Elastic Image Registration For Movement Compensation In Digital Colposcopy

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Abstract.

Colposcopy is a widespread and reliable diagnostic method for the early detection of cervical cancer. The basis of the diagnosis is the comparison of the progressive color and texture changes in a sequence of images of the uterine cervix. Before a computer based multiple image analysis is made for these images, camera and tissue movement must be compensated for. We use an elastic registration algorithm, representing the problem as an optimization over a set of continuous deformation vector fields. The regularization has been modelled after a linearized 2D elasticity operator describing equilibrium in an elastic material. Final results show that this registration algorithm works reliably and thus permits the subsequent temporal and multiple image analysis to be performed correctly.

1 Introduction

Colposcopy is a diagnostic method used to detect cancerous and precancerous tissue regions in the uterine cervix [1]. During the exam a sequence of images of the cervix is captured at different times after the application of a contrast agent (typically a 3-5 % acetic acid solution). The images are then visually inspected in search of lesions with characteristically abnormal features. One of these features is the color change (rate of progressive whitening) of certain areas. In order to develop a computer-aided diagnostic (CAD) tool for this type of images the movement between images must be compensated so that pixels corresponding to the same tissue point can be compared for the whole sequence. This will permit the temporal assessment of the aceto whitening process.

Due to 3D aspects of the scene, camera motion and the elasticity of the tissue being imaged, the geometrical transformation between the images is a non-trivial elastic transformation. The progressive change in tissue color makes the registration a challenging problem

We have developed a registration algorithm for this type of images and show its application on real colposcopic images. We regard the problem as an optimization over a set of continuous deformation vector fields. Regularization is based on a linearized 2D elasticity operator.

2 Methods

The problem is formulated as a minimization of a criterion J with respect to a vector field **h** representing a 2D geometrical transformation.

$$\mathbf{h}^* = \arg\min_{\mathbf{h}}(J(\mathbf{f}, \mathbf{g}, \mathbf{h}\ )) \tag{1}$$

$$J(\mathbf{f}, \mathbf{g}, \mathbf{h}) = J_D(\mathbf{f}, \mathbf{g}, \mathbf{h}) + \alpha J_R(\mathbf{h}) \tag{2}$$

where $\mathbf{h}^*$ is the optimal solution and **f** and **g** are the images to be registered, J_D is a cost function measuring the dissimilarity between the images, J_R is a regularization term and α is a proportionality constant determining how much regularization will be used.

2.1 Criteria

The data criterion is the sum of squared differences (SSD) between the template image **g** and the moving image **f** deformed by **h**.

$$J_D(\mathbf{h},\mathbf{f},\mathbf{g}) = \sum_{(i,j)\subset\Omega} \left(\mathbf{f}(\mathbf{h}(i,j)+[i,j]) - \mathbf{g}(i,j)\right)^2 \tag{3}$$

To use the SSD criterion we only take into account the green color channel since it presents the strongest contrast in the cervix region.

The regularization criterion J_R penalizes un-smooth deformations. We have chosen J_R so that its gradient coincides with the linearized 2D elasticity operator describing equilibrium in an elastic material:

$$\nabla J_R(\mathbf{h}) = \xi\Delta\mathbf{h} + (1-\xi)\nabla(\nabla\cdot\mathbf{h}) \tag{4}$$

$$\begin{aligned} J_R(\mathbf{h}) = \frac{1}{2}\int_{(x,y)\subset\Omega} & \left[\xi\left(\partial_x h_x\right)^2 + (1-\xi)\left(\left(\partial_x h_x\right)^2 + \partial_x h_x\cdot\partial_y h_y\right)\right] \\ & + \left[\xi\left(\partial_y h_y\right)^2 + (1-\xi)\left(\left(\partial_y h_y\right)^2 + \partial_x h_x\cdot\partial_y h_y\right)\right] \quad \mathbf{dx} \end{aligned} \tag{5}$$

with ξ related to the Lamé parameters. We have used a value of $\xi = 0.5$.

2.2 Optimization

Gradient descent method with adaptive step size was used. On every iteration a new deformation is proposed:

$$\mathbf{h}' = \mathbf{h}_i - \lambda(\nabla J(\mathbf{f},\mathbf{g},\mathbf{h}_i)) \tag{6}$$

If the criterion decreases, i.e.$J(\mathbf{h}') < J(\mathbf{h})$, then the step is accepted and the step size is increased:

$$\lambda \leftarrow 2\lambda, \mathbf{h}_{i+1} \leftarrow \mathbf{h}', J_{i+1} \leftarrow J' \tag{7}$$

Otherwise the step size is reduced:

$$\lambda \leftarrow \lambda/10 \tag{8}$$

We iterate until convergence (given by a suitable threshold).

2.3 Other considerations

We used three multi-resolution levels reducing the image's size by half at each level, registering it and using the results as a starting point for the finer level. This considerably speeds up the algorithm, makes it more robust by avoiding local minima and significantly reduces the number of operations to do at full size (1125x750 pixels).

