Scientific Report

EU Supported Visiting Scientist Program (ICAI-CT-2000-70025)

- **Visitor:** Dr. David López Vilariño, Assistant Professor of the Department of Electronics and Computer Science of the University of Santiago de Compostela, Spain.
- **Host Institution:** Computer and Automation Research Institute (SZTAKI). Hungarian Academy of Sciences, Budapest, Hungary.
- **Research Field:** Design and implementation of analogical (Cellular Nonlinear Networks) algorithms.

1. Background

Active contour techniques are a well-known and efficient technique to approach the segmentation of images [1]. They consist in elastic curves which deform controlled by image features and shape constrains to adapt themselves to the boundaries of the structures of interest. The assumption of the moving structures appearing slightly shifted and/or deformed in two consecutive frames into a sequence makes the active contour framework an interesting medium for the spatio-temporal data transmission along the 2D image sequence analysis. Nevertheless, to this end it is necessary to approach some shortcomings into the current active contour formulations:

1. In order to give solution to the complete problem of the location of the desired structures into an image it is necessary to determine the suitable guide information for the particular application.
2. The active contours were initially designed as interactive models. For non-interactive applications they must be started close to the structures of interest.
3. Due to their parametric nature, the classical active contour techniques cannot manage easily changes of topology into the contour set. This constrains their application to those tasks where the number and approximated location of the interesting structures are known a priori.
4. All the active contour techniques require to a greater or lesser degree, a high computational cost, which renders them inappropriate for applications needing fast time response.

The two first constraints are mainly linked with the particular application and must be approached into this framework. Some details are given in the next section into the framework of the 3D reconstruction of the human ventricles and atria from 2D ultrasound images. The two last limitations are related with the particular active contour technique. In order to overcome them new strategies were formulated. Among them the called implicit models have received special attention in the last years. They consist in independent strategies based on wave-front propagation with velocity depending of the curvature [2,3]. This kind of strategies gives a smart solution to the problem of the topologic transformations among contours. Nevertheless, due to their characteristics of evolution they present difficulties to introduce control mechanisms and to impose geometric or topologic restrictions in the contour evolution. Moreover, their implementation characteristics, based on the processing of a higher dimensional function lead to algorithms requiring a high computational cost whose reduction provokes strong restrictions in the wave-front propagation.

Pixel-Level Snakes (PLS) appear as another alternative among the active contour techniques [4]. They consist in eight-connected contours into a binary image which evolve as the effect of the activation and deactivation of pixels of this image based on morphological operations. This methodology puts together characteristics from the parametric and geometric (implicit) deformable models in both the contour evolution process and the mechanisms for the contour guide which provide a high control and flexibility allowing to manage the topologic transformations in a simple way. Moreover, PLS appear to be particularly suitable for their projection onto a Cellular Nonlinear Network (CNN) architecture like the CNN Universal Machine [5] which would allow to exploit its topographic processing characteristics and consequently to reach the very high response velocities required for real-time applications.

2. Research activities

The author of this report gave a seminar at SZTAKI to introduce the concept of pixel-level snake to the members of the Analogical and Neural Computing Laboratory. The active contour techniques were briefly described, showing the main characteristics and shortcomings of the current strategies. Following, a PLS algorithm based on simple linear *analogic* CNN operations was approached from a basic structure to illustrate the main features of this active contour technique. Then, new capabilities were provided to face the main limitations associated with the classical active contour techniques. Finally examples to illustrate the characteristics of the PLS were showed and some potential applications of this new active contour technique were discussed.

The algorithm of PLS presented in the seminar has demonstrated a good performance in multiple applications. Nevertheless, it presents some limitations and exceptions which reduce its efficiency. One of the more critical parts is related with the handling of topologic transformations where a considerable effort is required to obtain well defined final contours after the topology changes based on local operations. The requirements are strongly relaxed into a region framework as it is demonstrated in [6] where another active contour technique based on CNN is proposed. In this, the propagation of trigger waves is controlled by external information to lead the wave-fronts to the boundaries of the objects of interest. Into this framework, the topological transformations affecting to the contours associated to the wave-fronts are inherent to the mathematical formulation and therefore extra processing steps are not needed for their management. Unfortunately, sophisticated stop criteria are usually required to control conveniently the wave-front propagation which may increase considerably the computation complexity in real applications.

