuss these results in Section 4. Finally, we draw a conclusion of our study in Section 5.

2. Material and Methods

2.1. Experimental Design and Image Acquisition

To collect US data of the MTJ, we recorded isometric plantarflexions in lower limbs (Figure 1). First, we manually placed the US transducer on the medial gastrocnemius MTJ of the left leg. After the correct placement of the transducer, the subject performed one maximum voluntary contraction during recording.

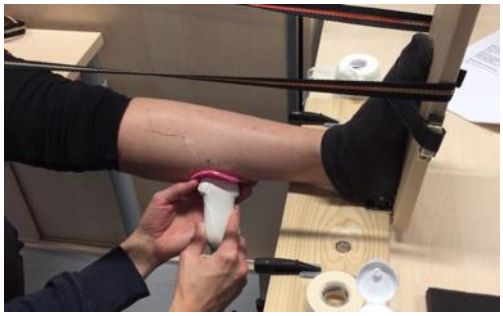

Figure 1. Observing the plantarflexors of the lower limb with US during an isometric contraction.

Table 1 shows the hardware configuration and properties of the US system. The chosen video of this data set consists of 70 frames (2.8 s). We recorded one isometric plantarflexion, consisting of a contraction phase of approx. 2.52 s and a relaxation phase of approx. 0.28 s.

Table 1. Configuration of the image acquisition setup.

Ultrasound system	myLab 60, Esaote SpA, Genova, Italy
Transducer	LA923, Esaote SpA, Genova, Italy
Transducer length	100 mm
Image depth	74 mm
Number of channels	192
Frequency	7 MHz
Framerate	25 fps
Image resolution	800 x 600
Video file format	.avi
Codec	24 bits RGB (RV24)

2.2. Speckle Reduction with Sticks Filter

US images usually contain a high amount of speckling. This is problematic for most image processing methods, because the decrease of spatial resolution and contrast-to-noise ratio impedes an effective feature extraction, edge detection and image analysis [9]. Ideally, areas of the same tissue type are displayed as uniformly shaded gray areas rather than black and white speckles. This can be achieved by using smoothing methods such as mean or median filtering. At the same time, however, useful information e.g. transition areas between muscle and tendon tissues should remain preserved. Since smoothing filters [10] uniformly blur the whole image, they are not well suited for preprocessing US images.

A more advanced approach is the sticks filter [11] which is a special type of adaptive weighted directional mean filter. In this approach, the masks are a composition of several lines, as seen in Figure 2.

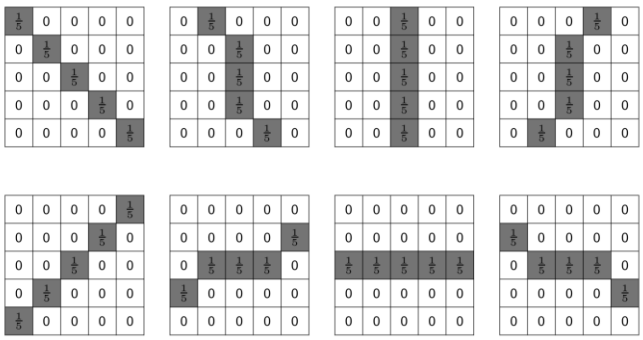

Figure 2. Sticks filter masks with size 5 x 5. [12]

A given filter size of *N x N* results into *2N - 2* short lines, called "sticks". The weight values within these sticks are set to *1/N* and all the other ones to 0. The procedure for finding the right stick for a certain pixel is as follows:

For each pixel, all filter masks are applied one after the other. For each mask, the pixel values are multiplied with the corresponding weights and summarized. The highest sum of all sticks is then selected as a new value for this particular pixel. Hence, these sticks are mainly oriented along bright areas of the US image, rather than along cross

sections between bright and dark areas. This characteristic leads to a reliable edge preservation while speckles are filtered effectively [12].

2.3. Image Processing

Our proposed image processing methodology can be subdivided into two steps:

I. Image preprocessing: Speckle reduction with sticks filter.
II. Image processing: Segmentation of one feature (medial gastrocnemius) and calculation of the MTJ position.

Figure 3 shows the process flow of our proposed method for image enhancement and tracking.

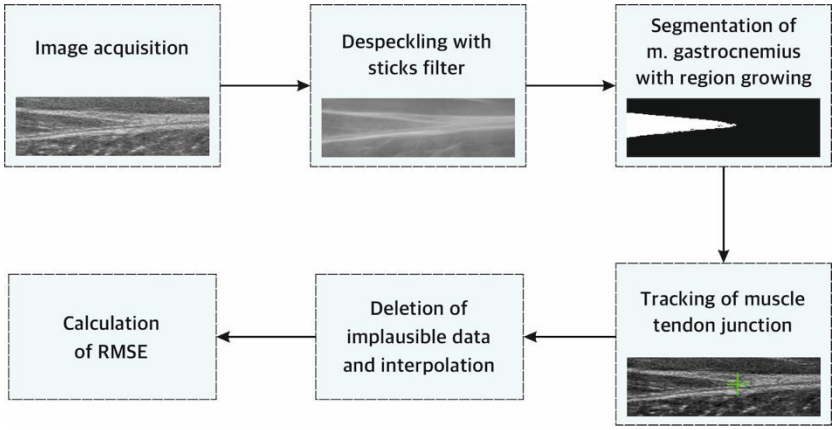

Figure 3. Block diagram of processing architecture.

