Measurements over the Aquiles Tendon through Ecographic Images Processing

M-Consuelo Bastida-Jumilla, Juan Morales-Sánchez,
Rafael Verdú-Monedero, Jorge Larrey-Ruiz, and José Luis Sancho-Gómez

Dpto. Tecnologías de la Información y las Comunicaciones,
Universidad Politécnica de Cartagena
Plaza del Hospital, 1, 30202, Cartagena (Murcia), Spain
mcbj@alu.upct.es

Abstract. Boundary detection has a relevant importance in locomotor system ecographies, mainly because some illnesses and injuries can be detected before the first symptoms appear. The images used show a great variety of textures as well as non clear edges. This drawback may result in different contours depending on the person who traces them out and different diagnoses too. This paper[1] presents the results of applying the geodesic active contour and other boundary detection techniques in ecographic images of Aquiles tendon, such as morphological image processing and active contours. Other modifications to this algorithm are introduced, like matched filtering. In order to upgrade the smoothness of the final contour, morphological image processing and polynomial interpolation has been used with great results. Actually, the automatization of boundary detection improves the measurement procedure, obtaining error rates under ±10%.

1 Introduction

The use of ecographic images leads to pathology detection in the locomotor system even before any symptom may appear. Thus, it is very important to quantify accurately the parameters that determine the existence of an injury in order to avoid more serious symptoms. Since the Aquiles tendon is frequently damaged, especially for professional athletes, this structure has been chosen for this study.

The ecographists can diagnose the pathology once the tendon border is established. To that end, a manual contour of the tendon is drawn on the ecography. Based on it, necessary measurements are taken. Among all of them, we can remark the ecogenicity, which shows the mean of the grey level inside the tendon contour. This measurement, along with the area, is the one which best identifies the pathology, and it turns out to be the most interesting, in medical terms.

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When distinguishing between several grey levels, a computer can make a quantification which is more accurate than that from the human eye, exceeding the 64 grey levels to which the human eye is limited.

As the contour is drawn manually, the diagnosis may vary from one specialist to another. Hence it would be paramount to define the perimeter of the tendon from an objective point of view, making the disparity of criteria minimal. Thus, the possibility of developing a reliable tool to determine the border of the Aquiles tendon is felt to be a subject of study. With that purpose, different image processing and border detection techniques, such as morphological processing, active contours and geodesic active contours, have been used.

2 The Aquiles Tendon in Ultrasound Scan Images

The Aquiles tendon is composed of a set of fibres which stretch together along all its length. A transverse cut of the ligament shows all this information. In Fig. 1 circular zones with high ecogenicity (or pixels with nearly white colour) can be observed inside the tendon corresponding to the fibres of tissue. These zones are surrounded by small areas with low ecogenicity (or nearly black pixels) corresponding to the space between fibres. Therefore, the ecogenicity is indicative of the kind of mean observed. High levels reveal the existence of hard tissues, whereas a low ecogecinity reveals the presence of a liquid mean.

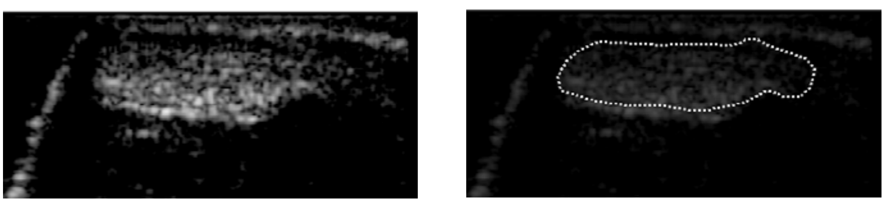

Fig. 1. One of the ecographies used (left) and medical draw of the tendon (right)

3 Image Processing Techniques

3.1 Morphological Processing

The *morphological processing* makes the task of transforming the shape or structure of the objects into an image possible, by basing on set theory. Considering the original image as a mathematical set, another set (the *structuring element*) will be used to do a set operation between them. Thus, a new set or final image is obtained. By selecting properly the structuring element and the morphological operation, any transformation of the original image can be achieved. Afterwards, the morphology of the objects in the image can be analysed [1] .