As a first step we register the images allowing only a translation. For this rigid registration, we minimize the J_D criterion using the same algorithm, described in Section 2.2. This step makes the algorithm quicker and more robust.

Automatically generated masks selecting the background and the cervix are used as region of interest (ROI) masks. The data criterion J_D only takes into account pixels within the ROI.

3 Results

The algorithm was tested with 45 image pairs acquired using cross-polarization filters. The data set consists of images taken before and 60 seconds after the application of the contrast agent.

Figure 1 shows the result of registering an image pair with different values of the regularization coefficient α. We can see that, using a value of $\alpha = 0.1$ leads to a good matching of the features in the cervix and to a smooth deformation. When the regularization is lowered ($\alpha = 0.01$) the algorithm allows stronger deformations and tends to overmatch certain features. This leads to unrealistic geometric transformations like the one shown in the lower right corner of Figure 1.

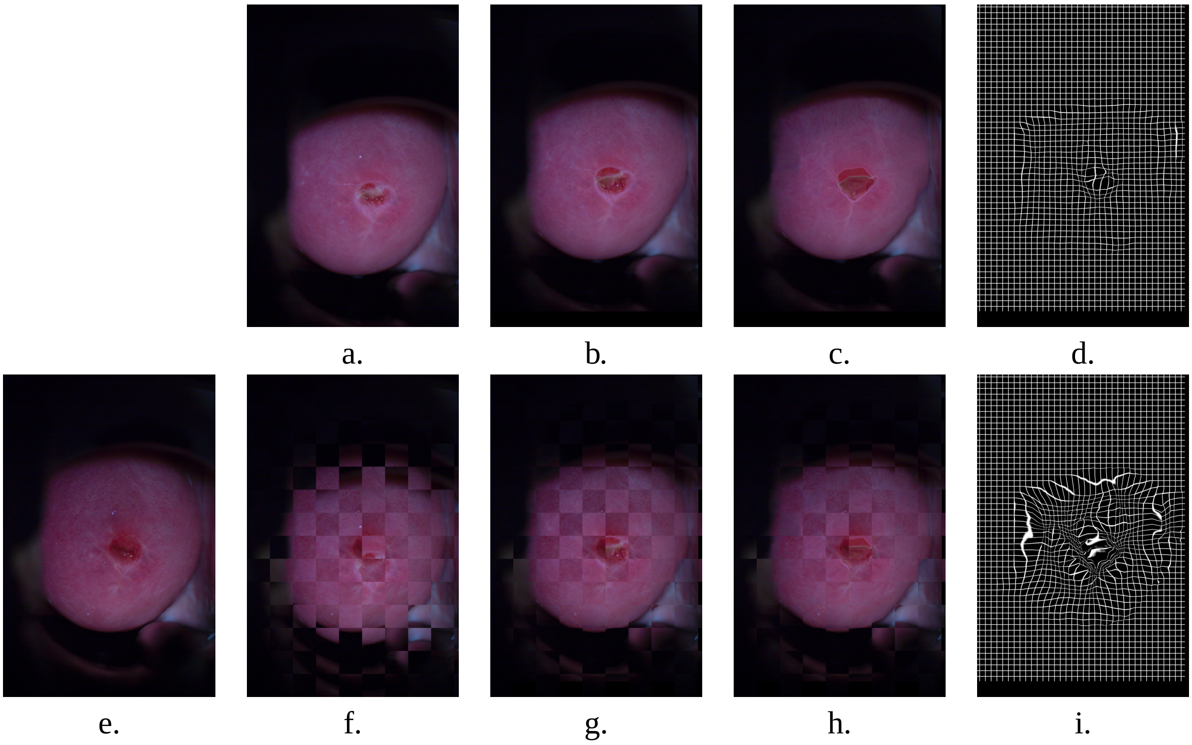

Fig. 1: Images resulting from registering a template (e) and a moving image (a) with $\alpha = 0.1$ (b) and $\alpha = 0.01$ (c). The checkerboard images (f,g,h) beneath the moving and registered images are used to compare them with the template image. Mesh grids of the geometrical transformations used for $\alpha = 0.1$(d) and for $\alpha = 0.01$ (i) are also shown. The mesh grid for $\alpha = 0.01$ shows how the registration will "over adapt" for an α too low.

4 Conclusions

The algorithm has proven useful for the registration of pre-aceto and acetowhite images offering an intuitive way of controlling the degree of regularization.

The use of a black and opaque speculum (the instrument that separates the vaginal walls during the cervix inspection) makes the background dark and smooth, reducing the need of a precise ROI mask. This and the use of cross-polarization filters help the registration by eliminating most of the glint. For different capture conditions (i.e. a transparent speculum or normal illumination) the precision of the ROI masks and the retrospective elimination of glint [2] become crucial to deter the algorithm from trying to align large and/or sharp glint areas instead of the actual cervical tissue.

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References

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