For image enhancement, the acquired US images are despeckled by a sticks filter. Based on preprocessed images, the medial gastrocnemius (MG) is segmented by using a region growing algorithm [10]. First, a seed point is placed by the user within the area of the MG. Starting from the seed point pixel, all neighboring pixels whose gray scale values do not exceed a certain difference (e.g. 10%) from the value of the initial seed point are combined to a region. This process is repeated at bordering pixels until no additional pixels can be added to this region.

The MTJ is defined as the most distal insertion of the muscle into the tendon (Figure 4). Starting from the proximal end, our tracking algorithm searches for the position of the MTJ ($P_{MTJ}(x,y)$) by scanning each pixel column (x_c^i) and measuring the y-distances between the lower image border and the MG muscle (indicated in white color). This process is repeated for every pixel column up to column (x_c^{i+1}), where the upper image border is reached for the first time. We then identify the x and y coordinates of $P_{MTJ}(x,y)$ at x_c^i.

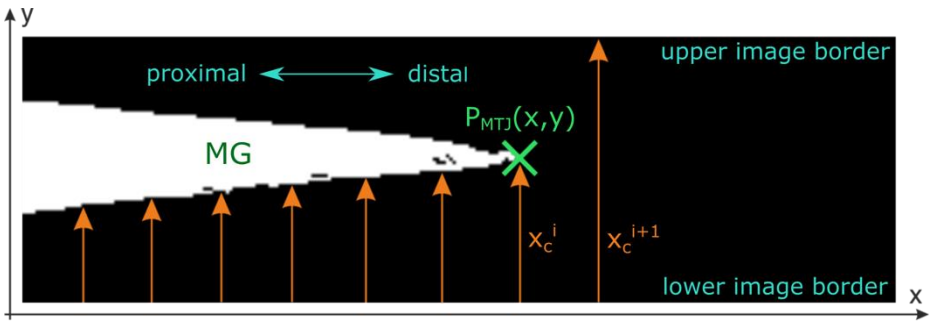

Figure 4. Computation of the tracking point based on region growing segmentation.

When the contrast-to-noise ratio is too low or the edges between tendon and muscle tissues are weakly pronounced, the segmentation of the MG fails. To compensate for errors, position changes larger than 5 mm are determined as false results and therefore replaced by interpolated positions.

To statistically evaluate tracking results, we calculate the root-mean-square error (RMSE, Eq. (1)) for all (n) images of the calculated MTJ positions $\hat{\theta}$ and the true positions θ.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\theta_i - \hat{\theta}_i)^2}{n}} \tag{1}$$

3. Results

Figure 5 shows original image, as well as five despeckling stages using a sticks filter. The filter windows are square and have the size s in pixel (px).

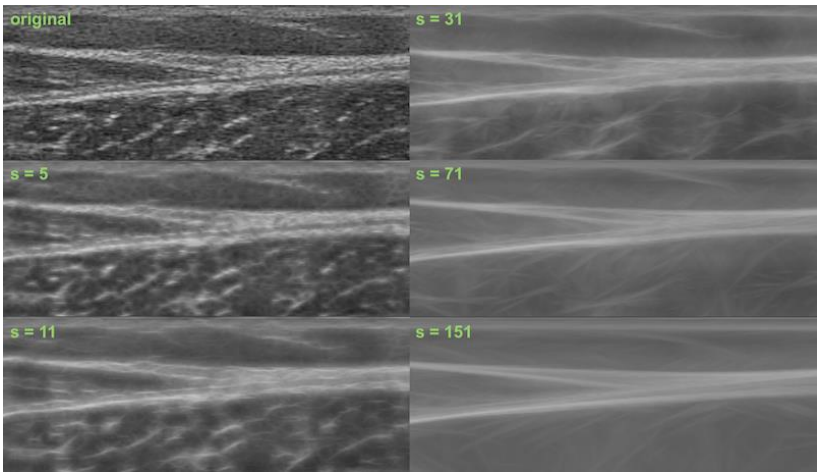

Figure 5. Comparison of results for different filter sizes.

The dependency of the resulting RMSE on the filter size for despeckling is displayed in Figure 6.