The morphological processing will allow getting input parameters for other border detection algorithms, as well as softening contours.

3.2 Active Contours

Active contours, also known as *snakes*, are based on elastic bodies physical models. In this manner, its evolution in time and space is determined by both elastic and stiffness parameters. Regarding border detection, and apart from these parameters, other forces will take part in the process by deforming the original contour. These forces stem from the information displayed on the ecography (internal forces) or from other elements which are alien to the image (external forces), e. g. forcing the final contour to have a determined surface.

The shape of the *snake* is determined by an energy functional in which internal forces, and external forces are involved (see [2,3]). The so-defined contour represents the force effects such as the spatial gradient of the image or the relation between the final area and the goal area.

At this point, the preliminary results obtained with morphological processing can be useful. Morphological analysis provides a binary image or matrix with an initial perimeter corresponding to the image subject of study. Taking that image as a starting point, the *snake* will be initialized and the external forces will be established.

Furthermore, the internal forces are based on the gradient of the image. More specifically, the Laplacian will be used to calculate the internal forces. The gradient shows the maximum variation direction, whereas the Laplacian (being a second order derivative) finds the presence of the edge, or more precisely, the sharp level changes in the image.

3.3 Geodesic Active Contours

The *geodesic active contour* or *levelsets* are an improvement of active contours in which external forces are not necessary. *Levelsets* also produce better results with texture and topology changes (allowing the detection of more than one object) and can detect edges that appear more diffuse.

The *levelsets* algorithm is based on the thresholding of a geodesic curve for each iteration. The solution will correspond to the zero level. As a result of this, the contour is not a flat image anymore but an image with different colour levels, and thus, a three-dimensional image. The correspondence between a *snake* and the evolution of the zero level of the geodesic curve is already demonstrated [4]. Geodesic active contours improve some aspects of the previous method and are still based on the same principles of deformable body models.

The edge detection model suggested in [4] is the following:

$$\frac{\partial u}{\partial t} = |\nabla u| \, div \left(g(I) \frac{\nabla u}{|\nabla u|} \right) + c \cdot g(I) \, |\nabla u| \tag{1}$$

where $c \epsilon \Re^{+}$, $\kappa = div(\nabla u / |\nabla u|)$ is the Euclidean curvature and $g(I)$ is the edge detector function. This equation involves a geodesic curve or *levelset* evolving according to:

$$v_t = g(I)(c + \kappa)\bar{N} - (\nabla g \cdot \bar{N})\bar{N} \tag{2}$$

where $\bar{N}$ is a unit vector normal to the curve.

Expression (1) establishes the *geodesic active contours model* and the solution to the edge detection problem is given by the zero level of the geodesic curve in a stable state. In reference [4], the existence, stability and consistency of this solution are demonstrated.

The image-dependent force is given by the stopping function $g(I)$. Its goal is to stop the curve evolution when it reaches the object boundaries. The function used is as follows:

$$g(I) = \left(1 + \left|\nabla \hat{I}\right|^p\right)^{-1} \tag{3}$$

where $\hat{I}$ is a smoothed version of the original image (obtained via some kind of filtering) and $p = 1, 2$. With this stopping function, for an ideal edge $g = 0$ $(\nabla \hat{I} = \delta)$ and the contour will stop $(u_t = 0)$.

This gradient term attracts the curve toward the object boundaries, which is very useful when the object edges have high variation of the gradient, including holes. The second advantage is that the necessity of a constant speed introduced by c is almost unnecessary, since with the gradient term the boundary detection of non-convex objects is still possible. Despite this fact, c can be included to increase the convergence speed considering $c \cdot g(I) \left|\nabla u\right|$ as a constraint in the geodesic problem.