Keeping in mind the characteristics of the wave-front propagation we propose to face the topology changes into this region context while the contour evolution is managed from the contour context. This strategy to implement the PLS clearly outperforms the previous one not only concerning the efficiency of the operation but also in the algorithm complexity which makes easier the projection into a CNN chip-set architecture. Together with the commented strategy for the management of topologic transformations we have also carried some minor changes in the contour evolution module which produce a notable improvement in the robustness and efficiency of the PLS algorithm.

This new algorithm was intended for tasks of segmentation in sequences of ultrasound echocardiography images into the framework of the project *Sensing Computers and Telepresence (TeleSense)* under the Hungarian National Research and Development Program (NKFP 035/02/2001), coordinated by Dr. Csaba Rekeczky. The aim of the operation is to define the contour of the human ventricles and atria from consecutive frames as a previous step toward a 3D reconstruction of the chambers. The contour evolution was guided by a combination of local information from the ultrasound images which push the active contour to the boundaries of the structure of interest, together with internal information which keeps smooth the contour shape. The external information is derived from a combination of a filtered version of the current frame and the result of a diffused edge detection onto this image. The internal information is derived from the diffused version of the binary image containing the current active contour. The operation is carried out assuming the chamber boundaries to appear slightly shifted and deformed in consecutive frames which allows to start the segmentation process from the result of the previous frame. This methodology is possible along all the frames of the sequence except for the first frame. For this, the contour evolution starts from a seed situated into the chamber constrained to move outwards by a new additional term of internal information inspired in the balloon forces and the advection terms of the parametric and implicit formulations.

The algorithm was first tested on a simulation environment called MATETT [7] from which demonstrated a high efficiency on the contour location. Unfortunately the speed processing appears to be too low when it runs on a conventional computer.

In order to exploit the capabilities of the massively parallel processing of the CNN, the algorithm of PLS was implemented onto a 64x64 CNNUM chip, particularly on the so called ACE4K [8]. The implementation was described in Analogic Machine Code, taking advantage of the Image Processing Library particularly developed for this architecture. We have already tested the implementation on the chip and compared the results with the previously obtained by simulation. The efficiency on the contour location are comparable, however the speed processing has been increased in several magnitude orders which allows to aspire to the real-time processing of the US echocardiography sequences.

3. References

[1] M. Kass, A. Witkin, and D. Terzopoulos. Snakes: Active Contours Models. *International Journal on Computer Vision*, 1:321–331, 1988.

[2] V. Caselles, F. Catte, and F. Dibos. A Geometric Model of Active Contours in Image Processing. *Numer. Math.*, 66:1–31, 1993.

[3] R. Malladi, J.A. Sethian, and B.C. Vemuri. Shape Modeling with Front Propagation: A Level Set Approach. *IEEE Trans. Patt. Anal. Mach. Intell.*, 17(2):158–174, 1995.

[4] D.L. Vilariño, D. Cabello, X.M. Pardo, and V.M. Brea. Cellular Neural Networks and Active Contours: A Tool for Image Segmentation. *Image and Vision Computing*, 21(2):189–204, 2003.

[5] T. Roska and L.O. Chua. CNN Universal Machine: An Analogic Array Computer. *IEEE Trans. Circuits Syst.*, 40(3):163–173, 1993.

[6] C. Rekeczky and L.O. Chua. Computing with Front Propagation: Active Contour and Skeleton Models in Continuous-Time CNN. *Journal of VLSI Signal Processing Systems*, 23(2/3):373–402, 1999.

[7] C. Rekeczky and D. Hillier. MATETT: Echo Target Tracking Simulation Toolbox for MATLAB.Version 1.0. Analogical and Neural Computing Laboratory.

Computer and Automation Institute (MTA SzTAKI) of the Hungarian Academy of Sciences. DNS-5-2003. Budapest, Hungary, 2003.
[8] G. Liñán, S. Espejo, R. Domínguez-Castro and A. Rodríguez-Vázquez. ACE4k: An analog I/O 64 x 64 Visual Microprocessor Chip With 7-bit Analog Accuracy. International Journal Of Circuit Theory and Applications, 30:89-116, 2002.

Budapest 12, November 2003 David López Vilariño