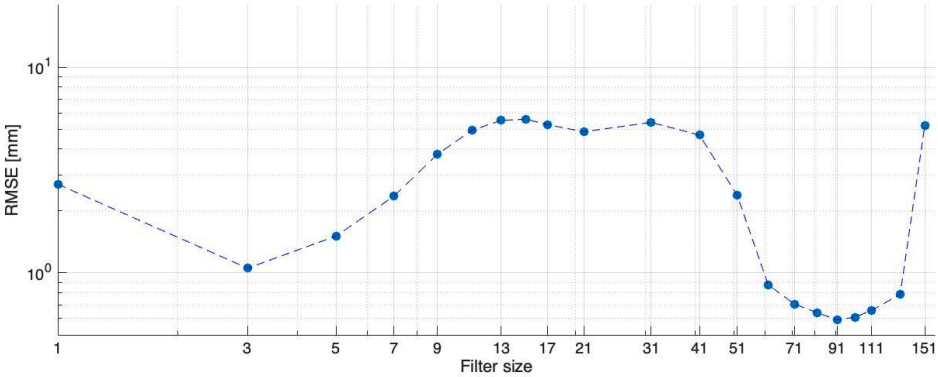

Figure 6. RMSE dependent on filter size.

The MTJ shifts approx. 25 mm during the maximum voluntary contraction. Using the original image (s = 1 px) for tracking leads to a RMSE of 2.696 mm. Applying the smallest filter with s = 3 px results in a RMSE of 1.055 mm, which is a relative error decrease of 60.9%, compared to the RMSE of the unfiltered tracking result. However, choosing 3 px < s < 9 px leads to a decrease in tracking accuracy. The tracking error reaches a plateau with filters between 9 px < s < 41 px. Tracking accuracies in this area are lower than those for unfiltered image data.

The tracking error starts again to decrease for filter sizes between 41 px and 131 px. A filter with s = 91 px yields the best result of all trials with a RMSE of 0.591 mm. This is a relative RMSE reduction of 78.1%. Choosing filters with s > 131 px again leads to decreased tracking accuracies.

4. Discussion

Segmentation methods for the MTJ are not only affected by speckle noise, but also by unwanted features such as muscle fascicles. Since the sticks filter searches for the optimal filter direction for each pixel, it naturally preserves large linear objects such as tendons. Objects smaller than the filter size, such as muscle fascicles are suppressed in the same ways as for speckles. This effect is shown in Figure 7. The tissue of the soleus muscle (SO) is marked by a blue circle. The fascicles remain preserved when using a smaller filter size (s = 11 px) but disappear when using a larger one (s = 151 px). Hence, using a sticks filter with a window size larger than 71 px leads to an image where only the tendon structures remain.

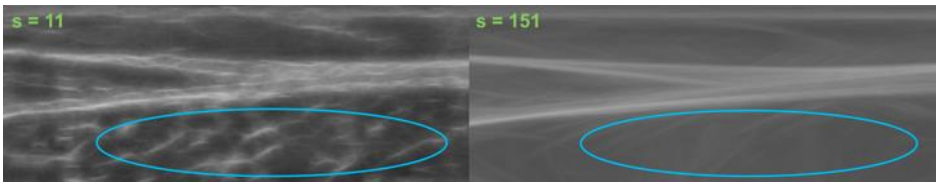

Figure 7. Effect of choosing a large window size when despeckling with sticks filter.

Since region growing is based on the successive inclusion of similar neighboring pixels to a region, bright and dark speckle patterns effect the resulting segmentation and further tracking of the MTJ. A sticks filter with s = 3 px smoothens the speckle pattern and creates an evenly gray distributed image, respectively. Hence, the speckle noise is suppressed and the region growing algorithm yields a better result. However, when we utilize a filter with s > 3 px, the speckle reduction does not improve significantly. Instead, the local transitions between bright and dark tissue types are blurred and the position of the MTJ cannot be calculated as accurately. With filter sizes between 61 and 131 px, the sticks are preferably aligned along tendons. This results into sharper edges between muscle and tendon tissue which is the optimal base for applying segmentation methods. With s = 151 px, the sticks start to become too large to be aligned along tendons, which leads into a strong blurring of the MTJ and an increased tracking error.

5. Conclusion

We demonstrated that image enhancement using a sticks filter can increase the tracking accuracy of the MTJ in ultrasound images. With large window sizes, the sticks filter decreases the RMSE by up to 78.1%.

However, correlations between tracking results and filter sizes are strongly dependent on image properties and observed features (e.g. muscle tendon junction). Hence, a generalized recommendation for optimal filter sizes in ultrasound images cannot be given.

Choosing a filter with s = 3 px for ultrasound images of muscle tendon junctions improves tracking results by 60.9% compared to unfiltered images. The image enhancement process with s = 3 px for an image size of 800 x 600 px took 12.2 s. The same image filtered with s = 91 px took 81.2 s, which is a relative runtime increase of approx. 565%. Hence, using a sticks filter with s = 3 px results in a time efficient and significant image enhancement to track the muscle tendon junction in ultrasound images.

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