4 Processing Scheme

4.1 Morphological Processing

A binary mask of the tendon can be obtained by using *morphological processing*. By means of this mask, an initial contour and a target area are calculated. This contour is similar to the edge of the tendon, and the area can be used to calculate the external force factor. An example of binary mask is shown in Fig.2. Although, at first sight, the area provided by the mask is not exactly the same as the one drawn by the doctor, with this mask an ellipse can be obtained. By fitting the ellipse to the mask, the initial contour will be established. This ellipse can be used not only to provide an initial curve, but also a target area. The next step consists of implementing a close active contour using this data.

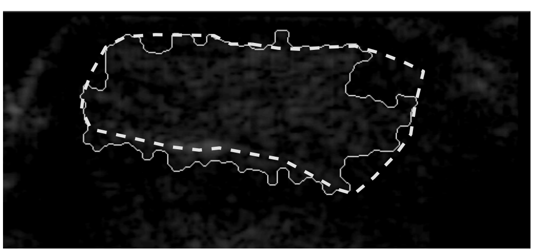

Fig. 2. Binary mask (continuous) and the medical contour (discontinuous)

Obviously, the real area does not coincide with the mask area. Despite the error introduced by using the binary mask area as the goal area, the effect of the internal forces, or the image forces, should be able to compensate it.

4.2 Active Contour

The first step to initialize the edge detection is to establish the curve for the first iteration. With that purpose, the ellipse that best fits the morphological mask will be used. Next, a smooth version of the image will be used to blur the possible gaps in the tendon. Since there are great variations of textures inside the tendon and even in nearby tissues, it is complicated to find a filter which equalizes the texture of the tendon without joining it to neighbouring tissues. That is the reason why, instead of using symmetrical filtering, matched filtering will be employed.

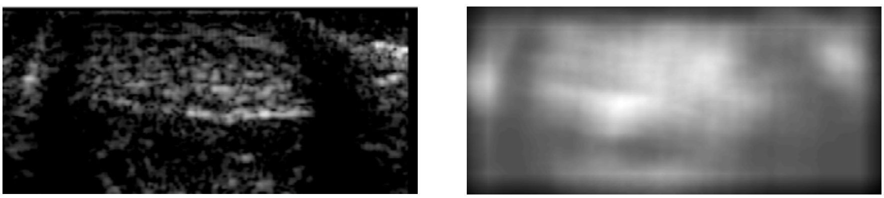

Fig. 3. Original image (left) and output of the matched filter (right)

With this filtering, the zones that are more correlated with the filter are found, using a fragment of the image as a filter. This way, warm colours show great similarity (i.e. similar texture), whereas cold colours show low correlation with the fragment of the image.

To calculate a new mask which gives a more accurate initial contour, the output of the match filtering is subject to thresholding. Before that, the image edges are filtered with a Hanning filter to prevent the *snake* from getting stuck within the image limits. An example of the mask is shown in Fig. 4 along with the final result.

To calculate the internal forces, the gradient of the matched filtered image has been used.

The obtained contour has been fitted to the medical contour, but only in those areas where there is a high ecogenicity variation. Mainly it is due to the different texture of the inner part of the tendon, the difficulty to obtain a valid smooth version of the image and the high dependence on the initialization. The problem is that neither the external forces (target area) nor the internal forces (the Laplacian of the output of the matched filter) show an accurate value. Consequently, the interactions between these forces will not compensate the error but will increase it.

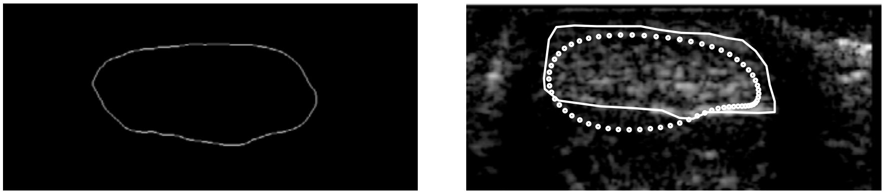

Fig. 4. Mask obtained after applying both matched and Hanning filtering (left) and solution curve (right, discontinuous) with the medical contour (continuous)

4.3 Geodesic Active Contours

Given the previous results, an edge detection technique which works better with topology changes and different textures will be needed. Geodesic active contours or *levelsets* are quite suitable for this case. By using this algorithm, the texture variation will not be a relevant issue. Therefore, a simple Gaussian filter can be useful to smooth the original image. The initial curve is given by an ellipse calculated from the thresholding of the matched filter output. However, for some of the images, this ellipse has had to be manually modified because of the variety of tendon sizes and shapes.

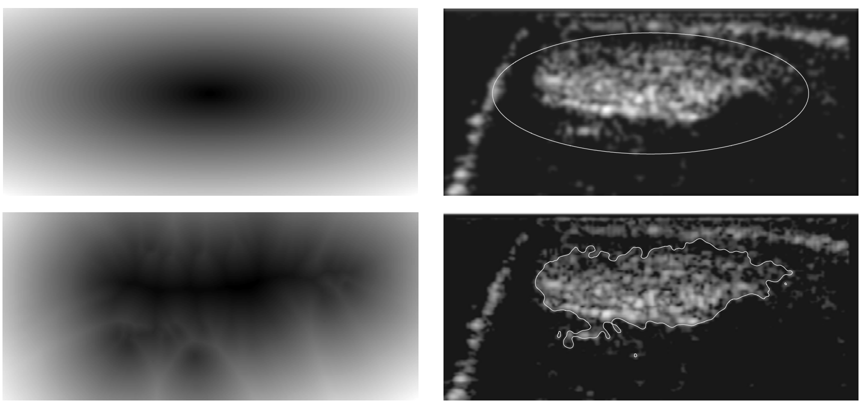

Fig. 5. Initial and final contours (left) and its corresponding zero levelset over the ecography (right) in first iteration (up) and after 3000 iterations (down)

The solution obtained is quite faithful to the boundary established by the doctor. The only problem is the roughness of the contour. Despite including a parameter to control the smoothness of the boundary, it is still too irregular. To improve the smoothness of the perimeter, morphological processing will be used. In particular, an average of closing and opening operations over the geodesic curve with the same structuring element is used. The result for the previous image is shown in Fig. 6. To calculate the internal forces, the gradient of the matched filtered image has been used.

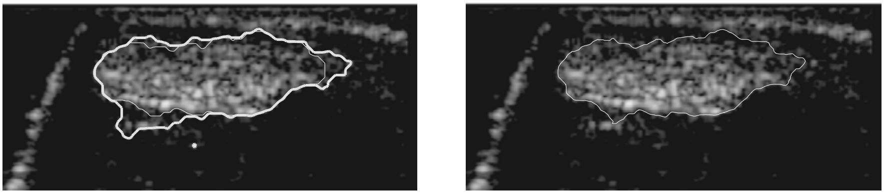

Fig. 6. Opening (left thicker) and closing (left thinner) results, and average (right)

The smoothness has improved, but it still turns out to be insufficient. Thus, polynomial interpolation has been used, obtaining the image in Fig. 7.

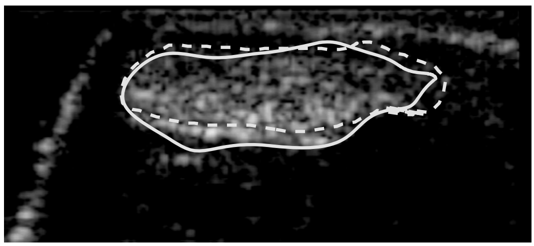

Fig. 7. Contour obtained after interpolation (continuous) and contour drawn by the doctor (discontinuous)

At the bottom area, the curve has reached a border, but this border does not coincide with the contour made by the ecographist. This feature of the Aquiles tendon is unachievable to the edge detection methods because the medical contour does not correspond to any edge. However, taking into account the information on the image, the used algorithm has detected properly the edges in the image.

5 Results

As stated before, from the medical point of view, the most important measurements are the mean ecogenicity and the area of the tendon; these will be the fundamental measurements. Besides, other complementary measurements will be taken to give more information about the obtained contour, such as the length of the perimeter, the width, the height and the eccentricity. Some contours obtained with geodesic active contours are shown in Fig. 8.

In Table 1, different measurements corresponding to images on Fig. 8 can be seen. The images have been chosen with illustrative purposes, because they provide good visual results. The obtaining of contours which are similar to those drawn by the doctor may not involve accurate numeric results as can be observed from the table in this paper. Measurements with a relative error in a range from -10% to +10% can be accepted [5]. In Table 1 the ecogenicity, area and perimeter

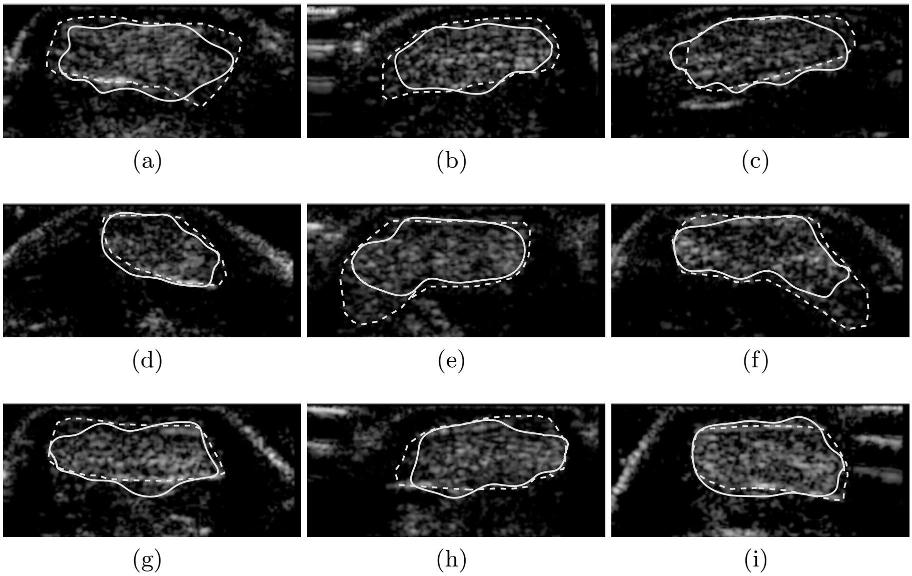

Fig. 8. Contours obtained with the *levelsets* algorithm with the best initialization (continuous) and drawn by the doctor (discontinuous)

relative error obtained from geodesic active contours can be seen. Most of the images have a much lower error than the ±10% acceptable error, even though there are some exceptions.

It is remarkable that Fig. 8(a) has a considerable ecogenicity error far above the ±10% allowed. The ecogenicity is a mean value and, thus, a sligthly different contour which includes areas with high ecogenicity can severely affect this measurement. This is the reason why the images in Fig. 8(b), 8(e) or 8(f) present a low ecogenicity error, whereas images in in Fig. 8(a) and in Fig. 8(i) show a higher error. However, as the area error grows, the medical and *levelsets* contour are more different, e.g. images in Fig. 8(d) or in Fig. 8(g).

As far as the perimeter is concerned, we can say that the more similarities with the medical outline have, the lower the perimeter error is. This fact can be appreciated in Fig. 8(d), 8(g) or 8(i).

The boundary detection via *levelsets* exclude those areas in which there is a liquid mean (i.e. low ecogenicity) next to the tendon. In these cases, no algorithm will be able to reach the medical perimeter, since only the intuition and the experience of the ecographist will make the difference between including these

Table 1. Relative error of the different measurements taken in percentage

Image	8(a)	8(b)	8(c)	8(d)	8(e)	8(f)	8(g)	8(h)	8(i)
Ecogenicity	−18.52	−5.70	−5.51	−0.60	1.55	0.63	−5.88	−6.55	−18.54
Area	0.65	18.81	4.10	1.90	0.85	−8.88	−2.74	9.50	−13.42
Perimeter	−8.32	10.77	7.25	5.28	1.75	−17.41	−4.52	5.70	−2.85

areas or not . Thus, the shape and features of the Aquiles tendon are responsible for some of the noticeable differences between contours.

6 Conclusions

The ecographies have occasionally provided irrelevant information, because of the great variety of textures (even inside the tendon), the subjectivity of the medical boundary and the reduction of the image quality due to a deficient image take. Besides, the a priori impossibility to obtain a line which delimits a border in some areas and the maximum ecogenicity in other regions makes the results not to correspond to the medical contour. These special features of the tendon and the ecographies poses special difficulties to the development of a completely objective tool, and thus, automatized.

The area delimited by the doctor contains information resulting from an expert knowledge of the nature and features of the Aquiles tendon which does not appear in the image. However, from the point of view of image processing, and taking into account the images given, the results can be considered as correct, but at the expense of high computational cost.

Although the difficulties detected during the development of the project, interesting applications have been found, such as using an average of opening and closing together with a polynomial interpolation to improve the smoothness of the contour, or the use of matched filtering to determine the extent of the injury by measuring the surface with a concrete texture.

Furthermore, the high dependence on the initialization is manifest, for both the active contours and the geodesic active contours. Nevertheless, this dependence is not so relevant. The specialists have no difficulties in determining an area inside which the tendon is, but without including neighbouring tissues. Actually, there are multiple initial curves that will lead to the same right solution. What is really hard to find accurately is where to determine the existence of an edge or border. Since the presented methods are capable of distinguishing between more grey levels, the edge detection will be more accurate than the one made by the doctor.

Given the implications of this project, that would allow the detection of the pathology before the appearance of any symptoms, and the relevance of the obtained results, it would be interesting to study the possibilities of improvement of the results and the drawbacks found. Mainly, the high computational cost of *levelsets* should be decreased (by eliminating the reinitialization of the contour or by implementing the fast version of the algorithm, *fast geodesic active contour* [6], [7]), we should likewise improve the procedure of caption of the ecography to obtain images with more definition, or also develop an automatic initialization.

On the other hand, the use of other techniques could be possible, such as *neuronal networks*, which take into account information which does not appear in the image, like the knowledge derived from the medical experience. Consequently, the network can be trained with a set of ecographic images in a way that the network can be adapted to the problem and including the knowledge acquired during the learning stage.

Another possibility could be the use of patterns for the *snakes* algorithm. By defining an established pattern of how the boundary of the tendon should be, we could force the curve to be similar to that pattern. Therefore, the *snake* algorithm would fit better in this problem and, thus, reducing the computational cost of *levelsets*.

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References

1. González, R.C., Woods, R.E.: Digital Image Processing. Prentice Hall, Englewood Cliffs (2002)
2. Liang, J., McInerney, T., Terzopoulosd, D., Liang, J., McInerney, T., Terzopoulos, D.: United snakes. Medical Image Analysis 10, 133–215 (2006)
3. Huete, V.M.: Implementación en Matlab de modelos deformables en el dominio de la frecuencia. Master's thesis, ETSIT: Escuela Técnica de Ingeniería de Telecomunicación (February 2005)
4. Caselles, V., Kimmel, R., Sapiro, G.: Geodesic active contours. International Journal of Computer Vision 22(1), 61–79 (1997)
5. Payá, J.J.M., Díaz, J.R., del Baño Aledo y otros, M.E.: Estudio de fiabilidad intra e interobservador en la medición del perímetro del tendón de aquiles en un corte ecográfico transversal
6. Goldenberg, R., Kimmel, R., Rivlin, E., Rudzsky, M.: Fast geodesic active contours. IEEE Transactions On Image Processing 10(10) (October 2001)
7. Southwest Jiaotong University: Texture Image Segmentation Using Without Reinitialization Geodesic Active Contour Model, Chengdu, P.R. China, Southwest Jiaotong University (October 2007)